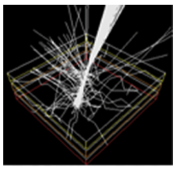
ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

CISBAT 11

CLEANTECH FOR SUSTAINABLE BUILDINGS

From Nano to Urban Scale

PROCEEDINGS VOL. II



International Scientific Conference
Lausanne, 14-16 September 2011

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FROM NANO TO URBAN SCALE

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PREFACE

The vocation of the CISBAT international conference cycle is to present new perspectives offered by renewable energies in the built environment as well as the latest results of research and development in sustainable building technology in a setting that encourages interdisciplinary dialogue and networking at the international level. The 2011 edition gathered on the EPFL campus the largest number of scientists, engineers and architects of its 20 year long history. Travelled from all over the World in an effort to promote clean technologies for sustainable buildings and cities, the participants presented 171 scientific papers during three intense days of conference.

Major international events, such as the “Deepwater Horizon” oil spill in the Gulf of Mexico and the Fukushima-Daiichi nuclear accident, which occurred in the last few years, certainly account for the growing interest of the scientific community - as well as the interest of stakeholders - for energy efficient technologies and decentralized energy systems in the built environment, such as promoted by the conference.

CISBAT was organized for the fourth consecutive time in scientific partnership with the Massachusetts Institute of Technology (MIT) and Cambridge University. Furthermore, the organizing committee is proud to have been supported again by a renowned international team of scientists in order to ensure the scientific quality and rigor expected from the conference. CISBAT 2011 also teamed up with the Swiss Chapter of the International Building Performance Simulation Association (IBPSA-CH) to strengthen the subject of “Building and Urban Simulation”, one of the conference's leading topics.

Thanks to the financial support of a growing number of institutional and private partners, such as the Swiss federal Office of Energy (SFOE), Bank Julius Bär and the public utility Romande Energie, the CISBAT international conference cycle has undoubtedly gained maturity and recognition on the international scene for its 20th Birthday Anniversary, and deserves a promising sunny future.

Prof. Dr Jean-Louis Scartezzini
Conference Chairman
Solar Energy and Building Physics Laboratory
Swiss Federal Institute of Technology Lausanne

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SMART ELECTRIC BLINDS

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ABSTRACT

Over 40% of primary energy is used for building applications and purposes. Control of electric blinds according to energy criteria can easily provide significant energy savings, particularly for well-oriented buildings.

A smart system for managing electric window blinds based on solar radiation and room occupancy is proposed. It regulates the incoming light and heat to realize energy savings by using electronic sensors. The system is low cost, modular, stand alone and easy to use (plug and play). This flexible wireless solution applies to both houses of excellent quality in terms of thermal protection and old buildings with poor thermal insulation.

The low cost system is composed of several wireless battery-powered electronic modules communicating through radio frequency (ISM 2.4 GHz, maximum transmission range of 100 meters). The system is optimized to reduce the electrical consumption of the electronic modules, so that the batteries need to be replaced only once a year.

The proposed solution is used throughout the year, in winter as well as in summer. In cold sunny weather, open electric blinds during the day and closed blinds at night can exploit each room as a solar energy storing system. In warm seasons, the reverse operation improves the thermal comfort of the residents by trying to reduce the air conditioning costs.

In addition to this, users can customize the settings according to their needs and wishes through the user interface.

The electric blinds of each room are controlled independently as each room has its own solar gain, attendance and orientation. The electric blind control system has several important benefits such as comfort optimization, adjustment according to room occupancy, independent control of each room (self-determining system), use and anticipation of solar gain and, as a result, the saving of energy!

Different tests and experiments have confirmed that energy requirements can be reduced up to 25% for well-oriented buildings.

INTRODUCTION

A smart system to manage electric blinds based on solar radiation and room occupancy is an efficient energy saver all year round.

In winter, intelligent blinds remain open to let free solar energy into the building during the day, thus reducing energy requirements for heating. Once the sun has set, the blinds are closed, reducing heat loss and continuing to save on the energy required for heating.

In summer, closed blinds during the day help keep excessive heat out of the building, which can noticeably cut the need for air conditioning. In the evening, opening the windows and the blinds allows the building to flush any heat build-up, again reducing the need for air conditioning.

If automated and controlled correctly, smart blinds can reduce energy requirements by 25%, while increasing the comfort of the residents!

CONCEPT

The proposed system consists of two electronic modules (Ep and Es), emitting radio frequency signals from the occupancy sensor and the solar sensor. A central module with user interface (LCD + Keyboard) allows the user to customize the settings. Several control algorithms are implemented in this core module. It also handles the coordination between the different RF modules. Finally, the module R acts directly on the electric motor of the blinds upon received RF signals.

The following figures show the position of various electronic modules inside each room and outside of the building.

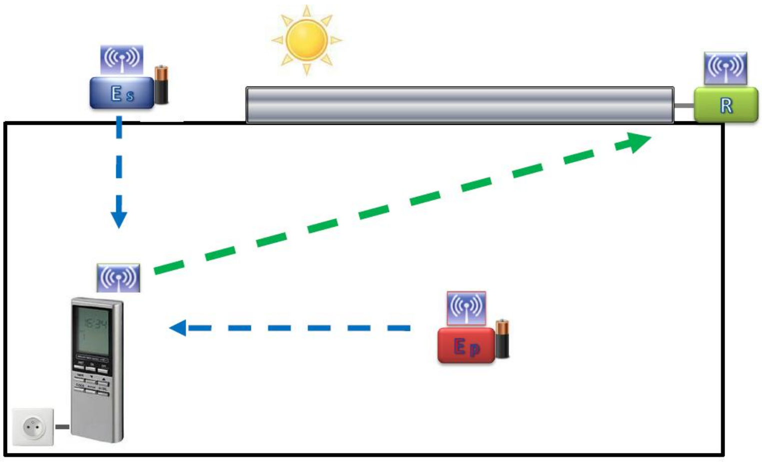

Figure 1: Electronic RF modules inside and outside of the room.

Figure 2: Electronic RF modules outside of the building.

PROTOTYPE

The communication network is a low-cost, low-power wireless embedded solution based on ZigBee communication protocol. The XBee radio frequency module operates within the ISM 2.4 GHz frequency band and an electric current of 40 mA in transmission mode and 10 µA in sleep mode.

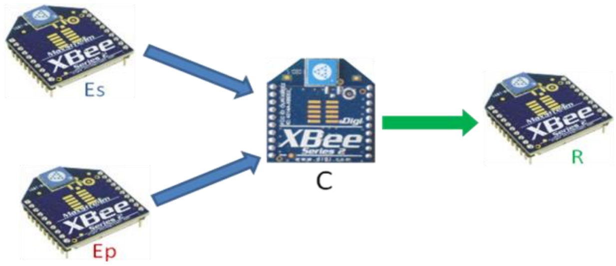

Figure 3: Device connectivity using multipoint wireless networks.

The two transmitter modules (E_P and E_S) installed inside and outside of the building contain a RF module (XBee), a sensor (occupancy or solar) and a battery supply. The receiver module (R) mounted directly on the motor blinds contains a XBee device, electronic relays and a 230 VAC line power. The central module (C) contains a XBee device, a microcontroller with implemented algorithms, a user interface (LCD + Keyboard), a real time clock (RTC), a temperature sensor to display the room temperature and a 230 VAC line power.

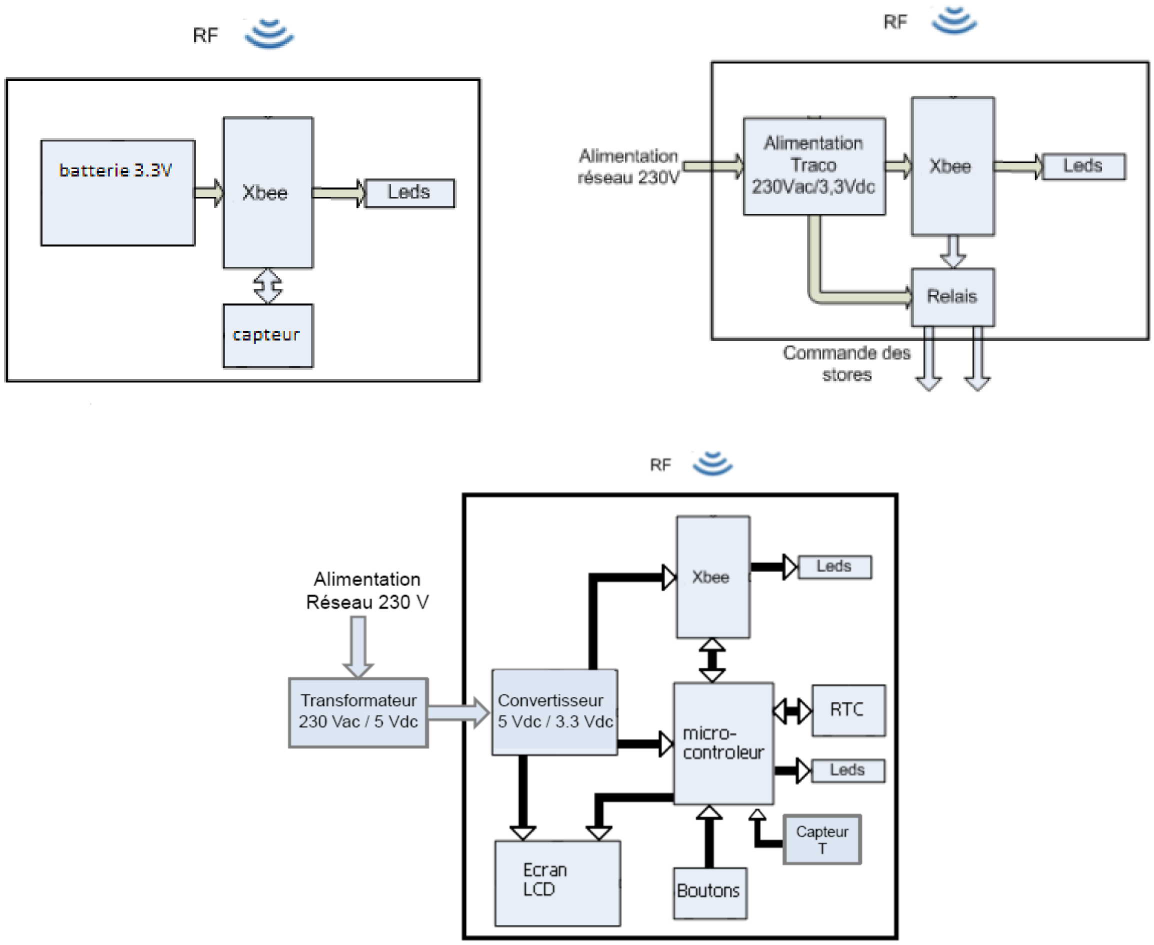

Figure 4: Block diagram of various electronic wireless modules E_P, E_S, R and C.

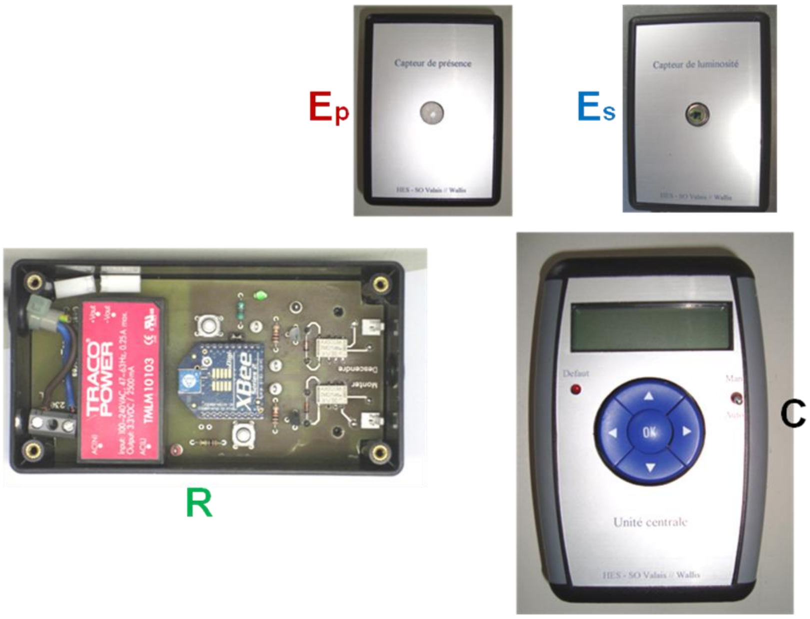

Figure 5: Stand alone prototype to control electric blinds.

CONTROL ALGORITHMS

Three operating modes are available: **Manual**, **Save Energy** and **Astro**.

In **Manual mode**, the users can manage the blinds as they wish by using different keys (▲,▼, ■). This mode is launched either by the user, with the switch on the central module, or automatically, when a presence is detected in the room.

Save Energy mode regulates the incoming light and heat to realize energy savings by using occupancy and solar sensors. This mode runs automatically when the room is not occupied.

In winter		
IF sunny **AND** room not occupied	→	Save Energy mode > Open electric blinds
IF cloudy **AND** room not occupied	→	Save Energy mode > Close electric blinds
IF room occupied	→	Manual mode
In summer		
IF sunny **AND** room not occupied	→	Save Energy mode > Close electric blinds
IF cloudy **AND** room not occupied	→	Save Energy mode > Open electric blinds
IF room occupied	→	Manual mode

Astro mode manages the electric blinds according to sunrise and sunset times, using for example a local sunrise/sunset calendar. This mode can also be customized according to the user's wishes, e.g. by shifting the calendar.

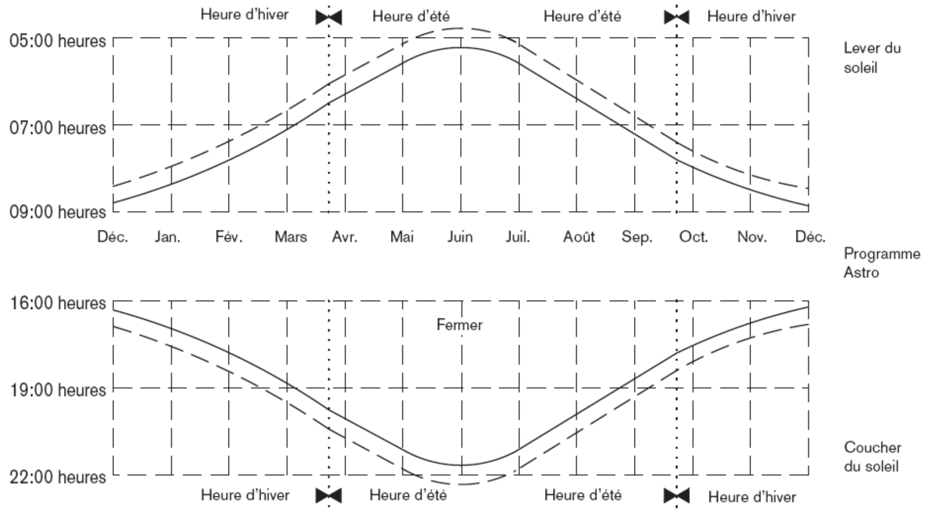

Figure 6: Sunrise/sunset calendar used in 'Astro mode' to manage electric blinds.

RESULTS

Comparative tests were made at the HES-SO Valais in Sion, in two adjacent similar classrooms of almost the same size and orientation. The rooms are interchangeable as the electronic modules can easily be moved from one room to another. Measurements were done using voltage and temperature data-loggers, as well as heat meters on the radiators of the 2 rooms.

The following figure shows how the room with smart stores benefits by storing the winter solar energy all afternoon while the sunlight is sufficient. Consequently, the heating demand is significantly reduced and the thermostatic valves are closed most of the time, as the temperature in the room remains high enough.

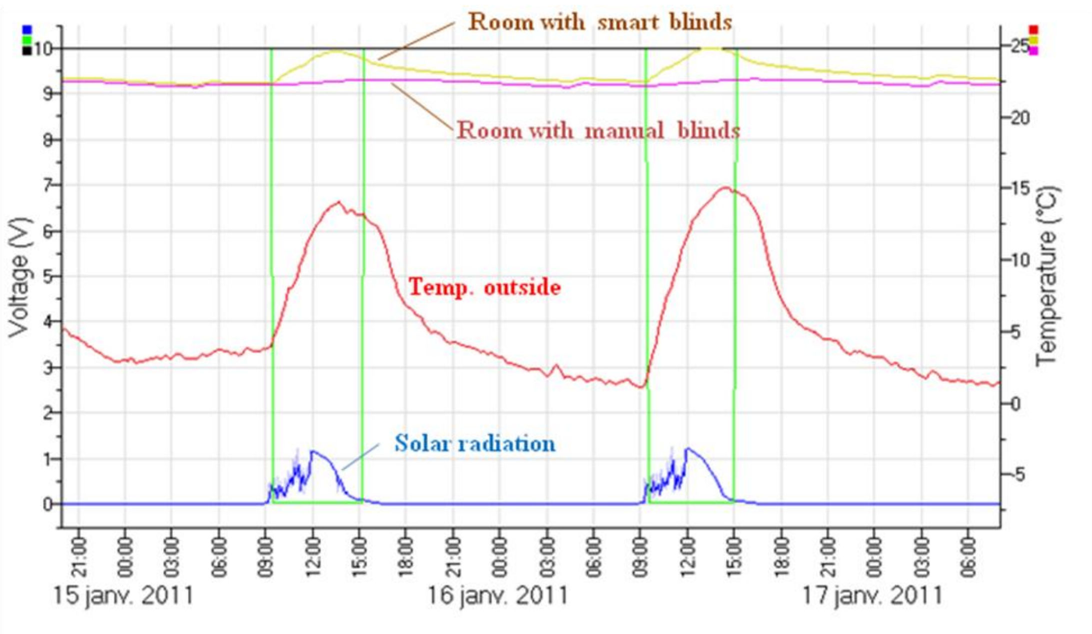

Figure 7: Comparative tests in 2 similar classrooms, during a weekend in January.

In summer, on the contrary, the smart blinds protect the room from unwanted solar gain, by blocking the sun's rays during hot days. Figure 8 shows how a good control of the shading system can improve thermal comfort by reducing overheating and glare.

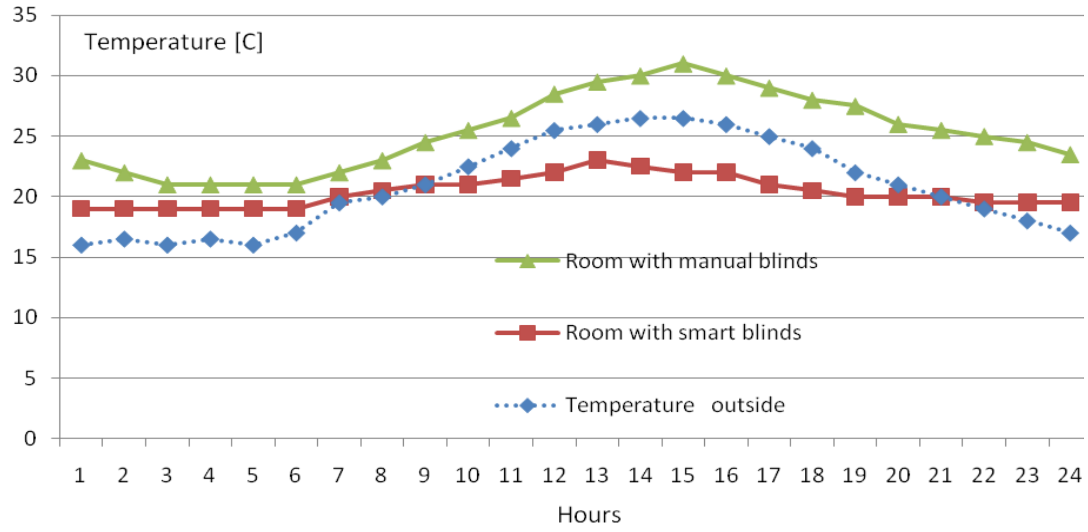

Figure 8: Comparative tests in summer, with the filtering effect of blinds.

CONCLUSION

An intelligent system for managing electric blinds not only helps to prevent overheating and glare, but also allows important energy savings. In summer, when the sun is shining and it's hot outside, blinds are worth their weight in gold. They can reduce solar radiation levels and produce a pleasant room temperature, which reduces the amount of electrical energy used to cool rooms. In winter, an intelligently controlled system brings the solar energy into the room, thereby cutting heating costs.

Comparative tests have shown that during the cold season:

- Energy gains up to 25% can be achieved during sunny days when rooms are less occupied and the **Save Energy mode** runs.
- When rooms are more occupied, a comparison of energy savings is more difficult because of user interference on the blinds. In the best case, during sunny days when the windows are closed and the various modules perform correctly, energy savings up to 15% are observed.

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OPTICAL CHARACTERIZATION AND ENERGY SIMULATIONS ON METAL-HYDRIDE SWITCHABLE MIRRORS

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ABSTRACT

The purpose of this work has been to examine the energy performance of smart windows based on gasochromic switchable mirrors. The metal-hydride switchable mirrors investigated change their optical properties reversibly between a transparent and a reflective state during hydrogenation and dehydrogenation of the film. This work that has been a research collaboration between the National Institute of Advanced Industrial Science and Technology (AIST) in Japan and Uppsala University includes optical characterization of the switchable mirrors and energy simulations for smart windows based on gasochromic switchable mirrors. Optical properties of switchable mirror samples have been measured for transparent and reflecting state and these data are used as input for energy simulations. A test room, for measuring the energy performance of smart windows based on switchable mirrors, has been built and is located in Nagoya, Japan. Measured data on energy use for the test room having smart windows and another test room having static windows are compared with data from three building simulation programs, WinSel, VIP energy and eQuest. The simulations and measured data show good agreement and the simulation results also address the importance of a good control strategy for the smart windows. This paper also shows some facilities and limitations with different energy simulation tools regarding the simulation of smart windows.

INTRODUCTION

Smart or switchable mirrors can be one way to conserve energy within buildings. They can reduce cooling needs in warm and/or varying climates since the transmittance of light and hence the solar heat gain factor can be reduced. This reduction can be achieved when people are present to give a comfortable level of daylight and when people are not present adapted to a level which leads to the lowest energy need for the building. The control strategy of such windows is important for their energy performance [1, 2].

METHOD

Switchable mirrors have been investigated optically using spectroscopic measurements and energy simulations for smart windows based on gasochromic switchable mirrors have been performed. For switching the gasochromic mirrors between reflecting and transparent states it is necessary to have the active surface facing the inside of a closed cavity having a controlled inlet of a hydrogen or oxygen gas mixture leading to reflective and transparent state respectively. To achieve this, the switchable mirrors are placed together with a low-iron glass in a test cell.

Optical characterization

A test cell was built, see figure 1, which can be used to measure angle dependent transmittance and reflectance for the switchable mirrors. The test cell has inlet and outlet for gas mixtures to control the state of the smart window. The switchable mirrors were measured in combination with a low-iron glass with known transmittance and reflectance values, similar to a double-glazed unit. From these measurements the angular dependent transmittance and reflectance for the switchable mirrors can be determined, by compensating for multiple reflections. Figure 2 shows transmitted and reflected light through the test cell. For transmittance it is necessary to compensate for multiple reflections and also consider that the light beam also is transmitted through the glass. For reflectance it is necessary to compensate for multiple reflections and also to remove the light reflected directly in the glass to get the reflectance of the switchable mirror glass.

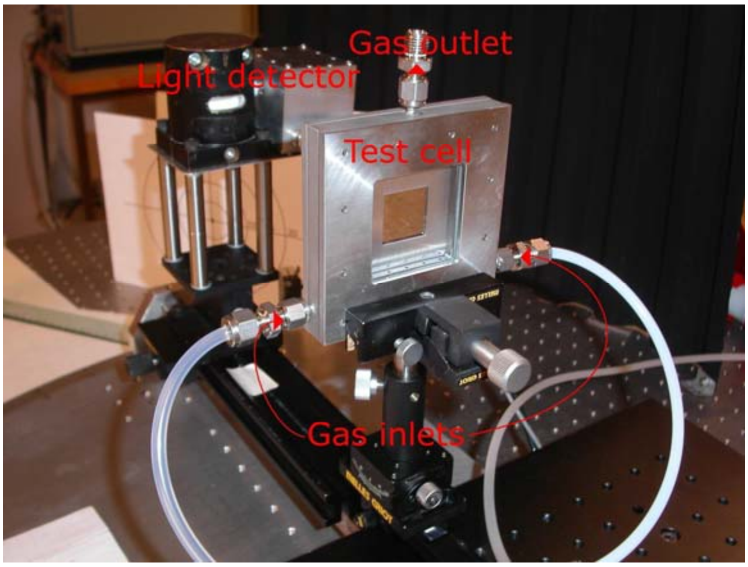

Figure 1: Optical measurement equipment. Sizes of the switchable mirror samples were 3x3 cm.

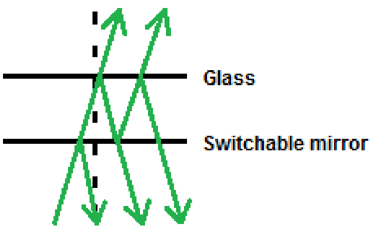

Figure 2: Transmitted and reflected light also include multiple reflections, which have to be compensated for.

Energy simulations

Energy simulations on smart windows require that the simulation tool can handle building components with varied properties over time. In this project simulations were made in WinSel (Karlsson, 2001), VIP Energy and eQuest. Meteorological input data for Nagoya, which has a similar climate as southern Europe but with a more even solar radiation over the year, has been obtained from the software tool Meteonorm [6].

WinSel

WinSel is a software tool for evaluating and comparing windows. The software calculates the energy for heating and cooling caused by the windows as a building component. The purpose is to be a simple tool for selecting windows. Using the window properties solar gain, g-value, and the heat transfer coefficient, U value, different windows can be compared for a building located in a specific climate using just balance temperature and a climate data file as input. WinSel is a static tool and simplifies the building into only a few parameters; balance temperature and thermal capacity. Due to the simplicity of the program, it is suitable as a tool for selecting the right type of window for a certain building. The result achieved from the program is the energy balance for the heating season and the cooling season. The energy balance is calculated hour by hour per square meter glazing area from the equation:

Energy balance = Solar heat gain - Thermal losses

For this project, WinSel was further developed so that the software can simulate smart windows with variable solar gain, g-value, and heat transfer coefficient, U value. For metal-hydride switchable mirrors both the g-value and the U value varies between the states and in the software these parameters can be time dependent and are regulated using different control strategies. Four different control strategies were developed to exemplify different approaches for controlling smart windows:

- EO - "Energy optimization" means that the windows are always kept in the state which is best from an energy perspective. In the simulations the windows are kept in mirror state whenever there is a cooling need and in a transparent state whenever there is a heating need.

- DO - "Daylight optimization" means that the windows are in a state which is optimized from a daylight perspective. The perpendicular component of the transmitted direct solar radiation was thus regulated by the switchable mirror in the window to a maximum of 200W/m2. This mode of the control mechanism reduces annoying glare when the sun is low in the sky and when the solar irradiation is close to perpendicular to the window. Solar radiation at glancing incidence angles does not turn the window into a mirrored state.

- O1 - "Office 1" mode corresponds to having the window in "daylight optimization" mode between 7:00 a.m. and 6:00 p.m. and otherwise in "energy optimization" mode.

- O2 - "Office 2" mode corresponds to having the window in "daylight optimization" mode during half of the time between 7:00 a.m. and 6:00 p.m. and otherwise in "energy optimization" mode. This is a simplified way of simulating that the office is occupied only during half of the time.

The different control strategies can easily be modified. Over a year the time resolution of an hour is assumed to be averaged and the simplifications of the strategies is a way to make the results more comprehendible. Switchable windows can then be evaluated and compared to static windows at different locations and in different buildings. The WinSel simulation parameters can be found in table 1.

Table 1. WinSel simulation parameters.

Parameter	Value
Climate (from Meteonorm 5.0):	Nagoya
Ground reflection	20%
Building balance temperature	12°C
Allowed temperatures	20-26°C
Transparent state	
U value	2,40 W/m^2K
g-value	50%
T_vis	35%
Reflective state	
U value	1,67 W/m^2K
g-value	6%
T_vis	5%

VIP Energy & eQuest

VIP Energy [4] is a commercial software simulation tool for whole building simulations and eQuest [5] has been developed by the Lawrence Berkeley National Laboratory and is based on DOE2.2. These software tools are based on dynamic simulation models and thus take the heat storage in the building structure into account. They also take the air flows in the ventilation system and leakage in other building components into account.

Since user precence is assumed to be time dependent and this controls the window state, it is desirable if the software tool can handle time dependent building components. In VIP Energy shading devices can be used to simulate smart windows. It is however not clear how this affects the U value of the window and it is not possible to have such components time dependent. Instead separate simulations were made for transparent and reflecting states and the energy needs were summarized hour by hour manually. To be able to do this we had to set the indoor temperature to a constant 22°C for the whole year. For eQuest the indoor temperature were allowed to vary between 20-26°C. Other simulation parameters were kept as similar as possible and a list of the most important can be found in table 2.

Table 2. Test room parameters used in VIP Energy and in eQuest.

Parameter	Value
Climate (from Meteonorm 5.0):	Nagoya
Ground reflection	20%
Ventilation volume	14 m^3
Floor area	5.75 m^2
U value, roof	0.49 W/m^2K
U value, south/west wall	0.33 W/m^2K
U value, window	2.40/1.67 W/m^2K

RESULTS

WinSel

The results from the WinSel simulations show the importance of the control strategy. For a south facing window for example the energy balance of the window switches from negative to positive with more advanced control strategies for the Nagoya climate as can be seen in figure 3. The energy balance results are presented per square meter window area.

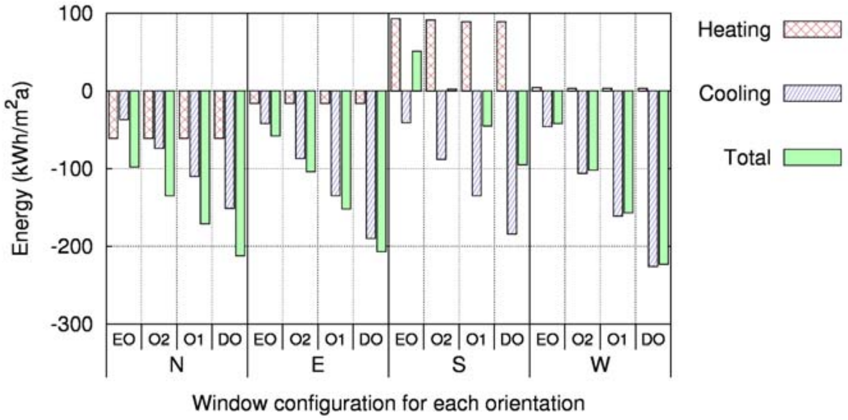

Figure 3. Simulated energy balance for the test building located in Nagoya using WinSel.

VIP Energy

The test room simulations made in VIP energy show similar results, found in figure 4, but are presented as energy use per square meter floor area. Comparisons are also made with static windows having g values equal to 30 and 70 % respectively and a U value equal to 1.6 W/m^2K showing that the switchable windows outperform the static windows if using control strategies “O2” (office with presence detectors) or “EO” (switchable window always controlled for a low heating and cooling need.)

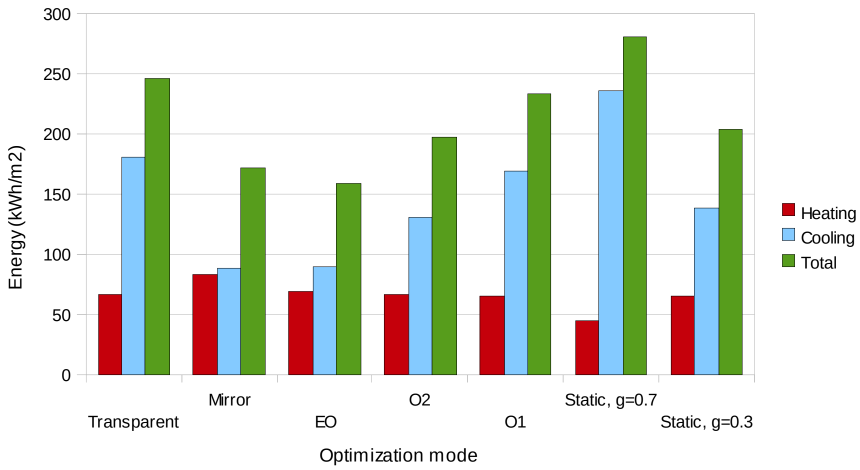

Figure 4. Simulated energy need for the test room located in Nagoya using VIP Energy.

Comparisons between three simulation software tools

Comparisons between simulations made in VIP Energy, eQuest and WinSel show differences of about 20% for the total energy need. Unfortunately the building models in the simulation software tools cannot be set up in exactly the same way. In VIP Energy shading devices are available but there is no support for time dependent building components. Therefore the indoor temperature were set to a constant value at 22°C and two separate simulations for transparent and reflective state were made and the results from these simulations were summed up manually. It is reasonable that this leads to a higher than expected energy need, as also can be seen in figure 5.

The results for WinSel and eQuest are lower but an explanation to the somewhat higher energy need given by the WinSel simulation software might be that the balance temperature is assumed constant over the entire year. One should also remember that this is a static simulation tool and has a very simplified way of handling heat storage within the building.

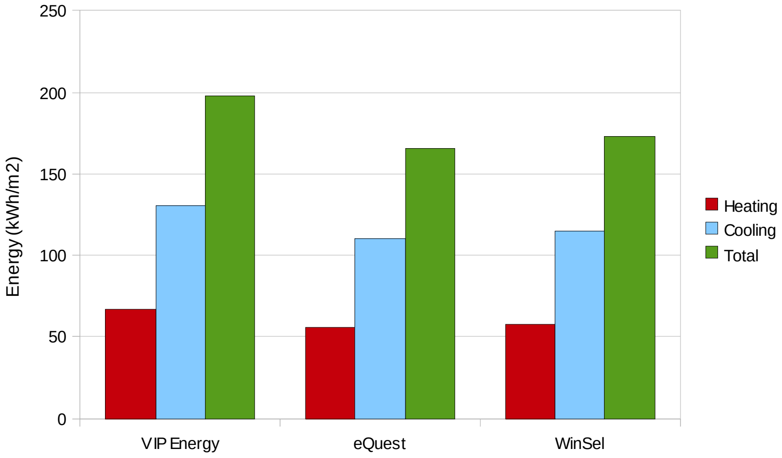

Figure 5. Simulated energy needs for "O2" optimization mode (office with presence detectors) for three different simulation software tools for the test room located in Nagoya.

DISCUSSION

Switchable windows based on metal hydrides show a large span between transparent and reflective states and are also colour neutral in their appearance. The transmittance is not lower for higher incidence angles of light, which is often the case for other coated windows. Switchable windows based on metal hydride can help reduce energy needs in buildings, but the control strategy is crucial. Metal hydride switchable mirrors have a reflective state instead of an absorptive state. What is to prefer is of course to some extent a matter of taste, but the reflective state has a technical advantage in that the window pane remains cool even when sun is shining upon it leading to longer life-time expectancy.

ACKNOWLEDGEMENTS

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THERMAL MODEL PREDICTIVE CONTROL FOR DEMAND SIDE MANAGEMENT STRATEGIES IN PREFABRICATED BUILDINGS

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ABSTRACT

This paper aims to present the design, analysis and development of a control scheme named Thermal Model Predictive Control for Demand Side Management Strategies. The control is implemented on a building in Athens, whose thermal model is derived using the Finite Difference Calculation Method. The development and testing of the thermal model is implemented while the predictive controller for heating/cooling strategies is analysed through simulation results. The advantages of the scheme are described, including the ability of the predictive controller to consult the users for energy and cost savings during the peak demand, in an acceptable way by them regarding the thermal comfort issue.

Demand Side Management (DSM) is a measure taken by electric utilities to influence the amount or timing of customers' energy demand, in order to utilize scarce electric supply resources more efficiently. According to IEA Demand Side Management working group, the term “demand response” refers to a set of strategies which can be used in competitive electricity markets to increase the participation of the demand side in setting prices and clearing the market[1]. The net effect of the demand response is to ease system constraints and to generate security and economic benefits for the market as a whole.

As far as the thermal comfort is concerned in order to reach the desired indoor temperature and humidity, the heating/cooling demand should be regulated thus satisfying a DSM strategy. In the framework of this paper “Thermal Model Predictive Controller” is developed implementing super cooling/heating strategies, through which a building or a building part is pre-cooled/pre-heated during low peak periods achieving peak shaving in an acceptable way by the users regarding the thermal comfort issue during summer.

In addition, the development of a Bidirectional Energy Management Interface (BEMI) will offer Technical and Economical Integration of Distributed Energy Resources. The penetration of PVs in these smart buildings, with daylighting strategies using BEMI with KNX/EIB protocol is investigated. The system of prefabrication includes a selected set of bioclimatic (passive and hybrid) systems integrated to the building envelope, which are chosen by the environmental and economic cost/benefit parameters available before construction.

Keywords: Demand Side Management, Demand Response, Building Simulation, Predictive Control, Smart Buildings, Renewable Energy Sources, Smart Grids

INTRODUCTION

DSM strategies have been considered in several buildings in Athens and in Kassel. A building in Athens, Greece, has been chosen for implementing the Thermal Model Predictive Controller for DSM actions. It is called Georgiadis building, it is named after its owner, it is located in Gerakas city and the KNX/EIB technology has been installed in it, where EIB stands for European Installation Bus. A DVD Club is situated at the basement of the building.

Furthermore, a bookshop and a shop which sells desalination plants are situated in the ground floor. Finally, an apartment with an attic is in the first floor. The bookshop has been chosen as the place to accommodate the experiments of this paper due to the owner's special interest to save energy in this building part. The Georgiadis building is depicted in the following Figure 1, where the DSM strategies have been considered. The results from this building can be applied to a complex of prefabricated buildings.

Figure 1: Georgiadis Building in Gerakas, in Athens, in Greece.

CONCEPT

The aim of a DSM strategy is the reduction of the peak demand. Taking into account the fact that the peak demand is mainly caused by the operation of air-conditioning units during summer, the DSM cooling strategy intends to reduce the consumption of these units during the peak periods. However, this reduction should not be against the thermal comfort. This means that the indoor temperature and the humidity should not be increased more than a specified limit, so that the users still feel comfortable in it. The Thermal Model Predictive Controller is based on the Thermal Model, which is used for the prediction of the indoor temperature during pre-cooling and DSM phases. In addition, it calculates the heat fluxes of the walls and the Inflow, Outflow and Stored energies of the examined room. The Thermal Model plays a significant role in order to define the duration of the pre-cooling phase. The pre-cooling period is independent from the indoor temperature reduction [2].

The TMPC-DSM controller operates in three phases every day. The period in which the TMPC-DSM controller pre-cools a room is called Pre-cooling period or Pre-cooling phase, while the period in which the TMPC-DSM controller acts to air-conditioning units during the peak demand is called DSM phase. Moreover, the period in which the TMPC-DSM controller does not operate or act to air-conditioning units and only receives information from the Power Predictor is called Inactive phase.

ABSORBED SOLAR RADIATION

An Anisotropic Solar Radiation diffuse model based on the Hay-Davies-Klucher-Riendl (HDKR) model is applied to the bookshop of the examined building [3]. The HDKR model estimates the absorbed beam, diffuse and ground reflected solar radiation by the surface of the outer wall, the windows and a part of the roof of the bookshop, which is made by glass. The following Figure 2 depicts the measured Solar Incident Radiation on a horizontal surface by the ISET-Sensor–monocrystalline pyranometer and the absorbed radiation by the surface of the northern wall, the windows and the roof glazing in the bookshop from 18/9/2005 until 25/9/2005.

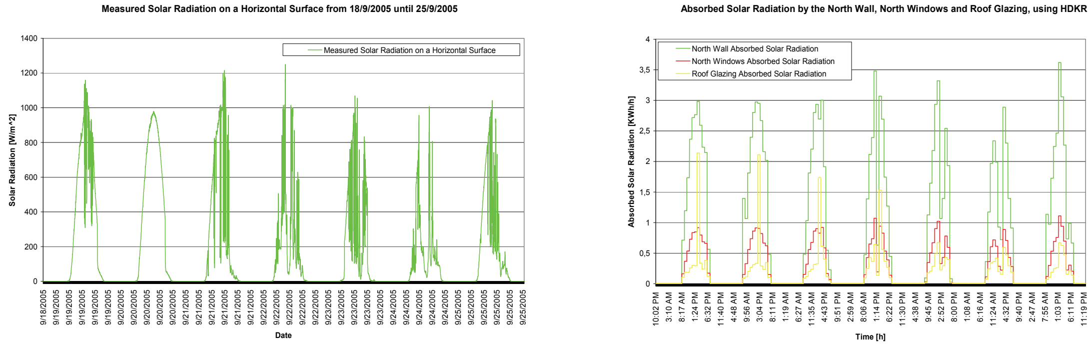


Figure 2: Measured Solar Radiation on a Horizontal Surface (left) and the absorbed radiation by the surface of the northern wall, the windows and the roof glazing in the bookshop (right) from 18/9/2005 until 25/9/2005.

THERMAL MODEL

The Dynamic Thermal Model of the Bookshop is developed based on the Finite Difference Calculation Method [4]. Inflow Energy is considered to be the energy resulting from the heat flux due to the difference between the indoor temperature and the surface temperature of the inner wall. The internal heat sources with the rates of heat transfer from the air-conditioning units leave the shop, interact to the indoor and inner surfaces temperatures and are therefore assumed as Inflow Energies.

Respectively, Outflow Energy is the thermal energy due to the difference between the surface temperature of the outer wall and the ambient temperature. The solar radiation is applied onto the surface of the outer northern wall part and is also considered as Outflow Energy.

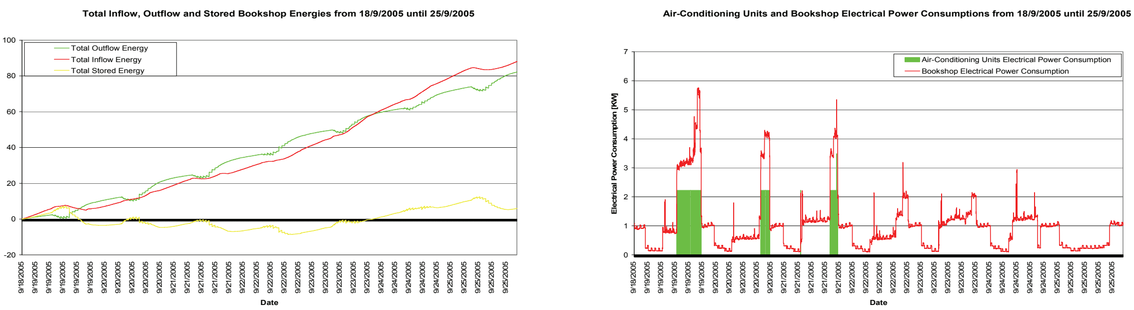


Figure 3: Total Inflow, Outflow and Stored Energies of the Bookshop (left) with the electrical power consumption of the air-conditioning units in comparison with the bookshop electrical power consumption (right) from 18/9/2005 until 25/9/2005.

The Total Inflow, Outflow and Stored Energies of the Bookshop with the electrical power consumption of the air-conditioning units in comparison with the bookshop electrical power consumption are depicted in Figure 3. Figure 3 verifies the fact that the thermal model is based on the energy balance equation. Obviously, the peak demand is mainly caused by the operation of the air-conditioning units during summer, it occurs at 19:00 and its duration is 2 hours, which is the prediction horizon of the DSM phase. Moreover, it is concluded that the use of Photovoltaics is not the optimal solution in this case, because their maximum electrical power is produced at midday.

ANALYSIS

The pre-cooling period is 26 minutes at maximum [2]. Therefore, the prediction horizon of the pre-cooling phase is also 26 minutes and is reduced by 47 seconds at every sample. The maximum desired predicted indoor temperature is defined to Tin_max = 27°C. Figure 4 depicts the predicted indoor temperatures, using the TMPC-DSM controller, during the Pre-cooling and DSM phases in comparison with the predicted and measured indoor temperatures on 19th, 20th and 21st September 2005. Three different cases are investigated respectively these days, when the bookshop is opened during afternoon. The predicted indoor temperatures are obtained by using the Finite Difference Calculation Method.

More specifically, Figure 4 (left) illustrates that the SCADA suggests the user to accept the indoor temperature which reaches 27,5°C on 19th September. The SCADA informs the user that if the indoor temperature is decreased to 27°C during the peak demand for that day, then an additional electric energy consumption of 1,67 KWh will occur. That will cost him €0,12 due to the increased operation of the air-conditioning units during the Pre-cooling and DSM phases. It is assumed that the user accepts this increase of the indoor temperature in our simulation results. If he does not accept it, the Thermal Model Predictive Controller will be deactivated and the indoor temperature will be regulated by the KNX/EIB thermostat. In this case, the SCADA will inform him about the economic benefits from applying the DSM cooling strategy.

Furthermore, according to the indoor temperature prediction during the peak period, the Pre-cooling Phase is needed only on 20th September as it is shown in Figure 4 (centre). Both, the Pre-cooling and DSM optimization algorithms are applied for that day. Finally, Figure 4 (right) depicts that the predicted indoor temperature reaches 27°C on 21st September during the DSM phase and without the use of the Pre-cooling phase. Only the DSM optimization algorithm is applied for this day.

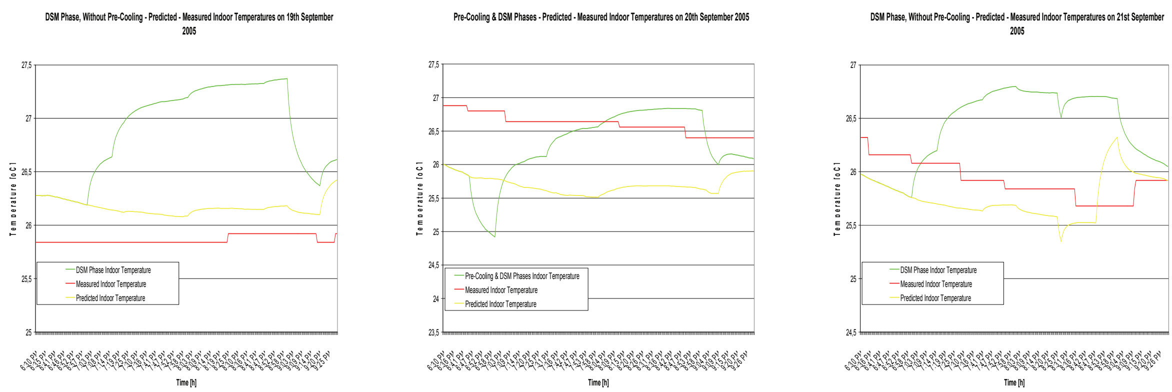
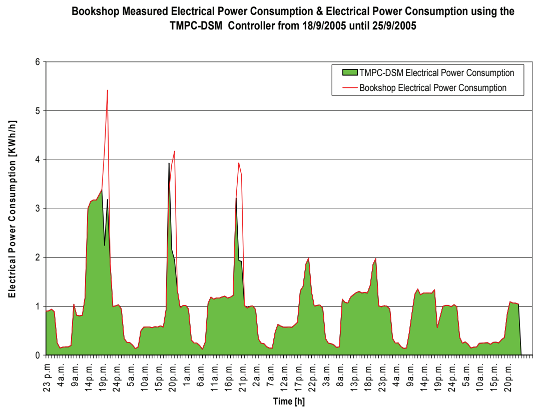


Figure 4: Predicted indoor temperature during the Pre-cooling and DSM phases in comparison with the predicted and measured indoor temperatures on 19th (left), 20th (centre) and 21st (right) September 2005.



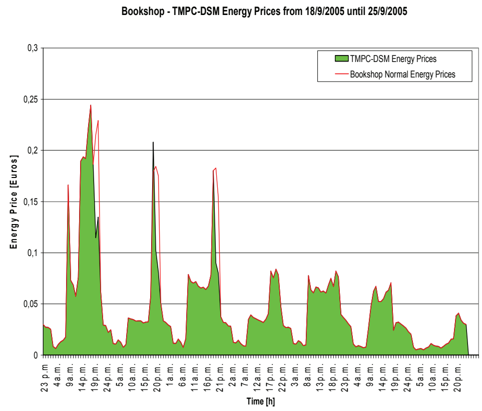


Figure 5: Measured and prices of electrical power consumption of the bookshop in comparison with that from applying the DSM cooling strategy.

The analysis of Figure 5 shows that the electric energy consumption of the bookshop is 93.180 Wh with €4,94 cost from 18/9/2005 until 25/9/2005. By applying the DSM Cooling Strategy, the energy consumption is reduced to 81.810 Wh with €4,43 cost for the same period. Therefore, energy savings of 12,21% with cost savings of 10,28% are achieved by applying the DSM cooling strategy using the TMPC-DSM controller. In the case where the maximum EEX prices occur during the peak demand as it is shown in Figure 6, the following Figure 7 depicts the cost profile of the energy consumption of the bookshop with the maximum prices during the electric peak demand and the prices which will be derived if the DSM cooling strategy is applied from 18/9/2005 until 25/9/2005 [5]. In this case the energy savings are the same as in Figure 5; however, the cost of energy is reduced from €5,67 to €4,93 by using the TMPC-DSM controller; attaining cost savings of 13,03%.

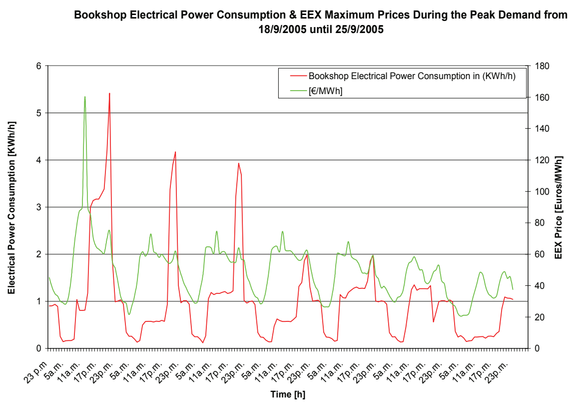


Figure 6: Measured electrical power consumption of the bookshop and EEX prices where the maximum ones occur during the peak demand.

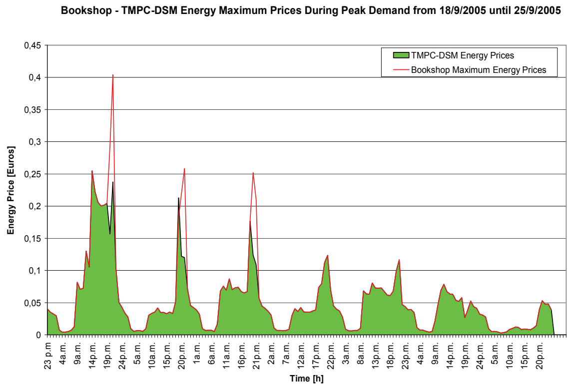


Figure 7: Cost profile of the measured electric energy consumption of the bookshop with the maximum prices during the peak demand and the prices which will be derived if the DSM cooling strategy is applied from 18/9/2005 until 25/9/2005.

Table1 illustrates the total with the daily energy and cost savings, by the application of the TMPC-DSM controller.

Date	Without TMPC-DSM (KWh)	TMPC-DSM (KWh)	Energy Savings (%)	Without TMPC-DSM (€)	TMPC-DSM (€)	Cost Savings (%)
19/9/2005	40,2	36	10,44	2,75	2,45	11,05
20/9/2005	24,14	20,73	14,14	1,29	1,09	15,96
21/9/2005	28,84	25,08	13,05	1,63	1,4	14,05
Total	93,18	81,81	12,21	5,67	4,93	13,03

Table1: Total and daily energy and cost savings using the TMPC-DSM controller.

CONCLUSIONS

One of the attractive results of the approach adopted in the paper is that a simplified thermal model based on finite difference calculation, assuming that there is one-dimensional conduction in x, can describe adequately the dynamics of the system. The application of Thermal Model Predictive Control for Demand Side Management Cooling Strategies proves that energy saving of 12% is feasible. The cost savings by using the TMPC-DSM controller depend on the prices of the energy during the peak periods. It is concluded that cost savings about 13% can be achieved. The results from this building can be applied to a complex of prefabricated buildings.

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Urban Ecology and Metabolism

SPATIAL PLANNING AS A DRIVER FOR CHANGE IN BOTH MOBILITY AND RESIDENTIAL ENERGY CONSUMPTIONS

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ABSTRACT

This paper presents the results of the first part of an important two-year research dedicated to analysing the impact of territorial structures upon GHG emissions in the Walloon Region (Belgium). The rationale of the research is to provide regional authorities with up-to-date figures about the long-term influence of land planning decisions upon energy consumptions and GHG emissions, both in the residential building stock as well as for home-to-work commuting. The analysis has been conducted at the regional scale (16.844 km^2) and includes both urban, periurban and rural settlements. It appears that those sectors that perform well on mobility also tend to perform well in terms of building consumption. This opens an avenue towards a much more progressive approach in terms of spatial planning, where compact cities may be viewed as part of the solution, still not the whole solution. This is especially true when one considers the entire territorial structure of a region and its strong inertia over time.

INTRODUCTION

This paper presents the results of the first part of an important two-year research dedicated to analysing the impact of territorial structures upon GHG emissions in the Walloon Region. The rationale of the research is to provide regional authorities with up-to-date figures about the long-term influence of land planning decisions upon energy consumptions and GHG emissions, both in the residential building stock as well as for home-to-work commuting. Ultimately aspects covered by the research should cover both direct consequences (increase of travel distance due to sprawl f.i.) and indirect ones (brakes to the deployment of renewable technologies due to low building density f.i.) in a prospective approach at a 2040 horizon. This first year of research focused most especially on direct relations, considering ex-post factors: *what has been the impact of the past evolution of the territorial structure on building and energy consumptions in the Walloon Region?*

Territorial structure is here addressed via three main variables: the location of households, employment and mobility infrastructures (road, bus, train). Following Newman and Kenworthy [1], it is considered that the combination of these three variables is, first, a structural property of the territory that may affect energy use via its incidence on mobility and housing consumption patterns. Increasing household densities generally implies more compact buildings (terraced houses and apartments), which tends to lessen energy losses. Mixing employment and households allows the latter to find a job at closer locations, which may reduce their work travel distances as well as travels related to shopping, leisure etc. Obviously it should be acknowledged that there is an important behavioral dimension in this relation [2]. The proximity of jobs does not constitute a guarantee that households will effectively select a job nearby home. Developing the analysis on a statistical basis allows to highlight empirical trends in the relation between these variables and observed behaviors.

The combination of these three variables is assumed to be an element that can somehow be handled by urban planning policies. Even if one can consider the effective influence of urban planning upon employment and household locations with modesty or even criticism [3], it should be acknowledged that planning policies, at a European level, led to quite striking differences at this respect. This is particularly the case when one compares land occupancy in Belgium and the Netherlands, two neighboring countries with quite a different trajectory in terms of urban sprawl and mixed-used developments. These policies can only affect settlement patterns on a longer term, given the inertia of territorial structures, which pleas for a consideration of these effects at a 2040 horizon.

METHODOLOGY

The overall methodology of the research is based on spatial correlations between energy performance indicators (for both mobility and residential building consumptions) with territorial variables (density, mixity, job/housing ratios, accessibility to public transport and road infrastructure) at a very disaggregated scale. Quite importantly it should be stressed that, by contrast with Newman and Kenworthy well known approach, our analysis has been entirely conducted at the regional scale (16.844 km^2) and includes both urban, periurban and rural settlements.

For home-to-work commute, the model has been based on the general survey realized in Belgium every 10 years amongst all citizens more than 16 years old. The survey provides figures about distance travelled by citizens and their mode choice at the statistical unit level. This data has been used to build a mobility energy performance index, following Boussauw and Witlox [4]. It has been calculated for 1991 and 2001, corresponding to the last two general surveys in Belgium. The following conversion table has been used for estimating kWh per travel and passenger for the different travel modes.

Mode	GWh	%	kWh/pkm	Teq.CO_2	%	geq.CO_2/pkm
Car	18722,0	94,4	0,45	4894,7	94,9	118,3
Moto, scooter	251,4	1,3	0,41	64,6	1,3	105,0
Bus, tram, metro	417,6	2,1	0,35	93,7	1,8	79,5
Train	451,1	2,3	0,15	104,4	2,0	35,7
Bike	-	-	-	-	-	-
Walking	-	-	-	-	-	-
Total	19842,1	100	-	5157,5	100	-

Table 1: Specific energy consumptions and CO_2 emission per mode in the Walloon Region

This table is based on regional energy accounts, figures for distance travelled by mode as well as conversion factors for electricity to CO_2 emissions provided by electric companies. It does not take into consideration known variations between public transport emissions/energy consumptions according to their occupancy. It is hence unfavorable to urban transports, which have higher occupancy rates than rural ones.

For residential building consumptions, the model has been based on combining cadastre surveys with buildings heights provided by digital photogrammetry, for some 850.000 residential buildings in the Walloon Region (namely 85% of the residential building stock). As the cadastre provides the age of buildings, this variable was used to estimate envelope and heating system performances for each building. This approach was also used by [5] and [6]. Thermal needs of buildings were estimated via a conventional method [7].

Building period	U Wall (W/m^2K)	U Window (W/m^2K)	U Roof (W/m^2K)	U Floor (W/m^2K)	Ventil. rate (V/h)	Window %
<1945	2,2	3,3	1,6	1,9	1	24
1945-1970	1,4	3,3	1,4	1,5	1	27
1971-1985	0,8	3	1,0	2,4	0,9	25
1986-1996	0,5	2,6	0,9	0,7	0,9	25
1997-2010	0,5	2,4	0,7	0,7	0,7	26

Table 2: Thermal performance of envelope for different building periods in the Walloon Region

Building periods were designed so as to match with important technical/thermal turning points, as for instance the adoption/changes of thermal regulation in the Walloon Region (in 1985, 1996 and 2010). Table 2 provides an overview of thermal performance parameters used in the model. It is based on the most recent housing survey realized in the Walloon Region, which provides information about insulation of buildings for a sample of 6.000 housings [8]. It hence includes information about renovated buildings. It can be seen from the table that wall, slab and roof performance of residential buildings in the Walloon Region are quite poor for older buildings. It should be stressed at this stage that some 52% of the housing stock in the Walloon Region is older than 1945.

Both analyses are conducted at the scale of statistical units, namely the most disaggregate spatial unit for collecting statistical data in Belgium. The territory of the Walloon Region is covered by 9.876 statistical units. The area of statistical units is varying between 1,3 ha and 5 834 ha with a median value of 47,7 ha, which corresponds to a circle of a bit less than 400 m radius. Statistical units correspond to neighborhoods in urban areas and encompass large depopulated zones in rural areas.

Home-work commute consumptions

The analysis highlights an increase of 20% in CO_2 emissions per person and travel in the Walloon Region between 1991 and 2001. This is mainly due to the strength of sprawl and a modification of employment catchment areas. It is striking to note that amongst the 20 municipalities which witnessed the most important increase in their emission related to mobility, 18 of them are localized in the south of the region and somehow polarized by the city of Luxembourg.

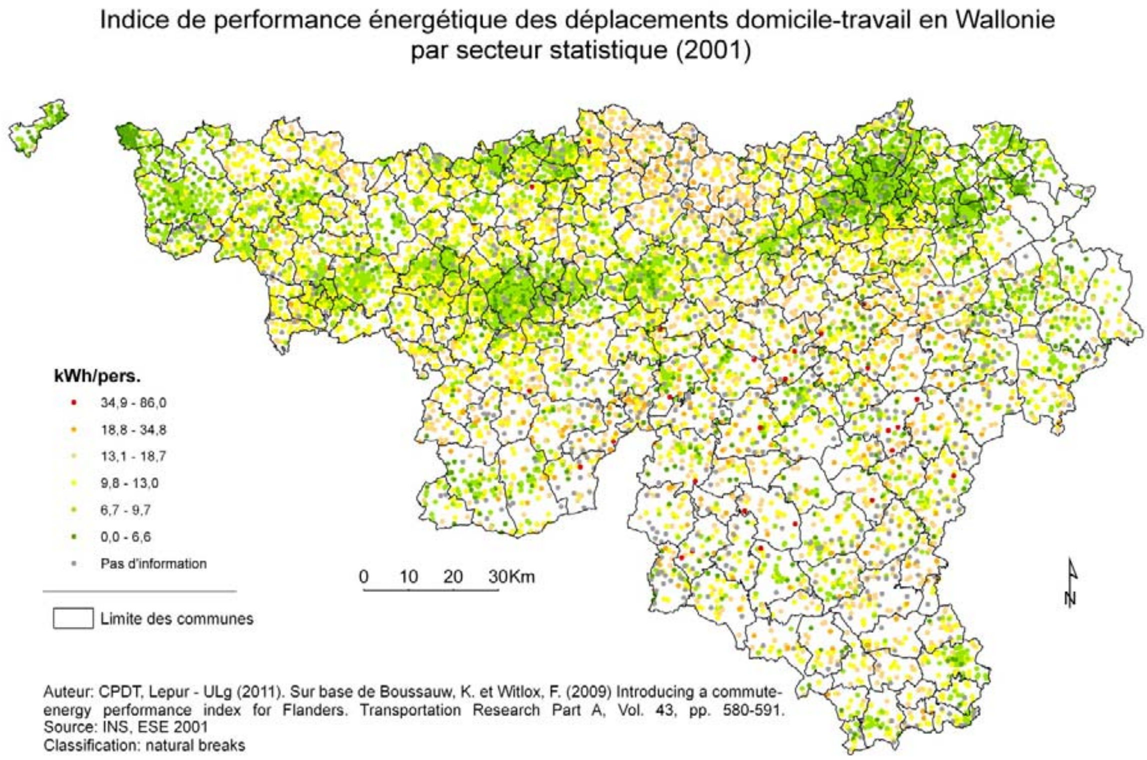

Figure 1: Energy consumptions per travel and person for home-work commute in the Walloon Region at the statistical unit level

Figure 1 highlights that urban areas are characterized by lower energy consumptions and CO_2 emissions and, at the opposite, rural and periurban areas by much higher energy consumptions. The issue of periurban areas is especially challenging since they now gather important volumes of population. Some of these areas witnessed a decrease or stabilization in their CO_2 emissions over the 1991-2001 period, due to the relocation of jobs outside Brussels.

In terms of urban planning, this should lead to contrasted solutions in these different urban patterns. Even though urban areas have better performances than rural and periurban areas, energy consumptions per travel and passenger should still be reduced as they concentrate a large share of the population. At the opposite population growth in remote rural areas should be contained as it usually leads to important and long car travel distances. Finally, in periurban areas, a combination of reconcentration of housing and economic activities around efficient public transport hubs is probably the best option to curb the actual mobility and CO_2 emission trends.

Residential building consumptions

When considering the entire housing stock, annual consumptions by floor square meter appear largely related with the age of construction, though they are also influenced by urban compactness and climate factors. Quite strikingly it appears that old urban areas generally have better performances than more recent periurban areas (Figure 2), especially for those buildings that were erected before 1985 at a time when there was no regulation on thermal performance of buildings. This period corresponds to an f intense sprawl in the Walloon Region. The thermal performance of existing residential buildings is very poor, with a mean annual consumption of some 350 kWh/floor m^2 (standardised consumption along standard calculation).

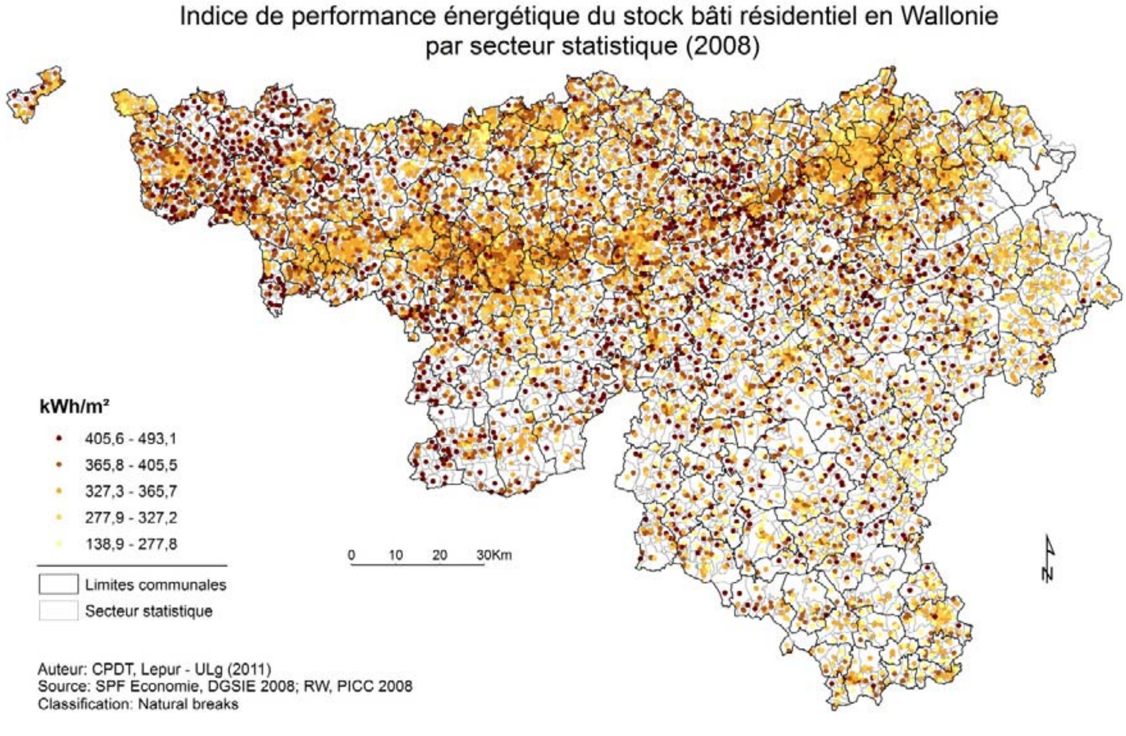

Figure 2: Energy consumptions in residential buildings in the Walloon Region at the statistical unit level

In dense urban areas, where the network of streets and buildings is now consolidated, improving the performance of buildings should now be an objective fully integrated within all urban regeneration policies. By contrast, in periurban areas, improving building performances could rather be achieved through demolition/reconstruction operations, especially in those cases where densification proves to be an interesting option when they have a due access to public transport, services, etc.

Residential vs. Mobility consumptions

As documented by the literature, it appears that these two indicators are both correlated to human density —as defined by Fouchier [9]— and mixity. Still correlation factors are rather weak (Table 3). Mobility performances are better correlated to mixity than to density, although these two variables are themselves correlated. By contrast, residential building performances are better correlated to density, which is linked to compactness, than to mixity.

	Net human density inhabitants + jobs per ha	Net functional mixity nb of functions in the vicinity
IPE mobility (kg éq CO_2/trip)	-,483**	-,504**
IPE buildings (kWh / floor m²)	-,603**	-,545**

Table 3: Correlation test between indictors of density and mixity with energy performance indices (**) Correlation significant at 0.01 (2-tailed).

These results somehow ponder assertions by Newman and Kenworthy, linking energy performance of cities to the sole density. First, because there is a very important variance amongst statistical units along the observed trend: low density units may be characterized by very good performances. Additionally, it stresses the importance of mixity besides density for understanding and influencing travel behaviors.

Finally the performance of statistical units along the two dimensions observed until now can be crossed for the entire region (Figure 3). These units have been classified along their belonging to a hierarchy of 8 classes of municipalities in Belgium [10], according to their size and level of equipment (presence of higher education, metropolitan services, schools etc.).

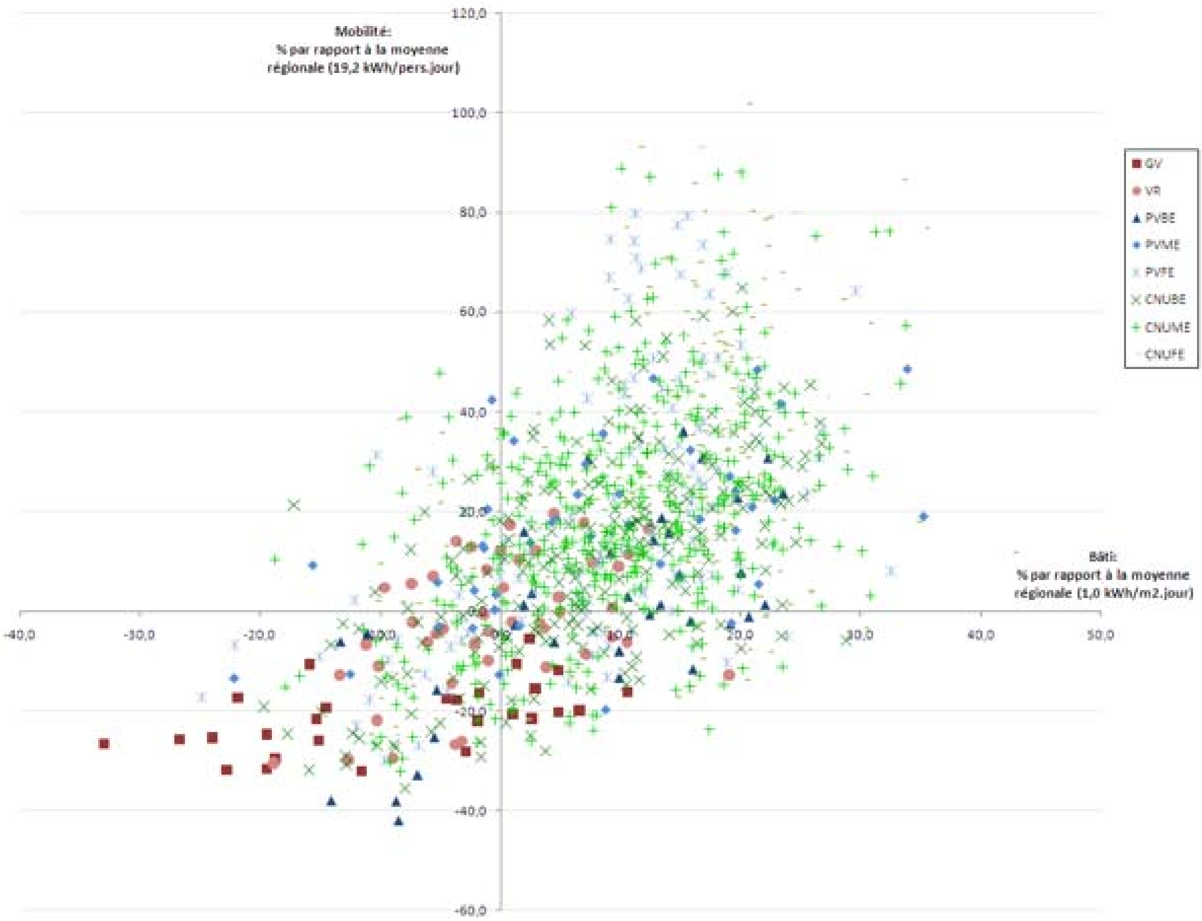

Figure 3: Scatter of mobility and building performance indicators along the hierarchy of municipalities established by Van Hecke[10] for Belgium. GV= Large city; VR = Regional city; PVBE = Small city with good services; PVME = Small city with medium services; PVFE = Small city with poor services; CNUBE = Rural municipality with good services; CNUME = Rural municipality with medium services; CNUFE = Rural municipality with poor services

In general terms, it appears that those sectors that perform well in terms of mobility also tend to perform well in terms of building consumption and that the reverse is also true. Additionally, most rural settlements have higher than average consumptions both for mobility and building. Finally and most importantly, good performances are observed in all 8 types of human settlements (urban, rural and periurban ones), depending on the distance to employment centers and specificities of the urban pattern.

CONCLUSIONS

A method for a combined analysis of building and mobility performances has been established and applied to statistical units in Belgium. Results indicate that these performances are closely related to the nature of the statistical unit, both in terms of density and mixity, and that performances along these two axes are closely related. Still the analysis further highlights that statistical units with higher than average performances can be identified in all types of settlements, may these be urban, periurban or rural.

This opens an avenue towards a much more progressive approach in terms of spatial planning, where compact cities may be viewed as part of the solution, still not the whole solution. Indeed, planning policies should be tailored to each settlement types in order to curb progressively the entire scatter of points of Figure 3 towards the lower left side of the graph rather than through a very hypothetical and unrealistic claim to concentrate the population in compact cities. This way of planning, based on sharing efforts by all settlement types, is especially pertinent when one considers the entire territorial structure of a region and its strong inertia over time.

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How Shopping Online can Modify the Mobility of Private Individuals and Reduce the Environmental Impacts Linked to Transports

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Abstract

This paper presents the results of an extensive analysis comparing the private individual movements linked to purchases in the « classic market » (retailers, hypermarkets, etc.) to the online market deliveries (hereafter : e-retail).

On the basis of a poll made on 5400 deliveries in France, we were able to compare the distances run by delivery vehicles, with the round trips that customers would have had to make to get the equivalent goods by visiting real shops.

This study shows that on average, e-retail services may allow customers to divide by 3 the CO_2 emissions bound to the movements for purchases.

This impressive outcome is mainly owed to the replacement of very numerous personal movements by optimized buckles of delivery.

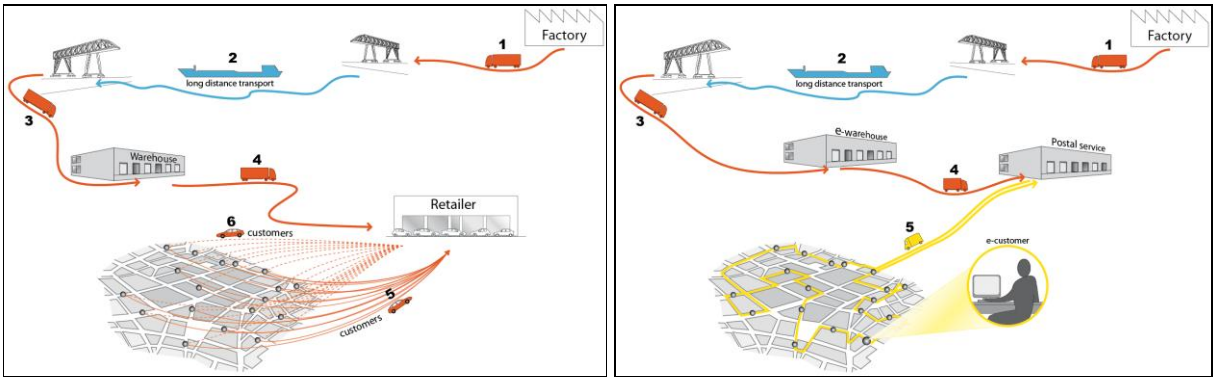

Figure 1 : Schematic description of the circuits intended by the two models.
Right : Classic retail circuit *Left : e-retail circuit*

This work emphasizes how a well organized postal service and dense parcel shop networks can contribute to a re-organization of the consumers' behaviour by the suppression of a great number of car movements inside and outside cities.

Introduction

This paper presents a work realised by Estia in 2009 on behalf of the French federation for e-business and remote sales (FEVAD). The results rely on a specific survey realised by Médiamétrie//NetRatings to characterize the movements of the Internet users. This study was supported by ColiPoste, the French leader in express parcels and Kiala, the European parcel shops network [1]. Mazet International was our partner to characterize the logistic scheme of classic retail model.

This study allowed us to measure the environmental benefits linked to purchases realized online compared with the ones realized in the classic retail market. It emerges that the purchases on Internet present multiple interests from the environmental point of view.

The principle was to compare the movements linked to the deliveries of goods/services ordered online with the movement that would have been necessary to get the same goods/services in the classic retail circuit.

We took in consideration the following specific distances :

- Distance run by the carrier between the last deposit and the client's home
- Distance run by the client between to go to the retailer or the post office

In order to take into consideration the whole supply-chain, we also took into account the upstream part of the logistic (from the production place to the first storage, and then from this initial storage towards the final destination (classic shop, parcel shop or Post-Office).

METHODOLOGY

Upstream movements

We took 3 different upstream circuits into consideration, according to the place of production of the goods:

- Asia : Nanjing
- East Europe : Gdansk
- France : Clermont-Ferrand

For each scenario, we have considered that the good was first forwarded towards an "Initial warehouse" located "somewhere" in the Paris region.

National movements

1. **Secondary supply :**
   For both classic and e-retail modes, we took into consideration the transfer of the product from the initial warehouse towards a "regional" one.

2. **Final supply :**
   For the e-retail model, two scenarios were taken into consideration
   - Transfer from the regional warehouse towards the postal sorting centre corresponding to the client address (according to the classic path followed by the parcels delivered by the French Post)
   - Transfer from the regional warehouse towards the parcel shop chosen by the client (according to the path followed by the parcels delivered through the "Kiala" circuit).

   For the classic retail model, we have considered the road followed by a good transported from the "initial warehouse" towards a regional warehouse, then towards the final shop, by a chartering company (Mazet)

Last km

The so called "Last km" corresponds to the final segment of the goods movement.

In the classic retail model, the customer makes a round trip between his place of residence and the store. For this study, the clients were asked to describe the movement they would have made to get the same good in a classic shop of their knowledge.

For the e-retail model, 3 scenarios were considered

1. Home delivery by the Post,
2. Withdrawal from the parcel shop chosen by the customer,
3. Withdrawal form a "classic" shop (in that case, the customer placed his order by Internet and went to remove the product in a classic store).

Questionnaire

Mediamétrie//NetRatings asked a panel of Internet users to describe their last three online orders (during the last 6 months).

- 2'056 buyers of 18 and more years old described 5'437 deliveries or orders (as shown on *Figure 2* hereafter, a delivery may include several products).
- The answers concerned all the categories of available products on the Internet.

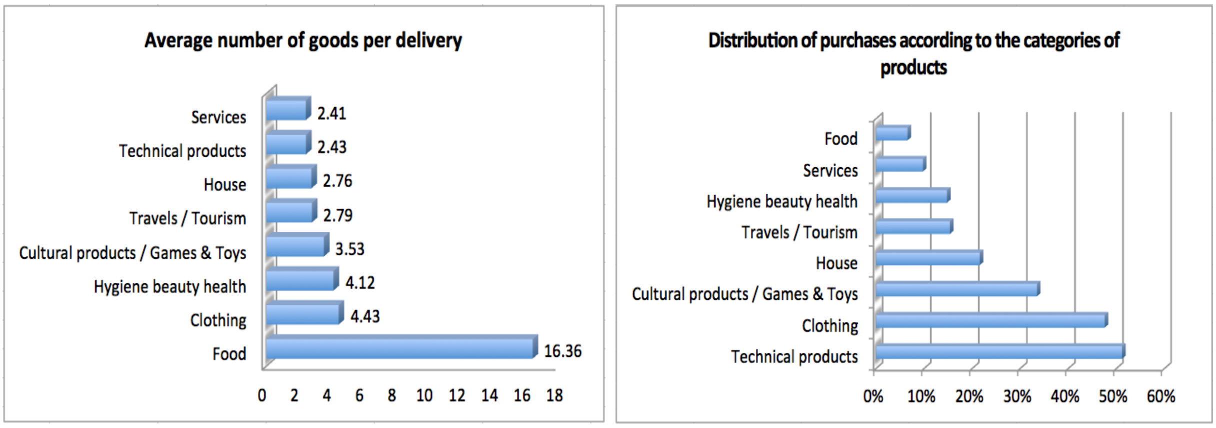

Figure 2 : Distribution of the deliveries that were taken into consideration for this study.

Environmental analysis

For each scenario, the environmental impacts (climate change, resources, noise, impacts on human health and ecosystem quality) were assessed with the Estia-VIA® method [2]. The emission factors were issued from the ecoinvent database [3], [4] and the Impact 2002+ method [5] (this paper focuses on CO_2 emissions, please refer to [1] for the other environmental aspects).

The functional unit used within the framework of this study is tonne.kilometer (tkm), and the average parcel weight is 1.7 kg.

RESULTS

Upstream movements

This is not a surprise to see that the further the product comes from, the higher the CO_2 emissions related to its transport are (see ***Figure** 3*, left part).

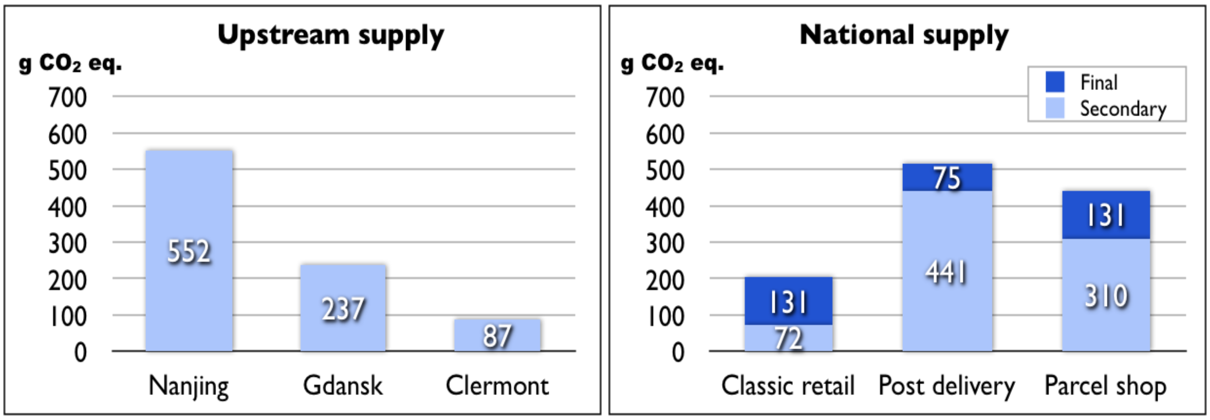

Figure 3 : CO_2 emissions due to the « Upstream » and « National » parts of the supply chain.

Left :The CO_2 emissions is directly linked to the provenance of the product. *Right :Thanks to higher payloads, the classic retail circuit is more efficient.*

It is more surprising to notice that the efficiency of the supply-chain of the classic circuit is significantly better than the e-circuit one (see ***Figure** 3*, right part). This is mainly due to the fact that the average payloads are much higher. In addition, within the e-circuit parcels are transported in heavy trolleys, while in the classic circuit, products are transported on palettes.

<u>Movements linked to the e-business model</u>

For each of their delivery, the clients were asked to describe how they got their product(s) (home delivery, withdrawal from the post office or a parcel shop in the neighbourhood, etc.).

Figure 4*Figure 4* hereafter shows that only 18% of the deliveries (withdrawal in a Post office, a parcel-shop or a classic shop) required a movement from the client. This shows that Internet orders allow, in most of cases, avoid to the customers to move. Here relies the main advantage of the e-retail mode as far as each spared movement corresponds to a reduction of the CO_2 emissions linked to the "last km" segment.

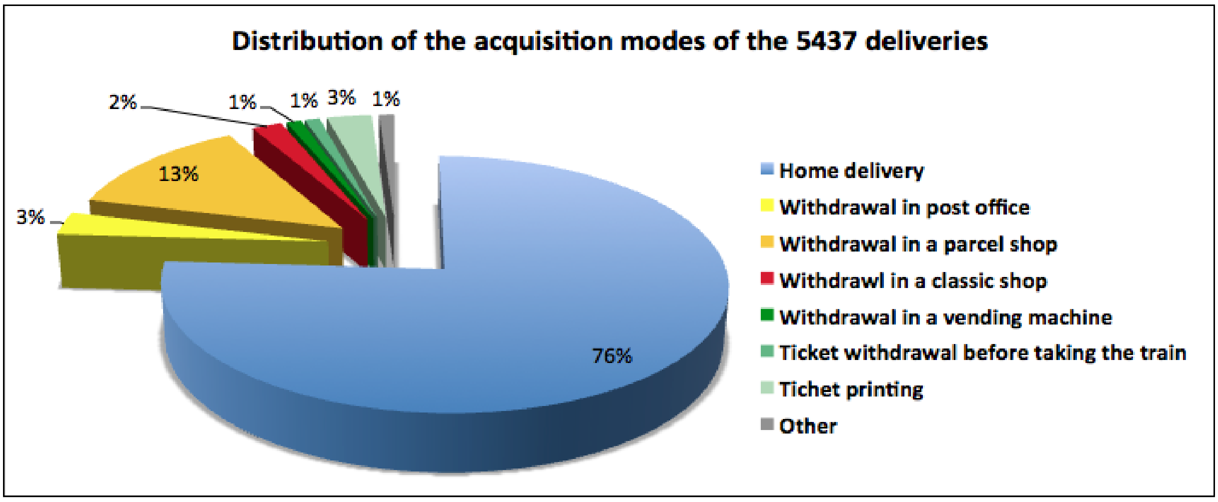

Figure 4 : Distribution of the acquisition mode of the 5436 deliveries.
In most cases, the e-business model implies no specific movement to get the ordered products

<u>Means of transportation</u>

Apart from the fact that most of e-customers do not have to move to get their parcel, ***Figure 5*** shows that those who have to (18%), less use their car and walk or cycle preferably (compared to the classic retail customers).

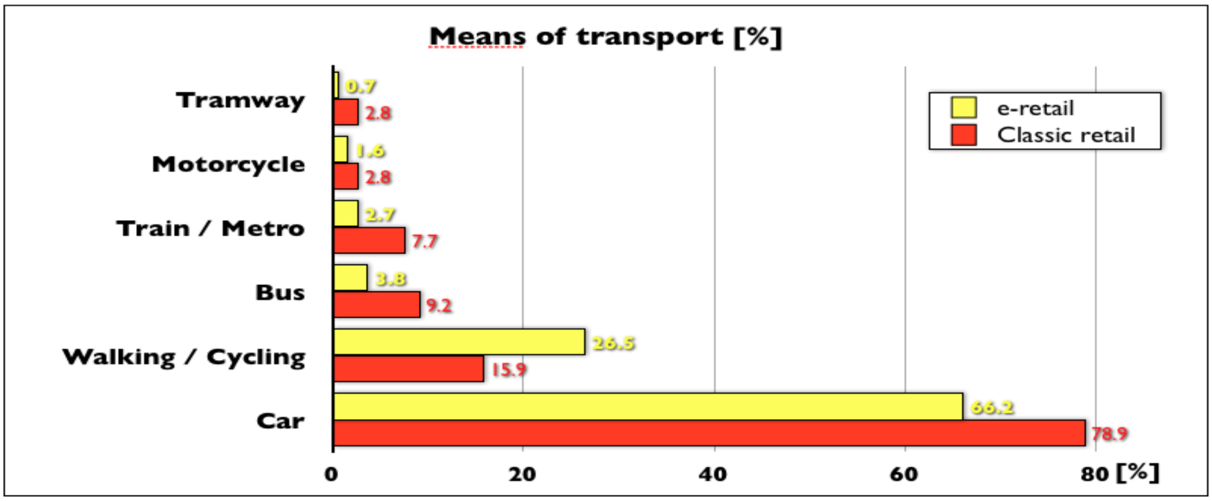

Figure 5 : Means of transport used by the clients.
In the classic retail circuit, most of people would have used their car. Moreover, the part of « walking and cycling » is much lower that in the e-model.

Distances

e-retail : The cumulated distance run by the e-customers who had to move to get their products (all means of transport) is equal to 3'650 km, which gives an average distance of 3.7 km per customer.

Classic retail : The cumulated distance that would have been run to get the same products in the classic retail circuit is 57'129 km (all means of transport), Which gives an average distance of 13.8 km per order.

This comparison gives an average value of 10.9 km spared for each delivery with the e-retail.

Climate change

Last km

Figure 6 shows that on average, for a "standard" parcel, the e-retail circuit leads to divide by 8.4 the CO_2 emissions due to the "last km" movement respectively 283 g eq. CO_2 versus 2381 g eq. CO_2). This reflects the potential of performance of this new consumption pattern which allows to avoid the movements of private individuals.

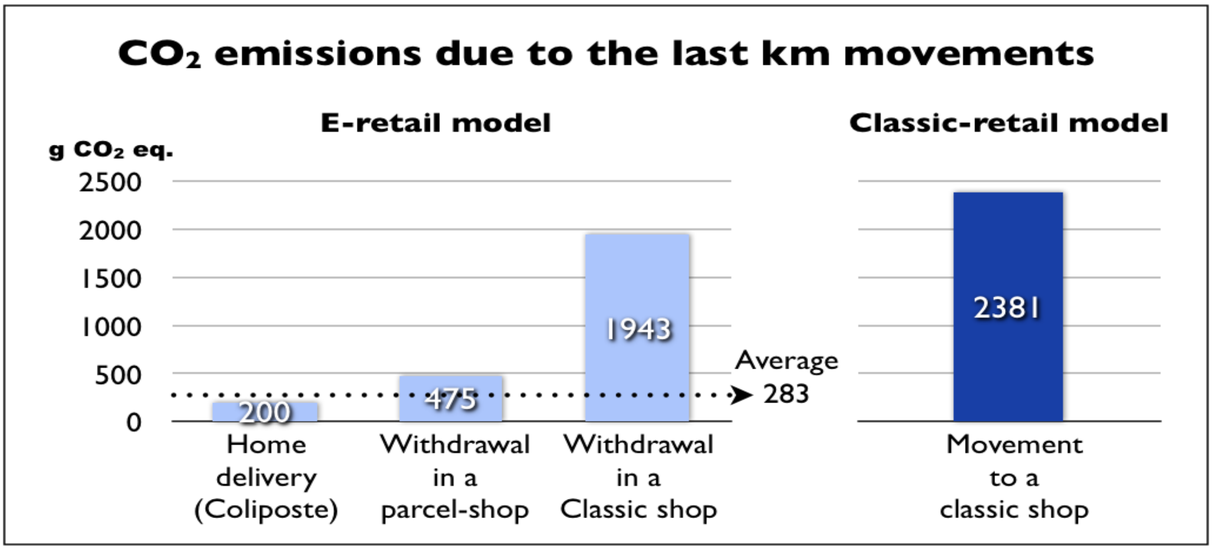

Figure 6 : CO_2 emissions due to the last km movements.
The average value for e-retail is 283 g eq. CO_2 per delivery.
This has to be compared to the 2381 g eq. CO_2 in the classic retail circuit.

Internet connection

To take into account the CO_2 emissions linked to the use of the Internet, we may refer to the 7g to 10g for a 15 minutes Google search mentioned in [6]. Even if we multiply by ten this additional emission, this is far to question the environmental benefits linked to the e-retail model (see *Figure 7*).

Global performance

If we take into account the CO_2 emissions due to the final part of the upstream logistic chain, the difference between the two models still remains very impressive (see ***Figure** 7*.) The right part of the figure shows that even if the products come from China, the efficiency of the e-retail on the « last km » segment leads to a division by 2.2 of the CO_2 emissions due to the global transport chain.

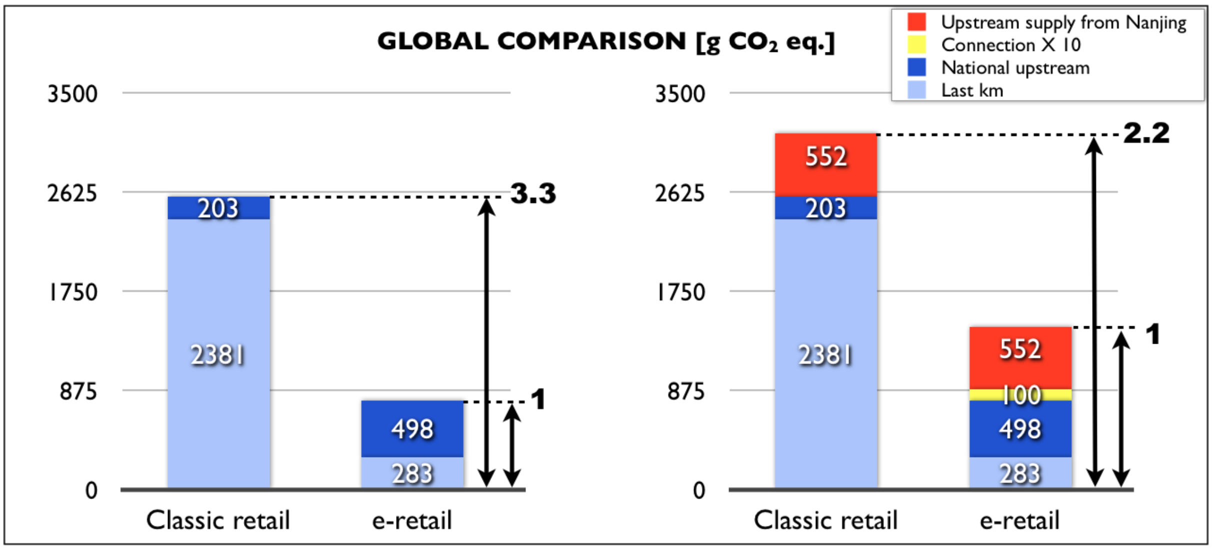

Figure 7 : Global comparison of the CO_2 emissions linked to the two models of distribution.

CONCLUSIONS

This study tends to confirm that the "last-km" is the biggest contributor to CO_2 emissions linked to purchase and that "e-retail" constitutes a serious opportunity to reduce our carbon print and to get closer to the objectives of the "2000 watts society" [7].

Besides that, if we consider other environmental aspects like land-use, it is not unreasonable to think that the development of this model could have a strong beneficial impact on the urban and country planning. A logistic platform is much smaller than a shopping centre, and does not require big car parks to welcome the customers' cars.

Moreover, as it is not necessary to display the products, the potential for energy savings in both lighting, cooling and heating is very important. These points should be carefully taken into account in further studies on this topic.

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IMPACT OF VEGETATION ON THERMAL CONDITIONS OUTSIDE, THERMAL MODELING OF URBAN MICROCLIMATE, CASE STUDY: THE STREET OF THE REPUBLIC, BISKRA.

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ABSTRACT

Urbanisation can only grow because of population growth and ongoing population movements. Expressing interest in urban microclimate on the thermal conditions outside is very important in this period of warming climate began.

The presence of trees leads to cooler areas in the urban environment. The parks contribute significantly to the reduction of air temperature. Three specific effects of vegetation shade, evapotranspiration and the effect of natural ventilation. In contrast to mineral surfaces, green spaces only store little heat and humidify the atmosphere through important evaporation, thus greatly reducing the air temperature. Evapotranspiration is defined by the loss of water to the atmosphere by evaporation and transpiration. The urban development projects can significantly change the image of a neighbourhood or town. In the city, the microclimatic component can unite several actors (architect, planner, landscape, political, developer, engineering firm,) advocating an interest in energy savings for the adjustment of thermal conditions of the urban space and the improvement of life. These components have largely been put forward when we discussed the relationships between vegetation and the city. Nevertheless, as we shall try to demonstrate this aspect in the plant site (garden 5 July - checker colonial) leads us to illustrate clearly the benefits of vegetation in urban areas. The trees act as a mask to sun and wind and as a source of control of the air temperature and the temperature of the surrounding surfaces. The effectiveness of these spaces depends on their density, shape, size and position. Mitigation of air temperature in the presence of trees can be explained by the decrease in surface temperature that induces a lower air temperature [1].

To know the real impact of vegetation on air temperature, thermal modeling work was necessary, was carried out on the street of the republic located in the checker colonial, flanked on one side by the garden 5 July, and another side by buildings, located in the center city of Biskra (Algeria) and spread over a typical summer day with a three-dimensional numerical model called "ENVI-met3".

Key words: Urban microclimate, thermal conditions, vegetation, thermal modeling.

INTRODUCTION

The cities will have to prepare for climate change: fabric dense urban vegetation will reduce the harmful effects of air warming.

In terms of protection from nuisance, the interests of vegetation are numerous: Reducing air pollution and improving air quality by attaching some dust, decreasing the effect of runoff by intercepting rainfall, protection against erosion due to wind and water.

OBJECTIVES

- Get really quantifiable improvements microclimatic characteristics of cities in warm climate conditions by introduction of vegetation.

- Determine the impact of vegetation on the urban microclimate by using a numerical modeling technique.

METHODOLOGY

When we discussed the relationships between vegetation and the city, we shall try to analyse and illustrate clearly the benefits of vegetation in urban areas.

The impact of vegetation can be quantified at different levels. Indeed, the consequences of this presence in the plant reflect microclimatic scale in terms of quantity of transmitted radiation, temperature of the air and plant leafs, humidity of the air and wind speed. To know the real impact of vegetation on air temperature, thermal modeling work was necessary. It was carried out on the street of the republic and spread over a typical summer day July 27th, 2009 (day included in the zone of overheating in the city of Biskra). The climatic conditions of the considered site are subject to arid climate. In the context of studying the impact of vegetation on the urban microclimate, it is interesting to see a reference situation (the current situation of the garden with vegetation). Thus, we considered the case where the garden is without any vegetation where trees are removed (the empty situation), so as to understand the consequences due to vegetation on the current situation.

The investigation is based on a three-dimensional model ENVI-met3 which simulates the microclimate conditions in an urban environment with high spatial resolution of 0.5 to 10 m and temporal 10sec. It is a 3D simulation model developed for numerical modeling of urban microclimate and again the majority of atmospheric processes that affect the microclimate. To define the height and the shape of a plant, the model uses standard normalized functions (Leaf area density profile LAD, Root area density profile RAD) which can be applied for grassy surface as well as for huge trees. The gas and heat exchange between the vegetation and the atmosphere is controlled by the local energy balance steering the leaf temperature and by the stomata conductance controlling the gas exchange (vapor and CO_2). The actual stomata conductance of a plant is a complex function depending on external meteorological conditions (air temperature, available solar radiation and many others) as well as on the plants physiological processes (Photosynthesis rate, CO_2 demand, CO_2 fixation...). ENVI-met3 uses a sophisticated model to simulate the stomata behavior of the vegetation.

RESULTS

A) The transmitted radiation

The calculation of direct and diffuse solar flux and global radiation in the empty situation (without vegetation) and the current situation (with vegetation) in a condition of clear sky is possible for the period of the study (Figure 7).

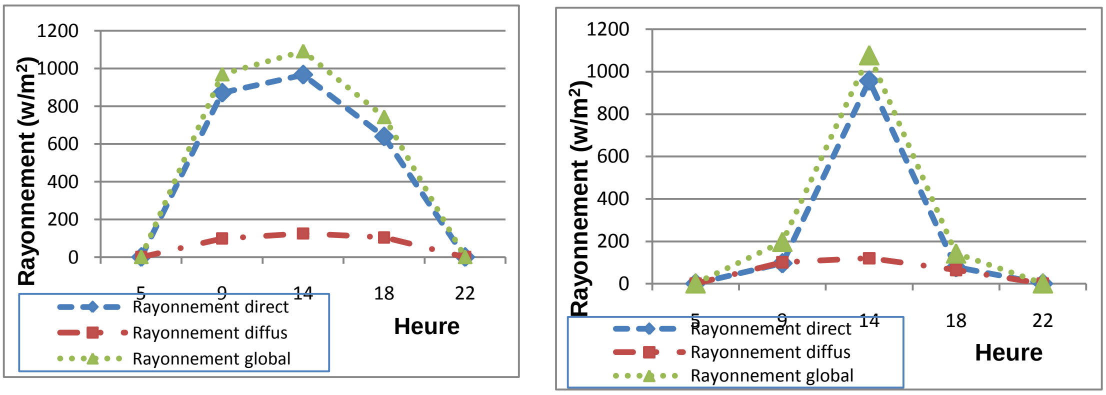

Figure 7: Incident solar flux transmitted the empty situation (right), the current situation (left). Source: ENVI-met3. Read by Leonardo3.

The global radiation values obtained by simulation we allow then to establish the following graph:

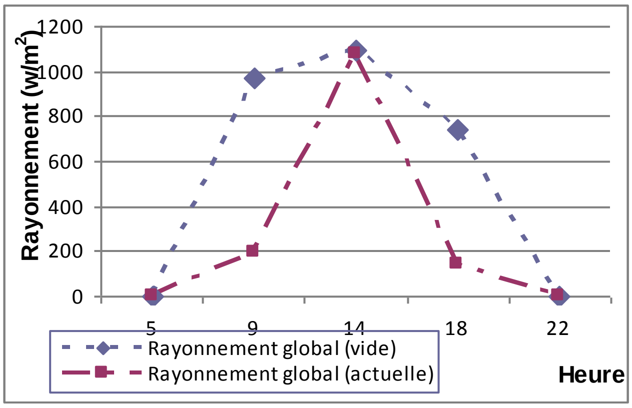

Figure 8: Incident solar flux transmitted, both empty and current situations. Source: ENVI-met3. Read by Leonardo3.

The densification of the vegetation causing profound changes regarding the incident solar radiation transmitted to the street level and especially next to the garden. The differences in global radiation are high between the situation without vegetation and the current situation (with vegetation); the incident solar flux transmitted into the empty situation is very high compared to the current situation. In the empty situation the incident solar flux transmitted may exceed 800 W/m^2 compared with the current situation (at 9h:00). Direct action due to the shade of trees results in a decrease in surface temperature, an indirect effect of district cooling can occur while increasing vegetation cover [1]. We can also see in both situations, overall radiations are almost equal at 14h:00 (1091.73 w/m^2) influenced by the sun azimuth during the summer and the temperature of the warmest day so the whole street becomes sunny in the empty situation (without vegetation) and in the current situation (with vegetation). The impact of trees on the microclimate is one that causes the greatest impact on characterization of thermal conditions in outside space.

B) Air temperature

We traced the evolution of air temperature in the empty and the current situation and at the surface of leafs throughout the period of the simulation. Variations in air temperature between the empty situation (without vegetation) and the current situation (with vegetation) indicate that there is a maximum deviation between the two air temperatures equal to 6.57°C (at 14h: 00) (Figure 9). The average maximum temperature of air is 1.92°C recorded at 5h: 00. The average minimum temperature of air is 5.04°C recorded at 22h:00. The leaf temperature is lower than the air temperature; the difference between the two temperatures is high: 1.89°C at 5h:00 and 1.88°C at 22h:00. The temperature of the leaves in the ENVI-met3 model is calculated by solving the energy balance of the leaf surface with respect to the actual meteorological and plant physiological conditions. Turbulent fluxes of heat and vapor are calculated from the given wind field and the geometry of the plant. The calculation of radiative fluxes includes the shading, absorption and shielding of radiation as well as the re-radiation from other plant layers.

A study was conducted in the city of Gothenburg from June to September 1997 [2], the difference in temperature between the surroundings and the park reached a maximum of 4.7°C, the average gap is about 3°C. The tree representing a heat sink while maintaining a temperature which heats up very little compared to other surfaces exposed to solar gain. According to [3]**,** the contribution of vegetation in urban environments with little vegetation offers significant gains in freshness. Also, a row of trees decreases the temperature of the surrounding air by 1°C.

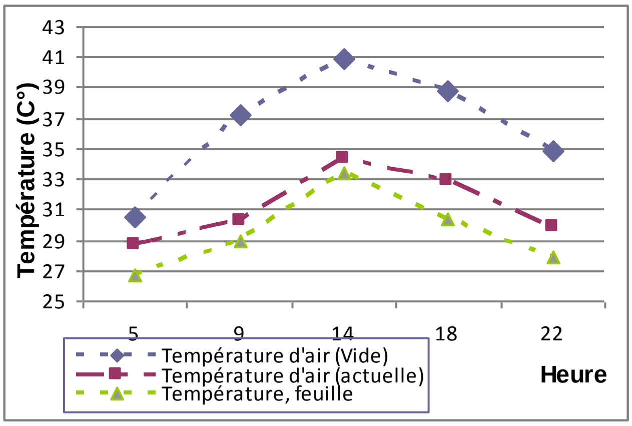

Figure 9: Temperature of air, both empty and current situations. Source: ENVI-met3. Read by Leonardo3.

C) Humidity

The 5 July garden is dense space. Water in the soil and in the evaporation surface helps to fresh the air [4]**.** Thus, vegetation, leaf transpiration, contributes to evapotranspiration and thus the refreshing air. The evapotranspiration of a tree can reach up to 400 liters per day, which represents a cooling effect equivalent to 5 units for 20 mean hours in hot and dry climate [5]**.** In our study, the absolute humidity in the current situation is greater than the empty situation. (Figure 10) There is a difference of 0.4g/kg at 5h: 00 between the current situation and the empty situation, while this difference is 0.19g/kg at 14h: 00 and 0.29g/kg at 22h: 00. According to the graph, absolute humidity varies between 1.19g/kg and 1.21g/kg with an average of 1.20g/kg in the empty situation, however, varies between 1.59g/kg and 1.5g/kg with an average of 1.53g/ kg in the current situation. The graph shows that the most important value was measured at 09h: 00 (1.75g/kg), which marks the peak of the curve due mainly to the effect of evapotranspiration of vegetation; the air temperature at this time is equal to 30.2 ° C. The thermal environment expressed by the air temperature and absolute humidity, shows considerable variability. The current situation presents values of very high absolute humidity compared to the empty situation; the latter provides higher air temperatures. It may be noted an inverse correlation between the values of absolute humidity and the values of air temperature which means that an increase in air temperature causes a decrease of the absolute humidity and vice versa.

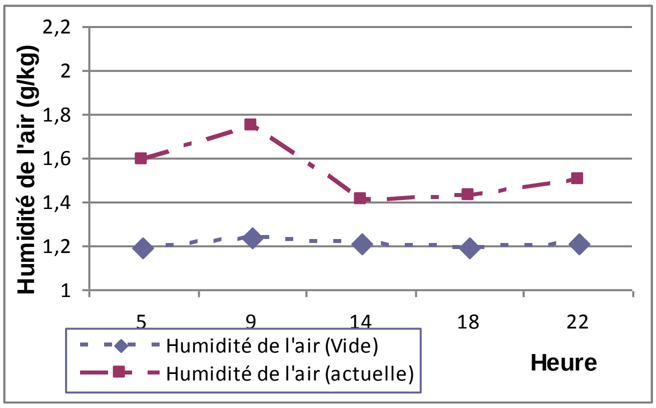

Figure 10: The humidity of the air, both empty and current situations. Source: ENVI-met3. Read by Leonardo3.

D) The wind speed

The wind speed in the current situation is much lower than in the empty situation. It may be noteworthy that in the current situation the wind speed reductions are observed when vegetation appears, because the street is oriented north west - south east opposite the prevailing wind direction which comes from the North West.

Other factors may help the spread of freshness created by vegetation, including wind: a large park located in an urban center upstream of the prevailing winds direction [6, 7]. In our study we recorded a value of 2.06m/s at 14h: 00 in the empty situation compared to the current situation where there was a value of 1.3m/s. (Figure 11).

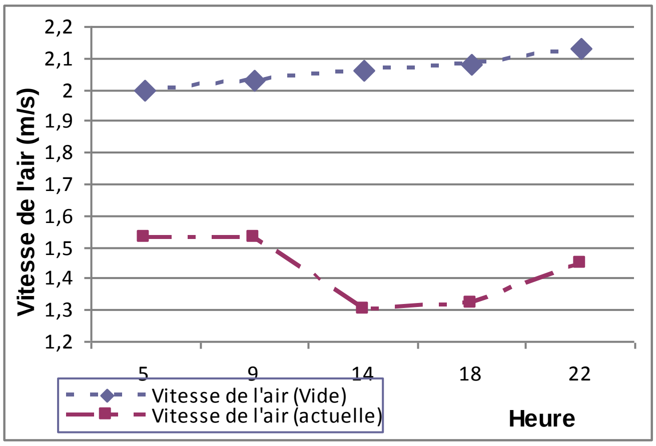

Figure 11: The wind speed, both empty and current situations. Source: ENVI-met3. Read by Leonardo3.

CONCLUSIONS

By altering the vegetation cover and climatic factors in modeling, simulations show us ways in which the thermal conditions of cities can be improved. Seen from the results of this study, the air temperature in the empty situation (without vegetation) changes significantly by contributing to the air temperature in the current situation with a maximum deviation between two temperatures of air equal to 6.57°C (at 14h:00). The existence of this result is followed by several parameters influencing directly the urban microclimate: The wind speed in the current situation is less than that of the empty situation, there was a value of 2.06 m/s in the empty situation compared with the current situation where there was a value of 1.3m/s at 14h:00. The absolute humidity in the current situation is greater than the empty situation. There is a difference of 0.4g/kg at 5h:00. Trees exhibit large leaf transpiration and provide shade to protect from direct and diffuse sunlight. The incident solar flux transmitted in the empty situation is very high compared to the current situation. In the empty situation the solar flux transmitted may exceed 800 W/m^2 compared with the current situation at 9h:00.

The vegetation is a key component of the quality of outside spaces. Indeed, vegetation helps cool the air. With the few lakes in the city, green spaces are the only evaporation surface in the city.

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THE ZIBAN AS SUSTAINABLE CITY IN THE SAHARA

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ABSTRACT

A sustainable city can feed and power itself with minimal reliance on the surrounding countryside, and creates the smallest possible ecological footprint for its residents. This results in a city that is friendly to the surrounding environment, in terms of pollution, land use, and alleviation of global warming.

The urban distribution of the region of Ziban was based on the potentialities of every grouping house, its palm plantation, its agriculture and quite other constituent elements of the socioeconomic development. The micro-region was distributed into Zabs, they are a set of small oases regrouped along the wadis, every oasis was independent economically and politically. Every oasis has its own architecture, its own devices and spatial organizations.

In front of the urban growth, the industrial attractiveness, the new administrative distributions, and the inappropriate organization politics; Ksour and dachra of these oases, real and effective illustration of pockets of less urban density eco-friendly, were abandoned and the rural exodus was the after effects that created an ecological imbalance on several plans: energetic, environmental, economic and social. Human concentration in any space exhausted of its resources, might be fatal.

This paper is a contribution of the definition and measurement of strategies towards building eco-friendly, and self sufficient spaces.

INTRODUCTION

The Ziban lies on the southeast of Algeria, at the southern foot of Saharan Atlas' mountain range. This site makes it deserving "The gate of desert" connotation and allowed the region to play through the different periods of its existence a role of encounter, exchanging [1] and transition between a well equipped north and a disinherited south.

The relief of this micro region is divided into four major groups: the mountain range and high plateaus, great plateaus; steppes and depressions. This whole is irrigated by a set of wadis that form the main gatherer of the Saharan Atlas' waters. [2]

1. MÉTHOD

A comparative and analytic approach that is based on the study of statistics of palm grove from 1904 to 2007.

1.1. LES ZIBAN SUSTAINABLE URBAN UNITS AND / OR POCKETS OF LOWER DENSITY ENVIRONMENTALLY ECO- FRIENDLY

The micro-region was divided into four Zab [3] which are a group of small oases clustered along the wadis, each oasis is independent economically and politically, [4] has its own palm groves, and cultural and architectural heritage. These agents have fostered the creation of small urban and self-sustainable units, such as Zab Biskra, Zab Guebli, Zab Dahraoui and Zab Chergui, the latter includes the area between the southern slopes of Aures and Shatt (shore) Melghir,to the east of Wadi Biskra. This zab is characterized by an agricultural nature rather than an oasis one. It includes about 25 Zab reigned by the capitals, Sidi Okba, Zeribet el-Oued and Khangat Sidi Nadji.

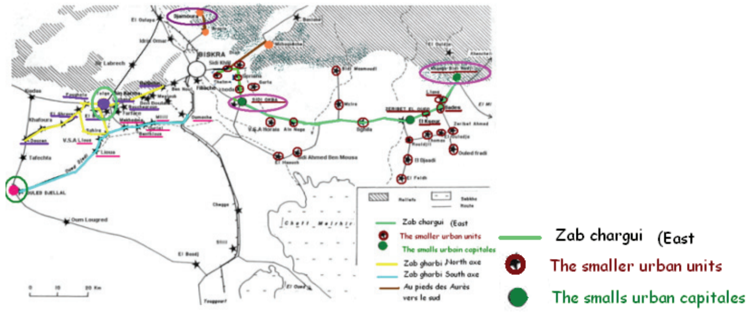


Figure 1: The smaller urban units and their Capitals. Source: Author & Dr. Alkama.

The Ziban are one of the best sustainable and urban forms in fragile-ecosystem oasis areas, through adaptation, environment respect and exchange of ecological advantages with this environment. [5] The palm tree, as a natural component, reveals beyond its economic and technical aspects; environmental and healthy criteria. [6

1.1.1. The palm capital of economic sustainability

Trade always had a significant place in the oases of Ziban, because of fertile soils and palm groves [4] which are the backbone of the oasis ecosystem, and also of the agricultural character of social life essentially by revealing:

- An ecological role allows to limit desert encroachment and to improve residents' incomes.
- The creation of a microclimate permitting the good development of underlying crops;
- Under these canopy of 20 to 30 m height , light creates luminous pleasant liveable atmosphere . Evapotranspiration and reduction of solar radiation produces a cooler climate and protects the soil which minimizes the solar gain.

Moreover, each Zab is characterized by a type of understory crops, the Zab chergui for instance had specialized, depending on the number of wells and the quality of soil, in winter and summer grain production, vegetable farming, and sometimes non-food plants. These features offer power and economic autonomy, as they allow the establishment of trade relations between the diverse regions of Ziban..

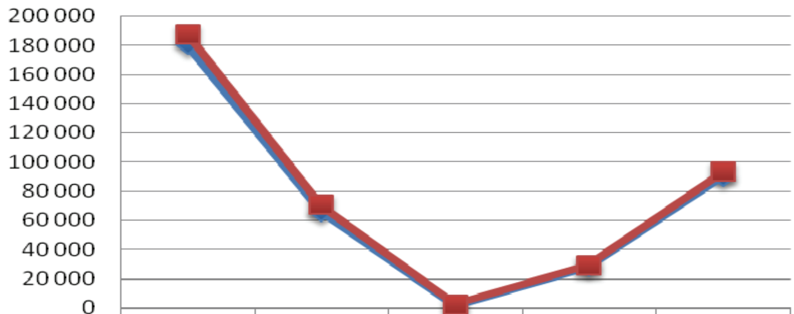
(a) (b) (c)

Figure 2 : human groups and their palm groves as a roof-ground, case of Chetma (a), Tolga (b) and Khanguet Sidi Nadji (c) Source: Google Earth (a, b)

1.1.2. The palm, capital of social sustainability

The date palm plays a major role in ensuring social stability of Zibanese oases population: it contributes in keeping knowledge and traditional skills that allow a judicious and sustainable use of natural resources, whether water in irrigation techniques, or biodiversity, in the choice of suitable cultivars.

To appreciate the importance of the palm tree, a comparison between population growth and palm groves in certain capitals of Ziban was established to come to Figure 3



	biskra	sidi okba	zribet Eloued	khanguet sidi nadji	Elkantara
population	7500	4400	1100	1100	3000
nombre palmiers	180 000	66 000	1 200	28 000	90 000

Figure 3: the relation between population and palm trees, examples of some capitals of Ziban, Source: Colonel DELARTIGUE [7]

1.1.3. The palm, capital of architectural sustainability

Ksour and dachra are traditional dwellings that meet climatic requirements through ingenious modes of construction, and reveal, in a subtle way, bioclimatic habitats patterns and the workings of the social organizations. [8]

The palm tree is a constructive element beside the stone, Toub, straw, soil and mud. The palm trunks offer planks of construction, poles, beams and lintels.

Figure 4 :The diversified usage of trunks (beams, spillways, fences, suspended ceiling) Source: Author **.**

After explaining how the Ziban illustrate the sustainable city in arid and semi arid areas, and after focusing on the principal component of this sustainability, which is the palm tree. The next part of this article explains the current situation of Ziban.

2. FINDINGS OF THE CURRENT SITUATION OF ZIBANS

The local architecture and palm trees are in danger of extinction in Ziban because of the following factors:
• The massive introduction of industrial materials, that are not familiar with the traditional constructive practice,
• The excessive incorporation of exogenous architectural types.
• The abandonment of a part of the housing and many traditional nuclei.

Meanwhile, we have noted that within 54% of the total lands of Ziban, 42% are agricultural lands and within the latter only 4% is planted. [9] The following curve and the integrated chart, clearly express the imbalance between an increasing population and a decreasing palmgrove.

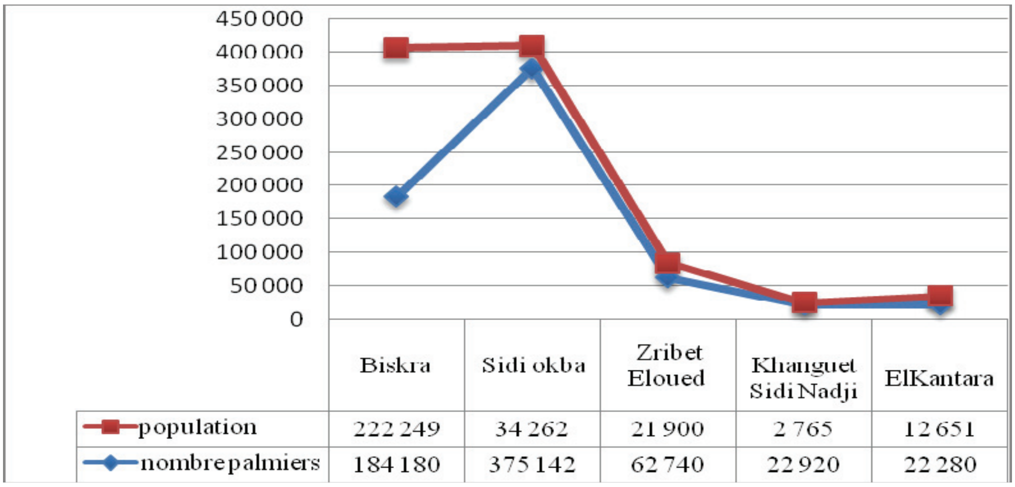


Figure 5: Relation population and palm trees, examples of some capitals of Ziban, Source: The 2007 Monograph of the wilaya

3.1. DATA ANALYSIS

The comparison between the curves of Figures 3 and 5 shows that there 's a ratio between population growth and its palm grove that has been unbalanced after the urban growth.

Capital	Ratio1904 palm/person	Ratio 2007 palm/person
Biskra	24	0.82
Sidi okba	15	10
Zribet Eloued	1	3
Khanguet sidi Nadji	25	8
ElKantara	30	0.82

Table 1: the ratios between the population and its palm grove before and after the growth!! in some capitals of Ziban,

From the curve of figure 5 there is a proportional relation between population and number of palm trees. A ratio of 19 palm trees per person was the result of the addition of the whole ratios and its division by the number of capitals. As for the data in Figure N7 the result is a ratio of 4.5 palm trees per palm. So from 1904 to 2007, there was a deficit of 14.5 palms per person.

Facing this rapid urban growth that has been done on account of the agricultural land, palm groves, and quality of life; does it become obligatory to curb this sprawl and return to an urban concentration that would reduce energy consumption and outlying environments destruction? [10] To do so, one must bring an end to this triple neglect: of the city, of its ecosystem and of its heritage. [11]

The micro region must keep its oasis identity while progressing. A revitalization of its ksour and dachra, through the rehabilitation of tourist tours; can revive the traditional nuclei by the receiving of tourist dynamics.

3.2. TOURISM A VECTOR OF LOCAL ARCHITECTURE REHABILITATION

The local architecture makes up a veritable cultural and economic resource, and the basis of an adequate, sustainable and environmentally friendly development. Its rehabilitation as one of the levers of development in these rural communities, facing new patterns of urbanization and construction, will shun the occupation of agricultural lands.

The tourist activity and new uses linked with may be used wisely, to avoid the inadequate environmental and socio-cultural transformations by local communities.

Some countries have moved towards the rehabilitation of local architectures such as New Mexico. In other cases; it is implemented in tourism as in Spain, Tunisia and Morocco. The rural tourist accommodations can have their own distinctive footprint, in each Zab. Their integration in sustainable development programs is the key to determine the environmental and sociocultural accommodation facility of each Zab

3.2.1. Rehabilitation of ksour to points of urban decentralization

The tourism development done through the rehabilitation of local architecture may open multiple perspectives. Ksour will attract people to the abandoned nuclei what makes of them points of urban decentralization. There will be a generating process of both: skilled manpower constituting a veritable employment exchange in the ksour, and local materials and traditional techniques which are predominant economic potentialities. This process will recover handicrafts, agricultural work and mainly get back the palm groves. This recovery will also promote the autonomy and the economic independence of each human grouping.

3.2.2 The tourist tours as a link between the traditional nuclei:

Based on the itineraries of caravanserais and traders we will conceive the connection of the various traditional nuclei, and we only recover the ancient routes of Zab cited above. The experience of tourist tours as a means of cultural heritage safeguarding has already been used in France. [12]

Zab Chergui is qualified by the cropland and an accumulation of a capital sustainably linked to trans-Saharan trade. This area of settlement is articulated around two notable centers Sidi Okba in the West: site of visit polarized by the tomb of the Islamic conqueror Okba Ibn Nafaa Elfehri and Khanguet Sidi Nadji in the East: site of the Rahmania brotherhood. The following map illustrates a tourism development and rehabilitation of Ksour into pockets of lower density so that they would be ecological components. [13] (Figure 6).

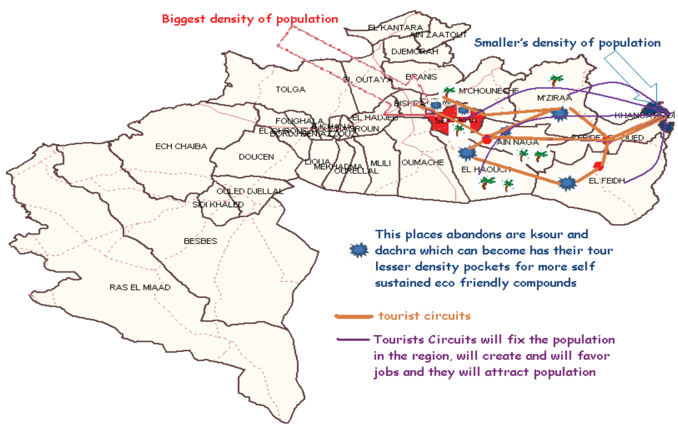


Figure 6: proposal for a tourist development Source : auteur (Health-Mapper).

CONCLUSION

The return to agriculture and palm trees, which is the original culture of Ziban specially and the desert generally, becomes a necessity. In order to promote the use of this element, it must be integrated in development and urban planning.
The ratio of 19 palm trees per person and the deficit accumulated over time is an urgent need that must be taken into account. The palm trees, sand stabilizer, are in the same time a local necessity for Ziban and Saharan regions and a global one for the world to reduce desertification and climate change.

The rehabilitation of the local architecture of traditional nuclei using a tourism development appropriate to the local characteristics of the region, may be an instrument of:

- Urban decentralization and reappropriation of abandoned spaces.

- Preservation of biodiversity in these oases.

- These abandoned spaces are ksour and Dachra, which can become again small urban units of less density and ecological components of the environment.

- The tourist tours will set the population, create jobs, promote crafts and particularly improve the incomes of farmers.

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STRATEGIES FOR SUSTAINABLE EXISTING NEIGHBOURHOODS

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ABSTRACT (STRATEGIES FOR SUSTAINABLE EXISTING NEIGHBOURHOODS)

There is a consensus that all climate protection strategies have not "only" the goal of protecting the environment. In addition to the scarcity of resources, security and independence are increasingly the subjects of today. The current developments in the Arab countries raise awareness of these issues once again in the Western and European perception. The efforts on energy efficiency and climate protection in the building sector are dynamic and it receives highest attention from politics. Meanwhile, districts and cities (on their scale) haven't yet been considered. Neighbourhoods and cities act as a social link between buildings, infrastructure, social structures, facilities and mobility. They definitely play a key role in the sustainable development of each of these parts. There is no doubt that the objectives of climate change cannot be achieved without the participation of cities and the development of integrated strategies. Several stakeholders and sectors must be brought together. Buildings, especially the existing ones, energy management, space and land planning, transport and mobility, etc. are to be integrated into a comprehensive environmental planning. The participation of citizens, communication and moderation of processes play a very important role. For example, without the active participation of citizens, changes in the existing building sector can be not enforced because of grandfathering. This paper discusses, based on a current project in Germany, how municipalities develop and pursue climate protection strategies. Approaches on the situation, the potentials, the definition of achievable goals and the development of targeted measures will be presented and discussed. The paper addresses the need of an active citizen's participation.

TERMINOLOGY

This paper uses the term emissions for the emission of green house gases from fossil fuels. As usual, these will be expressed as CO_2-equivalents, and for brevity we will drop explicit mentioning of the term equivalents.

INTRODUCTION

Scarcity of resources, rising prices of energy, and global warming are the prime motivation for many efforts of governments and international organizations on sustainable development in its broadest sense. Climate protection goals of governments are major instruments among these efforts. They typically focus on the dominant sectors of buildings, transport, and industry. Reduction of energy consumption and reduction of emissions, however, are often pursued independently of each other. For new buildings, ambitious energy standards are employed increasingly. At the same time, however, approaches applied for existing buildings have not been successful. Reasons for the rather slow progress are, e.g., grandfathering, economic concerns, demographic structures, and information and implementation deficits, to name a few.

Since 2008, the Kyoto Protocol signatories may use emission certificate trading as a means to achieve their climate protection goals at least in parts. Additionally, since 2005, the European Union (EU) has introduced obligatory emission trading for energy intensive industries as a means to achieve its climate protection goals. This concerns industries like cement and brick stone production, or fossil electricity and heat production. This induced the development of ecological cement which are increasingly used for buildings. More efficient strategies, like, e.g., recycling friendly construction of buildings, only remain future perspectives.

ASPECTS OF A SUSTAINABLE CITY

As part of a european urban development policy, the Aalborg-Charta [1] (Charter of European Cities & Towns Towards Sustainability) was adopted on May 27, 1994 as a result of the European Conference on Sustainable Cities and Towns in the danish town of Aalborg. Part III deals with the local Agenda 21 and addresses the local programs on sustainability. If you understand sustainability as the protection of natural resources, environment, health, economical and ecological values, then there is hardly anything else but the city or city district that combines these in an unparalleled way. A sustainable city is economically competitive and socially stable at the same time. It combines these two qualities in a lasting and sustainable way with a high quality of life. The building sector can contribute to all these aspects significantly. E.g., economic competitiveness also depends on whether a city is able to attract high potential individuals and make them stay. Among others, this is a question of having suitable flats and houses. Social stability depends to a certain extend on an appropriate mixture of social levels, which requires affordable housing space, which in turn depends directly on costs of construction and operation of buildings. Securing a certain level of quality of life depends on many factors. Environmental quality, noise levels, infrastructure and short ways to major facilities, cultural offerings, public transport, and housing standards are only some of them. And even here the building sector can contribute in parts.

Any strategies on sustainability consequently need to pay attention to all these named aspects and thus must strive for a holistic approach. The connections and interactions between all these aspects are numerous and are usually to complex to fit in any given set of regulations. E.g., the aspect of environmental quality comprises the minimization of green house gas emissions, say, in the sectors of building and transport. It also implies a multi-faceted landscape with less surface sealing and more green areas and water as a means to reduce the heat island effect. The heat island effect describes the observation that a particular area has a higher temperature than the immediate surrounding areas. According to [2] this may be 4 degrees Celsius and more. Notably this effect is seen in urban areas and it is sometimes even considered as a characteristic feature of the urban climate.

If you consider buildings as part of the (urban) environment, the term environmental quality even includes stability of value and the potential for alternate usage of buildings.

Urban mobility can contribute significantly to the sustainability of a city. First, short ways are by themselves a benefit. They are the result of a well planned infrastructure. Second, environmental impacts of individual traffic may be reduced by attractive alternatives of public transport and support for bicycles.

CONCEPTS OF CLIMATE PROTECTION AS PART OF A SUSTAINABILITY STRATEGY

As part of a national strategy in Germany, climate protection programs have been established as a means for sustainable urban development. The term climate protection here mostly refers to the protection of the natural environment and its resources. The focus is mostly on reducing global warming. It is understood that in the long run any governmental climate protection goals need to be broken down to the level of cities and municipalities. They represent the important link between all aforementioned sectors (buildings, transport, industry). Therefore, cities and municipalities are in the ideal position to tailor their strategies to local conditions to achieve climate protection goals.

The city of Riedstadt is located 25 km south of Frankfurt am Main and member of the climate protection alliance in Hesse, Germany. To achieve lasting CO2-reductions, Riedstadt wants to replace their past activities on environmental protection by a consistent and comprehensive climate protection concept. The development of such a concept is conducted in the framework of a project supported by funds of the federal ministry of environment, nature conservation, and nuclear safety. The project is mainly about developing, implementing, and accompanying a concrete strategy on climate protection. A knowledge transfer to other cities and municipalities will be supported amongst others by the Hessian initiative “100 Kommunen”.

THE CONCEPT'S BASIC APPROACH

CO_2-reduction shall be achieved by two means. One is to increase energy efficiency of buildings. The other is to increase the use of renewable energies for heating and electricity. Naturally, these two areas will be the main focus of activities, but urban mobility will be considered, too. Targets of emission reduction will be based on today's emissions. E.g., until the year 2050 a reduction by 50% shall be achieved. For the steps in note form, see Table 1.

1. **Carbon foot print**	2. **Estimate of potential**	3. **Measures**
- energy balance - use of typologies of buildings - carbon emissions by considered sector (building, transport, industry) - overall carbon foot print	- determination of local energy resources - determination of energy usage pattern - determination of saving potential of sectors and using renewable energy - determine the "target"	- involvement of all stakeholders - support civil engagement - development of technical measures - concept of regional supply renewable energy solutions

Table 1: Steps of the concept

MEASURES FOR NEW AND EXISTING BUILDINGS

Measures for new and existing buildings must be distinguished. The situation for new buildings is characterised by the fact that the energy consumption during operation is reduced, e.g., as a consequence of more and more stringent regulations, while the use of materials (and their grey energy) is increased. Numerous studies have shown that increase in energy efficiency not necessarily imply reduced emissions. The reason is that in quantifying the emission reduction one must not stop balancing at the building's skin. The grey energy of materials used to increase the energy efficiency and their associated emissions need to be accounted for. And these may add to the balance significantly. For example, the grey energy used for the construction of the highly efficient “Passive House” roughly equals the energy consumption over 50 years. This exemplifies that increasing efficiency wrt. buildings means more than just to reduce energy consumption during the operation of a building. Therefore, measures on energy efficiency will be inspected with respect to their true CO_2-reduction.

It must be remembered that any new building means one more building and just for that it implies impacts on the environment and use of natural resources. Concepts like the zero-energy or zero-emission house therefore are necessary and promising.

For new buildings the climate protection concept will consider aspects like efficient material use, re-use and recycling of materials, use of local materials, shortening of transportation paths. Moreover, planning of new buildings shall be subject to considerations on different ways of future usage (flexibility). Guide lines may be developed that outline aspects for certain usage patterns. Thus, planning may be such to reduce construction efforts for a later change. Obviously, this may be difficult to communicate in the private building sector, but the public building sector may very well submit to that for the hight emission savings potential.

The picture is different for existing buildings. In a country like Germany, buildings needing more than 250 kWh/m²a make up more than 70% all buildings. These cause more than 90% of the building CO_2-emissions. Any real progress on reducing the CO_2-emissions from buildings inevitably needs to happen with those existing buildings [3].

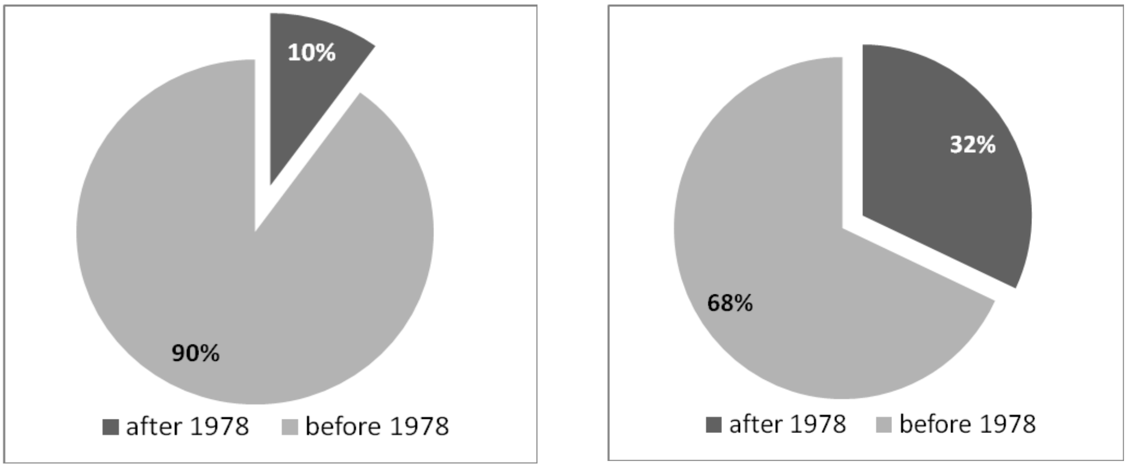

Figure 1: Share of carbon emission of old buildings in Germany (buildings built before 1978)

This is the point where a city may start to contribute by providing information and counselling on climate protection aware renovation measures. As a first step all of the existing buildings have been examined wrt. their energetic efficiency and several other categories. The result is a typology of buildings for all districts of Riedstadt. This allows a municipal consumer counselling office to demonstrate the CO_2-reduction effects of a given renovation measure and thus allows for hints to applicable public funding.

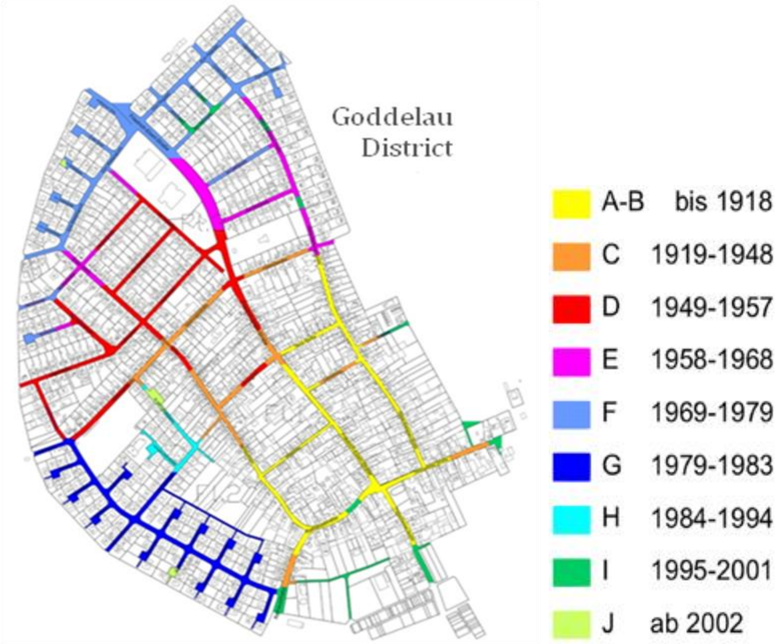

Figure 2: Building Typology of a District of the Riedstadt, street cluster and construction date

URBAN DEVELOPMENT

Urban development plans shall become more environmentally friendly. Research will seek ways to improve the efficiency of the structure of residential areas by suitable adaption of existing urban development plans. Moreover, recommendations shall be developed for future urban development plans that pay attention to energy and material efficiency as well as emission reduction. This not only involves meaningful energy standards, but also a prioritisation of materials, environmentally friendly energy supply, decentralization of energy production, as well as a balanced ratio of areas for buildings, transportation, and vegetation.

INCENTIVES FOR CLIMATE PROTECTION IN EDUCATIONAL INSTITUTIONS

Renovation measure often suffer from the user-owner dilemma, which typically leads to not applying the renovation measure for lack of monetary return. This is, because the owner may not be able to get the necessary return on her/his investment from the user. To eliminate this hindrance, communities try to accommodate the energetic quality of a building in a so called ecological rent index [4]. On the other hand it may happen that users are not participating in the costs of energy consumption. The usual consequence is that any energy saving potential from user behaviour is wasted. This is notably the case for public buildings like schools, nurseries, and administrative buildings. It requires incentives for the users to change the situation and there is a time-tested solution to this: Whatever the institution saves on the side of energy (and other operational) costs, is returned as further budgetary funds.

DEVELOPING RENEWABLE ENERGIES

As an important contribution to CO_2-reduction, renewable energies shall be produced and used. The city may act here on its own or in collaboration with other institutions or service providers. The detailed analysis of the potential of certain renewable energies under the consideration of ecological and economical aspects is then the very first step of the decision making process. Subsequently, municipal areas that are homogeneous in the energy consumption and production pattern are identified. This allows to project energy needs and CO_2-reduction potential for the future. For this to be meaningful, one needs to differentiate between different forms of users (household, business, industry, transport, etc.). They produce and consume energy differently [5]. Public utility companies play an important role in the developing renewable energies. First they already invest increasingly in renewable energies. Second, citizens and industry alike may not only act as consumers, but may also exploit public funding opportunities for providing electricity from renewable resources to public utility companies.

MODERATION OF THE PROCESS

Throughout the entire development of the climate protection concept, the process will be accompanied by participation of all stakeholders to achieve transparency and acceptance. This involves active professional moderation. The vast variety of stakeholders and their different interests (citizens, private and public institutions, industry, business, politics, societies, etc.) needs to be taken into account. To all of these, the process and the measures leading to a climate protection concept need to be communicated from the beginning. This will be done by establishing a climate protection round table to enable information and discussion. From the point of project management, the professional moderation of these round table discussions supports the lasting success of the entire project.

SUMMARY

A municipal climate protection concept as part of a holistic sustainability strategy of a city can make an important contribution to achieving governmental climate protection goals. This allows to take into account various important municipal sources of green house gases (building, industry, transport). A paradigm change is needed away from the sole focus on energy efficiency towards true green house gas emission reductions. This requires new directions in counselling municipalities and their citizens alike. Incentives for an energy aware operation of public buildings may help to alleviate the owner-user dilemma. The increased use of renewable energies is an important part of any municipal climate protection concept. Energy maps may provide possible future developments of energy consumption and green house gas emissions and may be used as input for decision making. Public utility companies may cooperate to decentralize the production of heat and electricity from renewable resources over the cities area in cooperation with citizens and industry. The vast variety of stakeholders and interests requires a professional moderation and communication to secure wide spread acceptance and thus the lasting success of any climate protection concept.

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PERFORMATIVE LANDSCAPES: PUBLIC SPACE AS FRAMEWORK FOR COMMUNITY EVOLUTION

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ABSTRACT

Public space can be designed to direct successful community development. Communities work when residents engage with their public spaces, and the spaces can evolve with community needs. The reciprocal influence between the community's constructed landscape components and the overall development of a community, including its social networks, environmental health, economic vitality, and building structure, can be examined to understand the basis for a framework design approach. Well designed open spaces tend to foster strong community pride and involvement, inviting improvement of existing built form, which simultaneously boosts a strong sense of community that demands exceptional landscapes. In this sense, community landscapes catalyze constructive community development.

To demonstrate landscape as integral to community building, five exemplary community case studies were examined, each representing a different landscape framework approach. The five approaches are: *Additive*, where public space is added to an existing community; *Incentive*, where public space aims to entice developers to construct the built form; *Creative*, where the preconditions of the site dictate revisions as construction begins; *Consultative*, where a master plan guides construction in a single phase; and *Transformative*, which are community projects that anticipate further evolution after construction. In the scope of this paper, one representative case study for each approach can be outlined in enough detail to demonstrate how landscape has been used as a community development catalyst [1].

As public open spaces continue to evolve with their communities, they can be understood as dynamic, rather than static and prescriptive. Communities with rich and varied landscape frameworks – as opposed to rigidly formed and programmed parks – are open to dynamic processes, and invite community input, which results in spaces that are able to accept multiple programs and iterations. The examples aim to prompt our consideration of how we build communities, how landscape frameworks are integral to community evolution, and provide inspiring examples of how to build outstanding communities through public space.

INTRODUCTION

Landscape as driver of urban form can be considered common theory, and a handful of examples have put this theory into practice. Notably, the design and implementation of canonical large scale parks, including Parc de la Villette in Paris, France designed by Architect Bernard Tschumi in 1983, Germany's Landschaftspark in Duisburg Nord designed in 1991 by Landscape Architect Peter Latz+Partner, and Landscape Architect James Corner Field Operations' 2001 proposal for Freshkills Park in New York, have all induced significant beneficial change to their surrounds. However, at the community scale, this process is less documented. Public space designed as the core for directing successful community development has set a course for landscape to perform in this realm as a framework. The framework landscape becomes the essential component through which the community evolves and lends insight on the effects of community input and sustained involvement. In this sense, community landscapes are considered performative in that they operate functionally in the constructive development of the community. This form of public landscape space, intentionally designed as catalyst for community building, is fascinating because the landscape framework promotes continual evolution.

METHOD

Five exemplary projects, with thoughtfully designed landscape spaces, demonstrate how a landscape framework performs to positively impact the development of the community. The projects each represent a different landscape framework approach. The five approaches are: *Additive*, which is when another landscape layer is added to an existing community to compliment its new purpose; *Consultative*, where community landscapes follow intense community consultation, resulting in a master plan designed and built as an entire unit; *Incentive*, which is the type of community landscape that exemplifies the large park or vast open space network, designed to entice private developers to construct the built form; *Creative*, which includes communities where the preconditions and challenges of the site require creative design revisions as construction begins; and *Transformative*, which are community projects that anticipate further evolution, often employing the latest landscape technologies to support the community toward a sustainable balance. The following five case studies, representing one of each of the approaches above, are outlined in detail, to demonstrate how landscape has been used as a community development catalyst.

Additive: Eco-Viikki

The Eco-Community Project, in Viikki, Finland, is located seven kilometres from downtown Helsinki. The project, at 57 acres, was developed between 1989-2010. The Client is the City of Helsinki, which was also involved in design along with Heikki Rinne. The driver is the Government of Finland's program of ecologically sustainable development, with a program to cut energy, based on the Rio Climate Change Conference and the Kyoto Agreement. Prior to development, the site was historically significant agricultural lands, to which were added the bioscience campus component of the University of Helsinki. The campus serves as the thematic focus for the community. Eco-Viikki strives for all aspects that have become synonymous with sustainability. The community recycles, including nutrients through composting and the cultivation of edible plants, and water through the collection of water runoff. It makes use of solar energy, decreases CO_2 emissions, water consumption, building material waste, and household waste, and mitigates health risks through indoor climate control including moisture risks, and outdoor issues such as noise, wind, and sun (Figure 1).

Figure 1: Viikki Eco-Community, allotment gardens. Source: City of Helsinki.

The master plan is based on a finger-like structure with alternating buildings and green open spaces. A wide range of landscape types and spaces promote this multi-function, while also accepting environmental transformations and natural processes. For instance, the allotment gardens evolve with the seasons and transform over the years. The agricultural fields related to the university are rotating, while new connections are made into the natural areas. Vegetation is selected to increase biodiversity, and a green belt forms an important wetland nature reserve. Community facilities, from Daycares to Teacher Training Schools, make use of the landscape for educational and research purposes. Although the campus and community is high density, the verdant sense is provided by the experimental farming areas, and the project boundary that opens out to the culturally important agricultural landscape [2].

Consultative: Borneo-Sporenburg

The community example of Borneo-Sporenburg in The Netherlands covers 120 acres. Completed in the years 1996-2000, the City of Amsterdam is the client, with the master plan created by West 8 urban design and landscape architecture. The master plan included guidelines for streetscape, parking, private open space, storey height, and plot width. The repeated typology is divided into three zones, which are interrupted by immense blocks of sculptural landmark buildings. The scheme allows urban dwellers to create, adapt, and find their own meaning in their surrounding environments. The open space system includes wide diagonal swaths of lawn and paved plaza areas, which acknowledge the industrial context, while supporting a diversity of uses and interpretations over time, 11 metre wide streets, and sculptural bridges and quays overlooking the harbour basin (Figure 2).

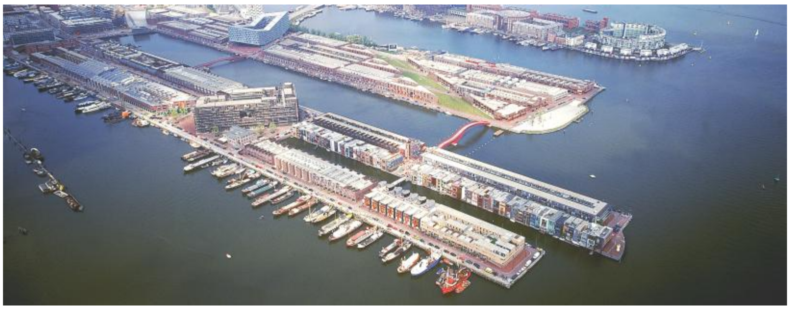

Figure 2: Borneo-Sporenburg, aerial photograph. Source: West 8.

Borneo-Sporenburg, which merely provided guidelines for development to entice indeterminate futures, is socially successful in its provision of a wide range of housing, making neighbours of people at all income levels. The streetscapes are very popular, primarily because the sidewalks are able to accept customization through the addition of benches and planters that residents set out. This permits this small scale space to be welcoming, and to be claimed by both the public and the unit owners, at this clever boundary of public-private interface [3].

Incentive: The High Line

The High Line, on the west side of Manhattan, started construction in 2004 and is anticipated to be complete by 2011, with a total size of 4.93 acres. The project was lead by James Corner Field Operations. The client was The City of New York and Friends of the High Line. Prior to construction of the High Line, real estate speculation was high, and its manifestation has indeed proven very successful in enticing private developers to its edges (Figure 3). The High Line occupies the surface space of what was originally a raised rail corridor for livestock cargo. The abandonment of rail activity allowed vegetation to occupy the rail corridor through the process of natural succession.

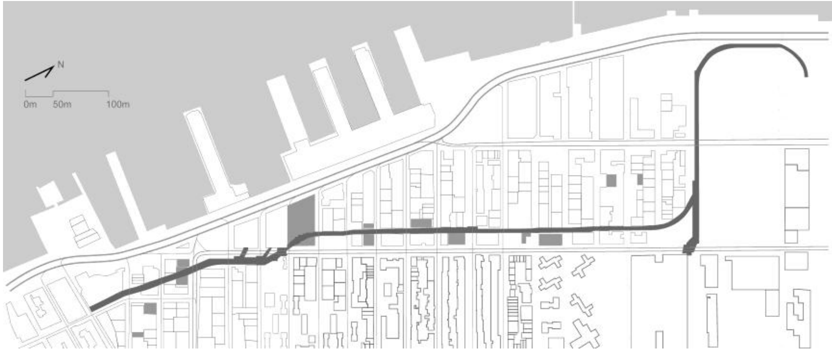

Figure 3: The High Line, with new adjacent developments highlighted. Source: Justin Miron.

During design development, the landscape architects studied the patterns and processes of the emergent vegetation to devise a solution for a park that could sustain diverse plant communities in relation to the projected volumes of site visitors, with a customized paving system. The existing gravel ballast covering the surface of The High Line was replaced with a growing medium of higher quality engineered soil to encourage the establishment of over 200 species of new vegetation and also accommodate the growth of larger trees in select locations. The incorporation of existing site features, including the rail tracks and ironwork details of the elevated rail line maintain the integrity of the infrastructural artefact.

From the overall concept to foster ecological succession, to the research, design, and development of a unique paving system to support the emerging vegetation, the design of The High Line demonstrates the multiple scales of possibility for intervention in community regeneration. It continues to influence regenerative effects on its context, bringing more people to The High Line to enjoy the unique urban experience and ecology. In this sense, urban form, community, and vegetation are interdependently succeeding.

***Creative*: Bo01**

Bo01, pronounced bo-noll-ett, is located in the Western Harbour of Malmö, Sweden. The project is 62 acres, and was designed and constructed between 1996-2001. The client is the City of Malmö, with Klas Tham as the principal exhibition architect. The site was previously an industrial brownfield site aiming to redevelop as a sustainable community with a high emphasis on quality of architecture, urban environment, and infrastructure. The project strives for complete local and renewable energy production and the minimization of energy consumption, a balance between production and consumption with 100% reuse of waste, and aims to create a high level of individual comfort. The landscape weaves between buildings which consist of dense three to four story apartment blocks that mix residential, commercial, and social uses, formed as small courtyards, commercial plazas, parks, and a major Oceanside promenade (Figure 4).

Figure 4: Bo01 Community, aerial photograph. Source: Klas Tham.

Public parks account for almost a quarter of the site, creating a sense of identity for the community, along with the Turning Torso tower, created by Santiago Calatrava, which acts as an iconic landmark. In order to detain surface runoff and increase biodiversity of both animals and plants, developers were encouraged to compensate for impermeable surfaces by the creation of different types of private green surfaces such as green roofs, vegetated walls, and wetlands. Urban drainage is made visible, accessible, and sustainable. The open system aims to bring aesthetic and environmental values to citizens, and consists of open drainage street canals, water features combined with art, and a saltwater canal and wetland [4].

The diversity of spaces fosters communal activity while also allowing for individuals to enjoy quiet outdoor time. Simultaneously, a small crowd is gathering by the Oceanside overlook, while a group of friends enjoy dinner by appropriating the bridge crossing the wetland, a couple sits in the greenhouse, and a lone fisherman stands at the docks. Adapting programs extends to spatial transformation, when half a courtyard is appropriated by the local residents' need for bicycle storage, and personal gardens extend into the grey zone of semi-public space. These often unaccounted for needs and transformations bring depth of character to the project, and imprint a stakeholder aspect in the community.

***Transformative*: Dockside Green**

Dockside Green is a 15 acre community adjacent to the Upper Harbour and downtown Victoria. PWL Partnership produced the 2006 competition winning scheme for the owners and developers, Vancity, one of Canada's largest credit unions. Two of the first residential phases and the central greenway have been realized. The project pursued high goals in energy efficiency and sustainable design. Closed-loop strategies include on-site wastewater treatment and reuse, and a biomass plant for central heating. Small businesses are encouraged to provide local goods. The development aims to be accessible to a diverse mix of people.

Figure 5: Dockside Green, building massing and water systems. Source: PWL

The community development is integrated with wildlife habitats and green spaces, which are traversed by waterways and walking trails, with green roofs providing some of this habitat, and connecting the upper units to planted areas. The outdoor areas of the grade level residential units cantilever over the freshwater demonstration wetland, providing physically distinct yet visually shared public-private space (Figure 5). A strong sense of community is promoted through the shared interaction of the residents, employees, neighbouring businesses, and the broader community, with the surrounding water rich environment. The encouragement of residents and employees as stakeholders in the health of the site aspires to further promote the community, its economy, and ecosystem. Dockside Green endeavours to provide a high quality of life with minimal impact to the environment [5].

RESULTS

The community examples demonstrate that when landscape is conceived as a framework, it supports the community toward a sustainable balance. All five communities had former uses that will continue to influence the further evolution of the community. They all share the goal of using landscape elements to sustain community functions, and use these as educational opportunities. They have support from local regulatory organizations, and use this to leverage the latest technologies for energy, waste, transport, water use, and recycling. Formally they all have multiple scales of open spaces with a variety of programming flexible enough to accept additional programming or alternate possibilities over time. The landscapes range from semi-public courtyards, to regionally accessible parks, to natural corridors making connections to the larger landscape. All of the landscapes were designed intentionally with quality materials. Attention to designing unique spaces and individual and stunning architecture, places these communities as international examples and desirable places to live.

DISCUSSION

As open spaces continue to evolve with their communities, community landscapes can be understood as dynamic, rather than static and prescriptive. This furthers the notion that urban open space is an ideal performative framework for positive community transformation in its ability to be continually shaped to suit community needs. These communities are designed around rich and varied landscapes, as opposed to a single community park with rigid form and programming. Landscape conceived as a framework necessarily develops over time, as the hydrology and ecology systems are established and sustained. These types of communities employ renewable energy sources, reduce pollution, and work with waste streams, with the landscape playing the critical role in supporting these functions. These performative community landscapes are open to dynamic processes, involving community input, to produce landscapes that are able to accept multiple programs and iterations. Further study is warranted to understand the relationships and scales of spaces and their programmatic and technical requirements and evolutions. For now, however, these examples prompt our consideration of how we build communities, how we can build better communities, and provide us with inspiring examples to do so.

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DESIGNING MATERIAL AND ENERGY FLOWS FOR A URBAN ECOSYSTEM

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ABSTRACT

Every civilization is largely defined by its ability to control energy flows and reserves. In this sense, it is hard to doubt that our civilization is only a transitional phase. Looking to the future the issue is: what will be the shape of the new solar society? We know that two different models are now possible, one still based on a centralized and delocalized production, an other one based on a local, diffused and highly networked production. If both models are possible, not only the diffused nature of the solar resource, but mainly the deep social challenge of giving people the ownership of the tools of energy production, makes the diffused model the real ecological challenge of a new civilization. And this challenge, has indeed a lot to do with architecture. Because it means to imagine our built environment, our private houses and offices as well as our public and common spaces, as the new, visible and tangible, spaces of energy production. It means stopping to think architecture as a static, armless space to start thinking it as a "productive" entity, according to the needs of its inhabitants but also to the global needs of the planets. Moving form these theoretical bases, the paper discuss the results of a post-graduate master, "Designers of Sustainable Architectures" promoted by InArch (Italian National Institute of Architecture), presenting a new design method based on what we called the "productive footprint", defined as the amount of different surfaces (mainly for energy and food production and water recycle) needed to sustain, through *on site renewable resources*, life in each specific context. The paper also argue the possibility to use the same "productive footprint" as a measure of the productive capacity of a project. Based on the relation between consumption and regeneration capacity, the footprint could be negative, balanced or positive, giving designer and citizens an easy and communicative tool to understand the metabolic impact of a built environment.

INTRODUCTION: TOWARDS A NEW CIVILIZATION

Every civilization is largely defined by its ability to control energy flows and reserves. Human history itself can be seen as an ongoing discovery of the possible manifestations and mechanisms of energy conversion: starting about ten thousand years ago with the first agricultural techniques that would determine and enhance the earth's productive capacity to answer to our vital energy needs – food - up until the discovery of how to release energy from the nucleus of the atom in the late 1930s, to the recent understanding of photosynthesis.

From the food we eat to the heat that warms us to the light that illuminates our world to the means of transport by which we move, the forms of energy that we use determine the shape of the society we live, in terms of both time and space. In this sense, it is hard to doubt that our civilization is only a *transitional phase* because, unlike preceding civilizations, it cannot last for thousands of years because even if they were used in the most efficient possible way, fossil fuel energy supplies are limited as well as the Earth capacity to absorb their outflows, with consequent increasing economical costs. This, as we know, will force our descendants, if not ourselves, to return to harnessing solar energy or developing new energy sources. As well as to re-design our relationship with the Earth, its resources and the global system of matter and energy flows.

Looking to the future the issue is: what will be the shape of the new *solar society*? We know that two different models are now possible, one still based on a centralized and delocalized production, an other one based on a local, diffused, distributed and highly networked production. If both models are possible, not only the diffused nature of the solar resource, but mainly the deep social challenge of giving people the ownership of the tools of energy production, makes the distributed model the real ecological challenge of a new civilization. And this challenge, has indeed a lot to do with architecture. Because it means to imagine our built environment, our private houses and offices as well as our public and common spaces, as the new, visible and tangible, spaces of energy production.

It means stopping to think of architecture as a static, armless space to start thinking of it as a "productive" entity, according to the needs of its inhabitants but also to the global needs of the planets. But getting to this productive point of view, the energy issue appears deeply connected at least to the issues of water and food, the other two main needs of human dwelling.

METHOD: THE PRODUCTIVE FOOTPRINT

The reason to adopt the *productive perspective* is actually linked to wider considerations about the search for a more balanced, or ecological, way of dwelling. In fact, if as we know, the Earth's vital signs (such as temperature, air, soil and water quality as well as biodiversity) tell us about a growing state of crisis of the planet, learning how to design *according to nature* should become our most urgent ethical and practical goal.

And since the only real example we know of a system able to produce well-being for unlimited time is nature itself, where nature means biological systems, systems able to use matter and energy without producing waste but just closed circular chains, nature has to become our main model and reference. And what nature show us are mainly relationships: an ecosystem is a system of highly networked (living and not living) elements which can be defined as "productive" if it is able to maintain air, water and soil quality, allowing life, or biodiversity, to prosper (when this not happen, the system is sick).

This is actually what we have to look for: the ability to design hybrid productive environments (where *hybrid* means part natural part artificial), capable to sustain life, in a wide sense. But this point of view, immediately call into question the choice of modern age of addressing the main needs of human dwelling dividing and spacing out as much as possible the place for shelter, the place for food and the place for energy production without taking care of all the outflows implied in this separation. So that, for example, cities, poor of green and permeable surfaces, and full of heat sources, became more and more islands of heat, needing growing artificial oxygenation through air conditioning.

It it quite clear that if we want to balance our built environment we have first of all to re-connect, through a systemic strategy, the main needs of dwelling. In other terms, we have to think that beside the specific and occasional requests of a program, each project should have an hidden, meta-program, general and invariable: to look for a form able to *relate* vegetation (food, fresh air, biodiversity), shelter (built, public and private space) and (renewable, distributed and clean) energy.

Which means we have to think the project as design of a set of *relationships*. Not in a metaphoric sense, but in an objective and measurable one. As we can actually quantify how much solar radiation a building (or an urban area) is capturing and transforming in usable energy, as well as how much energy the building needs, and how many trees and green surface the building is supporting, and how much productive land and water regeneration through a "living machine" are connected to the building, and how all these things are related and work together.

But how to actually design this set of relationships? In several years of teaching in the post-graduate master "Designers of Sustainable Architectures", promoted by InArch (Italian National Institute of Architecture), we experienced the difficulties of even young architects to change their point of view to imagine architecture as the dynamic scene of matter and energy flows, we understood that a new design method was needed.

We call it the "productive footprint" method, assuming that a paradigmatic shift is possible if we start the design process thinking about the energy flows, looking for the different surfaces needed to sustain, mainly through on site renewable resources, life in each specific context.

In this way, the meta-program of correlation (between shelter, energy and food/water/vegetation) become a new programmatic layer which has to be added to every standard program (a single family house, an office, a school, a new neighborhood, a city) which looks specifically to the matrix of *productive surfaces* implied by each of these objectives that have to take shape in the design process.

Beyond the didattic purpose, the idea of a "productive footprint" is an attempt to set a common ground in between the scientific perspective and the architectural one. It has to be understood, in fact, as a planning tool, which takes some "productive" needs and data as inputs for designing new city and buildings. The aim is not balancing totally the "ecological footprint" (negative) of the intervention by a "positive" ecological footprint, but, rather, to experiment with how much of this "positive ecological footprint" can be included into the architectural design. Experiments carried out in past (such as Biosphere 2), in fact, demonstrate that at the moment we do not have enough knowledge to exactly reproduce the nature's performance.

Of course, thinking about the built environment as something which has an energy footprint which has to be taken in account (instead of just imaging that energy, as well as food and water, will come to the site from far away, in a non renewable form, will be consumed and thrown away as waste), immediately generates new questions about what kind of food-footprint shall we imagine for an office or what kind of transportation-footprint shall we consider for a school and so on. But this is exactly the kind of questions which can help us understanding that if we want to change the way we inhabit our planet we have to change dramatically the way we think of architecture. Moreover, this kind of approach make it immediately clear that the most we reduce our need for energy, food and water, through more performative spaces, appliances and behaviours, the better it is.

For sure, understanding the "measures" into these relationships (how much of...) would be the element we need to define exactly the "productive footprint". From this point of view, each design process is a way to experiment with this crucial topic of the discussion.

RESULTS

Due to the need for renovation of existing buildings in the Italian contexts, we decided to focus the master on retrofitting case studies, which year after year change in location and program. So after working on housing in the historic centre of Rome [1; 2] we now focused on an office programme located just out of the city. Due to a ten years long collaboration with ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic Development), we decided to study the architectural and energetic re-design of two selected buildings of ENEA's Casaccia Research Centre area.

The Casaccia Research Centre is ENEA's largest complex of research and development facilities. It is an area of about 90 ha, located around 25 kilometres northwest of Rome, near Lake Bracciano. It is a centre dedicated to research, development, applications, and the dissemination of innovative technologies.

Here we selected two different buildings as case studies for a future renovation plan of the whole area. The first one is the main Entrance Building, the second one is an Office and Laboratories Building very close to the main entrance. Both buildings have been studied in relation with the surrounding open areas considered as useful surfaces to provide the "productive footprint" of the buildings together with the building's surfaces. In both cases, students were invited to keep the main volume of the existing buildings but they could redesign the envelope, carving courtyards or adding greenhouses, so to optimize the energetic behaviour as well the architectural performances of the buildings. We will present two selected project, one for each case study.

Project One. *The Entrance Building* (design: F. Calcerano, R. Delli Carri, A.Valeriani) is a glass and steel structure, with a very compact profile and just one store high. Despite the small dimension (about 200 m^2), it is characterized by a high energy consumption (116 MWh/year) related to the use profile and the building performances that requires a continuous use of the air-conditioning, and, also, of artificial light for 24 hours.

Moving from this analysis, the main idea of the project is to re-organize the building so to have two separate zones, defined by different use profiles: the core zone, with a continuous use (h 0-24), and an external zone with a daily profiled use (h 8-18). Furthermore, the external zone is protected by an additional buffer zone, made of greenhouses and other filters. To summarize, the basic idea is having three concentric rings, with different performances.

Moreover, since lighting was an urgent energetic problem, some glazed courtyards have been used to improve the daylight in the core zone. The whole system with rings and glazed courtyards, is not larger than the existing roof. The re-design of the roof itself is another important feature of the energetic, as well as architectural, project. Through a new tilt, the roof is turned in a garden and solar surface, able to optimize the passive and hybrid behavior of the spaces beneath as well as to generate all the needed electric energy. Simulations (COMSOL) show that, despite the occupied surface is now more than doubled (465 m^2), the intervention allowed for reducing drastically the energetic consumption to 7,4 MWh/year.

The building renovation proposal is actually part of a wider design strategy. In fact, even if in this case the energy footprint was easily located on the building, the open area in front of the entrance is turned in a sort of tecnological-landscape, a kind of learning-ground, where people can get curios about sustainability by looking at technological systems, exhibited as part of an open-air museum. The technological systems people can experience by walking in the park are: hydroponic greenhouse, phyto-depuration systems, rain water collecting systems, and also a geothermal exchanger (generally hidden and here emphasized).

Another important feature of the project deals with the design of a new mobility system: in fact, since the research centre location 20 km out of Rome city centre, 16 ENEA bus are now travelling everyday back and forward to connect the centre to the city, with an annual cost of 2.000.000 euro. The proposed mobility system consists of a pool of shared electric cars to be recharged in the 8 hours parking under PV shelters. The payback time of the whole investment is less than two years and the avoided emissions of CO2 is about 5600 t, equivalent to 900 ha of wood.

Project Two. *The Office and Laboratories Building* (design: F. Becchi, N. Di Molfetta, C. Escalona, F. Fontana) is a bricks and concrete, three stores, rectangular box with, as the analysis pointed out, many thermal bridges in between the vertical and horizontal structural elements, and a not really performative insulation covering, with a high energy consumption (209,3 MWh/year). The project here aims on one hand, to improve the energetic performance of the building and, on the other hand, to enhance the interaction between people who use the building, emphasizing the identity of the building itself as a facility for research and researchers.

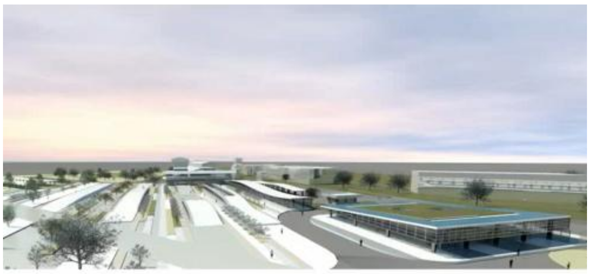

Figure 1: The Entrance Building, design: F. Calcerano, R. Delli Carri, A. Valeriani; *Figure 2: The Office Building*, design: F. Becchi, N. Di Molfetta, C. Escalona, F. Fontana.

This is the main reason why the analysis phase has been carried out together with a deep reading of the life and desires of people working in the building and the centre in general, through interviews and contextual analysis. The analysis process ended up in the choice of adding a new envelope to the existing one (energetic performance), shifting the "section" according to the environmental needs and modifying as well the internal layout of the offices (users satisfaction).

The new envelope has been conceived like a "selective and productive filter", which can mediate the relationship between outdoor and indoor. This filter, made of movable panels whose opening is controlled by a central system, is also a very clear element of the facade composition. By opening and closing the panels, depending on the external conditions, it is possible to regulate natural ventilation, passive cooling, solar gains, daylight.

The change in the building section, allow also to incorporate passive and active strategies to improve the energetic performance of the building and to reduce its energetic consumption. As passive elements, a bioclimatic atrium and two greenhouses, have been used to maximize the passive solar gains. In addition, buffer spaces have been added on the South sides of the building, to prevent overheating in the hot season, with a final total energy consumption of 99,4 MWh/year.

Main active elements are an earth-pipe geothermal system, a solar thermal system, and a photovoltaic system. All the systems that have been used (passive and active) have been conceived so to work as a "whole" and their precise dimensions and shape have been evaluated verifying their effectiveness and performances through thermodynamic simulations.

Due to the fixed dimensions of the suitable surfaces for PV on the building, some other photovoltaic elements have been used "at site". In fact, 44 PV horizontal "umbrellas", able to produce 44,1 MWh/year, have been placed in the external area of the building as new productive elements bringing in the open, public space the issue of solar energy production [3].

Because of the agricultural nature of the external landscape, the project imagine also to re-design the borders of the research center developing a system of biological gardens, for fresh food production and biomass, to be managed together with people from the surrounding neighborhoods.

Discussion

To design *relationships* instead of *boundaries* means a radical paradigm shift in our way of thinking architecture as a solid and inanimate artefact, alternative to natural and evolving space of plants and animals as well as to the productive land of the countryside and of the energy plants. From this perspective, a new hybrid and flexible reality replace these strong oppositions: a system of *weak and diffused urbanism*, a *country-city* and *landscape-buildings*, where the hard and impermeable concrete or asphalted surfaces, live in continuity with soft and permeable green surfaces which, in their turns, live in close continuity with advanced technological surfaces able to capture the diffused environmental energy.

This is not *greenwashing* but a dwelling-growing-breeding where every building is also a station for food and electricity production, as well as for water treatment and re-cycle, for services and irrigation. A system capable of sustaining *more life* than just human life. More life meaning also a better quality of life: because more green areas means more playgrounds, more relational spaces, more connection with the basic elements and cycles of life, more tastes, colours, smells.

This is why what we would like to propose, beyond a design method, is also an easy tool to communicate, not just to a few scientists and specialists but to everybody, the possible metabolic balance of a building or an urban area. We suggest again the use of the “productive footprint”, here at the end of the design process, as a final measure of the productive capacity of the project. The productive footprint should be based on the relation between consumption and regeneration capacity, so that the footprint could be negative, if consumption is bigger than regeneration, balanced or positive, if the regeneration capacity is bigger than consumption. Indeed, if the ecological footprint has been a very powerful concept to communicate a negative idea, the design processes now need also a reverse indicator, to suggest that a positive trend is possible. [4]

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THE RESILIENCE AS INDICATOR OF URBAN QUALITY

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ABSTRACT

The study aims to present the discussion about the evaluation of urban quality of a specific neoecosystem, defined as a highly complex living organism [...] in a continuing transformation, produced by the meeting of cultural and natural sites and made up of places that have an identity, a history, a character and a long term structure («organismo vivente ad alta complessità […] in continua trasformazione, prodotto dall'incontro di eventi culturali e naturali e composto da luoghi dotati di identità, storia carattere, struttura di lungo periodo»). (Magnaghi, 2010)

The contemporary neoecosystem is dependent on flows of energy, food, materials and information, that come from systems with different scales (municipal, regional, national). It is unable to activate a cycle that can regenerate itself and where even the waste products can be useful components for system maintenance. It is also characterized by a low resilience and thus by a low capacity to absorb disturbance and reorganize during the change so as to maintain essentially the same function, identity and feedback.

The reference model to contrast with that of contemporary neoecosystem is therefore «a self-contained system that is fairly homogenous and in which climatic fluctuations are reasonably small, a complex adaptive system» (Holling, 73). This system consists of many components and connections between components (complex) and is able to change.

This research will describe quantitative and qualitative assessment tools of environmental and social activities, to increase the quality of neoecosystems, focusing on the most relevant European experiences: the project for the city of Vitoria Gasteiz, European Green Capital 2012 and the city of Totnes, first Transition Town.

INTRODUCTION

In ecology, resilience is defined as «the capability of an ecosystem to react and reorganize after a shock, while maintaining the same function, identity and feedback» (Hopkins, 2010). The more robust and static a system, the less resilient and able to adapt to a change and to balance itself it is. A resilient system is composed by a variety of elements, which react differently to different challenges. Since the elements are well-connected to each other, the system is able to isolate itself in case of shock. It is characterized by a good feedback, because a system considered to the local is capable of perceiving the consequences of its actions in a short time and then of activating a solution, when these consequences are detrimental to the system. Therefore it is a dynamic system and sensitive to an external and unexpected change that does not focus on the presence or the absence of some species, but also on the number of organisms and on the degree of constancy of that number.

The concept of resilience is not tied exclusively to the maintenance (for present and future) of natural resources, such as sustainability, but also to the transmission of these resources. So the system can lose natural resources, acquiring the ability to compensate those with others, which can perform the same functions.

If we want to apply the evaluation of this capability, typical of natural ecosystems, to the city, considering it as a living organism, it is necessary to implement the assessment of the resilience with various parameters, associated with urban quality as «environmental harmony» (Lynch, 1981). The urban quality regards not only the environmental comfort but also to the needs of human psychophysics and social living.

In fact there is a strong relationship between the human values and the form of the city, as «the spatial structure that houses the activities of people, the flow of people, goods and information and the resulting configurations, involved to change significantly the physical space, in relation to those activities, surfaces, channels, environments and objects » (Lynch, 1981). Lynch (1981) identifies the following five dimensions of performance to measure the quality of a given settlement: (i) the *vitality*, i.e. the ability to ensure the physical health; (ii) the *sense*, i.e. the ability to facilitate the identification and the orientation; (iii) the *fit*, i.e. the ability to accommodate easily the activities; (iv) the *access*, i.e. the capacity to reach the areas; (v) the *control*, i.e. the ability to allow a direct care and management of sites by the real users. This approach emphasizes not only the importance of the specific characters of a settlement but also (and especially) the relevance of the dynamics that contribute to change it.

A methodology to define the most suitable parameters for the description of a resilient city is purposed in this paper. Significant national and international experiences were analyzed according to the definition of urban quality proposed by Lynch (1981). A strong correlation is pointed out between the increase of the resilience of a given settlement and its urban quality

METHOD

In order to point out the set of indicators- three steps have been identified. At first, some areas for the evaluation of the urban quality were identified starting from the 5 dimensions of performance by Lynch, which define the environmental harmony of a settlement. Then, the parameters used in national and international experience were extracted and analyzed to understand what parameters are descriptive of the selected areas. Finally, a set of parameters for the description of the resilience of a given settlement is proposed.

IDENTIFICATION OF AREAS OF EVALUATION OF URBAN QUALITY

The evaluation areas of urban quality were defined starting from the 5 dimensions of performance by Lynch (1981) that were redefined to consider significant elements that identify the contemporary city and its quality. These 5 dimensions were then extended with 2 more areas: the first one, illustrative, considers the specific characteristics of the settlement, including its natural/man-made and social capital and the second one, is related to the efficiency of the metabolic system.

1. *Descriptive physical characteristics*: describes the physical structure of the settlement, over the amount and diversity of the elements (natural capital/ man-made and social capital) that characterize it. It considers the density and population characteristics in order to understand and evaluate the relationship between shape and characteristics of the settlement and number and characteristics of the settled population.

2. *Physical settlement* (Lynch): considers the characters of the morphology of the city, linked to the improvement of bio-climatic conditions of the private and public spaces and of their living space, linked to appropriate levels of thermal, acoustic and visual comfort.

3. *Identification and orientation to significant characters settlement* (Lynch): considers the identifying characters of a settlement that allows the individual to navigate and have a sense of familiarity and unity of the settlement. It contrasts the significant characters of the settlement of an assessment with an evaluation of social welfare (migration over the grounds).

4. *To welcome and facilitate activities* (Lynch): evaluates the allocation of services and economic and social activities, their diversity and the participation of the population to them.

5. *In order to reach areas and nodes* (Lynch) considers pedestrian and bicycle accessibility and proximity to hubs and connectors elements of the community.

6. *Care and management of places by those who use it effectively* (Lynch) considers the active participation of management practices and enhance the quality of private and common places.

7. *Metabolism of the settlement, linked to carrying capacity:* the urban metabolism is evaluated with respect to the energy, food, water and waste cycle.

ANALYSIS OF NATIONAL AND INTERNATIONAL EXPERIENCES

Once defined the areas of quality evaluation, it was very interesting to look into some significant national and international experiences that propose an evaluation of contemporary settlements with a goal of sustainability at the urban scale. Table 1 shows a summary of the experiences analyzed focusing on the scale of analysis (city or neighborhood), context, promoters of the studies, the specific objective and precisely the areas in which the assessment is assumed.

	Scale	Context	Promotors	Objective	Areas	Note
Seattle sustenible (1993)	U	EU	Association	Sustainable development	**1- 4**	99 indicators
Indicators of european commons (1993)	U /N	Italy	Local governance/ citizen	Local actions for sustainability	**1- 3- 7**	11 indicators
Project of sustainable cities WHO (1993)	U	EU	International institution	Sustainable develop- ment	**1- 4- 5- 7**	57 - made on 47 EU cities
Habitat II (1994)	U	EU	International institution	Environmental impact assessment	**1- 5- 7**	27 indicators
Organization for Economic Coopera- tion and Develop- ment -OECD (1994)	U	Member countries	International institution	Sustainable development	**1- 7**	72 indicators/ Descriptive indicators
Urban audit European Commission. DG. XVI (1995)	U	EU	International institution	Evaluation of the social- economic status of the city	**1- 4- 7**	33- made on 58 EU cities
European Environment Agency (1995)	U	EU	International institution	Sustainable development	**1- 5- 7**	55 indicators
Leicester (1995)	U	UK	Local government	Sustainable develop- ment- National strategy	**1- 5- 7**	14 indicators
UNCHS/ HABITAT (1997)	U	EU	International institution	Guide urban development policies	**1- 5- 7**	53 cities (PVS)
TEPI (Toward Environmental Pressure Indicator) EUROSTAT (2000)	U	EU	International institution	Sustainable development	**1- 4- 7**	60 group of 45 technicians
Andalusian sustaina- ble development (2001)	U	Spain	Regional government	Sustainable development	**1- 4- 7**	70 indicators/
Ecological footprint London (2002)	U	UK	Government /research centre	Sustainable development	**1- 7**	
HQE^{2}R (2004)	U/N	France	International institution	Sustainable development	**1**	61 indicators/
Ecocities GL4 – Villasanta (2009)	U	Italy	University/ Government	Sustainable development	**1- 2- 7**	19 indicators/
European Green Cities Index. (2009)	U	Europe	Private Society	Environmental impact assessment	**1- 5- 7**	30 quantities qualitative
Urban Ecology Agency of Barcelona – (2010)	U/ N	Spain	Private society	Sustainable development	**1- 2- 4- 5- 7**	50 indicators/
SUME (2008)	U	Europe	University/ research centre	Assessment of urban metabolism	**1- 4- 5- 7**	5 european case studies

Table 1 summary of some experiences that offer an assessment of sustainability compared different groups of quantitative indicators

These analysis tools are promoted by international agencies or local governments and are linked to development programs of the European Community or the Agenda 21. There is an important starting point, because they provide an interesting methodology and intend to pursue the improvement of environmental sustainability at the urban scale

Within the tools analyzed, the work done by the Urban Ecology Agency of Barcelona is particularly interesting. The Urban Ecology Agency of Barcelona is a consortium made up of government the Barcelona City Council, the Metropolitan Water Services and Waste Treatment Body and the Provincial Council of Barcelona, The model proposed by the Agency is the Mediterranean town, compact, complex, efficient, with a high level of social cohesion that allows the proximity between uses and functions and at the same time enhances their mixture, multiplying the organizational complexity. This model considers as a function of the urban sustainability the equation of efficiency E/nH, where *E* is the energy and resources, *n* the number of legal entities (businesses, institutions, associations) and *H* the value of diversity. According to the equation, when E decreases, nH has to increase, opposite to what happens in contemporary neoecosystems, where E increases if nH increases (Rueda, 95).

The methodological approach proposed by the Agency is based mainly on two concepts: the Supermanzana and urban planning at three levels. The first one is the area defined by the main streets, in which, the secondary internal roads become limited traffic. In fact the first one have to ensure the functionality of the system, while the second one are related to pedestrian accessibility and public transport from the center (radius of 300 m-400 m). The concept of urbanization at three levels has a goal of maximum use of urban space and is characterized of three dimensions: the high (metabolic efficiency), which allows the uptake of energy and water, storage of organic waste; the surface, connected with the habitability of sites linked to the report by the population and the low (features) that consists of the infrastructure for decentralized energy and vehicles.

The hypothesis proposed in the project for the town of Vitoria-Gasteiz[1] is the evaluation of three development scenarios (current 2009 to 2020 - 2050), through the application of 50 indicators that relate to 8 broad categories of study, such as: land occupation, habitability, mobility and services, urban complexity, urban metabolism, green space and biodiversity, social cohesion and energy efficiency. Some studies of urban planning of expansion of the city (plans, projects) were carried out by the Agency. The first is the mobility plan for the restructuring of the urban transport network, which provides consolidation of the cycle network, reorganization of the surface car parks and any new, increased quality of public space and streets with regard to accessibility, pedestrian permeability, the presence of vegetation, thermal and acoustic comfort, air quality and safety. Then, follows the comprehensive plan for waste management (2008 - 2016), in agreement with the EU requirements for the generation and the reduction of waste, which includes the improvement of recycling, maximizing the value of all waste streams, the strengthening of the recovery and reuse of construction materials. Finally, the plan "climate change" (2010-20) was proposed, connected to the project of "zero-emission city Vitoria" (2020-2050), which aims to reduce greenhouse gas emissions through actions of greater efficiency and production efficiency and reduce CO_2 emissions from the residential sector, services and transport.

These tools can support the planning of urban transformation by the administrative staff and use specific indicators to assess the level of sustainability. Therefore, it seems necessary to connect them with needs of the community and characters of the settlement examined. Table 2 shows a summary of some experiences of participatory local development, aiming to create more resilient and self-sufficient settlements from a metabolic point of view. The summary is structured the same way as the experience of evaluation of environmental sustainability in Table 1.

1 Vitoria Gasteiz is the administrative capital of the Basque Country, with a population of 235,660 inhabitants.

	scale	context	promotors	objective	**areas**	note
Vorarlbeg (1997)	U	Austria	Local government associations	Self-sufficiency	**3- 4- 6- 7**	5 pilot municipalities.
SAGACités (2001)	N/ U	Cananda	Association	Actions against climate change	**1- 4- 5- 6**	
2000Watt - Basel (2002)	U	Switzerland	Private society/ Canton/ university	Sustainable development	**1- 5- 7**	
Appennino bolognese (2004)	U/T	Italy	Research centre	Local Development	**1- 5- 7**	
Transition town – Totnes (2005)	N/ U	UK	Resident association/ solidarity networks	Self-sufficiency/ resilience	**3- 4- 5- 6- 7**	community sharing
Vrin (2006)	U/T	Switzerland	Local government associations	Self-sufficiency	**1- 4- 7**	

Table 2 Summary of some "good practices" in European and international context

In fact the good practices, that start from participation and community awareness with respect to issues related to climate change, oil peak and also the need to create cities that are more resilient and self-sufficient at the metabolic level and accessible from a social point of view.

The experience of the town of Totnes[2] is very significant to explain fundamentals, process and results of the experiences summarized in the table, because it assesses the possibility of a change from all areas considered.

This town, since 2005 carries out certain practices that aim to create communities free from dependence on oil and highly resilient through the redesign and relocation of the energy resource of the community.

The goal is to activate an urban transformation towards a model of resilient settlement, not dependent on non-renewable resources. It is very clear and needs a very strong conscience of the community. However itis not systematized as in the experience of Vitoria because tools of investigation and evaluation are created by the community (and not by the administration) and so they are enriched by experiences of specific communities.

So some “best practices” were activated in Totnes and the promoter is precisely the citizen, the associations of inhabitants. They built a strong social network and solidarity among the inhabitants of the community.

The methodological approach is very simple and clear: awareness of the community than the present scenario, creating working groups compared the attitudes of the community. Best practices are activated respect to the same sensitive issues, facilitating the acquisition of new skills and forming relationships with local government practices implemented over.

This turns out to be the most effective community participation with respect to specific skills and resources. So the results are community initiatives, very punctual and related to the specific context analyzed. In the case of Totnes, recovered in a disused industrial site, using local and natural materials, have been set up practices of co-housing, groups of cyclists (cycling local), energy descent, local food production, creating a strong relationship between farmers and local producers, both catering for retail sale. Community gardens have been made, time and memory banks, book stores and a movie rental community, trees have been planted in public, a local currency was turned on and a group that deals with communication to the outside to give more visibility to initiatives. The objectives are less explicit and more related to initiatives and activities proposed, but as effective because they show how and how important it is that the process of improving the urban quality from the territory, which is necessary to understand the problems and the resources to enable practices to have real feedback for improvement.

2 Totnes is a community of 8,000 inhabitants in south west England and crossed by the River Dart.

SUMMARY OF PARAMETERS FOR FIELD

Thus, the third step aimed to clarify the parameters that synthesize and are deemed significant to describe the resilience of a settlement within the specific context of the specific areas of evaluation of urban quality. In the following we propose a summary by division, with the experiences related to considered references.

Areas	Parameters	References
1. Descriptive physical characteristics	- Population density - Population and social mix characters and inclusion of vulnerable population - Character and quality of the urban fabric, compared the efficiency of the form - Character and quality of the built - Social welfare	Indicators of European commons Seattle sustainable European Green Cities Index Urban Ecology Agency of Barcelona
2. Physical settlement (Lynch)	- Air quality and distance from pollution sources - Perception of well-being than physiological variable (thermal comfort, acoustic, visual) - Perception of well-being than psychological variable	Urban Ecology Agency of Barcelona Ecocities GL4
3. Identification and orientation to significant characters settlement (Lynch)	- Characters of the elements of urban morphology with historic and / or recognition by the community - Level of participation and ties to the community	Indicators of European commons Transition Town
4. To welcome and facilitate activities (Lynch)	- Complexity of activities and services - Promoting participation and involvement from the community	Seattle sustainable Urban Ecology Agency of Barcelona Transition Town
5. In order to reach areas and nodes (Lynch)	- Proximity to major areas and nodes, detected within the settlements - Accesssability of zones and nodes	Urban Ecology Agency of Barcelona Transition Town
6. care and management of places by those who use it effectively (Lynch)	- Public awareness with respect to issues related to water management, energy self-sustainability, the reduction of CO_2 emissions and the closure of production cycles - Participation of the comunity in the initiatives, connected with the concept explained above.	Transition Town Vorarlberg
7. metabolism of the settlement, linked to carrying capacity	- Local production - Water sufficiency - Energy self-sufficiency - Reduction in CO2 emissions - Efficiency of the system - Closing the waste cycle	Urban Ecology Agency of Barcelona Ecocities GL4 Transition Town 2000 Watt Vrin

DISCUSSION

The attempt to bring together experiences that come from very different processes and use different tools was crucial to understand how they are complementary. A quantitative assessment of the system-sustainability provides available methodologies and tools. On the contrary, "best practices" focus on the idea of resilience as a process starting from the specific capabilities of the settlement. Further work will identify quantitative indicators for describing how and how much increase of the capacity of a resilient settlement can describe the increase of quality.

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ECODISTRICTS

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ABSTRACT

The research is mainly based on the following fact: the ecodistrict concept is spreading more and more widely throughout Wallonia (the French-speaking part of Belgium located in the country's south) and all over Europe, but it has to be said that no clear definition of the concept yet exists.

The research focuses on two main topics:
- What is an ecodistrict?
- Is there a need for an ecodistrict seal of approval in Wallonia?

The research's outcome is the following:
- A definition of ecodistrict is provided
- Toolboxes are provided for better estimation of the overall performance of such a district
- Pros and cons about the opportunity of creating a specific seal of approval

The research's main hypothesis is that the context surrounding the ecodistrict project is absolutely crucial. A fully autonomous technological ecodistrict is not monitored. An ecodistrict should create close links with its immediate (existing) built-up surroundings, helping the neighbourhood to enter an eco-transition process.

Based on a benchmarking study, this research gives a definition of an ecodistrict in relation to ten factors: Density and Functional Diversity, Social Diversity, Ecomobility, Energy, Materials and Waste, Water Cycle, Biodiversity, Townscape, Health and Comfort, Participation.

Two variables are considered in our case:
- The kind of area: three different size of town are considered: city, town and village.
- The kind of project: new quarter, existing quarter and a mix of them.

Following the variables mentioned above, this matrix provides nine possible outcomes. The level of performance to be reached for all the presented factors is different for all cases. For example, the level of renewable energy changes according the spatial availability, so the requirements are higher for a new project than for an existing project, and higher for a village than for a city. Two cases are considered without interest and in the end, seven interesting cases based on the kind of area and the kind of project are considered.

INTRODUCTION

In terms of town planning, ecodistricts are matters of great interest among professionals, authorities and the general public alike. However, despite the expert testimony accumulated by certain European countries - in particular Switzerland, Germany, Austria and the Scandinavian countries - the term “ecodistrict” still has no precise definition in the Walloon Region. The term is often hijacked and many Walloon town-planning projects self-proclaim the term “ecodistrict”, using the concept as a marketing argument. In the long term, this situation is prejudicial in relation to the principles of sustainable development and generates a degree of confusion among the general public. The Walloon Region has been keen to rectify this situation by committing itself to the implementation of some truly sustainable town planning. The financing of the research is therefore motivated by an operational objective: to be able to offer assistance to the regional and communal officials called upon to assess the “ecodistrict” nature of a project.

At the end of October 2010, the research was able to culminate in the three following results: a precise definition of the “ecodistrict” concept, two tools for assessing development projects and deliberation on the appropriateness of creating an ad hoc seal of approval. Only the first two points will be developed in the context of this article.

Definition of an Ecodistrict

Sustainable districts, green districts, ecodistricts… To start, agreement had to be reached on the terminology and the ecodistrict concept had to be clarified. By relying on foreign experiences (benchmarking) and on the specific literature, the research has enabled a precise definition of the term “ecodistrict” to be formed.

Certain districts, whose inhabitants are looking for an alternative lifestyle, are organised around projects that function autonomously, even autarkically, and consequently have to be analyzed as closed, isolated systems. On the other hand, other districts are looking to be included within their context. They promote the local resources and develop systems (water cycle, energy, waste…) on various scales of relevance according to their environment: for example, the use of biomass coming from local agricultural waste. In this sense, they can have a really positive impact on the neighbouring districts by service-connecting, for example, a structuring common transport line, neighbourhood shops or facilities. This integration approach to the context is fundamental and starts from the principle that an ecodistrict cannot be and does not have to be self-sufficient. Firstly, this principle enables the risk of marginalisation of the district vis-à-vis its environment to be reduced. Secondly, it enables the nearby districts to be drawn by contagion towards more “sustainability”, through a process of eco-transition. Validating this principle induces consequences in terms of locality: an ecodistrict has to be established near to an existing urbanized fabric, or even in the middle of one, in the context of a transformation process.

An examination of the specific literature and an analysis of concrete cases studies have made it possible to establish that the definition of an ecodistrict is recurrently articulated around a certain number of themes. Our study has grouped them together according to the following ten themes:

Functional Diversity and Density, Social Diversity, Ecomobility, Energy, Materials and Waste, Water Cycle, Biodiversity, Landscape and Architecture, Comfort and Health, and Participative Processes.

In summary, an ecodistrict is part of a town which favours pedestrian transportation options which optimise its own environmental, social and economic resources in order to minimize environmental impact and which encourages surrounding neighbourhoods to involve in ecotransition.

ECODISTRICT ASSESSMENT METHOD

In the context of the research, it is possible to evaluate the quality of a project in the light of these ten themes, thanks to the performance levels framed by the results. In order to be in a position to take the various kinds of situation into account, these performance levels must be able to vary according to two parameters:

1. The kind of urban area (city, town, village)
2. The kind of project (creation, consolidation, transformation)

The diagram below represents the seven scenarii considered in the research.

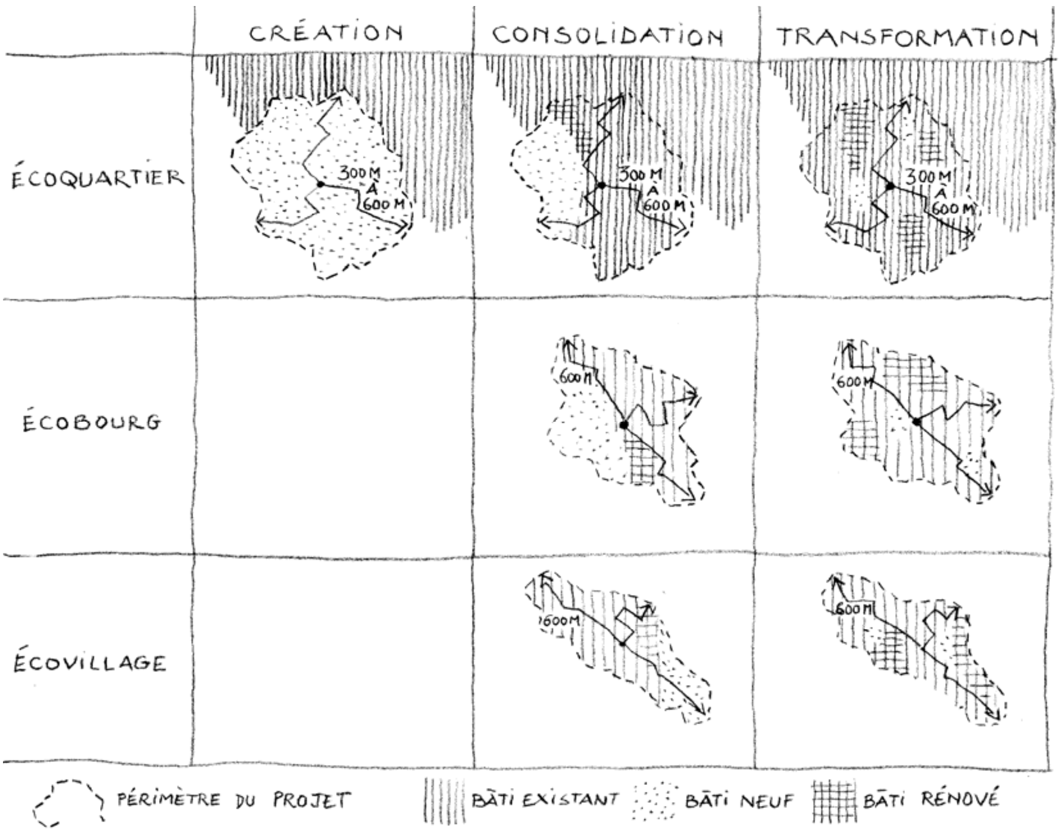

Figure 1: Diagram illustrating the seven scenarii considered. – Author: P. Vanderstraeten (2010)

1. The variation of the kind of urban area is justified in the following hypothesis: the inhabited territory of Wallonia is structured by three kinds of urban area: the city, the town and the village. The “Métrique Pédestre (Bernard Declève, 2009) – “Walkable Neighbourhood” (Richard Rogers, 1999) - structure the regime of distances. Cities, towns and villages are of course characterised by their size, but also by the level of their facilities, the kind of services for the population, the nature of the economic activities, the composition of the population and the ecomobility potential.

2. The variation of the kind of project stems from the principle that an ecodistrict project concerns both existing districts and new urban area extensions; in other words, existing districts can become ecodistricts following a renovation operation. Consequently, three cases can be considered:

- Creation: composed mainly of new buildings forming a new district, this kind of project concerns only urban environment. In order to service-connect various functions (mainly local services and public transport), a critical population threshold is necessary. This new town-planning project must therefore have sufficient size and density. The towns and the villages are not concerned because the critical population mass required is equivalent to that of these two kinds of urban area. However, it is not desirable to propose, in the years to come, the creation of new urban areas independent of the existing ones. Indeed, the parsimonious use of the Walloon ground, the policies of urban renewal and of reinforcement of existing nuclei, as well as those of safeguarding and developing natural, agricultural and forestry spaces, concertedly impose working on the renovation and development of the existing urban areas as a matter of priority.

- Consolidation: this kind of project concerns a new project of significant size but one which however does not reach the critical size of the "ecodistrict" evoked above. It is described as consolidation insofar as it represents a lever opportunity for reinforcing and engaging the eco-transformation of the existing district, town or village into which it is inserted.

- Transformation: this kind of project for its part designates an eco-transition project of an existing district, town or village. This kind of project mainly consists of multiple cases of renovation, public area developments and various network organisation and resource-sharing measures, but also, when necessary, some new construction interventions.

For each of these cases, the definition of the perimeter and the locality of the intervention are determined by the Functional Diversity and Density criterion, which plays a major role in the definition of an ecodistrict and in the service-connection of shops, services and facilities, and of structuring public transport in particular.

RESULTS

Assessment Tools

In order to enable objective assessment of the projects, two tools applicable to the various study stages of a file have been developed in the context of this research: key questions and detailed questions.

1. Key Questions

This tool enables rapid assessment of the overall approach of a file at the stage of an advanced sketch or a preliminary draught in the course of design. In accordance with the seven scenarii considered in the research, seven distinct questionnaires were drawn up. The assessor must therefore first choose the scenario to which the proposal to be analysed relates. Each questionnaire establishes the minimal but insufficient conditions for aspiring to the "ecodistrict" qualification. The key questions are divided into four categories: Locality, Programming, Development and Construction, and Resources. The questions are closed questions.

Far from requiring a profound knowledge of the file, this first filter makes it possible to estimate, via about fifteen general questions, whether the project duly meets the requirements for the development of an ecodistrict or whether it presents important lacunae from the outset. Thanks to its simplicity, this tool enables the positioning of signposts for orienting and improving a proposal overall; it therefore has an essentially teaching vocation. At this stage, these questionnaires are the result of an essentially theoretical deliberation. This is only the first stage of the work that will continue.

2. Detailed Questions

With more than 170 questions spread between the ten aforementioned themes, the detailed questions constitute the principal appreciation tool enabling comparative analysis: it will be possible to compare different projects or several variations of the same project or to check whether the project is indeed reaching the performance levels that had been set beforehand. Unlike the Key Questions tools, this one requires a rather detailed knowledge of the file at the various stages of the project's development (from the design to its complete implementation). The objective is to be able to measure the quality of a proposal with great precision, taking each theme into consideration, and to be able to classify and rank several proposals. At the conclusion of this test, the assessor is able clearly to identify the strengths and weaknesses of a project, thanks to the overall and the thematic weighting. In the study, the themes are not ranked between themselves, but it would be completely possible to accord them different weights according to certain priorities to be defined.

More precisely, each theme breaks down into two, three or four structuring questions. For example, the Energy theme enables a proposal to be assessed through the performance of its buildings, its public lighting, its renewable energies and its grey energy. As for the Key Questions, the requirements can vary according to the seven situations. For example, for renewable energies, the degree of requirement will be accordingly higher as space is available and natural resources are close.

	Creation	Consolidation	Transformation	Weighting
City	Do renewable energies cover at least 30% of the project's principal energy needs? - Yes 1/2 - Less than 30% 0/2 - At least 50% 2/2	Do renewable energies cover at least 25% of the project's principal energy needs? - Yes 1/2 - Less than 25% 0/2 - At least 40% 2/2	Do renewable energies cover at least 20% of the project's principal energy needs? - Yes 1/2 - Less than 20% 0/2 - At least 30% 2/2	/2
Town	Not concerned	Do renewable energies cover at least 30% of the project's principal energy needs? - Yes 1/2 - Less than 30% 0/2 - At least 50% 2/2	Do renewable energies cover at least 25% of the project's principal energy needs? - Yes 1/2 - Less than 25% 0/2 - At least 40% 2/2	/2
Village	Not concerned	Do renewable energies cover at least 35% of the project's principal energy needs? - Yes 1/2 - Less than 35% 0/2 - At least 60% 2/2	Do renewable energies cover at least 30% of the project's principal energy needs? - Yes 1/2 - Less than 30% 0/2 - At least 50% 2/2	/2

Figure 2: Table illustrating the principle of performance variation according to the two variables: kind of urban area and kind of project – Source: CREAT-UCL & GUIDe-ULB: Ecoquartiers, CPDT, Theme 5, Final Report, 2010, Page 26.

Each theme is equipped with a toolbox that suggests possible solutions enabling the results to be obtained. It is divided into two parts: the first proposes a theoretical review of the criterion and the second justifies the calibration of the recommended performance levels. Many bibliographical references are included, as well as links to various kinds of tools (websites, software, organisations active in Wallonia…) that can coach and orient the project initiators.

Finally, numerous examples of high-performance projects are also used to illustrate the narrative.

CONCLUSION ON THE METHOD AND THE TOOLS

In addition to the typological and contextual diversity that it allows, the originality of the assessment method lies in the amplitude of the possible choices: according to the projects, the emphasis can be laid on any particular theme: there is no ideal, universal solution. The ranking of the various themes must above all result from political choices. The Detailed Questions provide the basis for constructing a contextual and differentiated charter that values local particularities and mobilises the joint commitment of the various players concerned.

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Integration of Renewables in the Built Environment

KEY INNOVATIONS OF STUTTGART'S PROJECT HOME$^+$ FOR THE SOLAR DECATHLON EUROPE 2010 IN MADRID

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ABSTRACT

The Solar Decathlon Europe [1] is an international competition for universities from all over the world to design and build a self-sufficient home, grid-connected, using solar energy as the only energy source and equipped with technologies that permit maximum energy efficiency [6]. At the hightest architectural design level.

An interdisciplinary team of architects, interior designers, structural engineers and building physicians at the Hochschule für Technik Stuttgart (HFT) accepted the challenge and has been working on the design of the building since October 2008. The basic idea of our design 'home$^+$' is to use traditional means of dealing with the climate in hot and arid zones and to combine them with new technologies. Thermal mass, sun shading and evaporative cooling will help to achieve a comfortable indoor climate with passive means. The key element of our passive cooling concept is a new building component that we call “energy tower”, which is also an important feature of the interior design. In addition night cooling via sky radiation and evaporation is used to discharge Phase-Change-Material (PCM) material embedded in the house's ceilings. Active cooling is supplied by a compact reversible heat pump with a capacity of 2.4 kW powered by photovoltaics.

The competition took place in June 2010 in Madrid and our project home$^+$ finally ranked 3rd with only 4.5 of 1000 possible points distance to the the winner. However, it received first awards in the desciplines "engineering and construction" and "innovations" and second awards in "Solar Systems" and "Appliances and Functioning" and a third prize in "Sustainability". The design and energy concept of home$^+$ has previously been described and published in [2-5].

Keywords: Solar Decathlon Europe 2010, Innovative PVT collectors, multi-colour PV modules, PCM-ceilings, cooling glass tower, low energy systems

1 DESIGN CONCEPT

The design is based on architectural and energetic considerations. The starting point is a compact and highly insulated volume, with a small surface to volume ratio. The volume is segmented into four modules, which are positioned with interspaces between them (Fig. 1).

These gaps are used for lighting, ventilation, pre-heating in winter and passive cooling in summer. One of these gaps is higher than the others, containing the “energy tower”. Based on traditional principles of climate control, the energy tower is a key element for the energy concept as well as for the outer appearance of the building and the interior space. The modules and the gaps are bound together by the building envelope, which is covered in large areas with photovoltaic elements. The interior shows a clear zoning. In north-south direction the terrace, the living area and the dining area are marked by the gaps, but can be used as one big space also. This is especially important for the two dinners we had to invite our neighbours in the solar village to in June 2010. The more private working and sleeping area is separated by the volume of the energy tower. In east-west direction each area is accompanied by a serving zone (kitchen, entrance and facilities, bath). The modular design of the building does not only facilitate the transport to and the assembly in Madrid, but also allows thinking about a modular building system for different requirements. Using the same basic modules it is possible to create living and working space for singles, couples, families or apartment-sharing communities in detached and semi-detached as well as in multi-family houses.

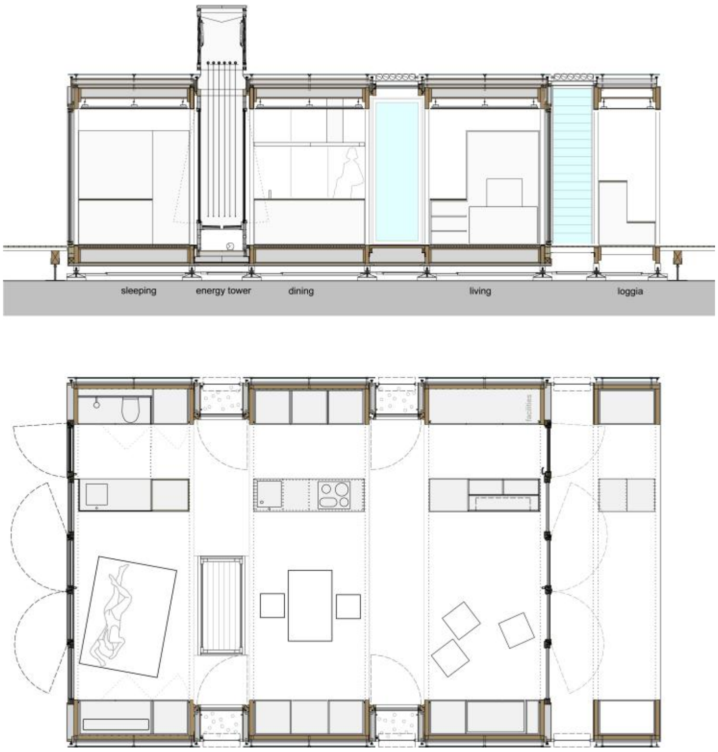

Figure 1: Floor plan and section.

2 ENERGY CONCEPT

The basic idea of our design is to use traditional means of dealing with the climate in hot and arid zones and to combine them with new technologies. Thermal mass, sun shading and evaporative cooling will help to achieve a comfortable indoor climate with passive means. The key element of our passive cooling concept is a new building component that we call "energy tower" (Fig. 2), which is also an important feature of the interior design. In addition night cooling via sky radiation and evaporation is used to discharge Phase-Change-Material (PCM). Active cooling is supplied by a reversible heat pump powered by photovoltaics.

Since the competition occured in June in a Southern Europe country, the most challenging part has been to satisfy the comfort level in cooling mode, which will be the focus of this study.

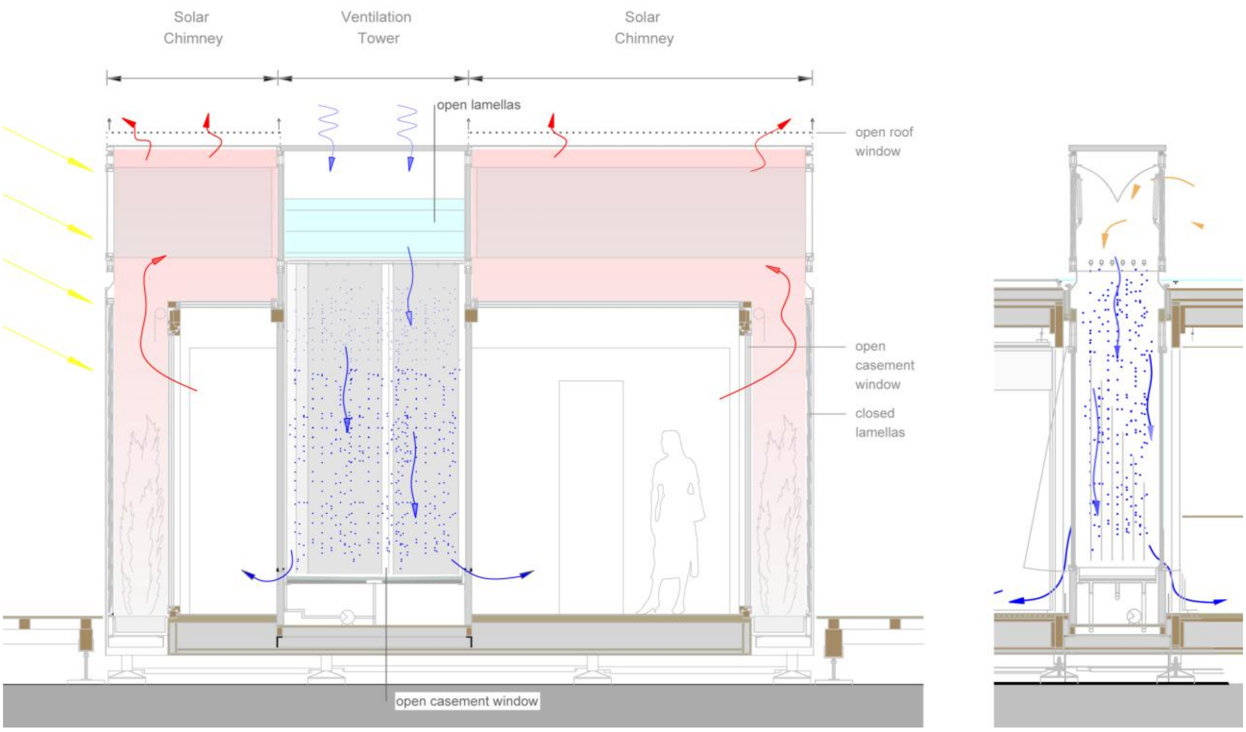

Figure 2: Energy Tower (Sections)

2.1 INNOVATIVE PV MODULES

With regard to a unique design we have different façade and roof PV modules. The roof should provide a maximum of electricity output. Roof and façades are visually connected using differently coloured cells in a unique 'pixel design' (Fig. 3). The cell colours are gold and bronze on the roof edge and façade while the roof is covered with monocrystalline black cells. The overall installed power is in the range of 12.5 kWp.

Figure 3: Multi-colour PV cell modules on the east and west façade (Source: J. Cremers)

2.2 PASSIVE COOLING SYSTEMS

The energy tower supplies passively part of the ventilation and cooling needs by evaporative cooling when the ambient conditions are not extreme (not too hot, not too humid). Free cooling operates in moderate climate conditions and/or at night by letting the air flow through the openings in the gaps (Fig. 4).

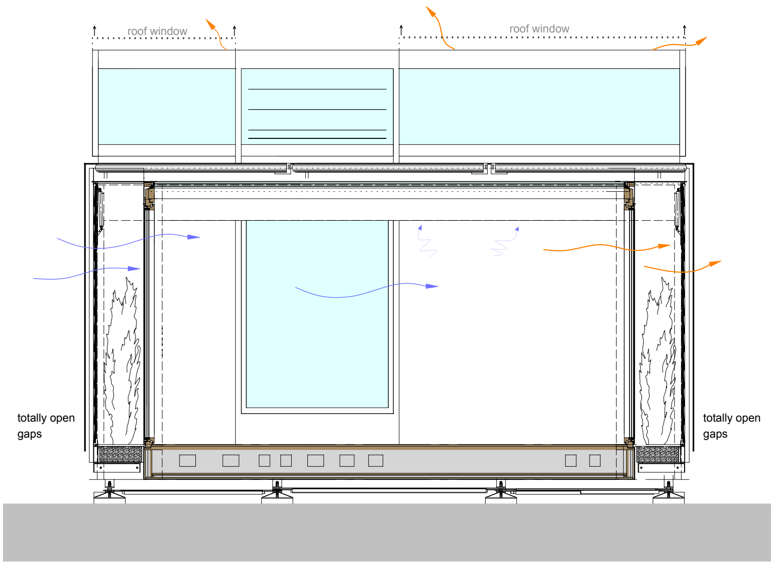

Figure 4: Free Cooling

2.3 LOW ENERGY NIGHT COOLING SYSTEMS

During the day, the PCM ceiling uses the latent heat of the PCM to store the heat and maintain the room temperature around the melting temperature (21-23°C). During the night, the PCM ceiling is actively regenerated using cold water from the night radiative cooling system on the roof (fig. 6). The main innovation is a photovoltaic/thermal (PVT) collector, which is not designed for maximum heat production, but for most efficient night cooling and a maximum PV power output during the day. The cold water produced at night is stored in a cold storage and used during the day to activate the radiant floor (fig. 5). The conventional ventilation system (active) is equipped with a heat recovery system between the return air and the supply air for winter and summer. Additionally an indirect evaporative cooling device enhances the cooling capacity through ventilation in summer.

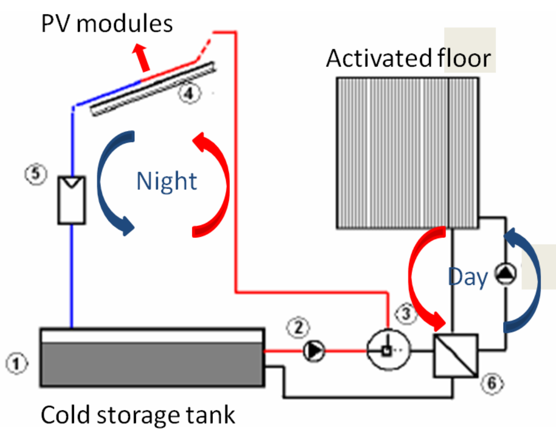

Figure 5: Night sky radiation cooling system

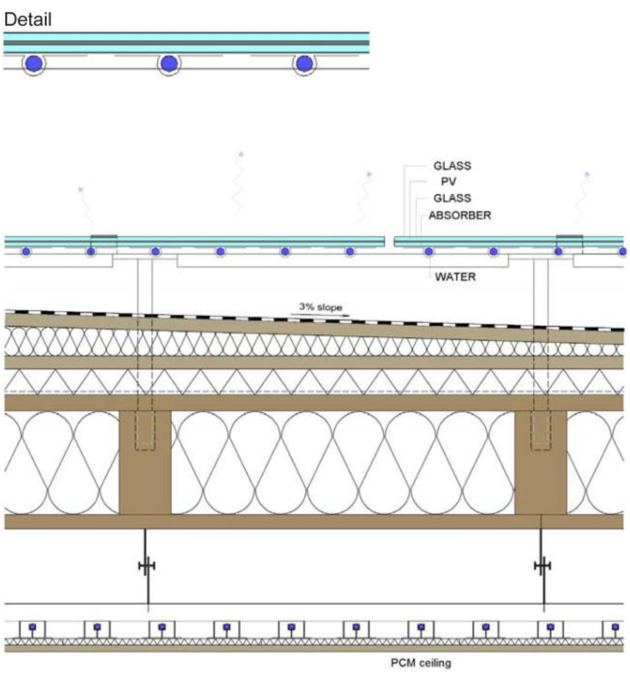

Figure 6: Principle of PVT collectors on the roof and PCM ceiling

2.4 BACK-UP COOLING SYSTEM

When the passive or the low energy cooling systems can not cover the demand, the reversible heat pump removes heat from the radiant activated floor to cool down the house. The choice of an electrical solution for the back-up is due mainly to the lack of thermally driven chillers in the range of small power and the lack of space available for the equipments (solar collectors, heat rejection devices,…). Therefore, the façades and the roof are covered with PV modules in order to provide the electricity needs of the house and inject the rest into the grid. A classic solar thermal system will provide the domestic hot water needs of the building. It is based on vacuum tube collectors located over the glazed roof lights of the gaps. Here, they act as the key shading system at the same time (Fig. 7).

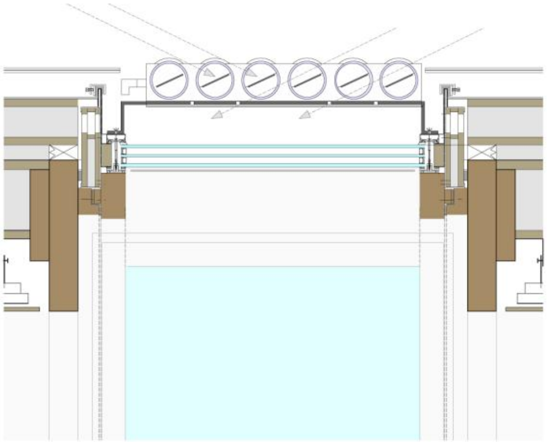

Figure 7: Vacuum tube collectors with two functions: production of DHW and solar shading system

2.5 CONTROL STRATEGY

Once we know all the components able to meet part of the cooling demand of the house, one needs to define the order of use of these elements in order to meet the required cooling demand. The passive technologies will be used with the highest priority and then the technologies that require low parasitical energy will have the priority. Fig. 8 shows the priority given for each subsystem in the control strategy.

Priority	Subsystems
1	PCM ceiling
2	Energy tower (if possible)
3	Free cooling
4	Night cooling / activated floor
5	Indirect evaporative cooling
6	Reversible heat pump

Figure 8: Control strategy of the energy concept

ACKNOWLEDGEMENTS

The HFT-SDE-project home+ has been substantially funded by the German Federal Ministry for Economics and Technology (BMWi) being part of the framework „EnOB (Forschung für Energieoptimiertes Bauen)“ (http://www.enob.info/).

FURTHER INFORMATION

For further information visit:
http://www.sdeurope.de (HFT Stuttgart's project website of home+)
http://www.sdeurope.org (official Solar Decathlon Europe website)

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AN ENERGY CONCEPT FOR MULTIFUNCTIONAL BUILDINGS WITH GEOTHERMAL ENERGY AND PHOTOVOLTAIC

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ABSTRACT

In multifunctional buildings varying cooling, heating and ventilation loads lead to high CO_2 emissions and high primary energy consumption. These can be decreased with suitable energy concepts using appropriately integrated renewables. Highest thermal comfort standards and special thermal needs, e.g. cooling loads of servers, LAN-equipment, storages or operating rooms, have to be fulfilled while using a minimum of fossil energy.

This paper presents an innovative energy concept, covering these requirements for a multifunctional office building, with the integration of geothermal energy and photovoltaic. The building is the new building of the E.ON Energy Research Center at the RWTH Aachen University and its completion is scheduled for autumn 2011.

The energy concept, see Figure 3, is based on geothermal energy and heat displacement in connection with a heat pump process. The geothermal field has 40 boreholes, each 100 m deep. Heat and cold base loads are distributed by concrete core activation. A sorption-supported air conditioning unit provides fresh air to conference rooms and CIP-pools. Offices are equipped with façade ventilation units, covering peak loads by supplying cold air during summer and hot air during winter. A gas-fired combined heat and power engine provides high temperature heat. The power production is supported by photovoltaic installed on the roof.

In order to gather local and global energy data with a highly detailed level, the building is equipped with an extensive monitoring system. The energetic flows of every energy source, energy conversion unit and energy consumer, as well as the thermal conditions are visualized via monitoring screens in the building and via mobile devices using web services.

The concept will be validated, evaluated and optimized by improving operation modes and control strategies, adapting user behavior and including weather predictions. The extensive monitoring and a complex thermal building simulation will provide necessary data.

INTRODUCTION

This paper provides a description of an energy concept for multifunctional buildings. First, the building, its use and the resulting energy demand are described. Second, the energy concept, designed to meet these demands, is outlined. Methods for optimization, including the extensive monitoring system and thermal simulations, are presented in detail. Related research projects and further research plans conclude the paper.

BUILDING

In multifunctional buildings varying cooling, heating and ventilation loads lead to high CO_2 emissions and high primary energy consumption. Those loads result from the building's use. This paragraph presents the specific building, for which the concept was developed.

Figure 1: E.ON Energy Research Center Main Building, Perspective of the façade, west

The building site is situated in Aachen, which is a city in the west of North Rhine-Westphalia, Germany. Figure 1 gives an impression of the building's west façade. The façade is designed in a grey-black metallic coating with a unitized curtain walling. The all over appearance is simple and quite artless but representative and presentable.

The building is the new headquarter of the E.ON Energy Research Center at the RWTH Aachen University. The building particularly integrates the following usable areas: office rooms and staff facilities (e.g. computer rooms, in the following called CIP-Pools), seminar and conference rooms, laboratories, common areas as well as areas for LAN- and server-equipment.

Offices, conference rooms, common areas and CIP-Pools have demand for cooling, heating and ventilation dependent on the outside weather conditions. LAN- and server-equipment has permanent cooling demand. Laboratories have volatile and unpredictable demand for process heating and process cooling.

Heating loads occur during winter while during transition times and summer cooling loads has to be regarded. As it can be seen in Figure 2, some CIP-Pools and conference rooms are placed in the middle of the building. Due to internal loads, cooling demand can also occur during winter, most widely independent from outside weather conditions.

The design constraints for the energy concept are kept with thermal comfort following EN 13779, indoor air quality 2 (IDA 2), with a temperature spread between 20 and 26 °C, which must not be exceeded for more than 50 hours per year.

ENERGY CONCEPT

In the following a detailed description of the concept, discussing the energy conversion system and the energy distribution principles, is presented.

Following the demand of the building, the energy has to be supplied on four different temperature levels: cooling energy at 6 °C for laboratory use, cooling energy at 17 °C and

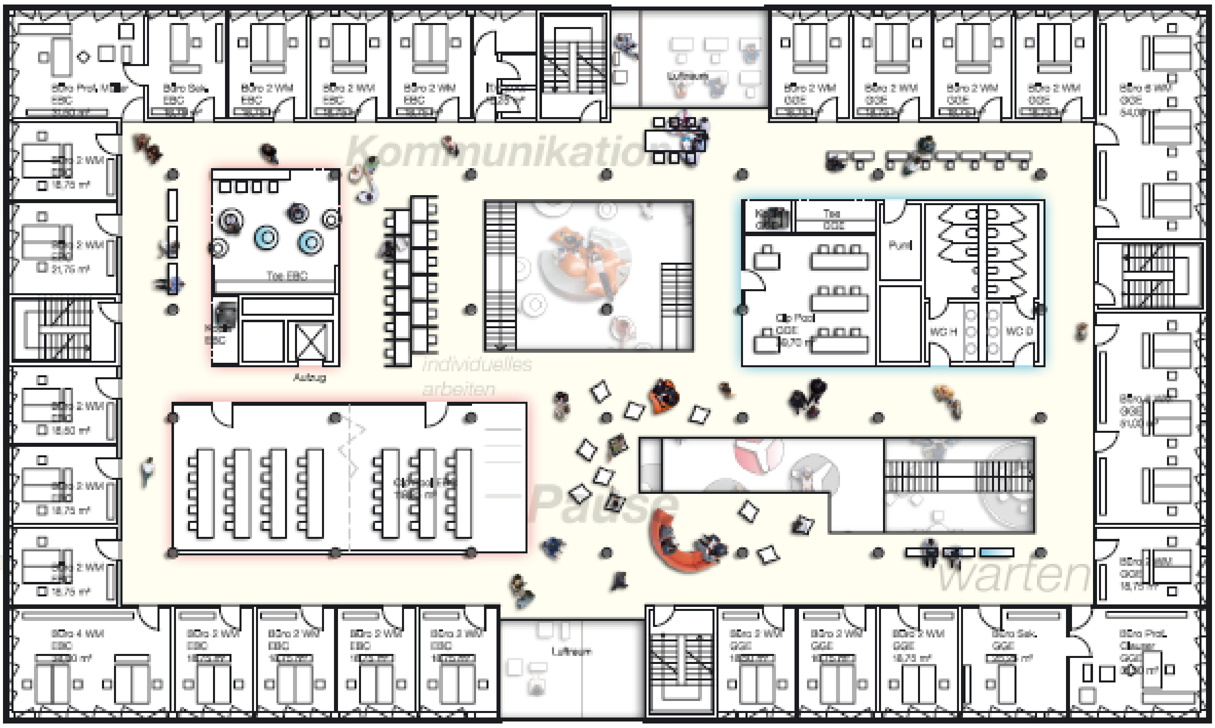

Figure 2: Floor plan of the first floor

heating energy at 35 °C for thermal comfort needs as well as process heat at 80 °C for laboratory use and brine regeneration.

Figure 3 provides a visualization of the concept, consisting of three layers: energy conversion layer, energy distribution layer and energy demand layer. The energy conversion layer is based on geothermal energy and heat displacement in connection with a heat pump process. The heat pump is equipped with a variable-speed centrifugal compression with magnetic, oil-free bearings, providing a high efficiency in wide areas of partial load. The geothermal field consists of 40 boreholes, each 100 m deep. It serves as a source of environmental energy and as energy storage at the same time. A glycol cooler offers the possibility to dissipate energy directly to the environment. On the 80 °C a gas-fired combined heat and power (CHP) unit provides process heat and electric power for heat pump operation. The power production is supported by photovoltaic installed on the building's roof. A condensing boiler system serves as a backup system for the heat pump and as a generation unit of process heat, exceeding the heat contributed by the gas-fired CHP unit. A sorption-supported air handling unit converts process heat directly into cooling energy for laboratories, CIP-Pools and conference spaces.

The heating and cooling base loads are distributed by concrete core activation in conference spaces, CIP-Pools and offices. The concrete core distribution system has high thermal capacity. Peak loads in heating and cooling are covered by façade ventilation units, equipped with four ways heat exchangers, able to cool and heat directly by air supply consisting either of fresh outside air or recirculation air, depending on thermal conditions, volatile organic compounds (VOC) and CO_2 levels inside the room. The façade ventilation units are able to recuperate heat or cold of exhaust air with high efficiency. Peak loads in conference spaces and CIP-Pools are covered by displacement ventilation with conditioned air provided by the sorption-supported air handling unit. Active chilled beams are controlling the thermal comfort at the laboratories.

The underlying principle of the concept is the use of geothermal energy and heat displacement. During winter, heat from the geothermal field and server rooms is integrated

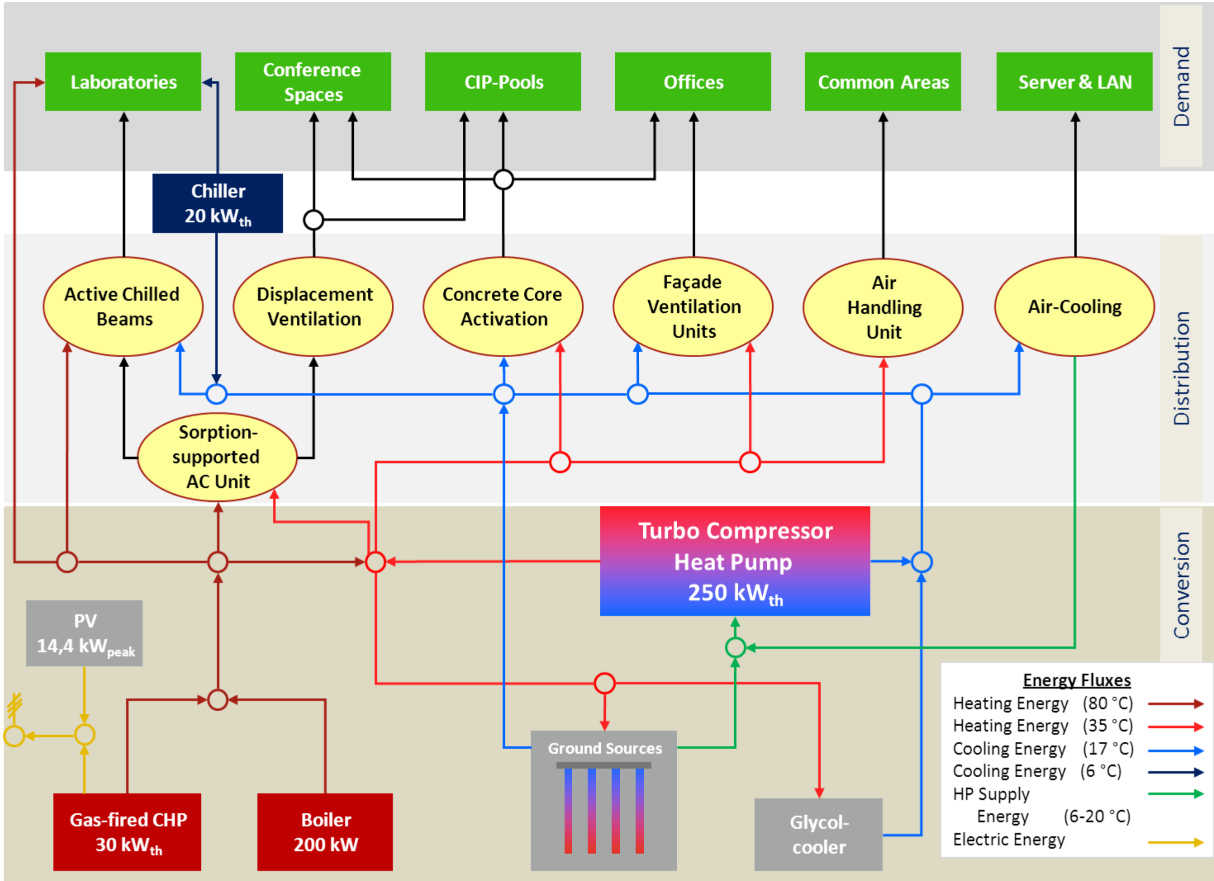

Figure 3: Visualization of the implemented energy concept

into the heat pump system. During summer, heat from the building, server rooms and laboratories is displaced to the geothermal field or cooled down by the glycol cooling system. A passive cooling can be realized by the concrete core activation using cold water from the geothermal field.

Winter mode: The heat pump provides main heating energy. It is supplied by waste heat from server and LAN cooling as well as geothermal heat. The system keeps this operation principle during transition periods until the server and LAN waste heat is enough to supply the heat pump. From here on no more heat is extracted from the geothermal field.

A change in operation is reached, when server and LAN waste heat exceeds the heat demand of the building. The heat pump reduces power, transferring a smaller amount of waste heat to higher temperature levels in order to heat the building. The remaining waste heat is either led back to the geothermal field or dissipated into the environment by the glycol cooler, depending of the annual energy balance of the geothermal field.

Summer mode: During cooling periods the heat pump and the sorption-supported air handling unit supply the building with cooling energy. As long as the geothermal field is able to store further energy, the waste heat from the heat pump is lead into the field. Exceeding energy is dissipated by the glycol cooler. Simulations of the geothermal field show that brine supply temperatures are kept between 4 and 16 °C.

In periods with moderate need for cooling, the heat pump reduces power or even stops working. Cooling will be provided by directly displacing heat from the building to the geothermal field.

Since test benches are operated and experimental work is performed in the building there is a constant need for high-temperature heat and low-temperature cold throughout the year. The high-temperature circuit is supplied by the CHP and the condensing boilers; the low-temperature circuit is supplied by the additional heat pump process, as it can be seen in Figure 3.

MONITORING SYSTEM

In order to gather local and global energy data with a highly detailed level, the building is equipped with an extensive monitoring system. The energetic flows of every energy source, energy conversion unit and energy distribution circuit are monitored. Thermal conditions, e.g. temperature, relative humidity, as well as CO_2 and VOC concentration, are recorded for every single room. In ten so-called reference rooms further sensors are installed, recording energy flows supplied to and extracted from the room.

The recorded values are stored in a HDF5 database and processed with python.

THERMAL SIMULATION MODEL

As a way of improving the understanding of the energy concept's overall potential a coupled simulation model of the building's envelope and of the technical equipment is being developed. The object oriented programming language Modelica is used for developing the model and the simulation environment Dymola is used for the dynamic simulation. The clear advantage of dynamic simulation over static simulation is its capacity to adequately depict the interaction between ambient, building and users. As such control strategies can be developed and compared to one another in terms of energy efficiency and user comfort.

Because the building's size makes a room by room modeling time consuming, regarding modeling and simulation time both, a zoning concept was developed. The underlining idea is the aggregation to one zone of rooms with similar use, which are conditioned by the same piece of equipment, or equipment combination. The result was 29 zones for the whole building. A further detailing of the zoning according to the outside walls orientation is currently being tested.

Different areas are conditioned differently, sometimes with the help of different equipment, so according to a particular goal it may be helpful to scale down the simulation and concentrate on one zone or one piece of equipment. This process of scaling reduces at first the complexity of the model, which can again be increased by adding more detail in the zone or equipment model. As such two models are to be developed for each relevant component: a simple one to be used in the whole building simulation and a more complex one to be used when simulating just one zone. One concentrating on one zone it is important to set the correct boundary conditions in relation to the other zones, in order to replicate the interaction from the whole building simulation. At present time the use of adiabatic walls between zones has been implemented and first test show differences between the two simulation set-ups, whole building and one zone, of maximum 0.5 K, which deem the solution as acceptable.

Apart from developing and testing control strategies that aim at improving the energy efficiency of the building when considering unrestricted access to energy, as provided by the grid at present time, the dynamic simulation allows the development of control strategies under the umbrella of demand side management. This means that the consumption can be adjusted or even delayed according to the availability or price of energy. The thermal storage potential of the building, especially in the heating period (1.09-31.05) has been appraised in preliminary simulations.

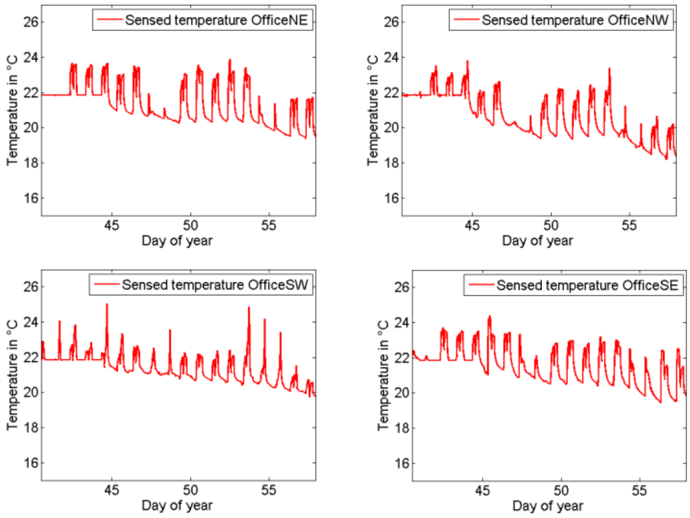

Figure 4: Cooling behaviour of four offices with different orientations, after the heating has been shut down

Figure 4 presents the cooling down behaviour of four different office rooms, with different orientations, one for each side of the building, after the heating system has been shut down. The heating system is set to 22°C and is shut down at 11 o'clock on a Monday in February. The peaks over 22°C are a result of the internal gains and solar radiation. For almost all of the offices the temperature drops under 20°C, regarded as a comfort limit, after more than a week. The results are very promising because a period of a week allows for more than enough time for different demand side management control strategies.

The next step after developing the model and after the building is completed is the validation of the model with the data gathered by the monitoring system.

OUTLOOK, PROJECTS AND ASPECTS OF RESEARCH

Already three research projects are directly linked to the buildings. The goal of the project energy concept is to compute local and global energy data, to calculate the building's energy performance, to verify proposed energy concept and to measure, publish and promote energy related building performance data. Different control strategies will be tested and evaluated in order to find the most energy efficient operation modes. The building serves as demonstration building for the EU 7th framework project PEBBLE, Positive Energy Buildings thru Better controL dEcissions (248537, FP7-ICT-2009-6.3). Its main goal is to develop a control system adapting user behaviour, including weather predictions and applying model-based predictive control to the building control system. The third research project focuses on the evaluation of possibilities of an air handling system with a decentralized control structure and on the development of adequate control strategies. These will be applied to the building's decentralized façade ventilation units.

Further research concerning load shifting, demand side management, integration of renewables to the built environment and thermal storage capacity of sorption-supported cooling processes, is intended to be performed.

CALCULATING EMBODIED ENERGY OF BUILDINGS WITH MINERGIE®-ECO 2011

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ABSTRACT

The MINERGIE® standard was introduced in 1998, with the more stringent MINERGIE®-P/-A and MINERGIE®-P/-A-ECO standards appearing later. Together they set performance criteria for energy efficiency, as well as for comfort, indoor air quality and use of renewable energies. A MINERGIE®-building consumes around 60 percent less energy than a conventional Swiss building, which in turn was built to one of the world's highest regulatory building standards.

MINERGIE®-ECO is an extension of the different MINERGIE® labels, covering the aspects of health (e.g. daylight availability, acoustics) as well as environmentally friendly products (good available resources, low environmental impacts, easy to dismantle and reuse or recycle). The application process of the former MINERGIE®-ECO demanded to answer 240 questions (yes 1. or 2. priority and no) as well as a daylight calculation. To ease the task to obtain the MINERGIE®-ECO label and to have a better evaluation of the environmental impacts of building, a national project, running between 2006 and 2009, was working on the generation of a methodology as well as software module (DLL) based on Life Cycle Impact Assessment data for building materials to allow an uptake in energy performance calculation tools for buildings.

Since then, the DLLs have been implemented in one existing building energy performance software (Lesosai 7.1) and the methodology has been integrated in an existing online Building Component Catalogue for the calculation of embodied energy (non renewable primary energy) of building components. This allows professionals without energy performance software to calculate the environmental impacts. Additionally, a procedure to cover the most commonly build interior parts (e.g. interior walls, concrete slabs) and building equipment allows the calculation of these parts with a few mouse clicks.

Methodologies for the calculation of the threshold value for the embodied energy had to be developed. The methodology has been tested with 15 case studies (5 new and 10 retrofit buildings) and proofed its practicability.

This approach has been used to present a comparison of the embodied energy and the GWP of one building in three versions with the structure and the same thermal comfort but significantly different heating systems and insulation standards.

FROM MINERGIE® TO MINERGIE®-ECO

In Switzerland, there is just one building label that was able to establish itself on the market. Ever since its launch in 1998, the MINERGIE® label, carried by the association under the same name, was able to achieve a market share of almost 25%, which is unique even by international comparison. This excellent market penetration is likely due to its simple procedure, tightly coupled integration with official regulations, the inclusion of all interest groups by means of events and courses, and its outstanding marketing.

Since 2006, buildings with healthy and eco-friendly constructions may be awarded with the MINERGIE®-ECO label. This is in addition to the labels MINERGIE® and MINERGIE®-P/-A which evaluate energetic aspects and comfort criteria. Since then, more than 300 buildings with approximately 950'000 m^2 energy reference area were certified according to the MINERGIE®-ECO standard. Thus, this label has received outstanding acceptance in the market. At the same time, MINERGIE®-ECO influenced the building material market. The availability of recycled concrete improved significantly, the number of solvent-free products significantly increased.

In the former MINERGIE®-ECO procedure, the daylight performance is a calculation while noise, indoor air quality, raw materials and construction/deconstruction are evaluated by means of a catalogue of questions. In this context, there are mandatory prerequisites that must be met (e.g. minimum amount of recycled concrete). Complying with the remaining other requirements generates points with a minimum requirement for each criterion. The total number of points must lower than the threshold applicable for each specific area (acoustic, lighting, etc.).

The MINERGIE®-ECO evaluation procedure has proven to be very flexible, easy to use and cheap compared to similar abroad labels. Nevertheless, the former procedure did not take the advantage of a full life cycle impact assessment of the building materials into account. The evaluation is only performed within the same functional unit which does not allow for a cross-unit comparison, for example between a wall cladding made of fibrous cement and a compact facade, because the effect of suboptimal alternatives cannot be shown using the former MINERGIE®-ECO method. This, in turn, may lead to a distortion of partial results.

Therefore, after more than five years of use, it was time to review and optimize the process and to expand its application to modernizations.

FROM MINERGIE®-ECO TO MINERGIE®-ECO 2011

Background

A project supported by the Swiss Federal Office for Energy in 2008 created the basis for a procedure that is now integrated into the new MINERGIE®-ECO (Version 2011). To this end, new software components had to be developed that are compatible with programs compliant with energy standards. The overall goal is to have a software that is capable of calculating simultaneously the operating energy and the embodied energy (primary energy, non-renewable) throughout the life cycle of a given building.

The technical documentation 2032 "Grey Energy of Buildings" [1] issued by the Swiss Society of Engineers and Architects (SIA) serves as the basis for calculation methodology. This paper fixes the applicable useful life of a building and its parts, of building elements that have to be included, and the structure and reference value for results. The data basis is provided by the Swiss "Ecological profiles database for the building sector" [2] which in turn are based on the internationally known Ecoinvent data base [3].

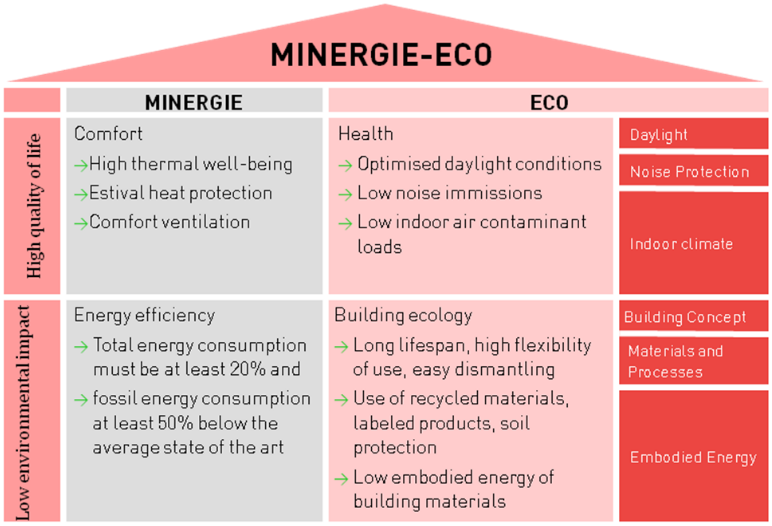

Figure 1: Newly structured criteria of MINERGIE®-ECO 2011.

Incorporating the LCA approach

This way it is possible to introduce the calculation of embodied energy within MINERGIE®-ECO 2011 while simultaneously getting rid of more than half of all specifications of the procedure because these mainly focused on aspects like raw materials and environmental impact during production and processing. As an environment indicator, embodied energy is able to sufficiently cover these aspects. First and foremost, this allows for an overall view of the used materials and their respective quantity which facilitates a significantly more precise statement on the environmental impact of a building. However, there are a few aspects that may not be depicted by means of a calculation such as the use of recycled concrete or wood with sustainability labels (resource conservation). This is why there is still a need for a specification catalogue. However, this was newly structured.

Shifting the focus towards aspects of the project phase

In contrast to the previous procedure that, in terms of scope, focused on the invitation to tender and implementation phases, MINERGIE®-ECO 2011 shifts the focus towards the project phase. During this phase, the potential to exert influence is significantly higher. The experience from the certification process has shown that this is where MINERGIE®-ECO meets the most difficulties, because choosing material and products is much more easily managed than conceptual aspects. At the same time, the applicants should receive better support in implementing the specifications during the tendering and realization. This is achieved by means of a check list for those specifications that the applicant wants to implement. The list includes all steps that must be taken during the tendering and the implementation phase as well as the proofs that must be turned in for documentation purposes. This check list is an important step towards building practice, thus also increasing implementation security.

Evaluation method with traffic light system

As mentioned before, -ECO is an extension and can be freely combined with the MINERGIE®, MINERGIE®-P and MINERGIE®-A label. Because there are no certification levels, the result of a certification process is either pass or no pass. The new MINERGIE®-ECO 2011 evaluation system is based on a traffic light system.

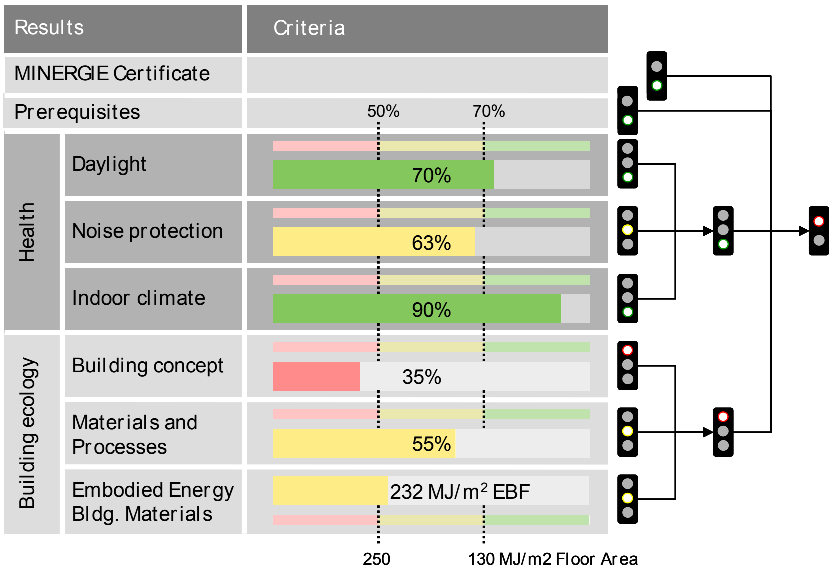

Figure 2: Presentation of results and applied traffic light system in MINERGIE®-ECO 2011

In MINERGIE®-ECO 2011, the evaluation is divided in 6 domains to be assessed as shown in figure 2. For each domain, the project is evaluated by a questionnaire and/or a calculation, and the partial results are divided into green, yellow and red based on threshold values. A red partial result means that a certification cannot be granted. This replaces former minimum performance degrees.

Newly developed instruments

Whoever was involved with the process of a LEED certification knows the difficulties caused by a lack of tools and the time request to get a result. Right from the beginning, MINERGIE®-ECO took the approach of providing all the necessary instruments in order to ease the evaluation of the project for planners and to reduce the time and cost of this procedure.

The purpose of a building label is not exclusively about documenting the finalized status quo, but also about striving towards project optimization. This, however, is only possible with an instrument that is able to depict all important features and capable of immediately displaying the results. The existing MINERGIE®-ECO instrument for proof assumes exactly this function and has proved its value.

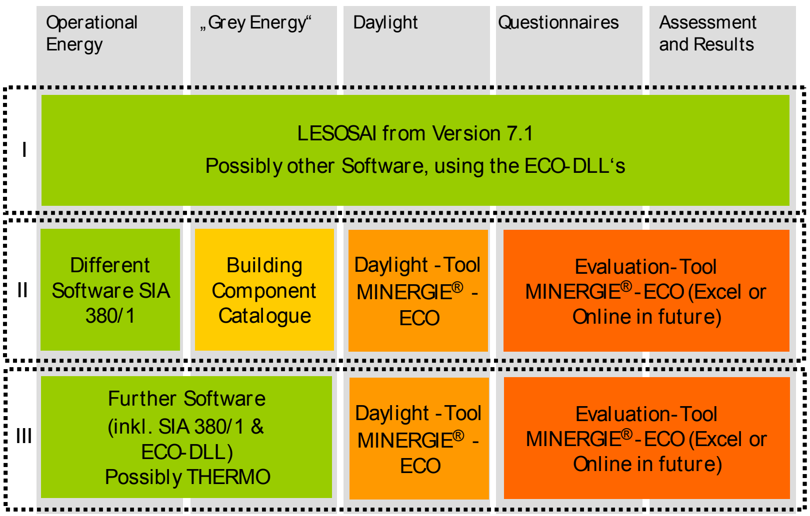

Figure 3: Different paths of certification in MINERGIE®-ECO 2011

Path I describes the "fully integrated way". Software like for example Lesosai Version 7.1 [5] and higher has all relevant elements included (calculation energy demand, daylight, environmental impacts and questionnaires) to make an integrated assessment and to provide a request of certification. The software is available for a fee. At the moment there is only Lesosai Version 7.1 and higher available for Certifications (April 2011)

The basis for a fully integrated instrument that is capable of simultaneously calculating the operating energy consumption and the embodied energy was created to be compliant with Swiss standards SIA-Norm 380/1 (Heating Energy demand in Buildings, based on EPBD) [6], SIA-Norm 380/4 (Electrical Energy in Buildings) [7], SIA-Technical bulletin 2031 (Energy pass for Buildings) [8], SIA- Technical bulletin 2032 (Grey Energy of Buildings) [1], MINERGIE® and accordingly MINERGIE®-P/-A and MINERGIE®(-P/-A)-ECO. That way is significant easier to optimize a project because there is no need to switch between different tools and because data only has to be entered once.

Path II describes the way where every step has to be made independently using the excel-based daylight tool for the calculation of the daylight situation, the electronic building component catalogue [4] (with costs) for the calculation of the embodied energy (primary energy non renewable) and GWP and the Excel-based Evaluation-Tool for the questionnaires, the assessment, the result and the request of certification.

The major difference of **Path III** compared to Path II is that the calculation of the embodied energy is included in the software calculating the operational energy. This way should be available in summer 2011 (THERMO [10])

EXAMPLE

Based on the methodology implemented in MINERGIE®-ECO 2011, a comparison of the non-renewable primary energy and the GWP of one reference building in three different versions have been made. The three building versions have the same structure and the same thermal comfort but significantly different heating systems and insulation standards. The results are shown in Figure 4.

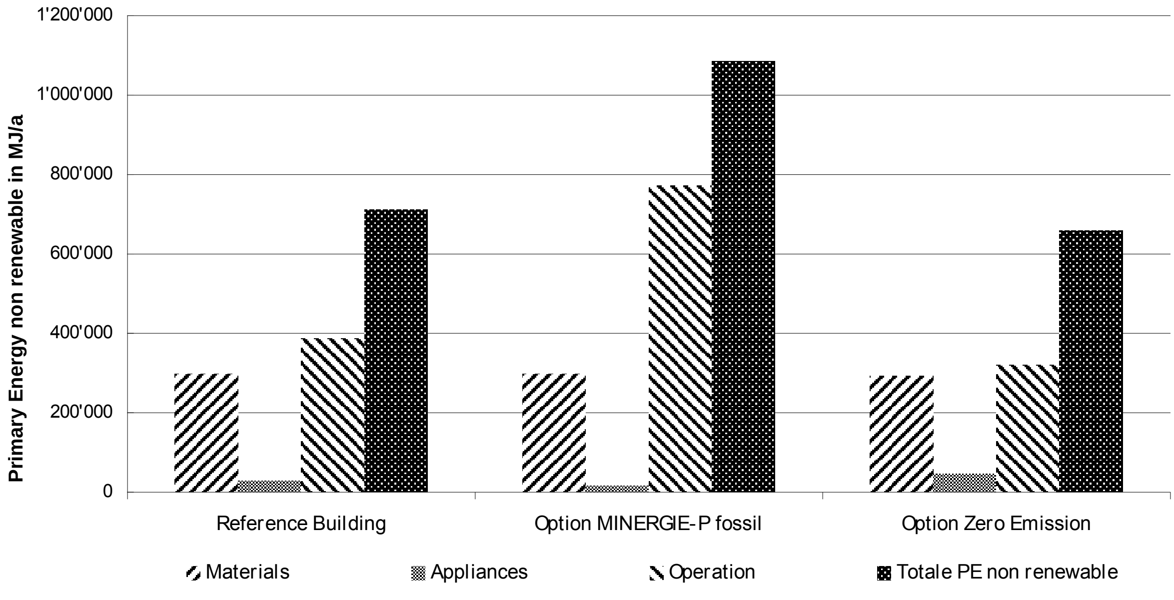

Figure 4: Comparison of three buildings with different energy concepts

The buildings with following specifications have been taken into account:

- The **reference building** is an existing highly insulated building (MINERGIE®-P), of 2’600 m^2 of heated floor area, with heat pumps to use the stored summer heat in the ground (40m) with 33 geothermal probes, 80m^2 area of photovoltaic to produce renewable electricity for the pumps as well as 110m^2 thermal collectors .
- The second building is a highly insulated building (MINERGIE®-P) with a minimal HVACR system with a gas heating system and without photovoltaic and solar collectors (**Option MINERGIE®-P fossil**).
- The third building is insulated on a minimum standard (requirement by law) and equipped with heat pumps to use the stored summer heat in the ground (350m) with 6 geothermal probes, insulated down to a 100m, 190m^2 area of hybrid collectors to produce renewable electricity as well as hot water (**Option Zero Emission**)

The total impact for the three building tpyes are only presented for primary energy non renewable (Figure 4) in this paper. For the conference the results for Global Warming Potential (GWP) will also be presented. The bar “total PE non renewable” represents the sum of the intermediate results materials, appliances and operation. The results in Figure 4 clearly show the largest impact (embodied energy of the materials) for the second building type with a traditional fossil-based heating solution. The third building type (Zero Emission) has a slightly lower impact than the first one (Reference) due to a lower impact of appliances although it has a slightly lower impact from the insulation material. The difference in the materials (insulation) between all the buildings is insignificant.

CONCLUSIONS

The MINERGIE®-ECO 2011 label is an evolution of the existing and well implemented label in Switzerland. It is making a large step forward with these adjustments – not in the direction of a thematically broad sustainability label of the “second generation”, but rather towards an integrated approach allowing for the easiest, most practical application possible. By including quantification of the environmental impacts of the building, based on a state of the art Life Cycle Assessment methodology, the assessment of the building performances has been shortened and the accuracy increased. In so doing, MINERGIE®-ECO does not want to reach so much a scientifically oriented audience but rather a high market share, thus coming closer to the objective of a sustainable way of building in Switzerland.

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INTERDISCIPLINARY RESEARCH ON THIN FILM PHOTOVOLTAIC FACADES AND BUILDING STANDARDS

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ABSTRACT
High-elevation houses display a rather bad relation between the flat roof surface and the total building surface[i]. The façade areas are much bigger. It is hence more interesting to cover the surface of the facades with solar cells than mounting solar cells on the top of such buildings. The amount of energy produced by facades represents about 70% of the energy generated by a tilted surface. Production of electricity is generally not a priority of architects who are more focused on cost efficiency per square meter. While crystalline solar cells are comparatively costly due to their high efficiency, thin film solar cells are more reasonably priced but have a lower efficiency per square meter. Consequently, architects may be attracted to construct facades with thin film photovoltaic (PV) -modules. Extensive mechanical tests are needed, however, as the specifications of PV modules do not comply with buildings standards. We present several examples of PV-facades in the past with all kind of technologies realized in Switzerland.
The main project will be the two 60 m tall houses "Sihlweid" in Zürich (Switzerland). There surfaces will be transformed into PV-Facades with thin film tandem modules. This is a part of a retrofit project of these two buildings in 2011 and 2012. Students of the Bern University of Applied Sciences are involved in their Bachelor-work in planning aspects of this spectacular project. The project has mechanical aspects. The structural rigidity of the PV-modules had to be tested in the test bench of the Bern University of Applied Sciences, Department Architecture, Wood and Civil Engineering in Biel with the original fixation of the facade elements. The requirements of the fire keeper department of Zurich had to be full filed. This is especially difficult as facades had stringent requirements against fire. The cabling of the PV-modules is another difficult task. Partial shading has to be considered. For that reason practical tests were done in the PV Laboratory of the Berne University of Applied Sciences in Burgdorf. This was done with the software PVSyst. Shading was measured with the "Suneye" – instrument and software. The construction work of the first house starts in summer 2011.
Keywords: *Thin film modules, photovoltaic facade, building standards, mechanical tests, installation considerations, interdisciplinary research.*

SOLAR ROOFS AND SURFACES COVER THE HOUSE
Roofs are more preferred for a maximum production of solar electricity. If we want to produce the needed energy for a house (Plusenergy-houses) we have to minimize the energy consumption for the house. Actually it's possible to build houses in mid Europe climate, which produce more energy than needed for the whole house for heating (via heat pumps), hot water (via heat pumps or combined with a hot water collector) and the electricity. But as higher a house as less roof surface per volume is available. For such houses it's impossible to produce the energy with the surface of the roof.

Plusenergy-house with solar roof (winner solarprize 2009)[ii]

PV-façade as visual learning for the population in Lausanne (CH) 1999[iii]

Façade surfaces are now dominant. PV-facades produce about 70% of an optimal oriented PV-surface. This orientation is therefore less interesting for a maximum power production. The idea here is to combine the façade surface which is needed anyway with a solar cell. If we use less efficient but cheaper thin film solar cells, we have a cheap façade surface material which produces electricity. The final result is a facade similar in price of a normal facade which produces electricity and offers therefore an additional advantage.

FROM THE PROTOTYPE TO THE FIRST PV-FACADE

The interest in thin film solar cells started in 1975, but at that time no products were available. Thin film solar cells are interesting for facades because of their low price and low efficiency. This results in much lower prices per square meter. That is the main figure which is interesting for an architect.

In 1984, the first products by Arco Solar and Solarex came on the market. The SolarCenter Muntwyler built together with the metal construction company Fahrni AG from Lyss the first prototype of a thin film PV façade. He was presented on different fairs in 1988 using Arco Solar G 200 with 20 Wp. The idea was to use the lower price per square meter to promote PV-facades. Unfortunately the producers of the solar modules weren't able to deliver more than prototypes. This was the end of this idea which came year to early. Since then we tried to promote PV-facades by different buildings.

The first realization came in 1999 in the city of Lausanne. The city was interested to present PV in very visible applications as a new source of electricity. In the former offices of the national exhibition of Switzerland in 1964 tow facades should be renovated. The facades would be covered with totally 15.36 kWp p-Si Modules from Solarex. For each of the facade 16 laminates of the MSX 240 were used. In the first years they injected the DC-electricity directly in the trolley-bus overhead line. Later this was changed to a normal DC/AC-grid connected installation.

PV FACADES STRUGGLES MANY PROBLEMS

PV-modules and installations were very expensive in the past. Prices for grid connected installations came down in the last 20 years by a factor of more than 3 even if deflation is not considered. PV is now much used even in Switzerland which lost his leading position in the grid connected PV-installations in the early 90-ies. Most of the installations are installed in Switzerland on old buildings. My suggestion goes up to 95% of all PV-installations. This doesn't prefer the construction of PV facades. PV facades must be installed on a new building or as part of a retrofit project. This needs an architect of building owner which want to install a PV facade. This is very rare. On the other side the PV-industry is not prepared for the needs of the building construction industry. The solar modules are not certified as façade element. The producer changes often the size of the modules. Especially thin film producers struggle hard in the market and went bankrupt. The stability of the different products is mostly unknown. One of the rare occasions is the thin film plant of the Applied University of Bern in Burgdorf where three different thin film installations are measured. All these factors explains why PV-façade in Switzerland were mainly showcase installations supported by governmental subsidizes.

PV FACADES REALIZED SINCE 1988

Some facades could be installed in the private sector. For this facades polycrystalline Solarcells were preferred. They have a nice "blue" look and the price per square meter is lower due to the lower efficiency. The modules were framed standard modules from Solarex/ BP Solar or Sharp. An exception is the thin-film roof coverage of the secondary school in Bussigny near Lausanne realized in 2004. For this project the architect Rudolph Lüscher wanted an unique black surface as big as possible with a fixed (low) budget. For these requirements the thin film solar cells are the best choice. Normally modules are inclined on a roof to enhance the production. This also solves normally the problem with the dirt. Due to the requirement of an unique black surface problems with dirt are serious. The choice was the laminates of the tandem thin film amorphous silicon module "Millenia MV 43" from Solarex / BP Solar. The laminates would be fixed with a glue on a rail system similar to a façade. The PV-Roof installation in Bussigny is therefore a façade horizontal mounted. Due to the technology "galvanic separated" inverters were required. The modules had a stabilized rated power of 43 Wp. The initial power was much higher. The choice for the DC/ AC PV-inverter was five Fronius IG 30. They have a input power of up to 5 x 3'600 Wp and a maximum output power of 5 x 2'650 VA 13'250 VA. At that time the installation was the biggest thin film installation in Switzerland. The project was installed as a commercial PV-project. This "horizontal façade" is an example for the wiring of the two new buildings in Zurich.

The school building in Bussigny with the "black surface"

The thin-film installation in Bussigny: "a horizontal installed facade"

PV-FACADE IN THE SWISS ALPS

PV-facades in the Swiss Alps have two additional advantages: they solve the main part of the problem with the snow coverage and they make profit from the reflection on snow. This could be demonstrated on two projects. The most known project is the new "Monte Rosa" hut of the Swiss alpine club SAC. This mountain hut would demonstrate that the main energy consumption can be produced by the sun. For that reason a special design of the hut was developed. The most impressive part is a PV-façade with high power Sunpower – solar cells. This is a very demanding choice for the design of the solar generator. The earthing for these cells created additional problems for the lightning protection and the earthing concept. The façade had to withstand wind loads up to 240 km/h. Due to the design of the façade 20 different shapes of the PV-modules has to be chosen. The DC-power is transformed by six Maximum

Power Trackers to 48 V DC. The energy is stored in batteries and will be transformed by 4 inverters to 230 V AC. The maximum cooling of the PV-modules is a very important point for the design of the facade.

SAC hut - Monte Rosa (left) and Ski resort PV-Façade “Trockener Steg” (right)

A more commercial application is the facades at the funicular station “Trockener Steg” in Zermatt. Due to the high wind loads a special rugged PV-module with a maximum wind load of 5’400 N/m^2 has to be chosen. The mounting of the modules could be done by local installers.

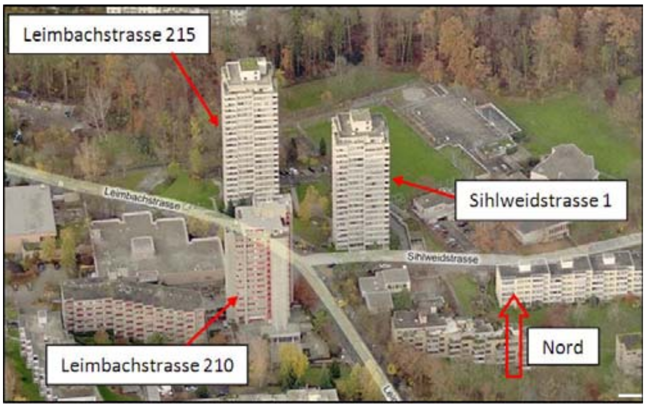
THIN FILM PV-FAÇADE ON TWO 60 M TALL BUILDINGS “SIHLWEID” IN ZÜRICH

One of the highlights of the PV Lab at BUAS Burgdorf is the thin film plant where three different thin film installations provide continuous data. Now, two 60 m tall buildings “Sihlweid” with PV-facades are projected in Zürich. As part of a retrofit-plan, the owner, the building cooperative Zurlinden BGZ, evaluated the use of thin film PV-modules instead of conventional façade elements. The plan is to install thin film solar modules on all four sides of the buildings. The power output per building will be about 130 kWp. Due to the different sides all four sides have different surfaces. The east-/west- and south side has more balconies than the north side. In a first calculation the following power output can be reached[iv]:

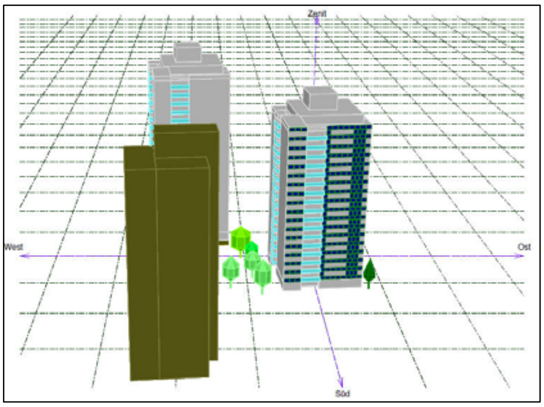
PV-surface	DC power/ kWp	AC power/ kW	produced AC energy / MWh/ year	Specific annual production/ kWh/ kWp/ year	Performance Ratio / %
East	24	20	12.59	518	76.1
South	34	27	18.88	559	69.1
West	34	27	11.67	345	49.9
North	49	39	8.834	180	46.7

Production overview of the four sides of Sihlweidstrasse 1

We can see that the maximum power output is highest on the north side with 384 modules Sharp NA 128G5 and 49 kWp. Due to the weak solar radiation on the north side the production will be only 8,834 MWh/ year. On the east side due to the shape of the building only 196 modules can be placed. Due to the shadowing situation only 190 will be connected and can produce power and energy. This gives a DC-power of 24 kWp and an energy production of 12,59 MWh/ year.



The overview with the two buildings with the retrofit project "Leimbachstrasse 215" and the "Sihlweidstrasse 1" (2011)



Shadow simulations with PVSyst on "Sihlweidstrasse 1" southside

Electrical installations in a 60 m tall building with many fragmented PV-modules are very difficult to realize. Lightning protection, fire safety, optimization of cable length, partially shadowing of PV-modules and the choice of the inverters and their voltages have to be taken into consideration. This is the objective of the student projects at BUAS. Through the different earnings per square meter, different approaches are needed to sell the solar electricity to the local utility company (EWZ) and the "feed-in tariff" regime in Switzerland. Other selling possibilities are also studied, and the students calculate the energy production of the first building on all four sides. The producer of the PV-element supports this project and will use the two retrofit buildings in Zürich as a showcase for the application of thin film modules in the façade application. Construction of the first building is expected to start in summer 2011.

ECONOMICAL CONSIDERATIONS

As discussed the decision for or against a PV-facade is normally not based on economical reflections. But also economic calculations could favor a thin film PV-facade. Thin film modules cost about sFr. 50.--/m^2 more than a cheap conventional façade surface[v]. We have additional costs for cabling, inverters and the installation cost of the electrical components. It's obvious that the surface cost will come down and are in the same region or lower than a conventional facade element. The additional production of electricity only has to pay the inverter, the cabling and the electrical components and their installation. It could be shown that even on the north side its economical realistic to use the PV-facade modules and to connect them[vi]. But of course it's less economic than the three sides of the building with more sunshine. These relations will be better and better as the prices for thin-film PV-modules came down. If we compare the costs per square meter with high performance PV-modules we have cost more than 100% higher.

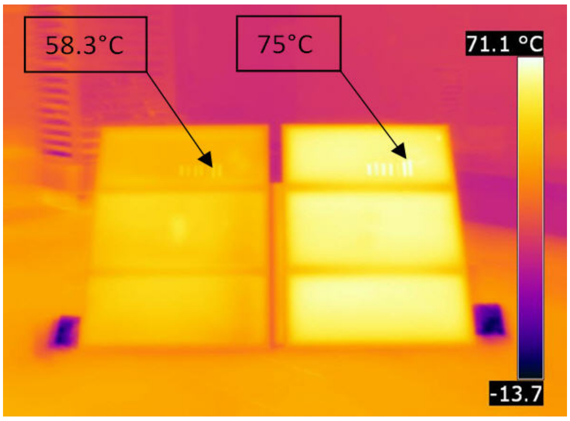
TECHNICAL CHALLENGE BY THE USE OF THIN FILM SOLAR CELLS IN FACADE APPLICATIONS

Solarmodules are well certified for the use in different applications on roofs or as standalone installation. Their specifications are not adapted for the use in facades. Here, national building codes and even local state legislation have to be fulfilled. According to the height and the construction of the building the wind loads have to be calculated and tests have to be done to prove that the PV-modules in the actual mounting construction is able to withstand the loads. These tests were successfully carried out in the laboratories of the Bern University of Applied Sciences of Biel, Department of Architecture, Wood and Civil Engineering at the end of January 2011.

MECHANICAL TESTS FOR THIN FILM MODULES

Thin film modules have a special glass cover. The mechanical behavior of this glass was not specified. Therefore we decided to test several of the modules and the mechanical behaviors in a special mounting structure for façades. First we calculated the maximum wind speed over 50 years. The peak is created by turbulences at the edges of the buildings. The peak load is more than 2'400 N/m^2, which is the standard load for this kind of modules. The first test was done in a test facility which produces positive and negative windloads. After the first successful test we started a sequence of tests following the Swiss SIA 261 standard.
Afterwards the destruction behavior of the module in the standard mounting has been tested. Here load impacts of more than 13'000 N/m^2 on the module could be realized.

Destruction test with more than 13'000 N/m^2 at test bench in Applied University in Biel



Infrared-temperature measurement on without (left) and with (right) insolation

The fire keepers of Zurich wanted an additional fire protection in the back of the modules because of the thin EVA sheet. We have measured the impact on the temperature difference[vii]. As seen in the project of the new SAC hut "Monte Rosa" this is a critical factor which has to be checked carefully[viii].

CONCLUSION

The two retrofit buildings in Zürich will be a showcase for the use of thin film modules in façade application. This application has an interesting potential for future PV-applications. New aspects as the visual impact, the visual stability of the modules, service aspects and the replacement of modules in 20-30 years should be studied. The PV-specialists and the architects have to establish a close collaborate to solve these problems. Facades can then be more than a protection against weather, noise and visual impact. They can produce a part of the energy of the building and his users.
The first installation "Sihlweidstrasse 1" will be realized in summer 2011. The second building "Leimbachstrasse 215" will follow in 2012. The PV Laboratory of the Bern University of Applied Sciences wants to measure the production of the buildings and will join the construction and the use this projects and the buildings.

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[vi] Nicole Reber/ Daniel Bützer; Projektarbeit 2: PV-Fassade „Sihlweid"; page 52-55; AUB, May 2011-05-15
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PROJECT: ENERGIE UND BAUDENKMAL (ENBAU) OPTIMIZATION OF ENERGY INTERVENTIONS IN BUILDINGS OF HISTORICAL-ARCHITECTONICAL VALUE

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ABSTRACT

The ENBAU project focuses on the energy (and constructive) analysis of buildings with historical and architectural values to be preserved.

The methodological approach has the objective of maintaining the architectural and historical appearance of the building while improving the energy balance. Minimal but focused building interventions are defined in order to obtain maximum energy savings.

Three buildings are analyzed by the working group and treated as case studies in order to define a set of interventions with the aim of improving the energy characteristics of the building and the indoor comfort conditions. Depending on the needs of preservation and conservation of the construction, the proposed measures can be varied according to different degrees of priority and feasibility.

INTRODUCTION

According to the National Centre of Information for the Protection of the Cultural Heritage (NIKE, www.nike-kultur.ch), in Switzerland, the percentage of properties to preserve is estimated at 3%. The majority of these buildings were constructed between the 19th and the beginning of the 20th century and can be found within the urban historic cores.

These buildings are characterized by a high energy demand. Although it is not always reasonable to obtain the MINERGIE standard (for such compley buildings), it is still necessary to improve their energy efficiency as much as possible.

In protected historical buildings (PHB) it is not possible to act freely on those elements (walls, roof, floor) that usually characterize the degree of thermal insulation of the building and protect the occupants from the surrounding and from the weather. On the contrary, it often becomes very difficult to find a reasonable solution when improving the thermal characteristics of walls and roofs means changing the appearance of a traditional building element or losing interior space.

Equally problematic is the definition of the actual benefits brought by the use of solar technologies when a building not only must undergo a thermal refurbishment but also must maintain its design.

Nowadays solar systems can be found everywhere. The situation becomes more critical as one would like to install solar thermal collectors and / or photovoltaic modules on historical buildings. Although there is an article of the law (article 18a LPT – Law on spatial planning) authorizing the installation on buildings of carefully integrated solar installations, as long as nearby monuments of cultural or natural importance of cantonal or national level are not affected. The regional authorities tend to pursue a restrictive policy, which in the best case scenario, at least allows to submit a project to a specific committee. In this case, the proper design of the installation is crucial.

PURPOSE OF THE WORK

For PHB it is not possible to freely work on those elements that usually define the thermal quality of the building, such as walls, roofs and floors. Therefore, it becomes particularly difficult to find appropriate solutions when better thermal characteristics mean changing the traditional external appearance of the building element or reducing the actual used internal area (e.g. through an inner layer of insulating material or by installing additional technical devices).

As far as the interventions on the building's envelope and on the technique are concerned, a focused refurbishment would not only permit to meet the energy consumption demands, but would also protect the historical/constructive characteristics of the protected historical building, ensuring its preservation.

It is therefore necessary, especially if one considers that the attitude related to the necessity of intervening "energetically" on historical monuments are divergent and in some cases almost irreconcilable, to develop a working method that will be as objective as possible and that will reduce the possibility of contradictions based on personal and arbitrary appreciations.

METHODOLOGY

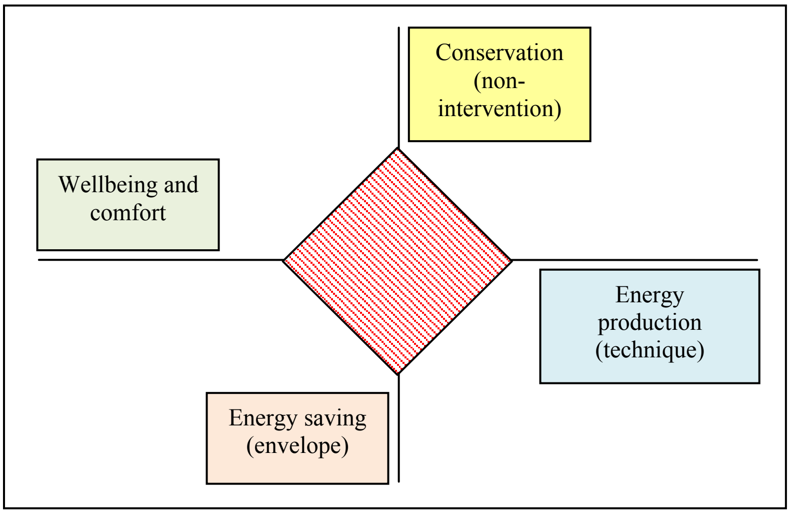

Figure 1: methodology, the refurbishment of historical buildings revolves around four different aspects: conservation, wellbeing and comfort, energy saving, energy production.

The aim of the methodological approach is to maintain the architectonical/historical aspect of the building while improving the energy balance. In practice, it will be determined the minimum building interventions in relation to the maximum energy saving.

By analyzing three case studies, it is possible to define a series of actions aiming primarily at the improvement of the energy characteristics of the building and of its conditions of indoor comfort. Depending on the needs of preservation and conservation of the construction, the proposed measures will vary according to different priority and feasibility degrees.

The main objectives of the project are:

- characterization of different types of historic buildings and analysis of the issues related to the reduction of the energy needs in order to develop appropriate technological solutions;
- as far as the technique is concerned, evaluation of the most suitable high-efficiency heating systems in relation to the conservative rehabilitation and determination the feasibility of a controlled ventilation system;
- development of a series of guidelines for the integration of solar installations on historical buildings.

Three residential historical buildings have been identified and analyzed by the working group. The characteristics, the needs and the requirements of the distinctive design features are especially investigated. It was decided to analyze only residential buildings as most of them do not need the same degree of protection and preservation typical of historical monuments of other types (e.g. churches). Moreover, in recent years there has been a growing interest in the refurbishment and redevelopment of these historic buildings. Considering that these buildings often do not meet the current energy and comfort needs, the definition of a series of interventions, single or combined, would therefore be of great interest for both the owner and for the designer/architect.

The analysis is divided into distinct stages:

- Inspection and energy analysis of the building: blowerdoor test, thermographic examination of the facades, on-site assessment of the historical and conservation needs by an expert of the Institute of Materials and Construction and by cantonal representatives
- Determination of the energetic characteristics of the building
- Assessment of economic, technical, historical and architectural feasibility of the interventions necessary to achieve the standards set by the cantonal legislation (adjustment of the thermal envelope and requirements for the technical plants).
- Verification of the feasibility to attain the MINERGIE standard: no primary requirement on the thermal envelope, heat recovery ventilation, fulfilment of the requirements for lighting and verification of the summer comfort according to SIA 380/4, observance of the energy index (energy needed for heating, domestic hot water production, eventually active cooling system / humidification / dehumidification).
- Verification of the feasibility to attain the standard MINERGIE-P: ≥ requirement for the thermal envelope ≥ 80% Qh, li SIA 380/1:2009, heat recovery ventilation, fulfilment of requirements for lighting and verification of aestival comfort according to SIA 380/4, blower-door test, mandatory use of label A or higher appliances, observance of the energy index (energy needed for heating, domestic hot water production, if eventually active cooling / humidification / dehumidification, auxiliary power required for circulation pumps).
- A set of guidelines for the selection of materials and the installation procedure will be developed. In general two different versions will be proposed, the first priority will consider the ecological characteristics of materials and the embodied energy of both materials and procedures. The “eco” analysis will also include the verification of the indoor comfort (natural light according to SIA 380 / 4, indoor acoustic comfort according to SIA 181 and outside acoustic comfort according to the noise pollution

ordinance). These analysis will be performed as a replacement of the MINERGIE-ECO certification which can not be used in case of refurbishment.

- Once the building potential for energy efficiency and the most suitable techniques are determined, it will be considered if and how to reduce the primary energy demand of the building by the integration in different level of renewable energy system such as thermal collector for domestic hot water and heating production, and photovoltaic systems for electricity generation.

CASE STUDIES

Two of the three case studies (one located in Ticino and one in Wallis), which are analyzed during the whole project time-frame, have already been chosen.

Casa Anatta (Ascona, Ticino). The building was constructed in 1904, the architectural features of Casa Anatta are the wooden panelling, the distinctive geometry of the building's stone base and its flat roof. Casa Anatta is currently being refurbished,

Figure 2: Casa Anatta – Monte Verità. Source: Wikipedia

Hotel de la Sage (La Sage,Wallis). The hotel was constructed at the beginning of 1900. It is located in the middle of the historical city centre of the village of La Sage whose altitude is about 1600 meters above sea level (5 minutes from Avolène). The building is characterized by its masonry structure and wooden roof. The owners have the intention to refurbish the hotel.

Figure 3: Hotel de la Sage – Avolène. Source: TripAdvisor.

The third building will be located in Graübunden in order to have a spread overview of the Swiss context.

The "theoretical" methodology will be implemented thanks to the three inspections, in fact during these occasions it is possible to practically test the working method.

By analyzing the characteristics of the building, and especially the specific problems related to the preservation of the architectural values and energy efficiency, it will be possible to adapt the methodology of analysis in accordance with the requirements of the various actors involved (architects, engineers, technical specialists).

FIRST RESULTS

One of the aspect that constantly emerges while examining historical objects is that the quality and the conservation state of a building is often not homogeneous. In fact in most constructions, roofs, transparent elements and facades have been restored or replaced in different time phases. Moreover the priorities taken into account during a refurbishment quite often focus on very different criteria (energy efficiency, preservation of the historical and architectural features, technical and or economical issues).

A systematic analysis of buildings allows to draw some general considerations. For example, if historical facades are considered, those are much better preserved compared to the covering elements. As consequence adding or integrating photovoltaic and/or solar thermal panel on them will alter an element which is perfectly functional and architecturally valid. For this reason, when possible and convenient it is better to integrate solar systems on roof where it is possible to mount them close to the optimum inclination (for our region of about 30°) reducing in this way the losses due to the vertical facade position. Moreover, in densely built areas, facades are the building's elements which suffer more the shadowing effect caused by the surroundings constructions.

Even though transparent and semi-transparent solar elements (especially photovoltaic glass) are becoming more popular, not all the transparent surfaces of historical buildings should be considered suitable to be replaced by PV modules. The main limitations are: their small dimensions and the fact that traditionally windows are positioned on the internal edge of the wall. If this feature has not been modified, the windows are then partially shadowed during the day by the wall-frame. Interesting artefact can be found in literature and some buildings can be considered as good practice cases.

Figure 4: Hôtel Industriel in Paris by Emmanuel Saadi. Copyright: Nicolas Morel.

CONCLUSIONS

The ENBAU project would like to shows the importance of an integrated approach, to treat historical building, in order to reduce or to limit the energy consumption and the carbon footprint. The project should take into account several aspects that are related to four macro categories, finding a balance between often conflicting demands is thus necessary.

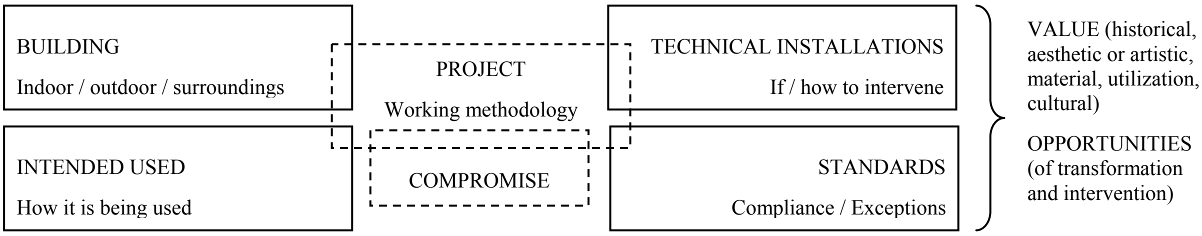

Table 1: connections and interactions among the four major categories.

A proper methodology is decisive to ensure that the changes to the building do not spoil it. Reaching a good degree of indoor comfort is mandatory, as is to reduce energy consumption.

To know thoroughly the building allows to better exploit its potential, it is thus necessary to identify the parts of the object which best lend themselves to go through changes, vice versa which elements are important to keep.

Also very important is the analysis of the needs and requirements of the building in order to determine its functions and employment (private or public building, open to a wide audience, used regularly / occasionally / seasonally, peak frequency), the expectations of the clients / users (comfort, aesthetical and technical issues).

Reducing the energy consumption of a building according to the preservation of historical material has to be done following a simple principle: achieve the maximum profit by exploiting the characteristics of the building and the environment. For example, before intervening constructively, it is worth to see if you can reduce certain temperatures, if the heating system is designed to heat people (and not the building) and finally if the users are able to optimally manage the building.

ACKNOWLEDGEMENTS

SUPSI is involved in this project with two institutes: ISAAC – Institute of Applied Sustainability to the Built Environment and more specifically the Agency and Centre of Certification MINERGIE of Southern Switzerland and the Swiss Competence Centre BIPV and IMC - Institute of Materials and Construction. A number of external partners are also involved: the Cantons of Wallis, Graubünden and Ticino and the Schweizer Heimatschutz (SHS).

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SELF – THE INDEPENDENT HOUSE

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ABSTRACT

Empa has developed together with Eawag – the Swiss institute for aquatic research - the self sufficient and mobile house SELF. It serves for testing and demonstrating technologies for houses of the future. SELF is a space unit, which is independent from external energy and water supply. It serves two persons for independent living and working, the whole year and everywhere in middle and southern Europe.

Solar modules are producing the energy needed for heating, cooling, ventilation, hot water, light, and appliances. Innovative technologies are reducing the energy and water consumption to a very low level and rain water is collected, purified and recycled.

Together with innovative building industries, Empa wants to explore within the CCEM House2000 project the efficiency limits of modern energy technologies.

1. INTRODUCTION

Our future energy supply has to be based on renewable energy. Heat is no longer a main issue; energy has become an electricity problem. Conventional technologies will not take us where we want to go. Already, our lifestyle and consumer behaviour have taken us far away from sustainable development. To have a chance to control this development and to return to sustainable development, we need to rigorously avoid unnecessary consumption and to make extensive and efficient use of renewable energies.

Energy-independent living and working is the ultimate challenge. Buildings that produce excess energy in the summer and have an energy deficit in winter are not really the solution. Energy cannot easily be shifted from summer to winter. Only if we can operate our buildings without fossil fuels year round we will have a sustainable solution.

Empa has decided in 2008 to face the challenge of finding solutions for operating buildings without fossil fuels. The research institute has created a space module called SELF, which is a research and development platform for investigating and testing new system solutions under real conditions.

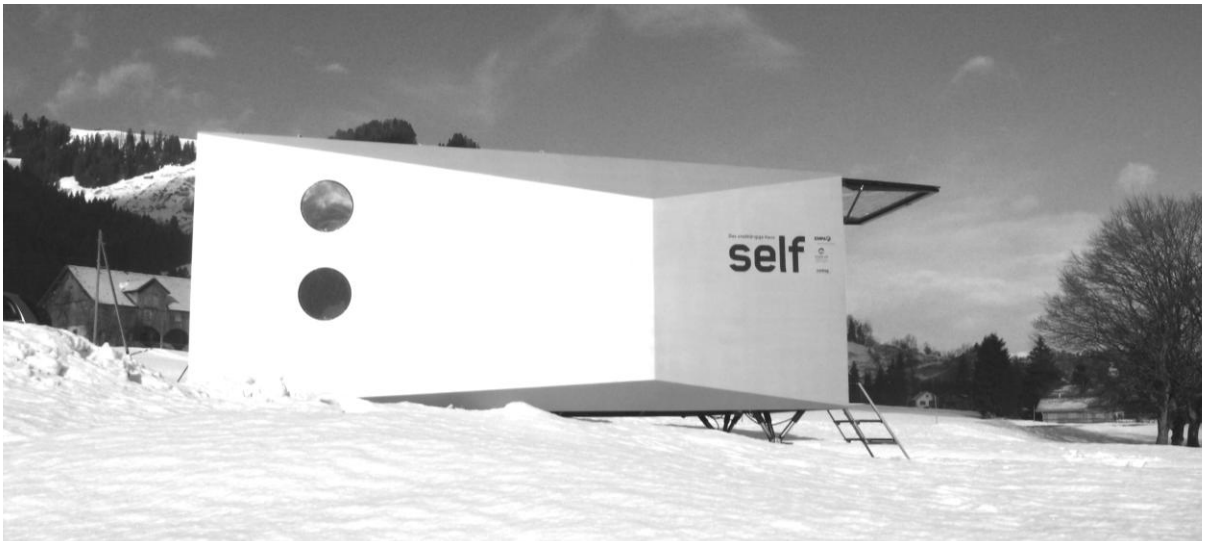

Figure 1: SELF, the independent room cell, during its first winter test at Sihlsee, March 2010, design by industrial designers Sandro Macchi, Björn Olsson

2. REQUIREMENTS FOR THE SELF ROOM CELL

It is difficult to construct highly innovative buildings, since investment risks are high and users' needs often don't match researchers' needs. The ETH Competence Centre Energy and Mobility's House 2000 project, provided an opportunity to build a demonstration house for forward-looking technologies. Empa decided to build not an actual building but a mobile space module that can be used for testing new technologies, as living laboratory for students, for presenting and demonstrating future-oriented technologies, and as lodging for academic guests and researchers. Because of the limited size and the required mobility and flexibility, the challenge was even greater.

Figure 2: Indoor view of the living room with work area

Spatial and technical requirements were based on these potential uses. Optimal use of space and ease of transport played important roles. Key requirements were as follows:

- Room module for comfortable, independent living and working for two persons
- Energy-independent (heating, cooling, ventilation, hot water, and all electrical components) year round in the central European climate zone. At least two weeks of operating energy reserves in case of no solar yield.
- Largely independent from water supply due to rainwater processing and gray water recycling.
- Maximum volume size for transport by truck without escort vehicle (max. width 3.5 m, max. height 3.2 m, weight ca. 6,000 kg).

3. CONSTRUCTION

The independent space module is intended not only to successfully demonstrate new technologies but also to show with its design that new territory is being covered. Every design measure was evaluated in terms of planned uses, space, weight, and energy-related consequences. The detailed results of the comprehensive design studies were constructed in 3-D and visually implemented using CAD [1].

3.1 Highly insulated building envelope

A 10 millimetre (insulating) aerogel mat and 40 mm vacuum insulation panels were used as thermal insulation. Although the overall envelope has some oblique angles, about 90 percent of it could be insulated with standard panels of 60 x 100 cm and half-panels. Custom sized panels were purposely avoided so that defective vacuum-insulated panels can be easily replaced at any time. In a standard section, the structure achieves a U-value of 0.1 W/(m²·K).

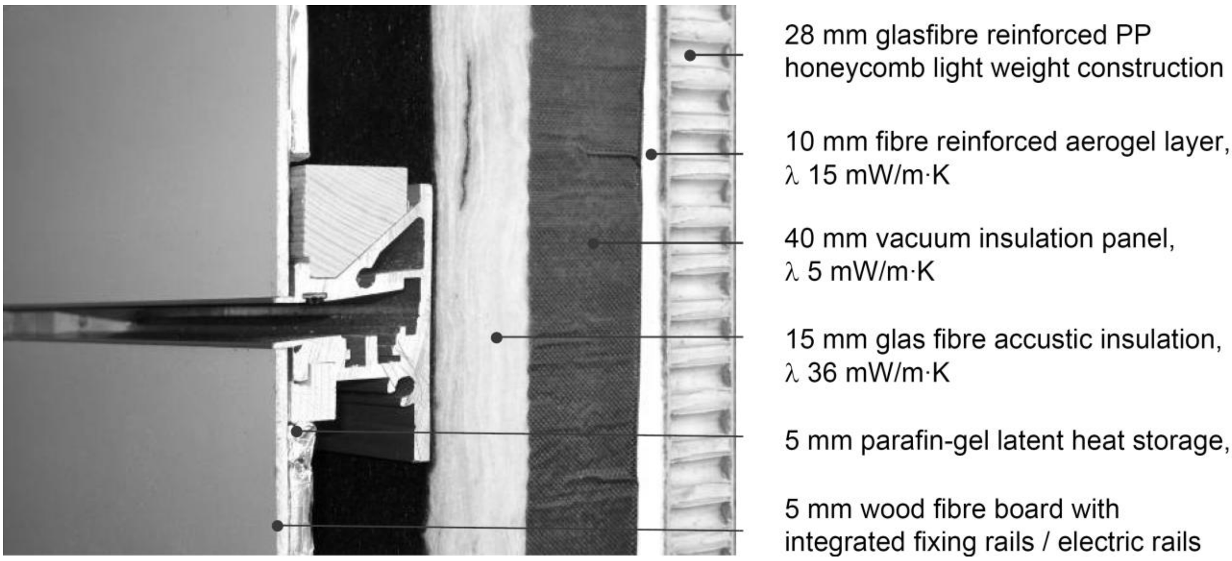

Figure 3: Structure of highly insulated building envelope, total: 150 mm thick, U-value 0.1 W/(m²·K)

3.2 Energy supply

The technological centrepiece is undoubtedly the photovoltaic and battery system that supplies the room cell with electricity. Because only a limited area is available for solar use, the best cells currently available were used. They cover the entire roof and the movable sun shade and have a cell-efficiency of 23%. The extremely light, almost unbreakable glass modules (they can even be walked on) are made of tempered 2 x 2 mm glass.

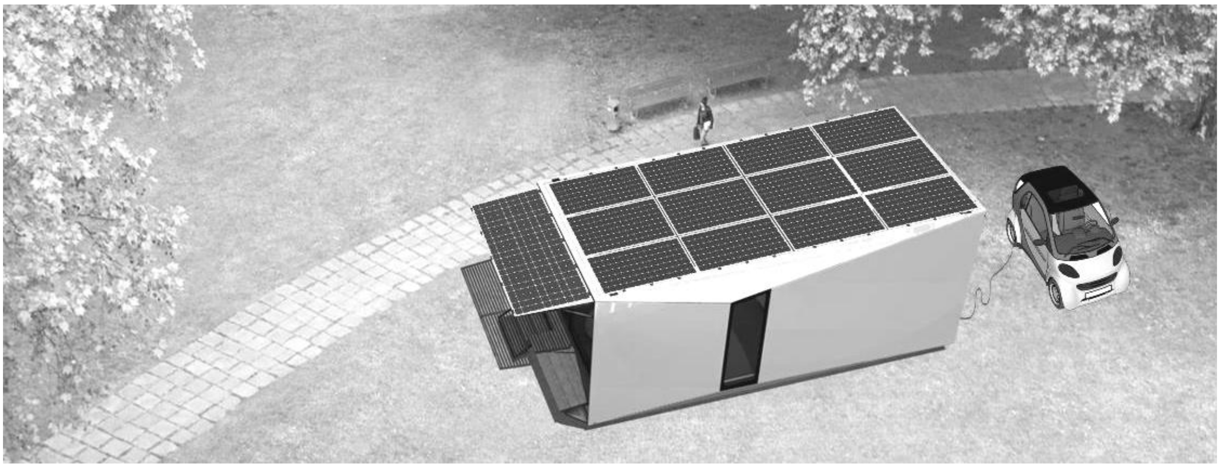

Figure 4: About 20 m² of solar cells cover the entire roof surface and supply 3.75 kW peak

Thermal collectors have not been installed, since the solar panels combined with a heat pump provide in the winter a better yield. In addition, overheating protection and a hot water temperature limitation are not needed in the summer.

Short-term energy storage (12 kWh) occurs directly in the room cell using lithium-ion batteries. For safety reasons and to increase flexibility, the seasonal energy storage is located in a separate supply module. It can also be used to supply energy for other field applications or for charging an electric car. The seasonal energy storage unit consists of lithium-ion batteries (24 kWh) and hydrogen metal-hydride storage tanks (150 kWh). Excess energy from sunny days can thereby be electrically stored or converted to hydrogen via electrolyser. When additional electricity is needed, a fuel cell can create it from the hydrogen. For cooking needs, the hydrogen can also be used directly.

Almost all electrical components are connected to each other via a 230 V-AC bus, which is compatible with the widest range of components. Despite great care during planning, however, electricity management may still be further improved. In particular, the converters, the charging and discharging regulators, and the measurement, control, and regulating electronics still consume too much energy. For an optimal electricity supply, the various components should be better adjusted to each other.

3.3 Water supply

In many countries, clean water is a bigger problem than energy. In order to be also as independent as possible in terms of water, Eawag, the Swiss institute for aquatic research, built a novel water purification system. The system uses the same filter technology as large water suppliers do, but it was designed for small units and in such a way that filter pumps are not necessary.

The drinking water processing system filters up to 100 litres of rainwater a day. Used drinking water (gray water) is collected and routed to a bioreactor, where pollutants are removed and the gray water is filtered. Another 100 litres of recycled water are available as hot tap water for the shower and dishwasher. Only toilet water is collected and periodically emptied. With this system, water autonomy can be increased by a factor of 10, and almost the entire water demand can be covered in rainy areas.

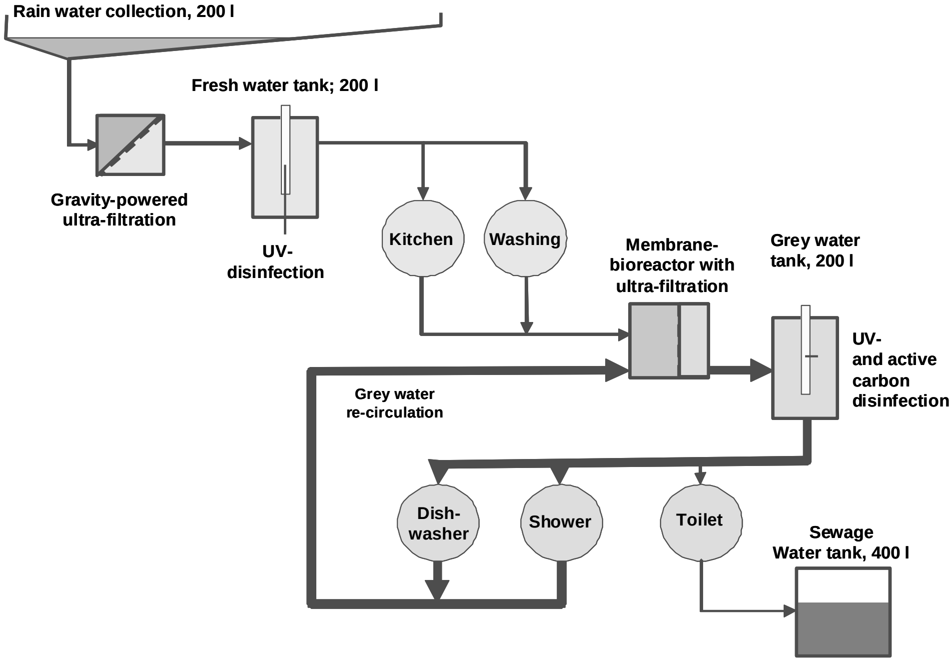

Figure 5: Water system with drinking and gray water processing

4 RESULTS

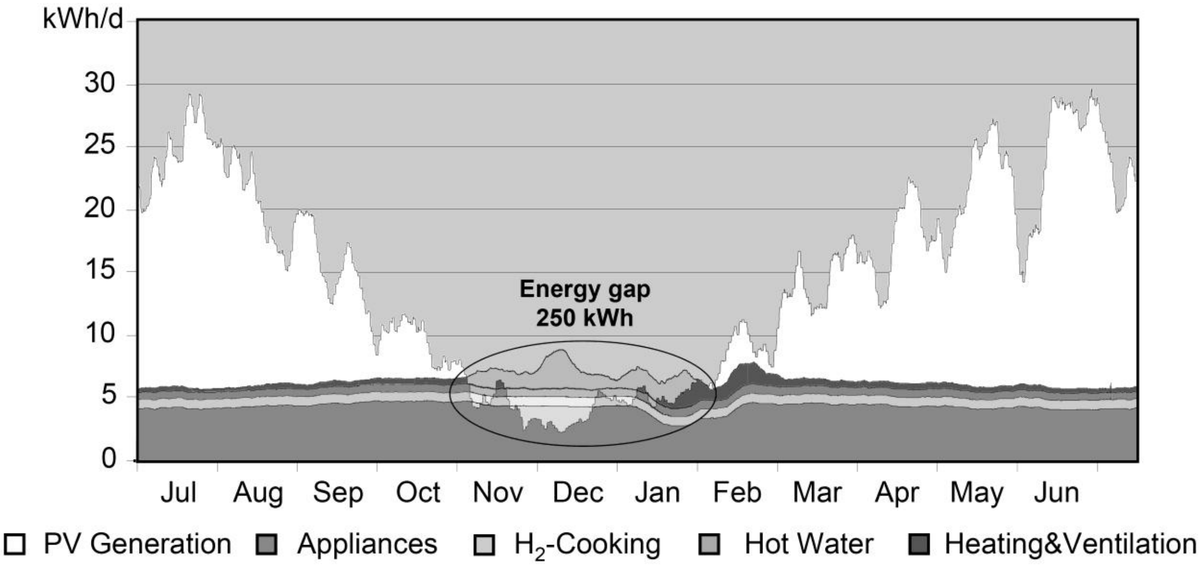

Figure 6: Energy yield and consumption over one year in Zurich. A small supply gap in the winter contrasts with great excess in the summer

The SELF space unit was presented to the public for the first time at Swissbau 2010 in Basel. In April, the Swiss television show Einstein reported on SELF [2]. Unfortunately, on April 2, 2010, the first completed room cell was destroyed in a fire that most likely was started by a technical defect in the battery system. Since then, however, Empa and Eawag have built a second space unit, which has already greatly benefited from knowledge gained from the first prototype.

SELF can especially give us insights into a future energy supply based on renewable energy. The project's objective is not to be representative of future construction, but rather to point out the challenges that still need to be faced.

We have gained the following insights:

- Electricity will be the most important part of energy in the future. In an energy-efficient building, the share of heating in overall energy consumption is relatively small. First, consumption needs to be significantly reduced; only then should renewables be maximized. SELF is designed for an average electricity consumption of just 200 watts.
- In the summer, sufficient energy can be produced quickly, even for the cooling system. In addition, SELF can be used nine months out of the year to charge an electric car for 80 to 100 km a day.
- Cold but sunny winter locations are predestined for solar power. Here, solar energy can mostly cover the energy demand even in the winter.
- If an efficient heat pump is used, only photovoltaic solar energy is advised. Thermal collectors are less efficient and much more complicated to install.
- Seasonal energy storage is still far from being efficient, and new concepts will not be available any time soon. Energy storage must therefore be solved with an energy network.

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EXERGY ANALYSIS OF OFFICE BUILDINGS USING GEOTHERMAL HEAT PUMPS

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ABSTRACT

Exergy is the amount of work a system can produce while transferring into thermodynamic equilibrium. In an exergy analysis not only the system itself but also its surroundings are considered. Exergy analysis considers the thermodynamically achievable efficiency of a system. Building energy demand fluctuates in response to outside temperature and internal gains. Therefore, in order to diagnose exergy losses and potential exergy gains, the selected reference state used in the analysis is extremely crucial. In this study we consider a dynamic approach for the exergy analysis of buildings and their energy systems.

The exergy analysis is applied to a "lowEx" low exergy office building. The building considered in this study is an office building with a ground source electric heat pump, ventilation with heat recovery, and thermal activation of building elements. Office buildings with geothermal energy systems use low temperature differences for heating and cooling. As a drawback, large hydraulic systems cause high pressure drops leading to a high electrical energy consumption of all pump devices. The electricity demand of the hydraulic pumps is in concurrence with the exergy savings achieved via operating a low temperature system. The same consideration can be applied for the heat pump: electric energy is used to provide heat with low exergy level. We analyze the exergy loss processes in heat generation, distribution and delivery and the exergy demand of the building and calculate the exergy efficiency of the whole system. The results will be used to identify the opportunities to increase the exergy efficiency of the process and an efficient application of electric energy.

The office building is modeled and simulated in the object-oriented programing language Modelica. The developed model can illustrate the dynamic thermal and hydraulic behavior of the building and HVAC installation. Different operation modes can be implemented in this model, thus allowing us to test strategies for reducing exergy demand. The developed model will be validated using monitor data of the building.

Keywords: Energy analysis; Exergy analysis; Building simulation; Primary energy

INTRODUCTION

Since 1970s, different governmental regulations are in place to promote the reduction of building energy demand, for example, optimizing the building isolation standards or improving energy supplying systems. Different certifications are used to evaluate the energy performance of buildings. These energy labels consider various aspects such as primary and final energy demand or C02 emissions of buildings. The primary energy factors have been enforced to consider the energy losses in the whole energy chain.

This study considers the exergy performance of buildings. The concept of exergy captures the thermodynamically achievable efficiency in a system. Exergy depends on the environmental state. This is on one hand an advantage of exergy analysis, because the approach allows inclusion of environmental differences and particularities. On the other hand, this complicates the analysis. Moreover, the researcher needs to decide how to capture the environmental specifics i.e., what reference state to choose.

The reduction of the exergy demand of heating and cooling systems can be achieved by efficient heat and cool generation (e.g. heat pumps), by the use of available temporal or spatial temperature potentials, and by storage as well as by heat exchange processes with low temperature difference.

In this work the exergy efficiency of a LowEx building is analyzed and compared to a conventional system. A simulation-model of an office-building is developed in the object oriented language Modelica. This building model is coupled to two different heating systems. The first one is a geothermal heat pump in combination with a thermo-active building system (TABS). The second system consists of a condensing boiler and radiators. The exergy demand of heat generation and heat distribution are compared to each other.

Figure 1 shows the exergy balance of a heating system. The exergy losses can appear at different levels: Exergy losses at heat generation, heat distribution and heat delivery.

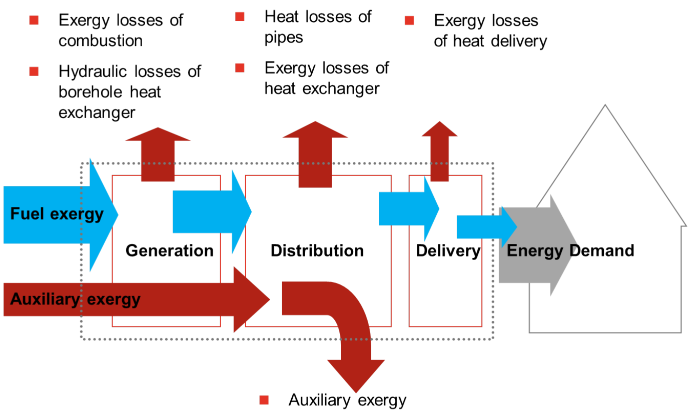


Figure 1: Exergy balance of heating systems.

Modeling and simulation

The system modeling has been done in the object oriented programming language Modelica. The Modelica libraries (HVAC and building library) developed at the Institute for Energy Efficient Buildings and Indoor Climate are used to simulate the dynamic thermal and hydraulic behavior of the system [1].

The building model takes into account:

- Heat losses through outer walls and windows depending on outside/Inside temperature, conductivity and heat transfer of the construction
- Ventilation heat losses
- Heat capacity of the walls and air

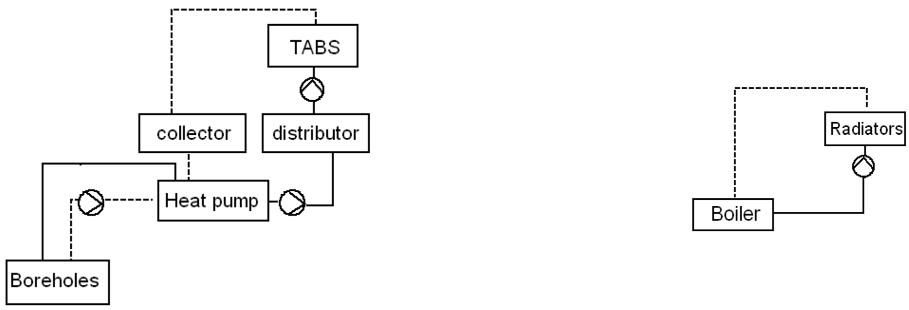


Figure 2: Left- A simple illustration of the hydraulic system of the heat pump system. Right- A simple illustration of the hydraulic system of the boiler system.

- Solar gains depending on the building's orientation
- Dynamic weather data (German test reference year for Berlin/Potsdam)

The U-Value of the windows and exterior walls are 0.8 W/m^2K and 0.19 W/m^2K respectively.

As it has been mentioned before, in the first system the building is connected to a geothermal heat pump with thermo-active building systems (TABS). In a thermo active building system the heat delivery system is installed the building construction. In this simulation, TABS is a capillary tube system embedded in the concrete ceiling. The tubes have a diameter of 2 cm and the distance between two tubes is about 15 cm. The model of TABS consists of a multitude of cells, each of which has two parts: a pipe and a wall. The following are taken into account:

- Pressure losses in the pipes
- Heat transfer from the pipe to the wall
- Heat storage and heat conduction in the wall

The compression heat pump model is implemented as a black box consisting of two heat exchangers that are connected to a module that calculates the heat flows and compressor power by look-up tables using manufacturer data [2].

Figure 2 shows the hydraulic configuration of the heat pump system. There are three circulation pumps implemented in this system. One pump circulates water between the geothermal boreholes and the heat pump. One pump brings the water from the heat pump to the distributer and one pump works between the distributer and the heat delivery system (TABS). The geothermal heat source is modeled as a perfect heat source with a constant flow temperature.

The second system simulated in this study consists of the building model, condensing boiler and radiators (figure 2). In this case there is only one pump implemented which circulates water between radiator and Boiler.

System controlling unit

The system controlling unit controls the pumps, valves and the operation of the boiler and the heat pump. The considered building is an office building which is occupied from about 6 am to 6 pm.

To keep the room temperature at the desired level, the controlling unit has the following tasks:

- From 6 am to 6 pm the room temperature must be in the range of 21-25 ○C.
- From 6 pm to 6 am, if the room temperature falls under 17 ○C, the heating system operates to increase the room temperature.

The controlling unit also monitors the temperature in the heat pump‘s compressor and the temperature in the distributer. If the distributer temperature becomes high enough, the heat pump will turn off. The distributer in this case plays a same role as a buffer storage.

Simulation Results

The building has a high isolation standard. Therefore, both heating systems are capable to keep the building at the desirable temperature range. Figure 3 shows the mean value of temperature in different rooms of the building in both simulations.

As it can be seen the temperature of the building with the radiator system has obvious peaks. These systems are faster and their environment reacts faster to the temperature level of the system. TABS systems are slower. The capillary mat inserted in the concrete will first heat up the concrete and then transfer the heat to the room mostly via radiation rather than convection.

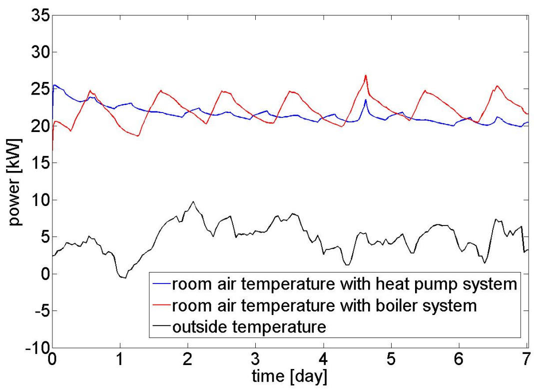


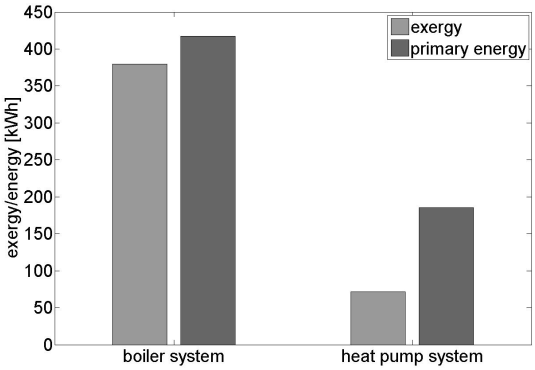
Figure 3: Room temperature and outside temperature.

The delivery losses appear when the room temperature becomes higher than the acceptable range because of false controlling. Since the delivery losses in both simulated systems are low, the delivery losses are not considered here.

In a boiler system gas burns and heat is transferred to water via a heat exchanger. In order to gain energy from the environment, in a compression heat pump, a compressor will be used which pressurizes and circulates the working fluid of the heat pump. In the case of the boiler system, the energy needed for heat generation is the gas consumption of the boiler. For the heat pump, energy demand of the compressor is the energy input of heat generation.

DISCUSSION

The exergy losses of heat generation in the heat pump system are lower than those of the boiler system (see figure 4). The heat pump system uses environmental energy to provide heat. The pump energy demand of the borehole system is also considered to be generation losses but it is still lower than the generation losses of the boiler. In a boiler, the valuable natural gas with high



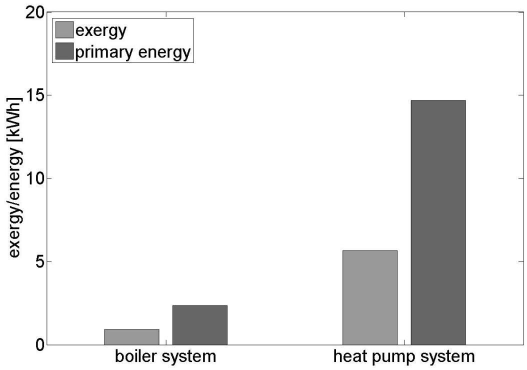


Figure 4: Left- Exergy losses and primary energy consumption of heat distribution in the heat pump (HP) and boiler system. Right- Exergy losses and primary energy consumption of heat distribution

exergy amount is converted to heat with a low exergy level. The exergy losses occur because of the irreversibility of the combustion process.

On the other hand, the distribution losses of the heat pump system are higher compared to the boiler system. TABS causes high pressure losses. In the boiler system water has to be circulated in a relatively short circuit. Heat pump systems normally have a buffer storage to minimize the operation intervals of the heat pump. Because of their loud noise, heat pump systems are usually kept in the cellar, which also expands their hydraulic circuit and thus increases the distribution losses.

As it has been mentioned before, the borehole model used in the heat pump system assumes a constant flow temperature. If a more realistic model of a borehole system was used, which for instance, would incorporate effects like the cooling of the ground, the exergy performance of the heat pump would decrease.

If the heat distribution pipes are considered to be outside the heating areas, heat transferred to the surrounding has to be taken into account as heat loss. In this case, due to higher temperature levels, the radiator system has higher exergy losses via pipe walls, but still the distribution losses of the TABS system will be higher, because from the exergy point of view, the electricity demand of the pumps is more valuable than exergy amount of the heat lost via pipe walls.

Since electricity is a secondary energy source, the primary energy consumption of the system during heat generation and heat distribution is also considered in this study. In order to present a comprehensive exergy analysis, other exergy losses in the entire energy chain, starting at the energy source ending at building, must also be captured. These include exergy losses of energy conversion for example fuel to electricity and exergy losses of energy transport. Exergy efficiency of electricity production plays an especially important role, if different heating systems are to be compared.

Figure 5 compares a combined heat and power system to the boiler and heat pump systems descriebd above. In this system a CHP provides the heat demand of a building stuck and simultaneously produces electricity. Therefore the exergy consumption of heat generation is the exergy of the fuel consumed minus the produced electricity. The same consideration is valid for the primary energy used for heat generation. In Germany, the primary energy factor of gas is 1.1 an of electricity is 2.6. Since the CHP system considered here has a different energy demand compared to the cases with Boiler and heat pump system, in order to compare the exergy and

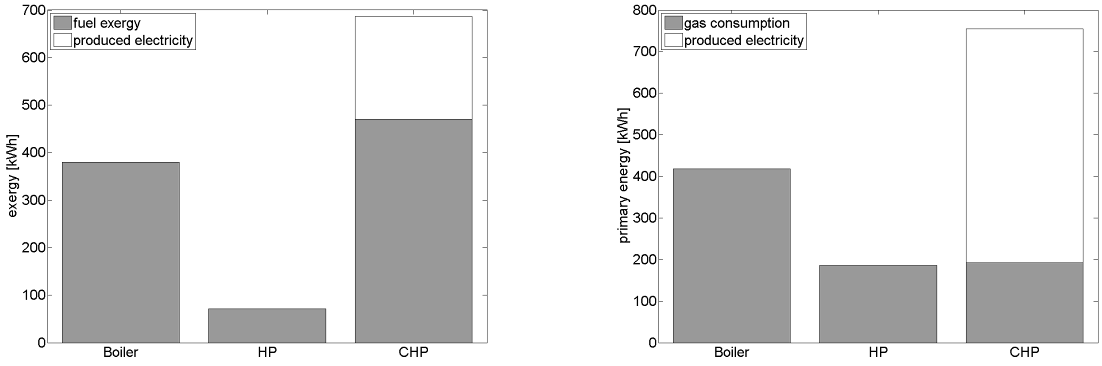


Figure 5: Left- The amount of exergy consumed to provide heat in different systems. Right- The amount of primary energy used to generate heat in different systems.

primary energy demand of different system, the ratio of exergy or primary energy consumption to the energy demand of the building is considered (Table 1). The ratio of exergy to energy demand of the building shows the exergy used to provide 1 kWh energy demand and the ratio of primary energy to the energy demand of the building shows the primary energy consumed to produce 1 kWh energy demand of the building.

As it can be seen, the results of primary energy analysis and exergy analysis are not the same. Primary energy analysis expects the CHP system to be the most efficient. The exergy analysis on the contrary indicates that heat pump system is the most efficient. To use exergy as a measure of efficiency in evaluation of the performance of the building and their energy systems, exergy efficiency of electricity production has to be considered.

Table 1: comparing exergy and primary energy used to provide 1 kWh demand energy

	Boiler	HP	CHP
exergy/energy demand	2.9	0.54	0.96
primary energy/energy demand	3.2	1.4	0.39

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GIS BASED THEMATIC MAPS AS DESIGN TOOL TO SUPPORT INTEGRATION OF RENEWABLE ENERGY AND IMPROVE THE ENERGY EFFICIENCY OF EXISTING BUILDINGS

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ABSTRACT

This paper presents the results of a study that investigates the use of Geographic Information Systems (GIS) to develop support maps for energy upgrading of existing buildings and for the integration of renewable energy strategies. Specific thematic maps can be drawn up using GIS in order to describe the variables that influence the energy demand of the buildings and the solar energy potential related to them, so to associate to each building data on its specific conditions. In this way such maps can provide basic information to identify the most effective strategies according to the prevailing factors.

The paper illustrate some of the different thematic maps developed on a portion of urban fabric and they are the result of studies aimed at understanding how, cartography usually available to local government in Italy can be used to elaborate specific maps, which collect important information to guide the design choices towards improved levels of sustainability. The text shows briefly the calculations made to describe such thematic maps, in particular focussing on the local solar potential at the micro-urban scale and specific indicators related to the geometry of the existing buildings. To facilitate the use of such maps, the conclusions presents a prototype of website aimed at their consultation.

INTRODUCTION

The energy renovation of existing buildings is becoming increasingly important in the priorities for action to reduce CO_2 emissions and increase energy efficiency, especially in European countries. This text seeks to identify appropriate strategies for the dissemination of information useful for this purpose, through the use of Geographic Information Systems (GIS). These tools enable you to develop specific thematic maps from the cartography normally available to local governments, by extracting information to support energy upgrading strategies in the existing building sector. An adequate communication of such processing would be a strong tool to raise the general awareness of the local actors to such an issue.

The diffusion of webGis based tool, as support to online consultation of geo-referenced databases, demonstrates the effectiveness of this type of information processing and representing. I cite for example the case of the webgis of the town of Laives, in the northern part of Italy (Bolzano province), (www.ecogis.info). It enable to access maps of the estimated local solar potential, as a support tool in photovoltaic and solar thermal system design, and monitoring of public building consumption. The fact that information about the solar energy potential are associated to each building implies a direct involvement of the common user, which can directly access the particular situation of the solar energy potential of its roof. The study here presented, adopts the same approach trying to extend the effectiveness of GIS, to support action in the field of energy retrofitting of existing buildings. The variables that come into play in this case are many more and each one requires specific thematic maps, as useful reference to guide the designer's choices and raise awareness of the generic inhabitant.

THEMATIC MAPPING

The factors affecting energy consumption in buildings are varied:

- factors of use, which refer to different activities hosted in the building;
- climatic factors: related to specific climatic conditions;
- technological factors: related to different choices adopted in the construction, which affect the thermo-physical behavior of the building;
- form factors: related to the different geometrical shape of the building.

The main objective that the study aims to address, is to investigate the possibility to use GIS to represent the differentiation of these factors on the urban tissue and therefore provide different information for each building. These calculations would allow:

- first, to produce information on individual buildings, that can be collected in dedicated geo-referenced databases;
- second, to use these information to assess the energy performance of a specific portion of the city, by finding out the relevant characteristics according to the different factors that affect the energy consumption of the buildings.

This second option would allow to identify the relevant characteristics of representative case studies, and to know their specific prevalence in the urban fabric (in terms of percentage on the total amount of buildings square-meters). In this way, specific energy assessment on representative case studies enable to identify, with smaller margins of error, the energy needs of existing urban areas or portions of them. These data can be compared with data on the real energy consumption of the representative case studies, but nevertheless, can be used to weigh the relative importance of specific design strategies in the definition of scenarios of CO_2 emissions reduction and the increase of energy efficiency of the existing buildings.

The following shows different possibilities to map the factors listed above using a GIS to compute standard information available in local Authorities.

Factors of use

The maps usually available to local governments, identify different categories representing the functions housed in the buildings. In the Italian case, especially for small municipalities, the database related to waste taxes payment procedures, can be very useful. It enable to collect more detailed information to distinguish between the different functions hosted in the building, and so allowing you to identify the different surface percentage for each function in every single building and to collect them in the same geo-referenced database.

Some of the information gathered in the database may be combined with data on supposed internal loads, split by different periods of time in the day. In this way thematic maps on the simultaneous distribution of internal loads can be created.

Climatic factors

Within this context we might include the following categories:

- temperature variation
- differentiation of solar radiation on the built surfaces and on open spaces
- differentiation of the relative humidity
- exposure to ventilation flows, and their distribution throughout the year
- differentiation and quantification during the year of pluviometric data

Among these categories, those that show a relevant differentiation in the urban tissues are solar radiation and exposure to air movements. The data and the tools available to local Authorities allow interesting insights into the differentiation of local solar energy potential but, concerning the aspects related to wind mapping, such evaluations require assessments with appropriate tools and specific monitoring procedures.

Insights on solar radiation mapping

Starting from a two-dimensional maps associated with the height of the roof eaves, GIS systems allows you to create Digital Elevation Model of a specific urban area.

Figure 1: Extract from the cartography (left) used to create the Digital Elevation Model (right) of the urban tissue under study

A Digital Elevation Model is a raster image that associates to each pixel the height of each point of the surface to be represented, each pixel is associated with a different shade of gray depending on the height. This technique allows to perform complex operations on maps, that effectively simulate the real three-dimensional configuration of an urban area. The images presented above show the reference map and the digital elevation model extracted from it, associating to each polygon representing the building, the height of the eaves and the height of the street level.

The Digital Elevation Model is a basic documentation to carry out simulations of the solar radiation incident on the buildings and therefore produce thematic maps, useful to provide information on the specific solar gains [2, 3].

Solar radiation Maps on horizontal surfaces

The inability to compute data on the inclination and orientation of the roofs from the available two-dimensional cartography, has led to store information on direct and diffuse solar radiation. These data have been collected on specific thematic maps, that show hourly solar radiation incident on the horizontal surface, representative of the average monthly amount. The awareness of the hourly amount of solar radiation incident on the horizontal plane, divided into direct and diffuse component, enable to calculate the effective solar radiation incident on a generic plane of different inclination and orientation, so to know the actual amount of solar radiation that affects a portion of a roof or a canopy.

Solar radiation Maps on vertical surfaces

The intention to describe on a map (from above) information concerning a vertical plane, has led to draw up maps of radiation incident on the facades at regular intervals from the street level. For the same facade, then there will be more descriptive maps of the solar radiation conditions at different distances from the street level. This type of representation allows to identify the different distribution of solar radiation on the facades, reporting the actual amount of solar radiation incident at the various floors of a building, and so enable to adopt “ad hoc” solutions to make optimum use of the solar radiation in winter and reduce the solar gains in summer.

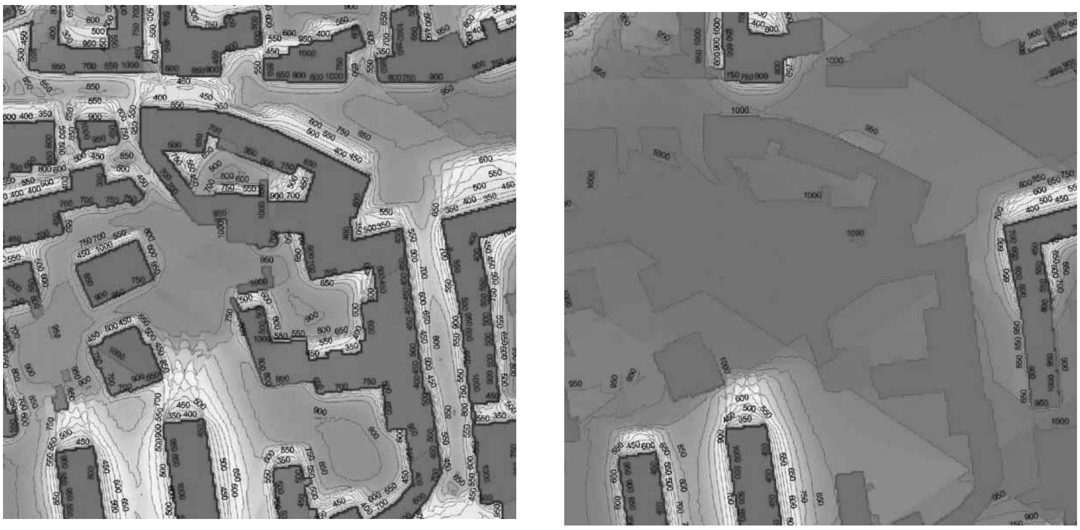

*Figure 6 **:** Map of daily solar global irradiance representative of the monthly average values at 4,5m from the ground (left), and at 7,5m from the ground, on the horizontal surface, month of January, unit kWh/sqm.*

Technological factors

Data normally available to local governments are unlikely to provide reliable information on the differentiation of characteristics that influence these factors. Thematic maps related to different kind of building envelope can be processed by using historical cadastral maps, linking different age of the buildings to different building technology and so to the related different thermophysical properties. Anyway it is difficult to have reliable information, often because, in the case of building refurbishing, the building envelope can be fully replaced, and smaller local public administration doesn't store these information on digital databases.

Form factors

When cartography available to local Authorities includes the height of roof eaves, different characteristics of the building shape can be synthesized through the calculation of specific shape indicators.
Infact, from the geo-referenced polygon representative of the building and the height of the roof eaves, the surface of the vertical part of the building envelope can be calculated. The use of GIS also allows you to identify information on the extension of the vertical surfaces shared with other buildings, and associate those information to each line representing the building's vertical surfaces. This information allows to calculate specific indicators related to the shape of the building, like surface area to volume ratio and the leaning coefficient (the proportion of surface leaning against the other buildings and the total vertical surfaces of the building, values from 0 to 1 gives information of the shared portion of the building envelope) [1]. As such indicator is calculated for each building, the data processed can be reported on a single thematic map, and can be effective to assess factors related to heat gains and losses for transmission.

Information on the exposed vertical surfaces and the shared ones, can be further enhanced with data on the orientation of the same parts of the building envelope (useful in defining appropriate strategies for energy conservation).

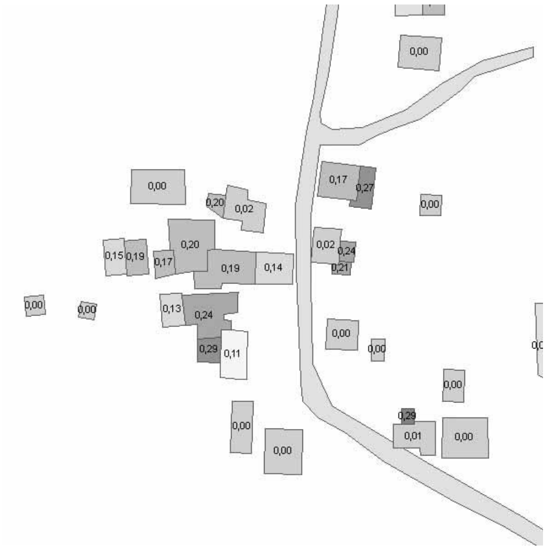

Figure 7: Extract from the thematic map of the leaning coefficient (values from 0 to 1 gives information of the ratio between the vertical surface shared between the buildings and the total amount of the vertical surfaces)

Visualizza dizionario dettagliato

Once calculated, data on the percentage of the total south exposed vertical surfaces can be associated to each single polygon representing the buildings in the GIS cartography (with a tolerance of plus or minus 30 degrees), consequently specific thematic maps can be produced.

The results would be reported in thematic maps of the exposure to the sun, which highlight the exposed sides of each building, in a range favorable for the installation of different kind of solar collectors and shading devices. The information included in the maps help the user to identify different types of devices according to the different orientation of the facades.

Storage and possible use of archived data

The information recorded in the thematic maps represent the geographical differentiation of factors that influence energy consumption of the existing buildings. These information are associated to each polygon representative of each building, and collected into the same geo-referenced database. At the macro-urban scale, the information associated to each polygon, enable to access usefull information to the sustainable upgrading of existing buildings, and find out case studies representative of the prevalent features of the urban fabric. On them it is therefore possible to make specific assessments on possible strategies to be adopted to reduce energy consumption. Farther on the calculated values can be applied to the buildings with similar characteristics, into the geo-referenced database of each urban portion. Since these data can be applied to all the buildings in the database, priorities to be adopted for effective strategies at the macrourban scale can be found out more easily.

Maps Publication

To enhance the use of this information, they can be collected in a specific website, that could handle geo-referenced data, a webGis. The information stored and associated to each building can be used to orient the users in the consultation of the information related to the assessments made on representative case studies. In this way, the most effective strategies, appropriate to the particular conditions of the specific building, can be easily identified.

As already introduced in the first part of this text, the representative case studies can be used to simulate the effect of the different strategies to be adopted in terms of saving energy and reducing CO_2 emissions. Since these data can be applied to all the similar cases in the buildings database, on the basis of different distribution of similar cases, it will be possible to understand which strategies are most effective for a portion of urban fabric and so to quantify the relative weight.

The local public Autorities could use these data to define CO2 reduction scenarios of different urban portion, and so to identify public policies that could encourage certain types of interventions rather than others. A possible application of this instrument may provide support to the Municipalities in the EC program of the “ Covenant of Mayors”, which aims to reduce CO_2 emissions up to at least 20% by 2020.

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HYBRID PHOTOVOLTAIC-THERMAL (PV-T) SOLAR CO-GENERATION AT THE BUILDING'S SCALE

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ABSTRACT

To achieve world-wide greenhouse gas emissions reduction targets and significantly reduce energy costs, the development of highly energy-efficient buildings with integrated active solar energy components (PV panels and thermal collectors) seems essential Especially in a build environment each available square meter with suitable orientation for solar application should be used in the most efficient way. Photovoltaic-Thermal (PV-T) hybrid collectors are co-generation components that convert solar energy into both electricity and heat and represent in principle one of the most efficient ways to use solar energy.

The aim of the study presented in this paper is, one hand, to develop and test a PV-T flat plate collector with improved efficiency and, from the other hand, to asses the performance of this type of collector as part of a solar thermal system using TRNSYS simulations.

The results show that in conditions of limited solar collector area, the use of efficient PV-T collectors in the building envelop can be more advantageous than standard PV and solar thermal components, not only from an energetic point of view, but also considering the exergy, primary energy saving and CO_2 emissions.

INTRODUCTION TO THE CONCEPT OF A PV-THERMAL COLLECTOR

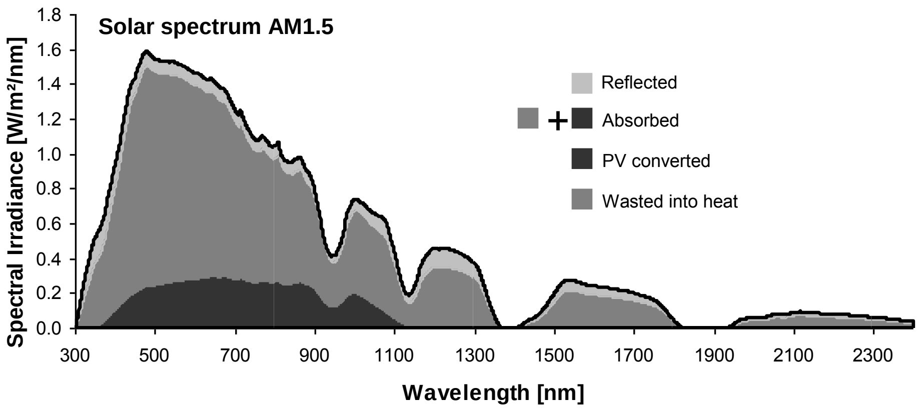

Figure 1: Spectral representation of the absorption, reflection and PV conversion of a standard sc-Si PV module.

In a PV module, only a small part of the absorbed solar radiation is converted into electricity, most of the absorbed solar radiation is converted into heat which is released into the environment (i.e. wasted). Figure 1 presents a spectral view of the photo-conversion efficiency based on measurements made on a single-crystalline silicon (sc-Si) solar cell encapsulated in a typical module. Approximately 90% of the incoming radiation is absorbed by the module, whereas only 15.5% is converted into electricity.

The development of co-generation components like PV-Thermal collectors (PV-T) can offer an improved solution by effectively capturing the produced heat in the PV modules.

A PV-T collector consists of a combination of photovoltaic (PV) cells and solar thermal absorber components. Many configurations of PV-T collectors have been developed during the last few years. They may differ from each other according to the cooling medium (water [1,2], air [3] or bi-fluid [4]) and the type of absorber used (flat plate [1,2] or concentrator [5]).

In this work the targeted application is a flat plate PV-T collector integrated in a domestic hot water system. The presence of an additional glass cover reduces to some extent the optical performance of the PV module but increases strongly the thermal performance of the collector, leading to a better overall energy conversion in comparison to unglazed collectors. The focus is thus on a flat plate PV-T collector construction using crystalline PV cells, with water as the heat transfer fluid and covered by a glass sheet (see Figure 2).

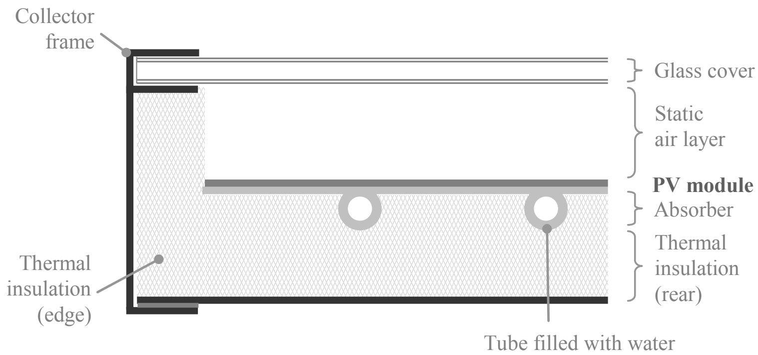

Figure 2: Description of a liquid flat plate covered PV-T collector

EXPERIMENT

Through a "rethinking" of PV and solar thermal technologies specifically for PV-T applications the PV-T collector was considered as an integrated technology in itself. This implied different boundary and operating conditions than separate PV and solar thermal technologies. Experimental investigations on materials and manufacturing processes were carried out merging both technologies [2, 6].

By modifying the PV lamination process, structure and the materials used, significant improvements of (solar) thermal properties (i.e. an increase of the absorption coefficient from 0.85 to 0.93 and a strong improvement of the heat transfer coefficient between the cell and the heat exchanger) and also in terms of electrical efficiency (increase of current density above 2 mA/cm²) were observed [6].

Based on the results obtained using this new approach, a full-size PV-T collector was built (see photo in Figure 3). Single-crystalline silicon cells were laminated on the surface of a specially coated metal absorber and covered by a high transmission foil. This PV-T absorber was built into a glass covered collector and ultimately tested. The aperture area of this collector was around 1.01 m². Thermal and electrical measurements on this prototype were carried out under a solar simulator according to EN12975 at the indoor testing facility of Fraunhofer ISE [7]. The thermal efficiency curve was measured in maximum power point tracking PV mode (‘hybrid’ mode, i.e. production of both electricity and heat) and in PV open-circuit mode (pure thermal mode, i.e. production of heat only). Results of the measurements are presented in Figure 3. The figure also shows the performance of a standard single-glass covered collector with a selectively coated absorber which was measured at the same facility.

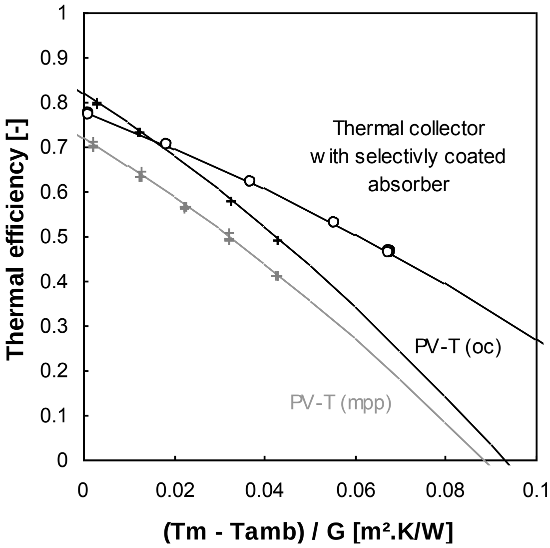

Figure 3: Left: Picture of the developed prototype during the measurement in the indoor solar simulator. Right: Thermal efficiency measurement results from the developed prototype in open-circuit (pure thermal mode) and maximum power point (hybrid mode) and from a commercial thermal collector with selective coating.

The performance tests showed a thermal efficiency almost as high as a good thermal collector and an electrical efficiency almost as high as standard PV modules of the same quality and layout. Moreover, this result indicates a significant improvement over previous research into PV-T collector concept development, in thermal performance for equivalent electrical performance.

Future developments follow analyses of parametric PV-T collector models which indicated clear opportunities for further (thermal and electrical) improvements of this collector type.

SYSTEM SIMULATION (TRNSYS)

The experimental measurements allow for a performance model of the developed prototype to be used in system simulations. The performance of PV-T collectors as part of a solar domestic hot water system was then investigated through system simulations with TRNSYS software.

In order to make a statement on the performance of PV-T collectors, an annual performance comparison between a domestic hot water system using conventional solar components (separate PV and thermal collectors) and a system using PV-T and PV collectors of the same total surface area (25 m²) was made. The differences between the installations are shown in the Figure 4. The first installation is a side-by-side installation of solar thermal collectors and PV modules, whereas the second installation is a side-by-side installation of PV-T collectors and PV modules.

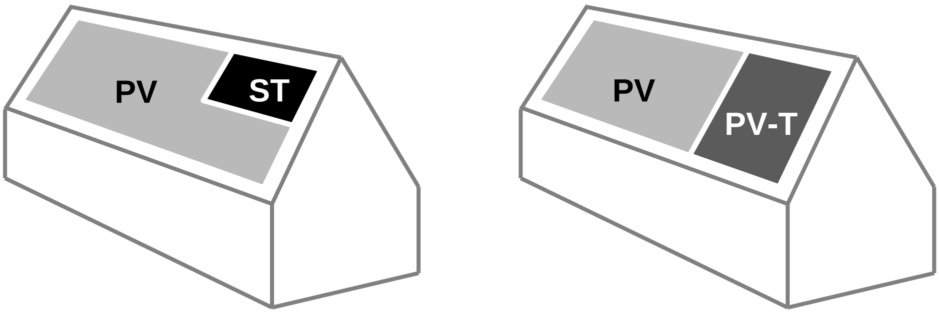

Figure 4: Side-by-side solar installations. Left: Reference solar roof consisting of PV modules and thermal collectors. Right: Solar roof with PV modules and PV-T collectors.

The thermal performance is indicated by the fractional thermal energy saved (f_{sav}), which is defined as the auxiliary energy saved by the solar system compared to a similar system without solar collectors [8]. Since it is clear that a larger PV-T collector area is required to obtain the same thermal performance as from a standard thermal collector installation (due to higher thermal losses, see Figure 3) the PV-T area is increased until the same thermal output as from the standard thermal collector installation is yielded. For both installations, the targeted fractional thermal energy saving was f_{sav} = 0.55.

	PV + ST	PV + PV-T	
Total Suitable Surface Area Available	25.0	25.0	m²
Area covered with PV modules	21.2	18.9	m²
Area covered with thermal collectors	3.8	0.0	m²
Area covered with PV-T collectors	0.0	6.1	m²
Energy and Exergy Production			
Electrical energy production of PV modules	2334	2075	kWh/year
Electrical energy production of PV-T collectors	-	556	kWh/year
Total electrical energy production	2334	2631	kWh/year
Total thermal energy production	1846	1819	kWh/year
Fractional thermal energy saving (f_{sav})	0.55	0.55	-
Total exergy production	2510	2796	kWh/year
Environmental Criteria			
Total primary energy saving	6789	7850	kWh/year
Total avoided CO_2 emissions	0.77	0.85	t(CO2)/year

Table 1: Results from the TRNSYS simulations for a 25 m² available roof surface using Paris (France) weather data.

As the total size of the collectors is fixed to 25 m², only the ratio between the area covered by PV module and thermal collectors (i.e. PV-T) is varied. As both systems are set to have exactly the same thermal output, a simple conclusion my result from comparing the total PV output of each system. However, the comparison of energy produced (in kWh) is not sufficient to fully evaluate the performance of PV-T systems. Coventry [9] and Fraisse [10] suggested several different comparison criteria taking into account the “value” of the energy produced (either kWh_{elec}, $kWh_{thermal}$ or both), through thermodynamic (exergy) and environmental considerations (saved CO_2 emissions, primary energy saved). This has also been calculated for both installations and the results are included in Table 1. This shows that for equivalent thermal performance (in terms of fractional thermal energy saving as well as thermal output) installations using PV and PV-T collectors have higher total PV output (+12.7%), higher exergy (+11.3%), higher primary energy saving (+15.6%) and higher avoided CO2 emissions (+10.6%) than side-by-side installation with conventional components.

Additional simulations have been carried out comparing the same domestic hot water systems but with different total roof area available and for different target values of f_{sav} (= 0.50, 0.55 and 0.60). For each case, the relative increase of electrical output was calculated and is presented in the Figure 5. Results of the simulations show that the relative increase of PV output from installations with PV-T collectors can exceed 50% on smaller available areas but decrease when the available area become larger.

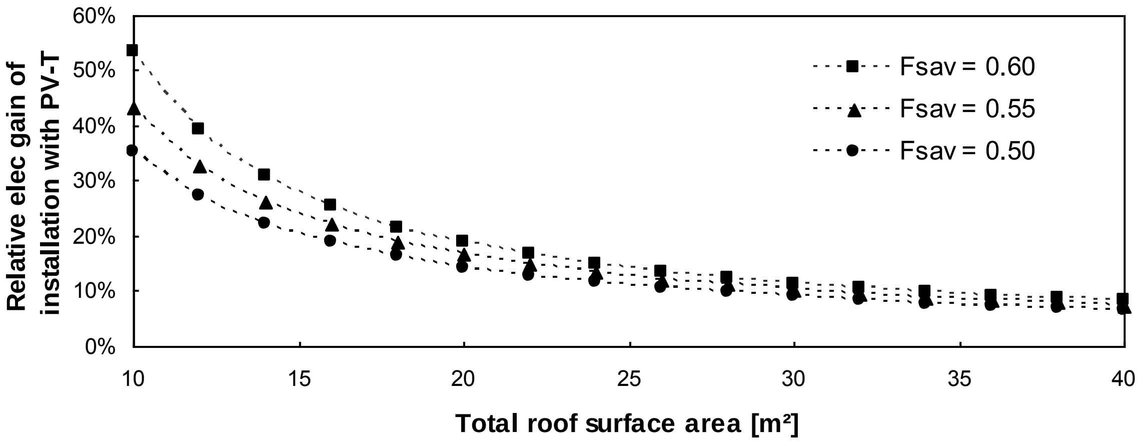

Figure 5: Relative increase of the electrical output of a PV & PV-T system compared to a system using PV & solar thermal components as function of the total available surface area for different target f_{sav}.

CONCLUSION

With a PV-T collector part of the incoming solar radiation, which is usually wasted by PV panels into heat, can be captured usefully leading to a more efficient use of roof area for energy capture. By focusing on improving the lamination of the PV cells on the thermal absorber the heat transfer between the PV cells and the fluid was improved. A prototype PV-T collector was built and performance tests showed a thermal efficiency almost as high as a good solar thermal collector and an electrical efficiency almost as high as standard PV modules of the same quality and layout. Moreover, this result indicates a significant improvement over previous research done on PV-T collector concept development, in both thermal and electrical performance.

TRNSYS simulation were carried out to asses the overall system performance of a system using this improved collector. The results showed that the integration of PV and thermal energy capture on a limited roof area not only provides for higher total PV output, higher exergy, higher primary energy saving and higher avoided CO_2 emissions than side-by-side installation with conventional components.

Based on the encouraging results from this research and the expectation that suitably exposed collector areas will need to be used most efficiently, it is expected that the development of a new generation well performing PVT-collectors will provide clear advantages over separated solar thermal collectors and PV modules.

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INVESTIGATION OF THE SPACE-HEATING USING WOOD STOVES IN VERY LOW-ENERGY HOUSES

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ABSTRACT

By definition, zero-emission, passive or very-low energy houses are characterized by a low energy demand. From an economical point of view, it is important to minimize the investment for the space-heating system because the low consumption make difficult to amortize the system investment compared to a direct electric heating solution. Indeed, this last strategy, characterized by a very low investment, has currently good economical performances but poor environmental performances when the electricity is directly taken from the grid (e.g. with the average European electricity mix). As a consequence, this last solution should be avoided.

Space-heating using a wood stove is a good trade-off between a low investment and good environmental performances. Nevertheless, the proper building integration of this solution faces the following two major issues. First, wood stoves ask for long production cycles while they operate with a limited power modulation in order to ensure an optimal combustion (i.e. minimize the emission of pollutants and reach the best efficiency). Unfortunately, these optimal operating conditions are not easily fulfilled in the context of passive envelopes, mainly because wood stoves are in general oversized for this application leading to increased on-off cycling. Second, compared to a conventional heating equipped with several emitters distributed in the house, a single stove is expected to ensure the thermal comfort within the entire envelope.

The present contribution investigates whether wood stoves can operate in their optimal production conditions while ensuring an acceptable thermal comfort within the entire passive envelope. The objective is to give guidelines to the proper integration of wood stoves in super-insulated envelopes. The influence of the system limitations and its control are analyzed as well as the influence of the architectonic properties of the building (i.e. the internal thermal mass or the internal spatial organisation of the house) using dynamic simulations.

INTRODUCTION

The proper integration of space-heating (SH) systems in houses equipped with a super-insulated envelope has some particularities. First, systems are oversized for this application. For example, the minimal power reached by wood stoves or boiler is close to 4-8kW, while the design maximal heating power required by passive houses is about ~2kW or, by definition of the passive house [1], less than 10W/m². Except for the direct electrical heating, the power modulation will not be large enough to adapt the production to the power magnitude of the building losses. For instance, best wood pellets stoves can modulate up to 30-50% of their nominal power, Pn. This leads to a relatively increased on-off cycling of the production. Second, the solar and internal gains can be equal or higher than the maximal power of the losses. These gains, intermittent by nature, will also increase the on-off cycling of the production.

On the contrary, most energy systems ask for long production cycles to reach their best performances. This is true for systems based on a combustion process but also for some other systems, like heat pumps. In the case of wood stoves, the start and stop phases are characterized by significantly higher emission of pollutants. It is clearly shown in [2-4] that the seasonal emission of CO by pellets stoves can be dominated by the start and stop periods. It is difficult to give the minimal required production length as it depends on several parameters, and also on the stove model. Anyway, to give a range of magnitude, measurements by [3] on a pellet boiler show that it takes 35min before the boiler reaches its nominal power. Wood logs combustion must be seen as a batch process [5]. The typical length of one batch is roughly ~45min.

The present contribution does not aim to quantity the amount of pollutants or the final consumption as a function of the followed stove technology or operating mode. For instance, simplified dynamic models for wood stoves or boilers can be found in [3,6]. The proper objective is to investigate the *control efficiency* as well as the *thermal comfort* for the SH performed by a single wood stove in a passive envelope, as a function of the stove heat emission properties as well as the building architectonic properties. In terms of comfort, it means that the oversized stove does not generate overheating in the thermal zone where it is placed and that other rooms have an acceptable comfort (i.e. not too cold). In some respects, this question of stove integration has already been addressed in [1-4]. Nevertheless, the present contribution focuses more on the proper integration of stoves in passive envelopes for SH purpose with a parametric study of the influence of the stove control strategy, production length as well as the building architectural properties (like the internal thermal mass or the internal spatial organisation of the house).

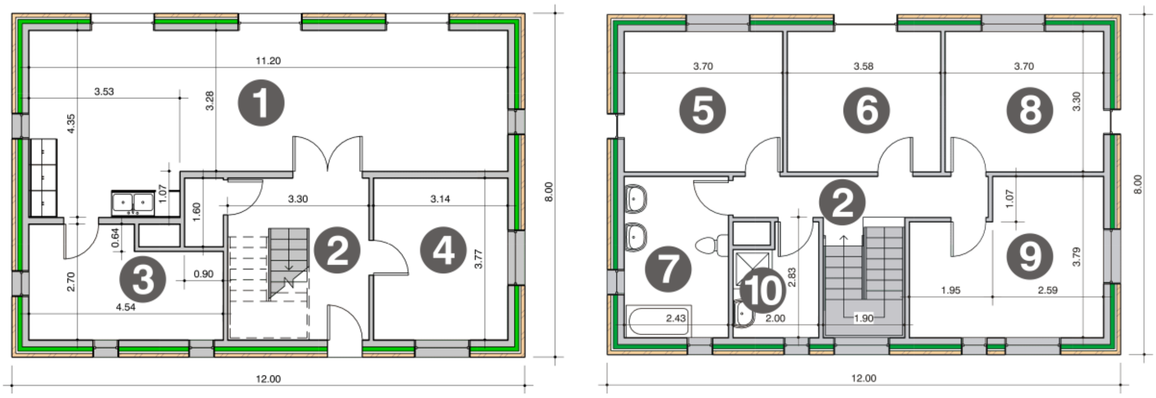
METHODOLOGY

Detailed dynamic simulations are performed on a detached house geometry using TRNSYS. Even though stratification could be introduced in this software, a single thermal node is here considered for each zone. In terms of ventilation, standard hygienic air flow rates are imposed for the fresh air and for the transferred air between zones. There is here no co-simulation to evaluate these rates as a function of pressure and temperature gradients (e.g. no ventilation network model). From a physical point of view, it can be considered as an idealized behaviour where mechanical ventilation is dominant and the doors between zones are closed. As far as the comfort is concerned, this is the most severe situation possible considering the worst distribution of heat within the envelope. Though simple, this assumption can be seen as conservative.

The benchmark single-family detached house

The geometry of the detached single-family house is kept constant throughout the cases. This is a typical two-storey's building with a net heated surface of 150m². The envelope has a protected volume of 420m³, 360m² transmission surfaces and 35m² of tripled-glazed windows. A brief picture of the house and its internal organisation is depicted on Figs.1. The living room where the wood stove is placed faces the South. Furthermore, no solar shading is supposed active during the heating season. Again, this can be seen as the most severe situation in terms of thermal comfort (i.e. the overheating in the room where the stove is placed). Two sets of simulations with two distinct internal organisations are considered. The first set corresponds to the Figs.1, while the second set considers an *open space* architecture where the living-room and the corridor are fused into a single room (i.e. zones 1 and 2 are merged in Figs.1). In this way, all building *free-floating* zones have a common wall with the central heated zone.

The house properties are defined to be conformed to the passive house standard [1]. This includes the envelope insulation, the air tightness and the controlled mechanical ventilation equipped with a heat exchanger. The exchanger thermal efficiency is here assumed to be 0.85. In order to capture the influence of the heat buffering within the envelope, five wall compositions corresponding to five different levels of internal thermal inertia are considered. Following the EN ISO 13790 [7], they range the five levels from *very light* to *very heavy* thermal mass. Finally, the set-point indoor temperature is 20°C.



Figures 1: Sketches of the first and second floors, respectively: coupled kitchen and living room (1), corridor with an open staircase (2), laundry room (3), office (4), four bedrooms (5-6-8-9) and a bathroom (7-10). The South direction is pointing upwards.

The simplified stove emitter model

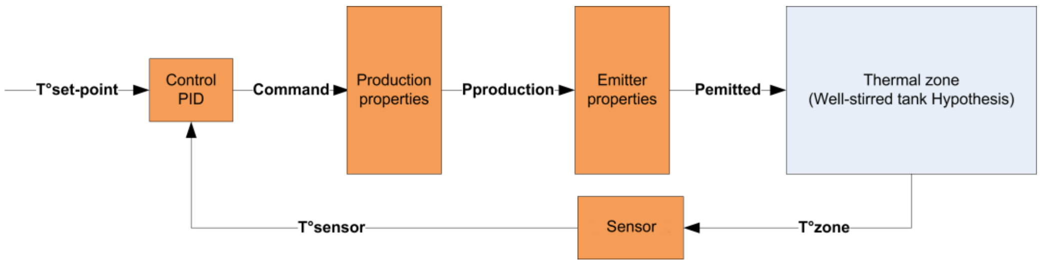
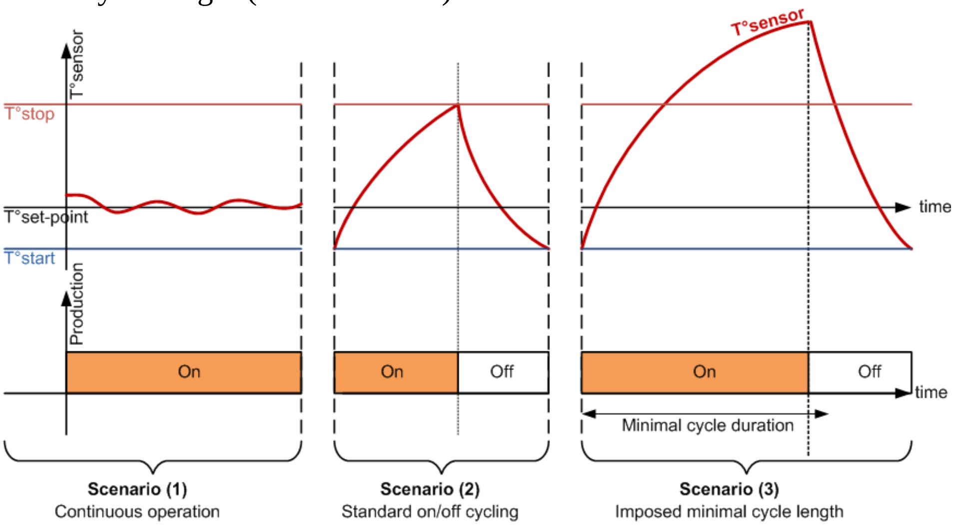


Figure 2: Block diagram illustrating the stove SH model connected to one thermal zone.

Starting from the perfect heating, the limitations of the heat emission using wood stoves are introduced progressively. In this way, the proper influence of each physical phenomenon will be distinguished. In the one hand, the perfect heating can be seen as a pure convective heating that delivers instantaneously, or more precisely within one time step, the exact amount of energy to enforce the set-point temperature within the room. On the other hand, the wood stove model is here divided into the production (or combustion) part and the thermal mass of the emitter, as depicted in Fig.2. The power released from the combustion is directly injected into the emitter thermal mass. The PID control here adapts instantaneously the power released by the combustion process. First limitations are introduced through the PID control, as shown in Figs.3.

- If the combustion power can be modulated continuously from 0 to Pn, the PID controller is able to track the set-point temperature and the stove operates continuously to counterbalance the envelope losses (see Scenario 1). Throughout the work, the PID parameters are tuned using the Ziegler-Nichols step response method.

- The limitation of the minimal combustion power is mimicked by a saturation of the PID to a lowest value. If the heat zone losses are lower than the minimal combustion power Pmin, the stove starts to cycle between a start and a stop temperature, here taken as 20°C and 22°C, respectively (see Scenario 2).
- The minimal cycle length of production to ensure the optimal operation of the stove is here enforced in the following way. The stove is only stopped if the stop temperature is reached AND if the stove has operated at least during a given period, the imposed minimal cycle length (see Scenario 3).



Figures 3: Limitations of combustion power modulation (Scenario 2) and enforced minimal cycle length (Scenario 3) compared to the ideal case without these limitations (Scenario 1).

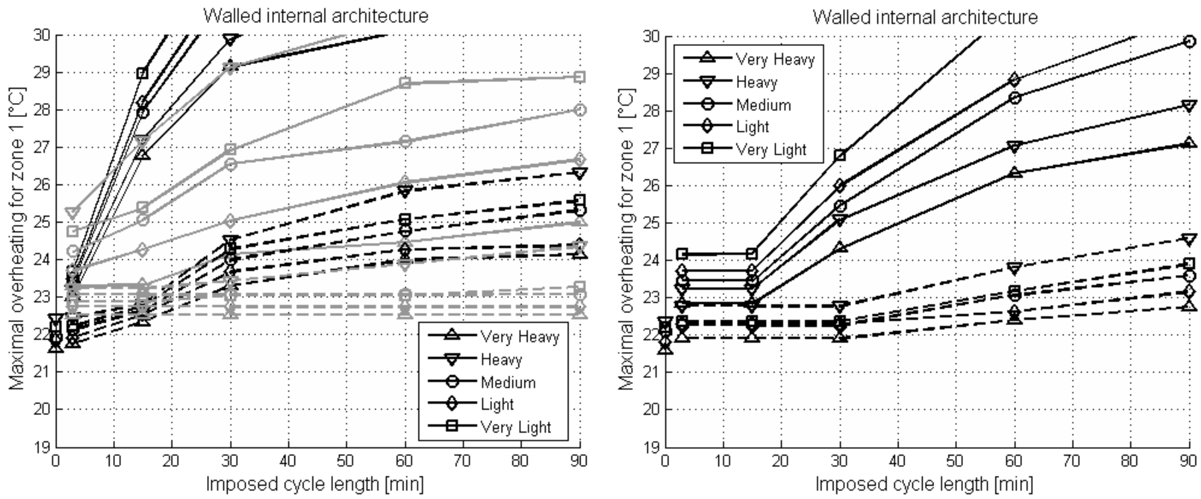
The second limitation analyses the thermal mass of the emitter. The emitter is here assumed to be a single capacitance node. The convective power as a function of the emitter's temperature is evaluated using a heat transfer correlation for vertical planes. The radiative heat transfer is evaluated analytically assuming that the stove is very small compared to the room dimensions. If one does not want to consider the emitter inertia, the emitted power is equal to the injected combustion power and the ratio between convection and radiation is fixed as a parameter. Finally, the comfort is evaluated using the operative temperature without taking into account the direct radiative flux from the stove to the occupant.

RESULTS AND DISCUSSION

Sampled results focusing on comfort are now presented for the typical weather conditions of Brussels (Belgium). The time step is set to 3min and the simulation length one year. Realistic parameters are fixed for the stove: Pn is 8kW, external surface 2.5m² and the capacitance 50 kJ/K. Two levels of modulation are considered: Pmin = Pn (no modulation) and 0.3Pn. The maximal and minimal temperatures encountered during the heating season are reported below. The last temperature takes place in the bedroom facing the North (i.e. zone 9 in Figs.1).

Fig.4.a shows that radiative sources have a better impact on the overheating. Furthermore, the stove power modulation has also a large influence in maintaining an acceptable comfort. Finally, the internal thermal inertia is also able to limit the overheating. It is interesting to see that the houses with large thermal inertia are able to keep the temperature below 25°C after cycles of 90min and without stove power modulation as long as the source is purely radiative. If the 30% power modulation is introduced, the maximal temperature is maintained below 23°C whatever the cycle length and building thermal inertia as long as, again, the source is radiative. A small overheating still remains but is slightly higher than the one obtained using the perfect heating. This small temperature overshoot is in fact generated by the solar gains,

but not by the SH system imperfections. On the contrary, a pure convective source without power modulation leads quickly to unacceptable overheating whatever the thermal inertia of the building is.



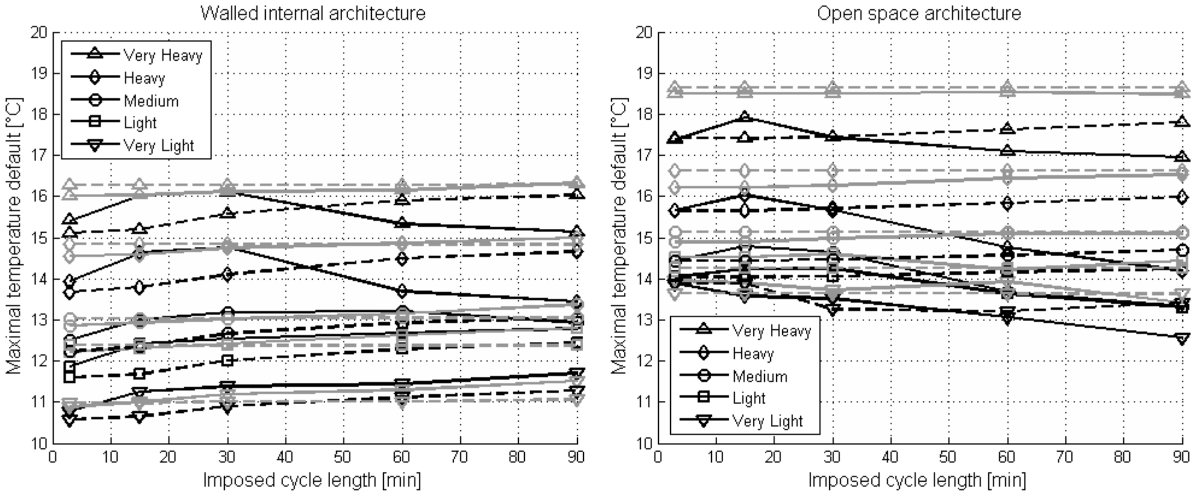
(a) Without emitter inertia *(b) With emitter inertia*

Figures 4: Maximal operative temperature during the heating season in the living-room for the stove without (a) and with inertia (b) as a function of the imposed production length and building thermal inertia. The pure convective source is shown in black lines while pure radiative source in grey lines, the stove without modulation is pictured by solid lines while the stove with Pmin = 0.3Pn by dashed lines. In picture (b), the ratio convection/radiation depends on the emitter's temperature. The perfect heating is plotted in the ordinate axis.

Considering the stove thermal mass, Fig.4.b, the stove temperatures lead to emitted powers that are mainly radiative (i.e. 60-70%). Results in Fig.4.b are thus between the pure convective and radiative behaviours pictured on Fig.4.a. Nevertheless, it is possible to notice the effect of the stove thermal mass for the shortest imposed cycle lengths: the stove inertia is able to absorb the combustion energy and the room temperature is not too affected by the power modulation limitations of the stove. For longer cycles, the selected stove has not enough thermal mass to absorb the delivered quantity of energy. It does not prevent the room temperature to overshoot the set-point temperature. Anyway, a very promising conclusion is that a stove with 30% power modulation and a realistic thermal mass seems to be able to maintain an acceptable temperature in a closed internal architecture for a 90min cycle and for the five different levels of building thermal inertia: the power modulation seems to be a robust solution for the proper integration of wood stoves in houses with a passive envelope.

Figs.5 shows that power modulation as well the radiative to convective ratio of the emission have not the main impact on the minimal operative temperature. In fact, the leading parameters are the building architectonic properties. First, the internal thermal inertia enables to smooth the temperature variations so that the minimal temperature can be limited up to ~16°C in the closed internal architecture. Second, if the internal architecture is an open space where the central corridor is heated by the stove, each room has common walls with the heated zone. The conduction through those walls reduces the temperature non-homogeneity. With a high internal inertia, the minimal temperature is reduced to ~18.5°C even though our building model corresponds to closed doors. The comfort is thus enforced by the high thermal inertia coupled to a favourable internal organisation.

On the contrary, the comfort may not be acceptable for light structures: even with the open architecture, Fig.5.b, the minimal temperature is only ~14°C. In this case, another process should thus be found to diffuse heat through the entire envelope. One should investigate the influence of opening the internal doors. As the mixing process is then also induced by temperature gradients, it supposes to compute the flow rates using a ventilation network model or a CFD. This is the next step for the present work. Furthermore, the methodology will be repeated for the Norwegian climate representative to Nordic countries and where the potential market for wood stoves is large. Finally, discussion on the energy consumption is also very interesting but deserves more space to be reported properly in the present article. This will be done in another communication.



(a) Closed internal architecture *(b) Open space architecture*

Figures 5: Minimal operative temperature during the heating season for the stove without inertia in the closed (a) and open (b) internal architecture as a function of the stove imposed production length and building thermal inertia. The pure convective source is shown in black lines while pure radiative source in grey lines, the stove without modulation is pictured by solid lines while the stove with Pmin = 0.3Pn by dashed lines.

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EVALUATION OF ALTERNATIVE NEIGHBORHOOD PATTERNS FOR BIPV POTENTIAL AND ENERGY PERFORMANCE

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ABSTRACT

Neighbourhoods can be designed to achieve net-zero energy consumption for a set of houses by addressing key parameters such as building shapes, their density within a site, and the site layout. Building shape can significantly influence energy consumption and can provide advantages in capturing solar energy [1]. Spatial characteristics of neighborhoods and land use can affect solar potential and energy demand of buildings.

The current study presents an investigation of the effects of two major parameters on the potential of building integrated photovoltaic (BIPV) and energy demand of two-storey single family housing unit assemblages, located in Montreal, Canada (45ºN). The houses are designed to conform to passive solar design principles [2] and rule of thumbs [3]. The parameters are geometric shapes of individual units and site layouts. Shapes include rectangular and L shapes with different values of the angle enclosed between the wings of this shape. Site layouts include a straight road and south and north facing semi-circular roads. The EnergyPlus simulation package [4] is used to simulate configurations consisting of combinations of the parameter values. Effects are evaluated as the change from reference configurations of the response parameters -- electricity production potential of BIPV covering complete near south facing roof surfaces and heating and cooling demand. The reference shape is rectangle and the reference layout is a straight road. The design methodology consists of first determining the site layout, second designing the unit shapes to conform to this layout, and third combining the shapes in different configurations. For each site, several configurations consisting of combinations of groups of three to six units of a given shape are studied. The results indicate a significant increase in total electricity generation (up to 33%) achieved by the BIPV systems of the housing units of certain configurations, compared to the reference (rectangular shape in straight road site). L variants may require up to 8% more heating demand than the rectangular shape; however the BIPV systems of these shapes produce up to 35% more electricity, annually. Variation of surface orientation, particularly in curved layouts, enables the spread of peak electricity generation over up to six hours.

INTRODUCTION

In the design of solar houses, two main surfaces– equatorial facing roof and facades can be manipulated to optimize solar energy utilization. Shade from adjacent surfaces in self-shading shapes (such as L shape) can affect significantly solar radiation on equatorial facing facades [1]. Orientation of a building and its position with respect to neighboring buildings have a large impact on its accessibility to solar radiation, and on energy performance. Several studies have focused on investigating the distribution of solar radiation on different surfaces in a built environment [5], as well as on the availability of solar energy and its optimization, at the urban scale [6; 7]. Notwithstanding the interest in the effect of urban development on solar energy, several aspects are not sufficiently addressed, such as interaction between individual shapes and the site layout. The current study presents an investigation of the effects of some design parameters on solar potential and energy demand of two-storey single family housing unit assemblages, located in Montreal, Canada. These design parameters include: the shape and orientation of individual units, and the site layout. The solar potential refers in this paper to the electricity generation by building-integrated photovoltaic system (BIPV), integrated in the near south facing roof of these units.

DESIGN APPROACH

The two-storey housing option adopted in this study represents one of the most common types of single family homes in Canada. The design ensures that the overall east-west dimension of the house – the solar façade, is larger than the perpendicular dimension (north-south), to maximize passive solar gains in winter. A constant floor area of 60 m^2 is employed. The characteristics of the housing units are described in Table 1. A geothermal heat pump with a coefficient of performance (COP) of 4 is assumed to supplement the passive and active solar heating. Cooling strategies are not investigated in this study.

Thermal resistance values:	Exterior wall: 6 RSI Roof: 10 RSI Slab on grade: 1.2 RSI
Thermal mass	20cm concrete slab
Window type	Triple glazed, low-e, argon filled (SHGC=0.57), 1.08 RSI
Area of south glazing (% of floor area)	Around 20%
Shading Strategy	Interior blind
Air infiltration rate	0.8ACH @50Pa

Table 1. Characteristics of housing units

The rectangular and L shapes are selected in this study because they can be considered as the basic shapes for passive solar design. Other shapes can be derived from combination / variation of these shapes. The main wing of L shape is assumed to be oriented east-west, so as to have the long façade facing south. A depth ratio (a/b) of ½ is adopted throughout this study. This ratio is selected in order to minimize the shade cast on the main wing, while maintaining a functional plan [1]. L variants are characterized, in addition to the depth ratio, by the angle β– the deviation from 90^o of the angle between the wings of the L (Table 2). An additional shape, termed hereunder Obtuse-angle (O), can be considered a special L variant with β =70º.

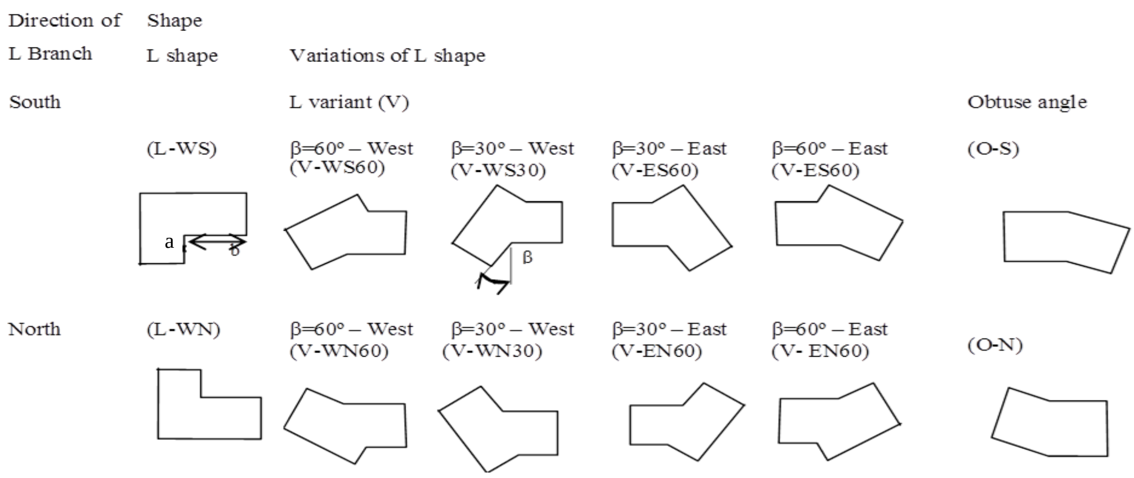

Figure1: Characteristics of L shape and L variations, for site II and site III

Throughout the study, a hip roof is considered with tilt and side angles of 45^o. A photovoltaic system is assumed to cover the total area of all south and near-south facing roof surfaces. This area includes the triangular portions of hip roofs in L-shape and its variants, and the two near south facing surfaces in obtuse-angle roofs.

Three site layouts are studied - Site I, II and III, presented in Figure 2. The circular road is selected to represent an extreme case of curved road design option. The housing units are positioned with respect to the shape of the roads in both sites.

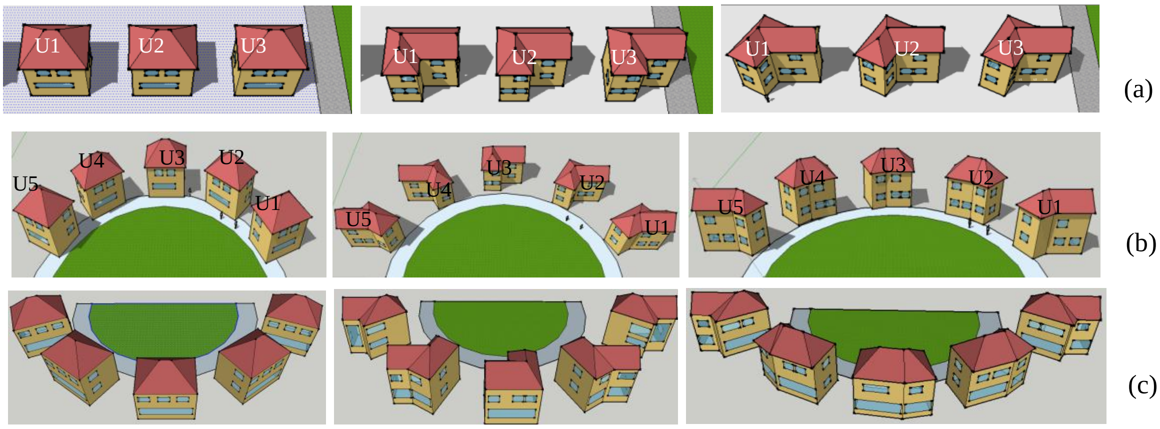

Figure2: Configurations used in each site, (a) site I, (b) site II, (c) site III.

PRESENTATION AND ANALYSIS OF RESULTS

This study is performed for Montreal, Canada (45^o N Latitude).The EnergyPlus building simulation software is employed to study the energy performance and energy potential for two design days_ a sunny cold winter day (WDD), and a sunny hot summer design day (SDD), and for whole year simulations. A simple model of a roof integrated PV system with a constant electrical conversion efficiency of 12%, is used.
The effect of rectangular unit rotation from the south on electricity generation per m^2 of roof surface and on the energy demand for heating and cooling is determined. Heating loads are converted to electricity consumption using a COP of 4, associated with a typical geothermal heat pump. The cooling demand of the west oriented units is slightly larger than the east oriented units. This can be explained by the larger solar heat gain of these west oriented units in the summer. Electrical loads for lighting, domestic hot water and appliances are assumed as follows: 3kWh/m^2/year, 2.75kWh/day/person and 800kWh/year/person, respectively [8].

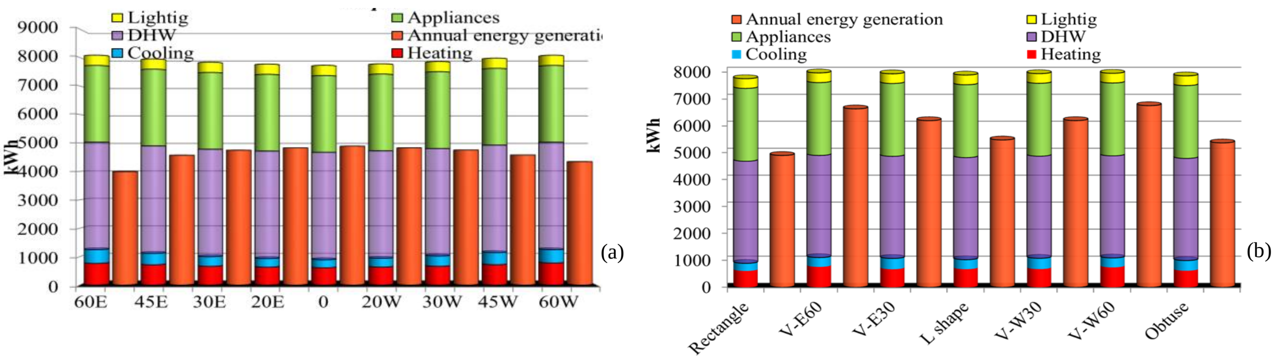

Figure 3. Effect of orientation on Annual heating and cooling and energy production for, (a) the rectangular shape, (b) L variant.

Effect of shape on BIPV potential. The electricity generated by the BIPV of south and near south facing roof surfaces of each unit shape is compared to electricity generated by the reference case. The results indicate that the rotation of the branch by 30º in the L variant produces an increase of about 13% of electricity generation per m^2 of the rotated hip roof, for the SDD, and 9% reduction per m^2 for the WDD. This effect is presented in Figure 3b.

The comparison of the total electricity production by the roof indicates an increase of the annual generation of L variant shapes of about 34% relative to the rectangle. This effect is attributed to the larger south facing roof area ($31m^2$) for the L variant, in comparison with $25.6m^2$ (for the rectangular shape). The comparison of the average electricity generation of all configurations of site II and site III are presented in Table 2.

Electricity generation	L variant relative to				Obtuse-angle relative to			
Shape	Rectangle		Obtuse-angle		Rectangle		L variants	
Sites	Site II	Site III	Site II	Site III	Site II	Site III	Site II	Site III
SDD (m^2)	1.02	0.92	0.98	0.89	1.04	1.04	1.02	1.12
WDD (m^2)	1.04	1.07	0.97	1.04	1.07	1.04	1.03	0.97
Annual(m^2)	1.04	1.05	1.02	1.01	1.06	1.04	1.02	0.99
Annual (total area)	1.33	1.34	1.10	1.00	1.34	1.34	1.00	1.00

Table 2: comparison of the electricity generation of the configurations of site II and III

Effect of shape on energy demand. The shape of units affects significantly the energy demand for heating and cooling. L shape, L variant (V-30W) and obtuse angle shape require 7% ,8% and 2% respectively, more heating energy than the reference case. The cooling load of L variant exceeds that of the reference case by about 19%, while obtuse angle and L shape require 8% and 4%, respectively, more cooling energy than the reference. The increase of heating demand of the L shape and its variations can be explained by: 1) the decrease of the solar gain in the winter due to the shade cast by the wings, and the rotation of the wings in the L variations; 2) the larger area of the building envelope of these shapes as compared to the rectangular shape, for the same floor area. In the summer the cooling load is increased due to the increase of solar radiation on the rotated wings, in addition to the large envelope area, mentioned above. Comparison of the cooling and heating consumption, computed using a COP of 4, of all L variants is shown in Figure 3b.

Table 3 presents a comparison of the average heating and cooling load for each configuration of sites I, II and III to the corresponding average energy load of the rectangular configuration. While the heating load does not dramatically change, the cooling load can increase by up to 37% and 22 % for L variant, in site I and site II, respectively. The cooling load for L variants decreases by 13 %, in site III. The increase of energy demand in L variant configuration however is counterbalanced by an increase of energy generation: L variant produces 20% and 33% more electricity in site I and site II, respectively, as compared to the corresponding rectangular configuration.

Site	Site I		Site II			Site III		
	Heating load	Cooling load		Heating load	Cooling load		Heating load	Cooling load
L shape	1.07	1.11	L variant	1.05	1.22	L variant	1.01	0.87
L-VW30	1.05	1.37	Obtuse	0.99	1.23	Obtuse	0.98	1.51

Table 3: Average energy demand for all configurations relative to the rectangular configuration

Effect of site layout on BIPV potential. The performance of all configurations, in terms of average electricity generation per unit area and of the total annual generation averaged per units, is compared for each of site II and III shapes to the corresponding configurations of site I. The results indicate that the site layout has no significant overall effect on the electricity generation per unit area.

Effect of site layout on energy demand. The arrangement of units with respect to each other in a site can result in shading different surfaces of a specific unit. An additional effect is, as mentioned above, the orientation of each individual unit. To isolate the adjacency effect from the effect of orientation, only the central due south unit in a site is compared to the corresponding isolated unit. The results indicate that in general the heating load increases for all units in sites I, II and III while cooling load decreases, as compared to the corresponding isolated units (Fig.4). The increase in heating load reaches 12 % and 22% for the rectangular shape in site I and site II, respectively. L shape heating load increases by 15% in site II as compared to 12% in site I. One reason for this effect is the shade cast on the east and west facades, in all configurations, and partially on south facing facades in site II.

Comparing the configurations of site II to their corresponding in site I, it is noted that the heating load for both rectangular and L variant configurations increase by 7% in site II.

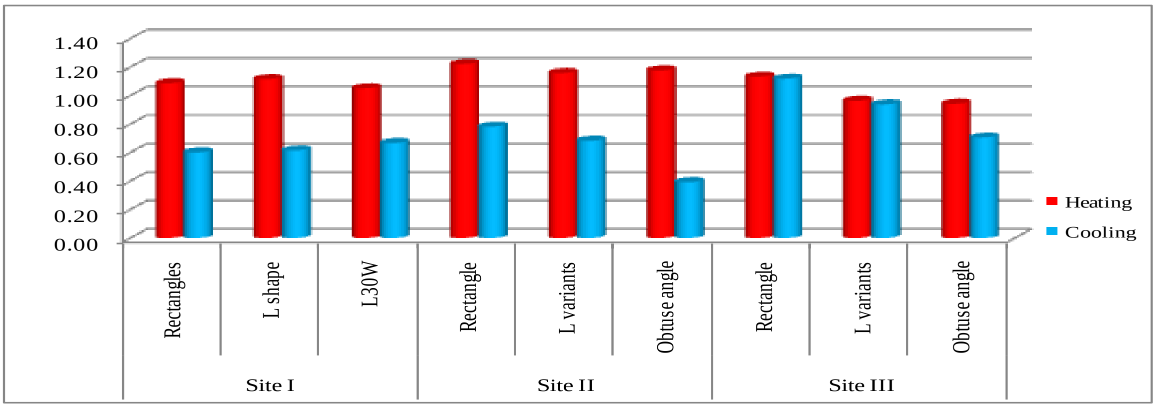

Figure 4: Comparison of energy consumption of the mid unit of each site to the isolated unit

An important result of the interaction of site layout and configurations is the shift of peak electricity generation. A significant shift of the profile of the electricity generation is obtained by the BIPV of different units. A maximum shift of 3 hours is obtained in site I. In site II the rotation of whole units in additon to the rotation of individual façade, increase the gap between the time of the peak electricity generation. A difference of peak time of up to 6 hours is observed in the configurations of site II. Figures 5a and 7b show the effect of L variant configurations of site II on the electricity generation profile of the hip roof of different units for winter and summer design days.

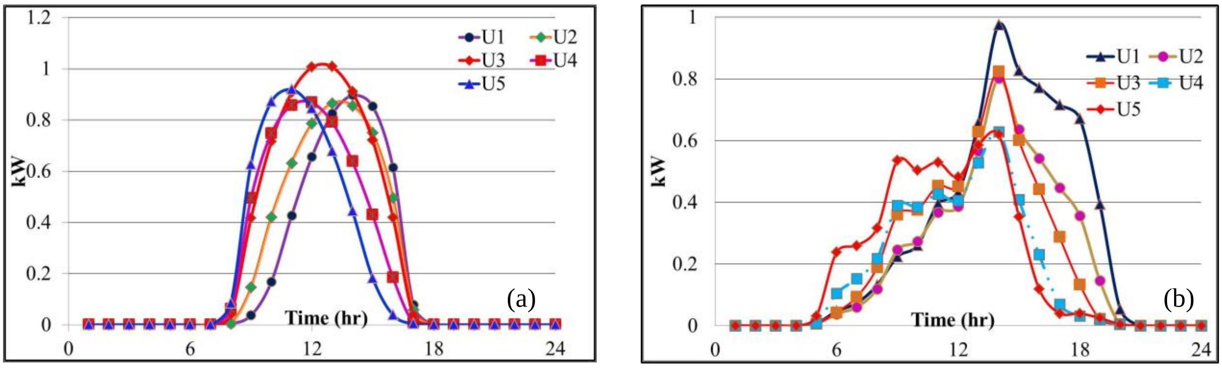

Figure 5: Hourly electricity generation (kW) for the hip roof of L Variant in site II: a) WDD; b) SDD

SUMMARY AND DISCUSSION

This study presents the effects of several parameters affecting solar response and energy demand for heating and cooling of housing units in different neighborhood patterns. The results indicate that heating and cooling demands are affected significantly by the shape of units; for instance L shape and L variant require about 7-8% more heating demand. Rotation of part of the branch of L does not affect significantly the energy demand. Energy demand of isolated units is in general less than the same units studied in a neighborhood (about 12% difference for both rectangular and L shapes). One reason for this effect is the shade cast on the east and west facades, in all configurations, and partially on south facing facades in site II. Some configurations of building shape are more suitable for implementation in a specified site layout than others. For instance, the L variant configuration, employed around a curved road, yields 33 % more electricity generation than the rectangular configuration, used in the same layout. The energy demand for heating of this configuration is only 5% higher than the rectangular configuration. A difference as large as six hours of peak generation of different units can be achieved by the implementation of L variations in a specific site layout. Shifting peak generation time towards peak demand time can lower net energy cost and also reduce net peak demand from the grid.

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SIMULATION AND COMPARISON OF DIFFERENT DISTRICT HEATING NETWORKS IN COMBINATION WITH COGENERATION PLANTS

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ABSTRACT

The combined production of heat and electricity can have a great effect on reduction of the primary energy consumption in buildings. A possible solution to this approach is to supply medium-sized district heating networks in combination with cogeneration plants (CHP).

The behavior of the district heating network in combination with a cogeneration plant with different configurations needs to be observed so that the most energy efficient configuration can be known.

To achieve this, a thermo-hydraulic model for the CHP which uses manufacturers' data and can be controlled by both heat and electricity demand is created in Modelica – an object-oriented, equation based language to conveniently model complex physical systems. The model is built using Modelica standard libraries as well as the components available in libraries developed at the Institute for Energy Efficient Buildings and Indoor Climate. The CHP model is then implemented in a district heating network model which also contains other blocks such as consumers, storages, boiler and many controlling units.

The complete district heating network is then simulated for different conditions. These conditions include using centralized or decentralized storage(s) when the system is controlled both by electricity or heat demand, and by using heat demand for buildings built with the new Energy Performance of Buildings Directive (EnEV2007) standard or older buildings built during 70s and 80s. The simulation results as well as the primary energy consumption of each configuration are then compared.

INTRODUCTION

As explained by [1], in order to reduce disruptions in supply, promote sustainable development and reduce Greenhouse Gases (GHG) which are the three main goals in EU's energy policy [2], increasing efficiency at the consumer's side as well as expanding the use of renewable energies are often discussed as solutions. Often overlooked is the great importance of reducing fossil fuel consumption by distribution of generated waste heat from power generation in District Heating Networks (DHN).

District heating expands the range of potential users of thermal energy to residential buildings. Since residential buildings require relatively low temperatures, it allows the implementation of CHPs with higher efficiencies [3].

There exist several configurations in which district heating in combination with CHP can be realized, each having various characteristics as well as advantages and disadvantages. In order to find the most efficient district heating network in combination with CHP plants, a complete model of the district heating network with different changeable configurations is needed to simulate various conditions. These conditions can be categorized as follow:

- Storage type (central versus distributed)
- Control type (heat led versus electricity led operation)
- Building type (various insulation standards)

To achieve this, a thermo-hydraulic model of the CHP which different control strategies is built in Modelica using standard libraries as well as the components available in libraries developed at the Institute for Energy Efficient Buildings and Indoor Climate (see [4]). The CHP model is then implemented in a district heating network model including other components such as consumers, boilers, pipes, etc. and its controllers.

CHP MODEL

The CHP plant is modeled as a black body, which means it uses actual manufacturer's curves for the heat and electricity production as well as fuel consumption and efficiencies of the system.

The CHP model consists of two main circuits, one for fluid flow and another for the controlling purpose of the CHP (Figure 1). The heat transfer to the working fluid in the network (in this study considered to be water) happens in a heating volume inside the CHP model. The amount of heat produced in the heating volume is either controlled by the difference between inlet temperature and the temperature setpoint for the outflow or by the electricity demand and in both cases is limited by the capacity of the chosen CHP and minimum difference between inlet and outlet temperatures. This is done by using two PI controllers, one for heat and one for electricity depending on the chosen control strategy. If the system is controlled by heat demand, the PI controller gives the required capacity at which the CHP should work in order to reach the desired temperature of the outflow. During the electricity demand operation, the PI controller outputs the required working capacity of the CHP. In the latter case, the temperature controller is working as a limiting measure in case the heat demand is met but the electricity demand is not in order to prevent overheating and boiling of water in the network. This means that the system can be controlled by electricity demand as long as all the produced heat is consumed at the same time.

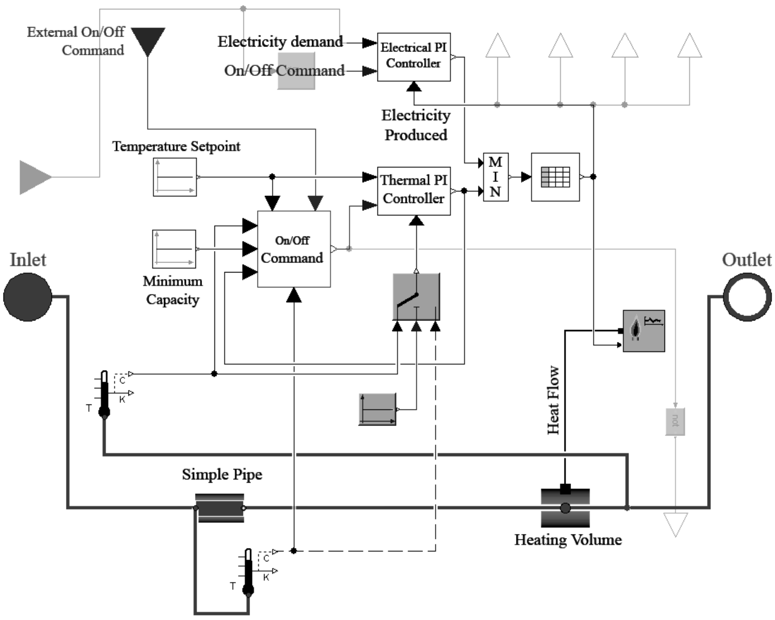

Figure 1: Fluid and control circuit of the CHP model in Modelica/Dymola

In order to have a realistic behavior in the model for on and off timings and durations as well as minimum working capacity, many logical components are used in an On/Off Command Block. This block prevents the CHP to be turned on directly after an off command and vice versa, prevents the system to work under a certain minimum capacity and turns the CHP on and off using a smooth function to prevent non-linearity in the calculations.

DISTRICT HEATING NETWORK MODEL AND ITS COMPONENTS

The district heating network should be in such a way that it can supply heat to consumers using CHP, central as well as distributed storages and when necessary with a help of a boiler. In this network configuration, consumers are assumed to be in parallel and are connected similarly to the flow and return pipes. A single pump is assumed to be sufficient and is positioned so that the network is able to work in all the operating conditions (Figure 2).

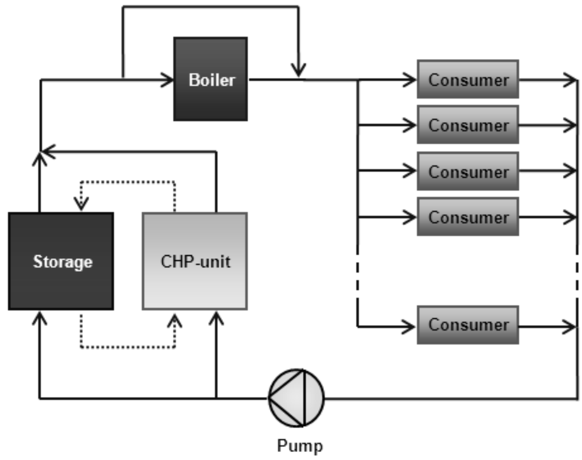

Figure 2: Simple scheme of the district heating network layout

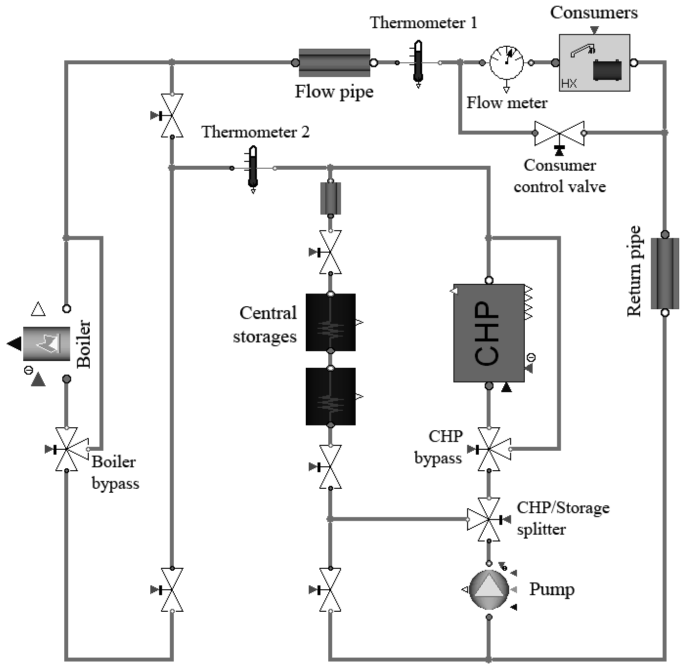

Figure 3: Complete model of the district heating network in Modelica/Dymola

The network is modeled so that it can be controlled effectively during a given simulation period. There are different flow circuits designed for different situations in order to fulfill certain tasks. The first circuit is directly from the CHP to the consumers, this is the case when enough heat can be produced by the CHP to meet the demand and central heat storage is not charged. If the CHP output is not enough, an auxiliary heat source (in this case a central boiler) is used to supply the excess heat. When the energy demand on the consumer side is low enough, CHP can charge the central storage through another circuit. When the central storage is fully charged, it is used to supply heat to the consumers and CHP remains off until the storage is fully discharged. Figure 3 represents the district heating network model and all its flow circuits.

The central storage in the network can be disabled in case simulation of distributed storages is of interest. There are simple heat loss models which use the overall heat transfer coefficient of the storage as well as the size of the storage to model the heat losses.

The consumer model consists of heat as well as hot water demand and each consumer can have a separate demand profile. A decentralized storage is also implemented in the consumer model. In case a central storage is available in the network, the decentralized storage should have a very small volume to partly fulfill the hot water demand.

Pipes used in the model are under ground and the heat transfer between soil and pipes is considered in detail.

RESULTS

The simulation is done for four different cases for the first week of January with weather data of Berlin. These cases are listed in Table 1. For these simulations, a CHP with maximum electrical power of 26 kW and maximum thermal power of 46 kW is used. A gas boiler with maximum thermal output of 100 kW is considered as the auxiliary heat source. Flow temperature is set to be 70°C and a total storage volume of 40 m^3 either central or distributed between consumers is considered.

The network is supposed to supply heat for house heating and hot water demand for 20 houses.

Case	Storage Type	Controlled by	Building insulation
1	Central	Heat demand	70s/80s
2	Distributed	Heat demand	70s/80s
3	Distributed	Electricity demand	70s/80s
4	Distributed	Heat demand	EnEV 2007

Table 1: Different simulation and study cases

Total energy consumption and energy losses in 4 cases are shown in Figures 4 and 5. It can be seen that the energy consumption of CHP is higher when the building insulation standard is higher or in other words the energy demand is lower, this is due to the fact that in this case, the boiler is not required and CHP can meet the demand on its own. In other cases, due to high heat demand, the boiler has to work at least in its minimum capacity. Therefore, the heat production by the CHP will be reduced.

Different system configurations have different amount of heat losses and different energy demands. Therefore in order to compare the energy efficiency of the different system configurations, for each case, primary energy factor according to the German Energy Saving Ordinance EnEV is calculated and the results are shown in Figure 6.

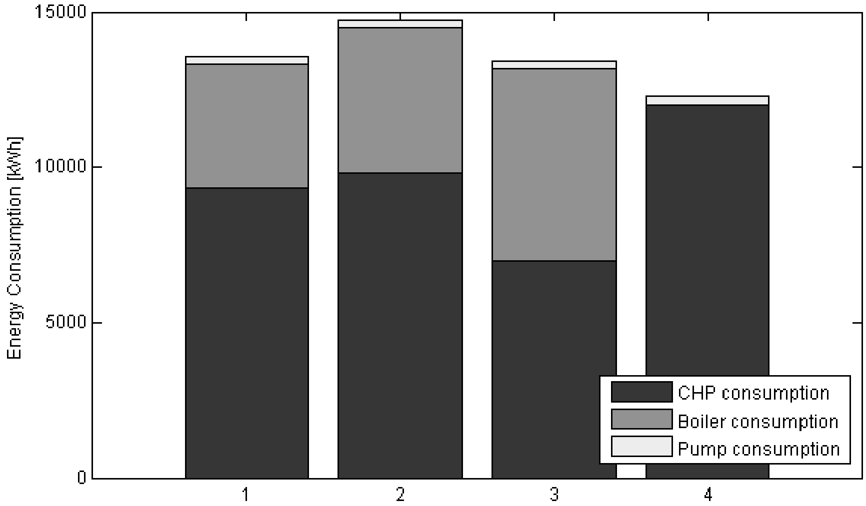

Figure 4: Total energy consumption of the network components in 4 cases

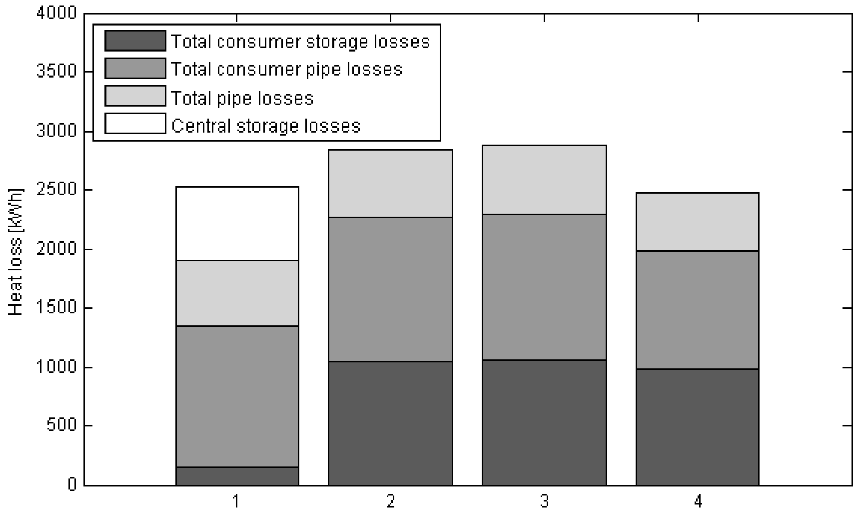

Figure 5: Total losses in the network in 4 cases

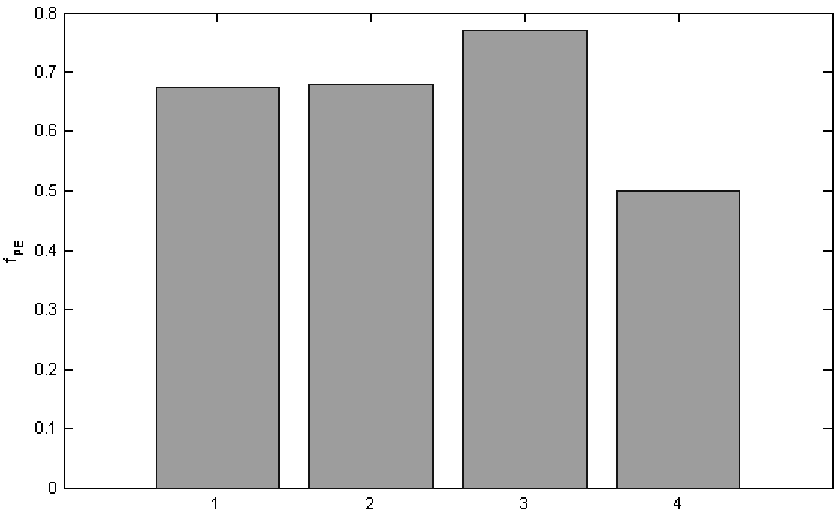

Figure 6: Primary energy factors for different variants

DISCUSSION

As it can be seen in Figure 5, when using central storage, the total losses are lower because of the lower storage surface area in comparison with distributed storages. On the other hand, the heat losses of the distributed storages can also be considered as heat gains, if the storages are placed in living areas; therefore, its nature will be changed in efficiency calculations.

As expected, the case in which the network is controlled by electricity demand has the highest boiler consumption, since by following the electricity demand, the heat demand is not met and more excess heat is required. The higher boiler consumption without electricity production will also increase the primary energy factor significantly.

In is also possible that due to lower heat demand, the electricity demand cannot be followed. In order to prevent this from happening, a re-cooler can be used to cool down the flow to the CHP if the heat is not used by others. In this case the exact electricity demand can be met. This has the disadvantage that the produced heat is lost which will reduce the efficiency at certain times.

In case 4, since the boiler is not used, the lowest primary energy factor is derived, which will lead to the conclusion that choosing a CHP with a heating capacity equal or greater than the heat demand will lead to a more efficient solution for the energy networks if all the produced electrical energy is consumed either locally or by the electricity grid.

A large part of the losses is the pipe losses in the network as seen in Figure 5. These losses can be reduced by lowering the flow temperature of the network. Lowering the temperature has also the advantage that low exergy sources such as renewables can also be implemented in the network. This also reduces primary energy factor even further and increases the overall efficiency.

ACKNOWLEDGEMENT

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NEW CHALLENGES IN SOLAR ARCHITECTURAL INNOVATION

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ABSTRACT

Among the century's main challenges, climate change and the need for energy sources diversification are of great importance. In this context, renewable energies undoubtedly have an important role to play. Photovoltaic (PV) electricity is especially well suited to face these energy challenges. It is now established that the low thin film photovoltaic panels production costs will allow, even in continental climate, to reach low electricity cost, providing easy installation, public acceptance and high reliability. However, architectural considerations are often neglected in the current integration of PV panels. Taking into consideration specific architectural aspects like the surface appearance and the colour of the PV modules can become the key for the successful development of new, well integrated solar systems.

To achieve this goal, our team, within the Archinsolar [1] project framework, works on the development of new generation of photovoltaic elements based on silicon thin films technologies (amorphous and micromoph). These new elements will be ultra-reliable and manufacturable at a very low cost, allowing a good architectural integration, respectful of the environment, landscape and built environment.

GENERAL CONTEXT

The renewed debate on nuclear energy following the recent events in Japan, the numerous political decisions made in favor of the development of renewable energies as well as the attitude of the public, which is always more concerned about environmental issues, lead to the development of new and more adequate technologies adapted to our current energy needs.

Photovoltaic energy is particularly well positioned as it is proven that a large part of the electricity needs of our modern society could be covered by photovoltaics, providing intelligent energy management if applied. In the long-term, solar energy should even be used to provide a significant part of the world's energy consumption. As an example, the well oriented roofs of Switzerland (130 km^2) could cover around 1/3rd of the 58 annual TWh with standard crystalline modules.

It is then reasonable to argue that, today, there is no "versatile" solution available on the market which is inexpensive, aesthetically acceptable and easy to install. Nowadays photovoltaic energy is still limited by to heavy investments. These investments are notably associated to the unit prices, to the BOS costs (mounting, support, inverter) and to the planning costs (linked to the experience). Indeed, the price of the modules proposed on the market is still one of the most important factors which retain potential purchasers. In the built-environment and in specific landscape, aesthetic aspects will play an increasingly important role, as the pressure not to install PV in areas reserved to agriculture is increasing.

These crucial aspects are of utmost importance to succeed in competitively positioning photovoltaic energy either on the electricity market or for internal use. Only then photovoltaic electricity will be able to contribute significantly to the general electricity production.

SIMPLICITY OF INSTALLATION AND MULTI-FUNCTIONALITY FOR LOWER COSTS

Technologies based on thin-films such as amorphous or microcrystalline silicon [2-3], have the potential to lead to a stronger cost reduction of the solar kWh (<30€/m^2 for the thin layers) and offers the unique potential to cover large surfaces at a particularly low cost. Furthermore, thin film Silicon technology is based on abundant and non hazardous materials.

To reduce the high expenses related to the installation of photovoltaic modules, solutions to simplify the installation of system is required. Currently, an installation of photovoltaic modules on a roof remains complex and needs the intervention of several working corporations, from engineers to roofers. A general simplification of the systems, in particular an improvement of the mechanical stability and a simplification of the electrical connections are taken into consideration. Furthermore, the size and the weight of the module, using composite materials [4] is taken into account and should be adapted to allow only one roofer to be able to install the system.

Integration solutions allowing the replacement of other building components by photovoltaic panels will reduce the overall cost of the installed system. Simple and modular building elements such as roof tiles and slates, or solar roof windows (semi-transparent), and other components are certainly the most innovative aspects. These elements should then ensure multifunctionality such as mechanical stiffness, water vapour barrier [5-6], building element, insulation, sun protection or capturing the heat energy in addition of solar power generation.

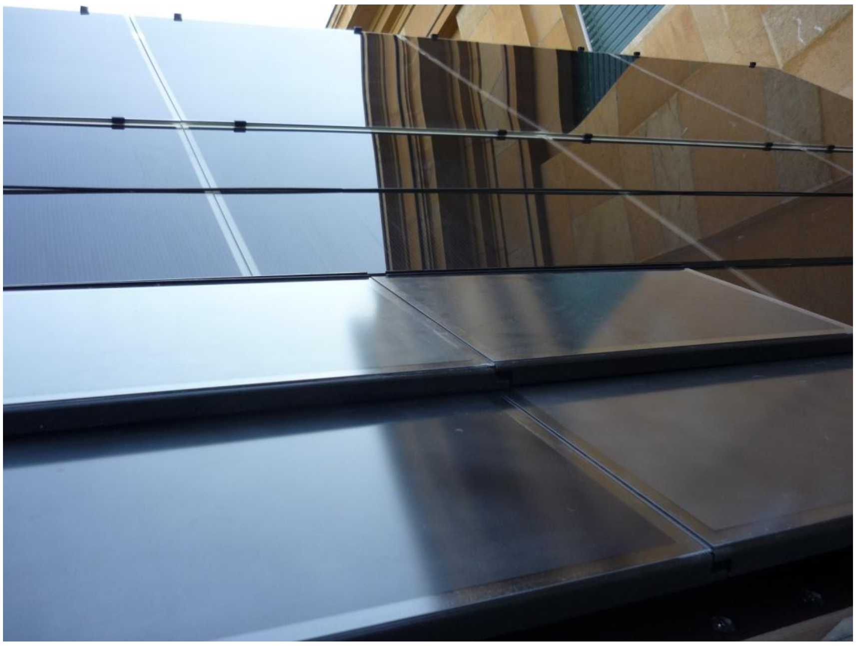

Figure 1: Demonstration of multifunctional solar tiles. In addition of generating electricity, the tiles ensure to the roof its water tightness which therefore allows an installation without additional aluminium frame and resulting costs. By using textured glasses which act as anti-reflectors, it is possible to improve the general aesthetic of the roof.

ARCHITECTURAL ASPECTS AND AESTHETICS OF THE PV MODULES IN THEIR ENVIRONMENT

From an esthetic point of view, the color variation, going from the typical brown of amorphous silicon to the typically black for micromorph, constitutes one of the great starting advantages of these kinds of modules.

The desire for optimum equipment performance is sometimes in conflict with site and building conditions [7]. While effective in establishing proper orientation of solar panels, these installations give a discontinuity in the building and its architecture.

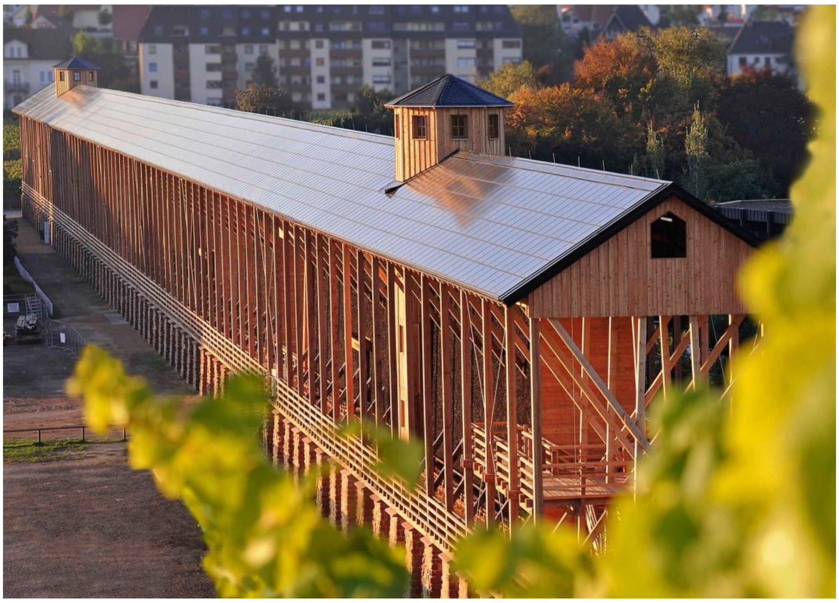

Figure 2: The saline of Bad Dürkheim in Germany is a very good example where the combination of photovoltaic modules (here thin silicon films modules) and historic building has been done harmoniously.

Providing architects with a pallet of various products, with amongst other aspects, different color levels, is essential. A recent survey [8] showed that a majority of architects would prefer other colors than the classical blue of crystalline solar modules, even if a lower efficiency is the price to pay. In the long term, we can imagine that every roof could be completely covered with suitable tainted photovoltaic modules and cost effective. Due to the inherent homogeneous aspect of the thin films based modules, as well as the possible modification of these colors by the introduction of colored filters [9-10] or polymers, it is possible to consider a whole pallet of modules aesthetically interesting which will be better integrated in their environment.

Figure 3: a) The possibility to modify the colour of the PV modules, according to the color of the roof tiles give to the architects a pallet of aesthetically interesting elements. b) Example of a modified amorphous thin film module by the use of colored polymers.

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IDENTIFYING OPPORTUNITIES OF PASSIVE THERMAL STORAGE IN RESIDENTIAL BUILDINGS FOR ELECTRICAL GRID MEASURES

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ABSTRACT

The stochastic nature of distributed electricity production from renewable sources introduces new challenges for the electrical distribution network. As a recast of the EU-legislation 2002/91/EG obliges to build nearly zero-energy buildings by 2020, the importance of balancing local supply and demand at all times and reducing grid peak loads increases. The use of the structural thermal capacity of the building may form a solution to facilitate the achievement of this balance.

In the presented work a simplified residential building, heated with an air-water compression heat pump and equipped with a building integrated photovoltaic system (BIPV), is modeled within a dynamic building energy model, developed in Modelica and containing both a stochastic approach for the domestic occupant behavior and detailed modeling of on-site photovoltaic generation. Both the domestic load and the heat demand of a dwelling typically peak when the habitants wake up and arrive back home, whereas the BIPV system shows a profile depending on the local weather. This results in a large power injection in the electrical grid and possible grid instability. By actively controlling the indoor environment of the dwelling in periods of absence (i) during the day but within the thermal limits of thermal comfort (ii) and by means of an electricity-fired heat pump (iii), the stress on the electrical grid is reduced (i) by storing energy inside the building structure and the required peak load for heating and cooling during occupancy is reduced (ii). However, an increase of total energy demand is the result (iii).

To compare the potential peak reduction with the increase in total electricity use, a peak control strategy and a model based controller (MBC) are implemented and compared against a simple on/off control. Results show that only the MBC is capable of reducing peak loads, maintaining an adequate thermal comfort. Both MBC and peak control strategies show the importance of the thermal storage capacity, as peak loads and the total electricity demand decrease with a larger structural thermal mass.

In order to fully assess the possibility of passive thermal storage in buildings towards grid measures, a detailed study of both the accessible thermal mass as well as the influence of solar and internal gains on the storage capacity is required.

INTRODUCTION

With a current recast of the EU-legislation 2002/91/EG obliging to build *nearly-zero energy buildings* (nZEBs) by 2020 [1] and the recent communications of the European Commission on the deployment of a European *Smart Grid* [2], a first step is made towards an integrated approach to tackle climate change while still meeting all energy needs. As nZEBs face a problem of non-simultaneity between local energy demand and supply, energy storage or demand management becomes an important issue. On the electrical side, this non-simultaneity may affect grid instability [3].

To avoid peak electricity loads, active control of the building energy management system (BEMS) can be used to prevent heating or cooling during peak periods. This approach has already shown an important potential for peak reduction in commercial buildings. Reductions of the electricity costs are found in a range of 0 to 35 % [4]. However, differently from the residential sector, office buildings are characterized by more structured daily electricity demand profiles and an important flexibility for indoor climate outside the working hours.

In the presented work, an example of active control is presented to reduce peak loads in residential buildings. For this, a small light-weight and a heavy-weight dwelling are modeled to investigate the role of thermal mass on the opportunities for passive storage.

MODEL

Building model

A simplified residential building is modeled in the environment of Modelica. The single zone building has a useful floor area of 5.0 m x 5.0 m and an internal height of 3.5 m. A large window of 5 m², with a U-value of 1.1 W/(m²K) and a g-value of 0.755, is oriented south to allow passive solar heating, whereas automated shading is included to prevent overheating during the summer.

Two different construction types for the walls and the roof are modeled, i.e. a wooden frame structure and a massive concrete structure respectively represent the light-weight and the heavy-weight case. Both structures are well insulated resulting in an average thermal resistance of 3.65 m²K/W.

The building's climate system is modeled as a simplified heat pump system with a constant overall COP of 2.5, taking into account system inefficiencies and distribution pumps. The heat pump (HP) is dimensioned to compensate the heat losses in stationary conditions with an outside temperature of -8 °C and a indoor set point of 20 °C. It has a thermal power of 1 200 W for heating and cooling in base load condition, whereby thermal emission is modeled with a fixed radiative fraction of 0.40. No storage capacity is assumed to be included on the installation side. The power of the heat pump can vary as required by the building energy management system (BEMS) and as explained further-on.

User model

To implement the domestic electricity demand, a 15-min stochastic profile is implemented. The implementation of occupant behavior is described in [5]. The use of lighting and appliances in dwellings is implemented based on Markov-chains and is largely consistent with the model of Richardson et al. [6]. The output of the model are presence and activity of the building occupants determining comfort demand, and the usage of electric appliances and lighting resulting in internal heat gains Q_c, Q_r and the real electric power demand P_{el}. As such, the occupant behavior influences both the thermal response of buildings as well as its grid impact towards the assessment of distributed generation.

The resulting household electricity consumption is 22.1 kWh/m² and is found consistent with Belgian statistics.

BIPV model

Implementation of the photovoltaic system in Modelica is described in [7]. For local electricity supply by means of a building integrated photovoltaic system (BIPV), 1-minute radiance data are obtained with *Meteonorm v6.1* for the moderate climate of Uccle (Belgium) and the time period 1981-2000 based on the Skatveith-Olseth model for diffuse radiation [8].

Dimensioning of the BIPV systems is performed to achieve a predicted level of on-site net zero energy. The resulting BIPV size is 1.7 kWp for an ideal inclination of 34 degrees, directed directly southwards.

Building Energy Management System (BEMS)

Three control strategies are implemented: (i) an on/off control, (ii) peak control and (iii) model based control (MBC), whereby the on/off control is used as reference case. For this control strategy a set point for the heating system is implemented at an operative temperature of 20 °C. Cooling is provided as the operative temperature rises above 25 °C. The dead band of the on/off controller is 1 °C.

To be able to reduce peak loads the BEMS has to be coupled to the electrical balance of the dwelling. Since the on/off control does not take the electrical production or demand of the dwelling into account, it does not allow active peak reduction. Therefore a peak control strategy is developed to turn off the heat pump when the net electrical power demand exceeds a threshold power of 600 W. This threshold is selected as the sum of the domestic base load required by electrical appliances and the heat pump, thereby avoiding the heat pump from being activated when domestic electricity use peaks. When the HP is turned off the energy stored inside the structural thermal mass is released and the operative temperature decreases. In addition to the peak load reduction, the BEMS is programmed to activate the heat pump when the net electrical power supply to the distribution grid exceeds 600 W. The heat pump remains operative until the electrical balance becomes positive or until the operative temperature exceeds $T_{sethigh}$ for heating or T_{setlow} for cooling. The 5 temperature set points with corresponding conditions for heating or cooling are shown in figure 1. This controller allows peak reduction by active control of the heat pump. However it does not take into account daily patterns in the user profile and thermal comfort.

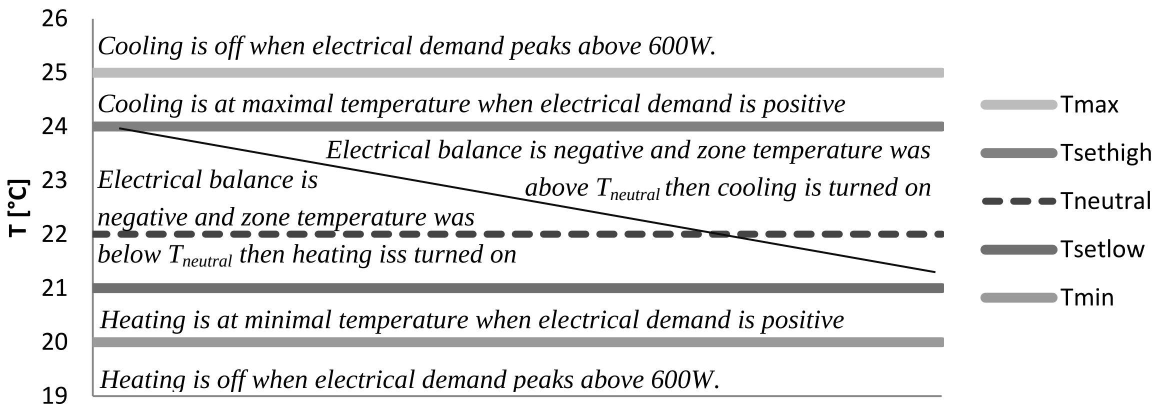

Figure 1. Set points for peak control strategy

Both the domestic load and the heat demand of a dwelling typically peak when the habitants wake up and arrive back home. This daily pattern is taken into account in the third control strategy by implementing a model based controller. For this controller it is assumed that peak loads follow a daily profile and are found between 7:00-10:00 and between 17:00-19:00. During these peak periods no heating or cooling is allowed to avoid peak power demands at district level. To avoid violation of the thermal comfort during the peak hours, a preheating period is implemented to store the thermal energy inside the building's structural storage capacity. Multiple options exist to activate this structural storage capacity. One of the possibilities is to find the optimal time to start the preheat period, given the predicted heat losses during the peak period and the power delivered by the heat pump. For simulation stability it is chosen to implement a constant preheat period of 4 hours and modulate the thermal power of the heat pump. Further optimization could be elaborated but falls outside the scope of the presented work.

The set point for heating or cooling during this preheat period is calculated by the expected heat losses during this peak period as predicted by a low-order building model. To calculate the preheat set point transient building behavior is calculated using equation 1.

$$T_i(t) = T_e + \left[T_i(0) - T_e - \frac{Q_t}{L}\right] \exp\left(-\frac{Lt}{C}\right) + \frac{Q_t}{L} \tag{1}$$

In this equation the total heat loss of the building by transmission and ventilation is represented by the loss-coefficient L [W/K]. The building's thermal capacity is centralized in the capacity-coefficient C [J/K]. Values for L and C are estimated by simulations using the detailed building model. Q_t [W] represents the total thermal energy flow towards the building, which can be further divided in the heating power Q_{heat} [W], the internal gains Q_{user} [W] as calculated in the user model.

At the start of each peak period future internal gains and outdoor climate data are predicted, assuming perfect forecast data are available. In the next step the temperature T_i at the end of the peak period is set to the minimal temperature allowed by reasons of thermal comfort.

RESULTS

Before the evaluation of the different control strategies can start, appropriate values for C and L have to be estimated. As an initial guess C en L can be determined based on information of the building itself as given by equation 2 and 3.

$$L = \sum UA + \rho c_a \dot{V}(1 - \eta_{recovery}) \tag{2}$$

$$C = \sum V_{structure}\rho c + 5c_a\rho V_{zone} \tag{3}$$

L is thereby the sum of the transmission losses trough the construction components and the ventilation losses. $\eta_{recovery}$ represents the amount of heat recovered by the ventilation system. The capacity is estimated using the total capacity of the building structure and the capacity of the indoor air. It is found, as also discussed in [9] that this prediction results in an important overestimation of the building capacity, since not the entire thermal mass of the structure will play a role in the capacity as the heat is not distributed uniformly over the entire structure. Therefore the values for L and C are estimated based on the simulations with the detailed building model. The operative zone temperature during the preheat and peak period is calculated using the building model. During these simulations internal and solar gains are eliminated, since they are part of Q_t and therefore not required to calculate L and C. In a next step equation 1 is used to estimate L and C. To get a better prediction the values for the preheat and peak period are estimated separately. The results are summarized in table 1.

Table 1. Estimated and Simulated values for the heat loss and thermal capacity.

	Estimated		Simulated	
	Light building	Heavy building	Light building	Heavy building
L [W/K]	41.31	41.31	57.00	61.58
$C_{preheat}$ [MJ/K]	22.58	51.33	8.01	26.02
C_{peak} [MJ/K]	22.58	51.33	4.67	9.24

Using these values for L en C, the different control strategies can be evaluated. Figure 2 shows the cumulated electricity demand over the year for the different cases. This figure shows that the heavy weight building performs better under Belgian climate data. With BIPV-sizes of 1.7 kWp there is a net electricity production of 43 kWh or 2.5% of the yearly electricity use for the heavy case, whereas for the light-weight building there is a net electricity demand of 28.9 kWh or 1.7% of the annual electricity demand.

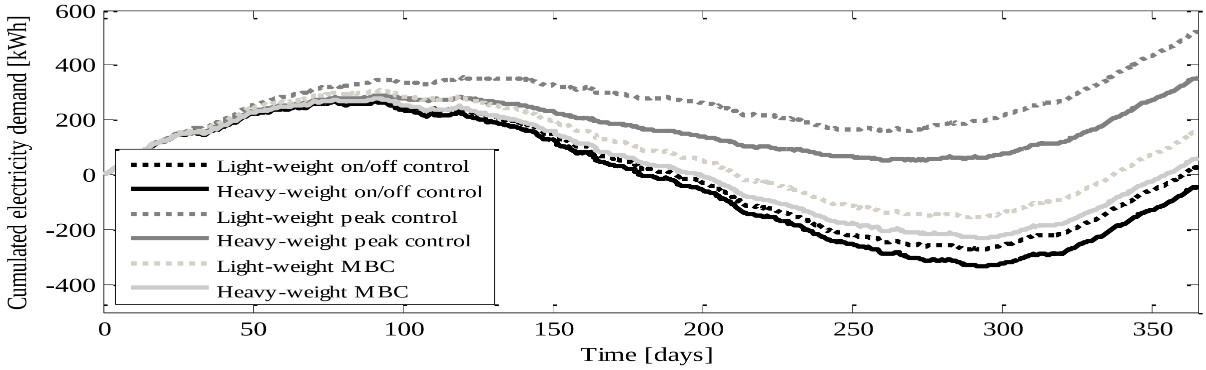

Figure 2. Cumulated electricity demand over a year for all test-cases.

This difference can be explained since the large thermal mass of the heavy building results in a slower temperature increase due to passive solar gains through the glazing. During the early spring, the automated solar shading remains open more of the time for the heavy building, allowing for more solar gains to be stored inside the thermal storage capacity. This thermal energy is slowly released in the evening reducing heating demands.

Figure 2 also shows how the ‘peak control’ strategy results in higher yearly electricity use. Since the heat pump is turned on as the electrical power balance exceeds 600 W, 328 kWh or 44% of the peak PV production is used by the heat pump instead of injected into the distribution grid for the light-weight building and 50% for the heavy-weight building. During these peak periods the building’s thermal capacity is charged. However not all stored thermal energy can be efficiently used inside the building. On the one hand the increased indoor temperature results in higher losses reducing the storage efficiency. On the other hand the peak controller is unable to account for future heat demand, resulting in situations where the building is heated until the upper set point and then immediately cooled to the lower set point, in order to avoid peak electricity flows towards the grid.

Another problem with the peak control strategy is illustrated in Figure 3. During the winter, when BIPV production is low, the reduction of the peak electricity demand to 600 W, causes the indoor temperature to drop below the lower comfort temperature of 20 °C. The lowest indoor temperatures are found for the light building scenario, as it cools down more rapidly after turning off the heating. Figure 3 also shows how this problem is solved by the MBC. The MBC preheats the building to prevent the temperature from dropping below comfort levels when the heating is turned off during periods where comfort is required. Still small violations to the comfort criteria are found, caused by non-perfect predictions of the heat loss during the peak period. Future improvements to the low-order model used for the MBC could reduce these errors.

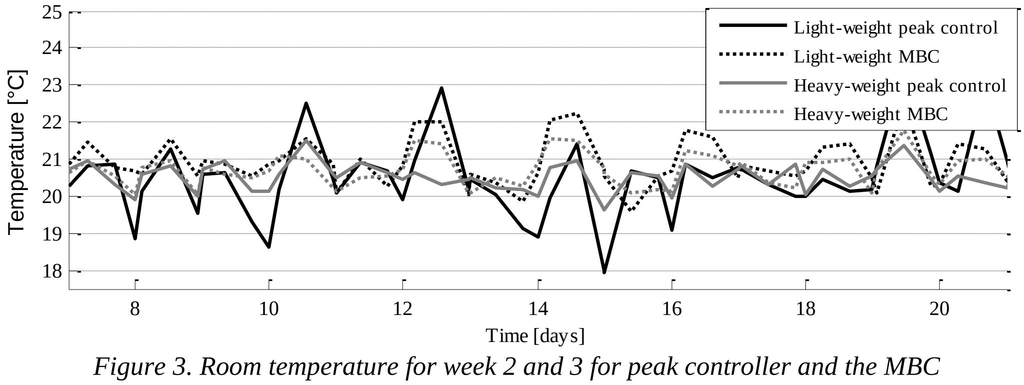

Figure 3. Room temperature for week 2 and 3 for peak controller and the MBC

When looking at the peak load reduction, implementation of the on/off control in the light-weight building shows a peak electricity use by the heat pump of 84.0 kWh/year when the electricity demand from the network exceeds 600 W. For the heavy building the reference scenario shows a peak load of 64.7 kWh/year or 10% of electricity use of the heat pump. Where the peak control strategy is able to avoid this peak demand completely, the MBC only turns off the heat pump between 7:00-10:00 and 16:00-19:00. This results in a residual peak load of 51.4 kWh/year for the light-weight and 21.0 kWh/year for the heavy-weight building. Most of this residual peak load is found during the preheat periods, where the higher preheat temperature set point, required for the light-weight building, explains the better results for the heavy-weight building. Better results could be expected as the variation on the stochastic user behavior decreases, allowing better prediction of the peak periods.

As far as the peak supply to the distribution grid is concerned, the peak control strategy is able to reduce the peak flow by 328 kWh of 44 % of the peak BIPV supply, by operating the heat pump. For the heavy-weight building a reduction of 374.2 kWh or 50 % is found. Although the massive building uses more energy during the peak supply period, the total energy consumption for the heat pump is larger for the light-weight building. The peak control strategy results in an electricity use for heating and cooling of 1221.9 kWh for the light-weight building and 1156.4 kWh for the heavy-weight building, or an increase of respectively 46% and 55% in comparison with the on/off control. The MBC does not allow the heat pump to be switched on during the peak hours and therefore no peak reduction is possible during these hours. In addition the energy demand during the preheat periods are often smaller then for the reference case, resulting in a smaller reduction of supply peaks. Reductions of 15 % and 16 % are found for respectively the light-weight and the heavy-weight building. Better results could be expected if the heat pump is allowed to be activated during the peak hours when it is required to reduce the peak flow to the distribution grid.

CONCLUSION

Dynamic simulations of three control strategies implemented for a light-weight and a heavy-weight dwelling, show the potential for peak load shaving by active building control combined with passive thermal storage. It is found that an active control strategy is able to store energy in the structural mass when peak supply by the BIPV occurs. This energy is used during the peak periods, when the heating is turned off. Only a fraction of the stored energy can be efficiently used during peak periods, resulting in an increased annual energy demand.

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ADEQUACY OF PHOTOVOLTAIC ENERGY IN OFFICE ENVIRONMENT

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ABSTRACT

Lighting uses today about 19% of the electricity produced in the world, so its efficiency has big impacts on energy consumption. If the amount of produced electricity is limited, such as the case in many off-grid PV systems, the electrical efficiency of the illumination and other consuming devices is even more crucial. The goal of this research was to find out how much PV-surface is needed for office illumination and to electrify common office equipment and what are the global variations in this.

A PV system was built in Espoo, Finland (60°11'N, 24°49'E) to study the electricity production over a year's period from several compass points and tilt angles. Based on these measurements, it was calculated how much panel surface is needed for powering up the illumination and some typical office devices. The consumption of LED lighting was compared to fluorescent lighting. The calculations were done by combining the solar panel- and lighting measurements and the statistical radiation [1] and device [2] data and extrapolated to other locations using the NASA SSE database [1].

During the darkest month (December) the measured PV system produced 5% of the electricity of the sunniest month (July), in the measured year 2010 with 90° tilt angle. For a module installed to an annual optimum tilt angle (48°) this ratio was 2%. Therefore backup power generation is required for reliable annual operation. In the areas closer to equator the solar irradiation is distributed more evenly throughout the year and therefore smaller amount of backup power generation is needed for all year long usage. Closer to poles the situation is opposite. Study showed also large variations in the office device consumption. Depending on the product category, the highest consuming device required 3-39 times more power than the least consuming device of that category. By selecting less consuming devices, significant savings on energy bills and/or sizing PV-system can be achieved. Only electrical consumption of the devices was compared in this context and other specifications of the devices may vary.

INTRODUCTION

Lighting uses today about 19% [3] of the electricity produced in the world. This means its efficiency has big impacts on global and local energy consumption and also on energy bills. If the amount of available electricity is limited, such as the case in many off-grid PV systems, the electrical efficiency of the illumination and other consuming devices is even more important. The goal of this research was to find out how much solar panel surface is needed for office illumination and to electrify common office equipment and how much savings can be achieved by selecting less consuming devices. Global variations in these requirements were also studied.

METHOD

PV-system study was done by combining the data of the PV measurements executed in the Lighting Unit of Aalto University with statistical data from the NASA Surface meteorology and Solar Energy (NASA SSE) database [1]. Lighting measurements were also done in Aalto University Lighting Unit. Office device consumption data was gathered from Sust-it.net website, which is an independent website gathering electrical data from different manufacturers. The yearly consumption calculations were based on working hours presented in the EnergyStar program requirements [4].

PHOTOVOLTAIC MEASUREMENTS

Tilt angle

Photovoltaic modules work most efficiently when they are perpendicular to the sun. Optimum tilt angle depends on the latitude of the installation, time of day and time of year, so it varies constantly. It is often not practical to build solar tracking system that aligns the solar panels continuously towards the sun, because it adds system complexity and installation costs. This is especially true for BIPV systems, because solar modules are often mounted to a surface of building materials. Fixed annual optimum tilt angle produces about 20% less energy during a year when compared to 2-axis solar tracking system [5]. By rule of thumb the rough estimate for annual optimum tilt angle is the latitude of the installation location and it shifts about -15° in the summer +15° in the winter [6]. The rule of thumb does not apply well to latitudes higher than 45°N or 45°S or to regions with special local weather conditions [7]. In the high latitudes the diffuse part of the solar radiation is larger than closer to the equator, mainly because of the cloudy conditions, which results to lower optimum angles. Optimal fixed tilt angles calculated at [7] based on the [1] can be seen in the Figure 1 below.

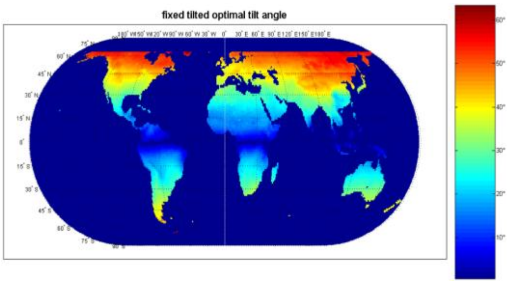

Figure 1 Optimal tilt angles for fixed tilted PV systems for optimized irradiation on module surface [7].

For this study, a PV system was installed on to the roof of Valotalo building in the Otaniemi campus area of Aalto University, Espoo Finland (60°11'N, 24°49'E). According to NASA SSE [1], the annual optimum tilt angle for this site is 48.5°. To verify the optimum tilt angle, on-site measurements were carried out. The solar panels were facing south and the tilt angle was modified in 10° steps. The measurements were executed when the sun was in its highest position of each measuring day (12-14 pm.) and measurements for each angle were averaged over 5 minute period (*Figure 2*). The measured values became quite close to calculated optimum angle of NASA SSE. The yearly averaged peak production is slightly over 50°, but this measurement series contained no tilt angle measurements from the months November-January when the sun is at its lowest position, which caused error to averaged results. These measurements were in no way conclusive, but they give good indication that the NASA SSE calculations are reliable enough for designing practical applications.

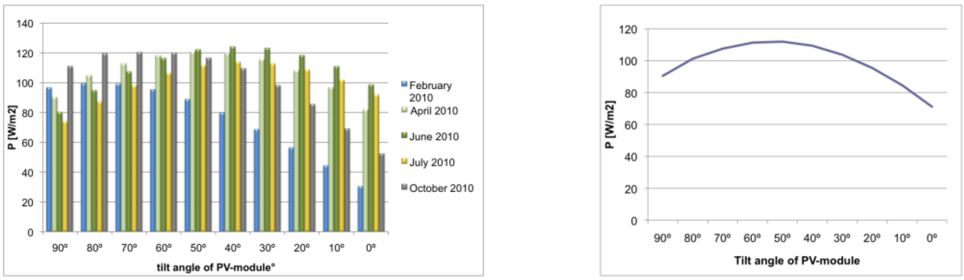

Figure 2. a) b)
PV-system power output based on the field measurements at Espoo, Finland (60°11'N, 24°49'E) for south facing PV-module at various tilt angles. a) Results of each measuring day b) The average value curve of the measurement series.

PV power production used in the consumption calculations

Photovoltaic electricity production data was gathered from the PV system installed on to the roof of Valotalo (60°11'N, 24°49'E). There were five solar panels, one pointed to each principal compass point (tilt angle = 90°) and an additional module pointed towards south to an annual optimum tilt angle, which was 48° for this installation site. The electrical production data was measured over one year and it is presented on the Figure 3 below.

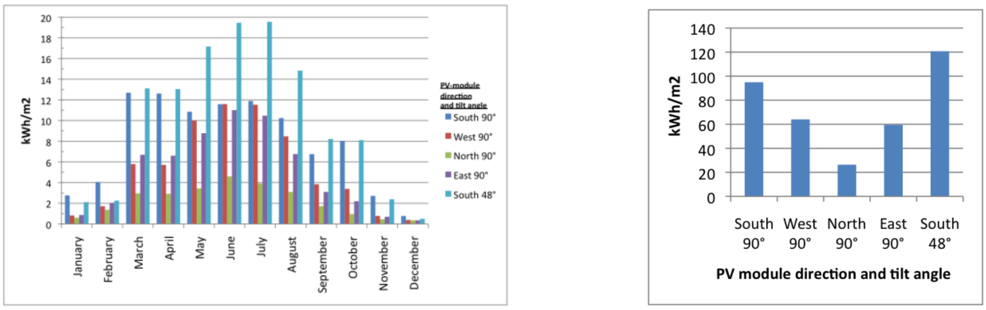

Figure 3. a) b)
Monthly a) and yearly b) production data from the PV system used in the calculations. Data was gathered in 1 min intervals from each direction and summarized over each month and whole year 2010.

The monthly variations in the PV production are significant. In December the PV system facing south (tilt angle = 90°) produces only 5% of the production of July. For an annual optimum tilt angle (tilt angle = 48°) this ratio is even less, only 2%.

Scaling the solar measurements to other locations

Power production of a PV system depends of the amount of solar irradiation. Local irradiation amounts depend on the latitude, longitude and time of year. Therefore the best way to compare actual irradiation levels between different sites is to study annual average values. Following Figure 4 was produced using the numerical data from the NASA SSE [1] and it represents the average global daily irradiation amounts for a latitude tilted surface in the world map by 1°x1° grid resolution.

According to SSE [1], annual average daily irradiation amount for the installation site (60°N, 25°E) is 3.07 kWh/m^2/day (1120 kWh/m2/a) for a latitude (60°) tilted surface. Irradiation difference between latitude (60°) tilted surface and optimum angle (48°) is -8%. The global maximum of average daily radiation is 7.41 kWh/m^2/day (2705 kWh/m2/a) at 26°S, 69°W. The global minimum of average daily radiation is 1.67 kWh/m^2/day (610 kWh/m2/a) at

75°N, 10°E [1]. Therefore the irradiation levels of the test site are 41% of the global maximum and 174% of the global minimum.

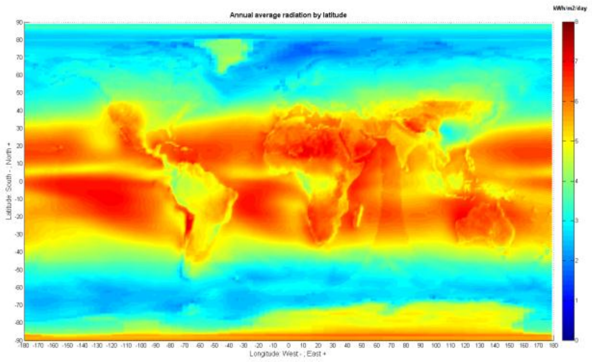

Figure 4 Annual average daily solar irradiation by coordinates. This figure is drawn based on the statistics of [1].

Field measurements at the installation site resulted to 2,95 kWh/m^2/day (=1079 kWh/m2/a) during the year 2010 for a 48° tilted surface (pyranometer used: Kipp & Zonen SP Lite2), so this indicates that the NASA Surface Meteorology Database radiation values are accurate enough for application design purposes. The temperature effects on PV materials are not included in this study.

POWER CONSUMPTION OF OFFICE DEVICES AND REQUIRED PV AREA

Lighting measurements

During the tests there were no suitable luminaires on the market, that would be available as a LED version as well as fluorescent lamp version. Therefore existing FL luminaires were modiefied to operate with LEDs and compared with the original model. The luminaires were measured in 4mx2m room and a table was placed in the middle of this room to represent working area. The measured results are presented in the Table 1 below.

					Working area	Whole area			
Lamp type	Dimming [%]	Electrical power of luminaires [W]	Lighting power density [W/m]	Daily power consumption [kWh/m2]	Average illuminance Em [lx]	Average illuminance Em [lx]	Required PV area at the highest producing month [m2]	Required PV area at the lowest producing month [m2]	Required PV area at the average yearly production [m2]
LED	62,5	21,8	2,7	0,022	285	250	0,03	1,29	0,06
LED	50	29	3,6	0,029	390	340	0,04	1,72	0,08
LED	37,5	38,7	4,8	0,038	510	450	0,05	2,29	0,11
LED	0	72,6	9,1	0,073	770	680	0,10	4,35	0,21
FL	0	60,8	7,6	0,061	410	380	0,08	3,63	0,18

lighting on time = 8h/day

Table 1 Lighting measurements for a LED and FL luminaires. Dimming reduces the power consumption of LED luminaires significantly and by selecting suitable dimming level more light per watt can be extracted from LED luminaire than from FL luminaire. Dimming has also significant effects on required PV area.

LED luminaires were able to produce more light per inserted watt than FL luminaires. When LED luminaires were dimmed 37,5% from the full power, they produced 510 lx to working area with 4,8 W/m^2, which can be viewed as a good result and the lighting level is still within the European standards of office lighting [8]. The dimming has also significant effects on the required PV area if the electricity is produced with PV system. Table 1 shows that the required PV area is 47,2% lower when LED lighting is dimmed 37,5% compared to full power. This dimming level uses 36,8% less power and PV surface accordingly if compared to FL lighting at full power and same time it produces more light. However the LED products are still developing rapidly, so in the future the LEDs are expected to be even more efficient.

Office device measurements

The estimated annual power consumption is calculated using published data [2] and the methods of EnergyStar program [4]. The Table 2 below contains ecamples of consumption calculations for widely used office devices. Each category contains an example of lowest and highest consuming device, based on the data of [2] to show the variation inside each group.

	Laptops (procucts compared: 150		Desktop computers (products compared: 258)			LCD displays 19" (products compared: 204)		LCD displays 24" (products compared: 94)	
Model	Dell Inspiron 1210	HP Pavilion DV7T	Apple Mac mini	Fujitsu Siemens	Model	Philips 192E1SB	AG Neovo ER-19	Acer S24HL	La Cie 324
Description	1.33 GHz Intel Atom	2.0 GHz Intel Pentium	2.4GHz Intel Core 2	3.2GHz Intel Xeon PC	Description	19" HD Ready LCD	19" LCD Monitor with 1280 x 1024	24" Full HD LED	24" LCD Monitor with 1900 x 1200
Sleep [W]	1,04	1,11	1,15	14,00	In-Use [W]	13,20	72,00	17,20	140,00
Idle [W]	5,01	21,09	7,73	315,00	Stanby [W]	0,80	15,00	0,55	2,00
Off [W]	0,97	0,60	0,22	1,50					
Annual power consumption [kWh]	19,18	59,55	28,65	1117,12	Annual power consumption [kWh]	27,46	149,76	35,78	291,20
Cost of electricity per year (grid price) [€]	2,45	7,62	3,67	142,99	Cost of electricity per year (grid price) [€]	3,51	19,17	4,58	37,27
Required PV area at the highest producing month [m2]	0,07	0,22	0,11	4,17	Required PV area at the highest producing month [m2]	0,10	0,56	0,13	1,09
Required PV area at the lowest producing month [m2]	3,22	9,99	4,81	187,39	Required PV area at the lowest producing month [m2]	4,61	25,12	6,00	48,85
Required PV area at the average yearly production [m2]	0,16	0,49	0,23	9,13	Required PV area at the average yearly production [m2]	0,22	1,22	0,29	2,38
highest/lowest power consumption	3,1		39,0		highest/lowest power consumption	5,5		8,1	

Table 2 Office device consumptions [2] for lowest and highest consuming device of each category. Calculated PV areas for powering the devices are based on the measurements at Espoo, Finland (60°11'N, 24°49'E).

Table 2 shows significant variation in the power consumption of typical office devices. Depending on the product category, the highest consuming device requires 3-39 times more power than the least consuming device of that category. This can have significant effects to electricity bill or to the capital costs of PV system, depending on how the power for the devices is supplied. However it is important to acknowledge that only power demand was compared in this survey, other specifications of the devices may vary.

Scaling the required PV area calculations to other locations

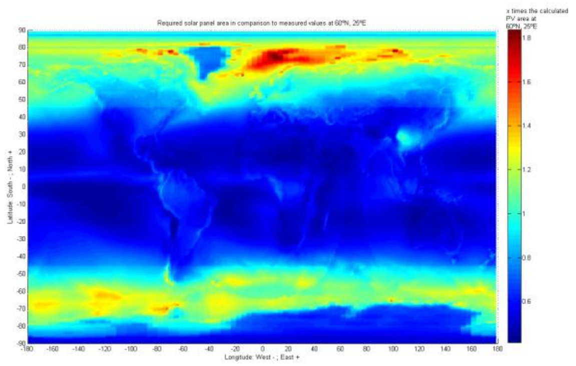

Figure 5 PV area scaling chart. Required PV area can be calculated approximately by picking a calculated PV area (Required PV area at the average yearly production) of a selected device from the Table 1 or Table 2 and multiplying it with the factor represented in this figure corresponding the selected location. This figure was created by using the NASA SSE [1] and comparing the values of the installation site (60°N, 25°E) to other locations.

The results presented in the Table 1 and Table 2 can be scaled to other latitudes and longitudes by using the Figure 5 above.

This figure was calculated by using the annual average irradiation values and it does not take into account temperature related losses that are usually more pronounced in the high irradiation areas. The accuracy of the figure is 1°x1°. Field measurements are recommended for actual system design purposes, but Figure 5 gives rough estimation of the PV potential variation around the globe.

CONCLUSION

The electricity production ratio between lowest and highest producing months was 5% for vertically tilted (90°) solar module in the measured year 2010, at measured site (60°11'N, 24°49'E). For a module that was installed to an annual optimum tilt angle (48°) this ratio was 2%. The closer the area is to equator, the smaller are the seasonal production variations.

In the measurements the LED luminaires were able to produce more light/watt than FL luminaires, especially when they were dimmed. There were also large variations in the office device consumption. Depending on the product category, the highest consuming device required 3-39 times more power than the least consuming device of that category. By selecting less consuming devices, significant savings on energy bills and/or sizing PV-system can be achieved. However it should be noted that only electrical consumption of the devices was compared in this context and other specifications of the devices may vary.

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Building and Urban Simulation

HEATING AND COOLING DEMAND ESTIMATION USING A SELF-LEARNING THERMAL BUILDING MODEL

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ABSTRACT

The increasing costs of energy encourage the development of energy-efficient buildings. Due to the high thermal capacity and the improved insulation of modern buildings, sophisticated predictive control techniques are required in order to reduce operating costs of energy-intensive services while increasing the comfort for the occupants. Weather and price forecasts, together with a model of the building's thermal behavior, are necessary to optimally account for the future boundary conditions of the building system using a predictive control strategy.

The performance of the control strategy mostly depends on the accuracy of the model. To estimate the unknown model parameters, a self-learning algorithm is proposed in order to reduce application costs and to account for changing building conditions. The estimator automatically adapts the model parameters using online identification techniques. Due to the fact that the measured temperatures are affected by measurement noise, these uncertainties lead to a dual-estimation problem.

An Extended Kalman Filter (EKF) is used for solving the dual-estimation problem. The method is applied to a linear control-oriented thermal building model describing the most important dynamics. However, the dual estimation yields a nonlinear problem which implies that the standard Kalman Filter approach is not applicable. After the convergence of the parameters, the self-learning building model enables the prediction of the energy demand of the Heating, Ventilating and Air Conditioning (HVAC) system of a building.

The algorithm derived is tested on measurement data taken from a modern alpine lodge. The data are collected both during an unoccupied period in winter time and during an occupied phase in summer. The EKF algorithm used shows a robust convergence of the parameters. Starting with rather inaccurate initial parameter values, the thermal building model parameters converge after approximately three weeks. The final values are in agreement with the values derived by an offline least-square method.

During occupied phases, the disturbances introduced by the occupants are significant. To still guarantee an accurate state prediction, the EKF is used to estimate this influence as well.

The prediction of the reference zone temperature shows average deviations of less than 1°C for two-day predictions and of less than 3°C for four-day predictions which shows that the proposed self-learning thermal building model is well suited to be applied to a model predictive control environment.

INTRODUCTION

Buildings are responsible for approximately 40% of the secondary energy use in the developed countries [1]. Most of the energy is spent for air conditioning services. The heating and cooling demands of a building system are directly linked to its thermal behavior. Predictive controllers have the advantage of optimally accounting for the thermal capacity of the building and its future boundary conditions such as the outside temperature or the solar gains through the windows. Therefore, model-based predictive control (MPC) techniques are a promising solution to reduce the energy demand while increasing the comfort for the occupants [2], [3].

A prerequisite for any MPC algorithm to improve the performance of the HVAC system is the availability of an accurate but also computationally efficient mathematical model. The model predicts the thermal behavior of a building and its HVAC components in order to estimate the building's heating or cooling demand for a time horizon of a few days.

One drawback of MPC algorithms is their higher implementation costs since for each building a new parameter set needs to be identified. In addition, the usage of the building or even the building parameters such as its insulation quality may change over time, which leads to an inaccurate model. To overcome this situation self-learning models have been described by several authors. In [4], an EKF is used online to parameterize the model of the heating system of a single-family house. A self-learning predictive controller is used in [5] to optimally control a small building with a warm-water heating system. The parameters are identified by an online recursive least-square algorithm.

This paper is structured as follows: First, the thermal building model used is presented. Second, the dual-estimation algorithm is introduced. Then, the self-learning thermal building model is applied to measurement data obtained during an unoccupied phase to identify the parameters. The model is then extended to increase the accuracy of the predictions during occupied phases.

THERMAL BUILDING MODEL

The thermal model of a passive solar house presented in [6] is used. The control-oriented model shows a good accuracy while being computationally efficient. The energy balance of the building represented by a reference zone is given by

$$C_r \frac{d}{dt} T_r = \frac{1}{R_{r2a}} (T_a - T_r) + \dot{Q}_{sun} + \dot{Q}_{hvac} + \dot{Q}_{dist}, \tag{1}$$

where C_r is the total reference zone heat capacity, and T_r and T_a are reference zone and ambient temperatures, respectively. The variable R_{r2a} represents the thermal resistance between the reference zone and the ambient nodes. Its unit is $[K/W]$. The variables $\dot{Q}_{sun}$ and $\dot{Q}_{hvac}$ are the heat gains from the sun and the HVAC system. In occupied phases, the occupants cause an additional disturbance $\dot{Q}_{dist}$. The main components of $\dot{Q}_{dist}$ are human body heat transmissions ($\dot{Q}_p$), internal heat gains from electric devices ($\dot{Q}_{ihg}$), and air exchanges through open doors and windows ($\dot{Q}_{ach}$).

$$\dot{Q}_{dist} = \dot{Q}_p + \dot{Q}_{ach} + \dot{Q}_{ihg} \tag{2}$$

Since during the unoccupied phase in winter time $\dot{Q}_{dist}$ is very small, it can be neglected. However, during the occupied phase, $\dot{Q}_{dist}$ becomes a significant variable which needs to be estimated separately, as discussed in the results section.

To compare the estimated reference zone temperatures with measurement data, a measured reference zone temperature $T_{r,meas}$ is defined, which is calculated as a weighted average of the measured room temperatures. Because the levels of this building have different room heights, the volumes of the levels are used to compute the weighting factors.

DUAL-ESTIMATION TECHNIQUE USING EXTENDED KALMAN FILTER

The simultaneous estimation of states and parameters describing the system dynamics is known as a dual-estimation problem. Even if the model is linear, the dual-estimation technique yields a nonlinear problem. The Extended Kalman Filter (EKF) is a well-known algorithm for the state estimation of nonlinear systems [7]. In the case of dual estimation, the EKF is used to estimate the augmented state vector containing both states and parameters. Eq. (4) shows the nonlinear discrete-time model considering process and measurement noises with the augmented state vector z_k

$$\begin{aligned} z_k &= \begin{bmatrix} x_k \\ \theta_k \end{bmatrix} = \begin{bmatrix} F(\theta_{k-1})x_{k-1} + G(\theta_{k-1})u_{k-1} \\ \theta_{k-1} \end{bmatrix} + \begin{bmatrix} G_\omega(\theta_{k-1}) \\ G_\theta \end{bmatrix} \omega_{k-1} \\ y_k &= H(\theta_k)x_k + v_k \end{aligned} \quad \text{with} \quad \begin{cases} x = T_r \\ \theta = \begin{bmatrix} C_r \\ 1/R_{r2a} \end{bmatrix} \end{cases}, \quad (4)$$

where θ_k denotes the vector of parameters, x_k, u_k and y_k are the state, input and output respectively, ω_k is the input disturbance, and v_k is the measurement noise, at time step k.

Neglecting the cross-correlation between the process and measurement noises, the resulting EKF update step for the estimated augmented state vector is

$$\begin{aligned} \hat{x}_k &= F(\hat{\theta}_{k-1})\hat{x}_{k-1} + G(\hat{\theta}_{k-1})u_{k-1} + L_{x,k}[y_k - H(\hat{\theta}_{k-1})\hat{x}_{k-1}] \\ \hat{\theta}_k &= \hat{\theta}_{k-1} + L_{\theta,k}[y_k - H(\hat{\theta}_{k-1})\hat{x}_{k-1}] \end{aligned} , \quad (5)$$

where $L_{x,k}$ and $L_{\theta,k}$ are Kalman gains for the state and parameter update at time step k, respectively. More details on the application and design of EKF can be found in [8].

PARAMETER ESTIMATION OF THERMAL BUILDING MODEL

Ignoring the $\dot{Q}_{dist}$ term, the estimation of the reference zone temperature during the unoccupied phase matches the measurement data quite accurately as shown in Fig. 1. Figure 2 shows the convergence of the parameters. The parameters values as estimated at day 28 are used to perform a prediction of the reference zone temperature. Figure 3 compares two-day and four-day predicted values with the measured data. During the unoccupied winter time, the prediction shows very satisfactory tracking for the two-day prediction and acceptable results with a maximum deviation of 3 degrees for the four-day predictions.

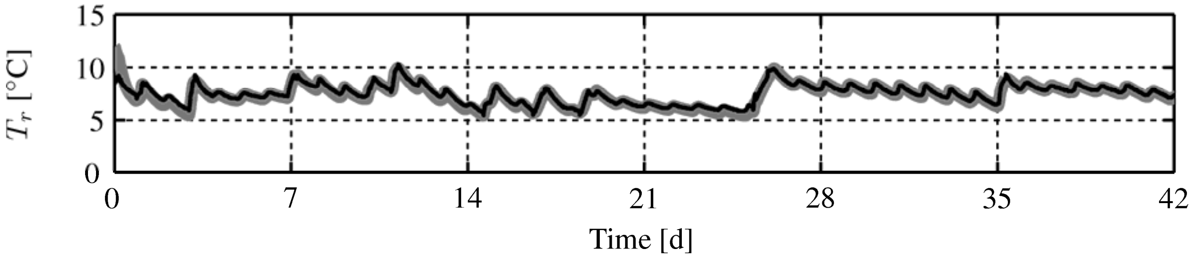

Figure 1: Comparison between state estimation (grey) and measurement data (black) of the reference zone temperature during the unoccupied phase in winter.

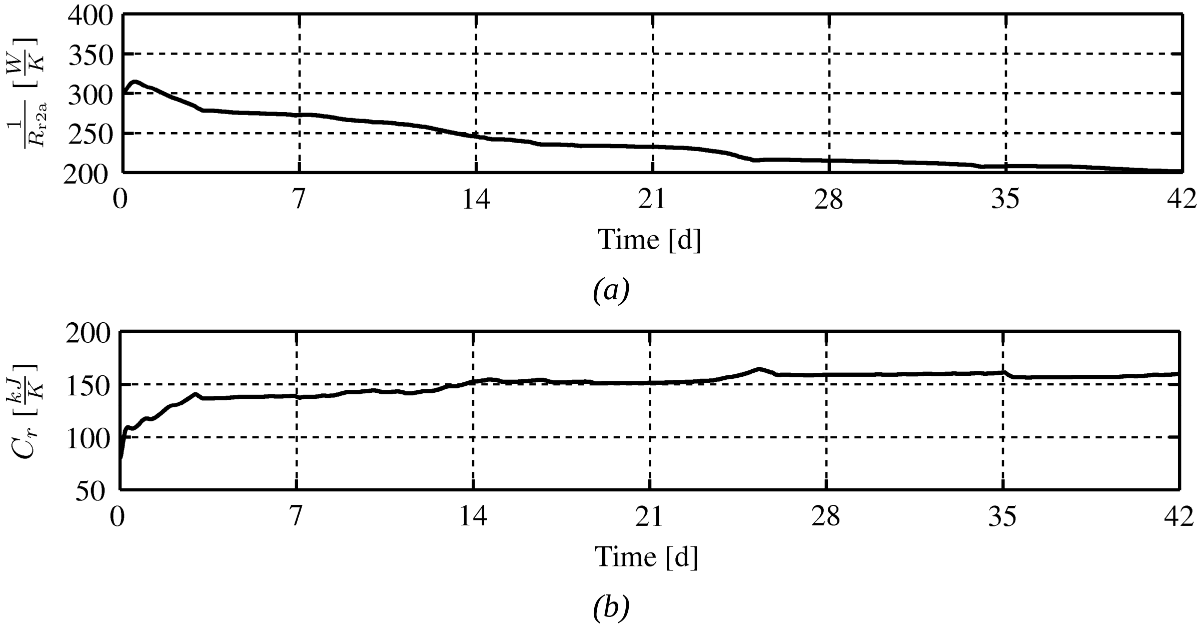

Figure 2: Thermal building model parameter adaptation: inverse thermal resistance (a), thermal capacity (b).

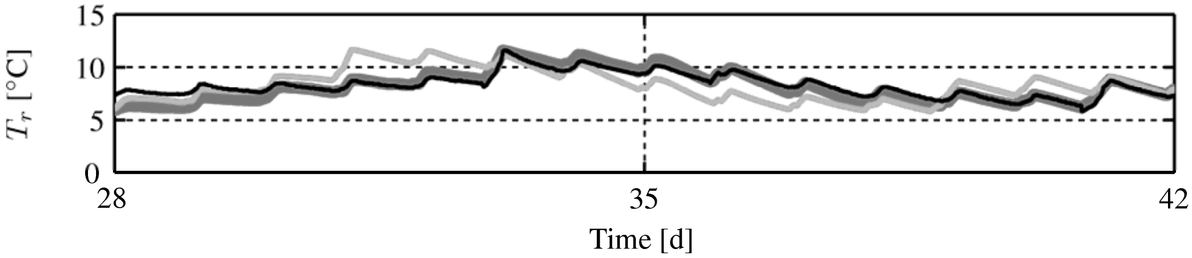

Figure 3: Comparison between two-day (dark-grey) and four-day (light-grey) temperature predictions and measured data (black) of the reference zone temperature during the unoccupied phase in winter.

However, during the occupied summer time the presence of people causes additional disturbances. Figure 4 demonstrates that neglecting the influence of $\dot{Q}_{dist}$ yields predictions that deviate significantly from measurement data. Therefore, ignoring the disturbance heat gain ($\dot{Q}_{dist}$) is not possible in this situation.

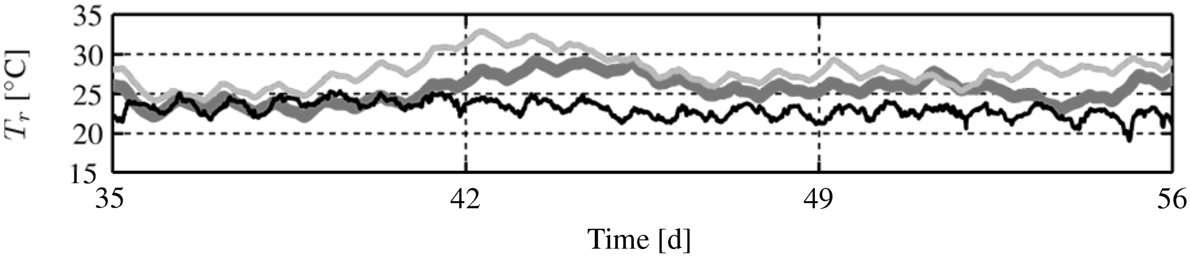

Figure 4: Comparison between two-day (dark-grey) and four-day (light-grey) temperature predictions and measurement data (black) of the reference zone temperature during the occupied phase in summer.

DISTURBANCE ESTIMATION

In order to include the disturbance heat gain ($\dot{Q}_{dist}$) in the thermal model, it is assumed to be varying slowly since the number of occupants changes only once per day. Therefore, this heat gain can be treated as a parameter which is adapted using an EKF. Figure 5 displays the result of the estimation. The thermal building model parameters C_r and R_{r2a} are kept constant during the disturbance heat gain estimation. The value of $\dot{Q}_{dist}$ turns out to be negative most of the times. Considering the special case of the alpine lodge, this effect implies that the term related to the air change is dominant. This result suggests that occupants are mostly affecting the building states by allowing the circulation of cool outside air into the building.

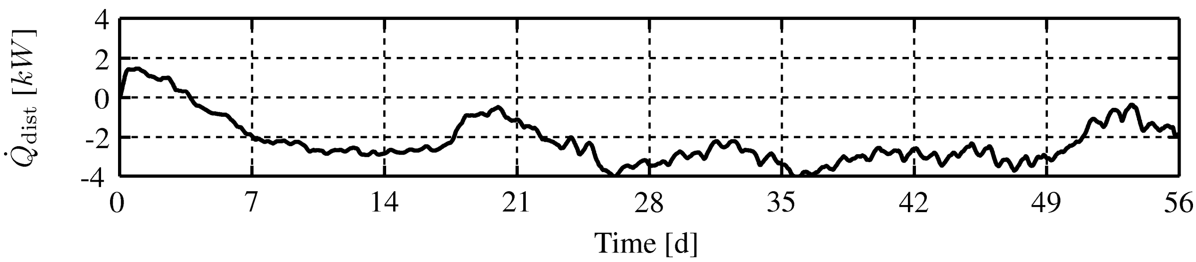

Figure 5: Estimation of the heat flow ($\dot{Q}_{dist}$) introduced by the occupants.

After the estimation of the disturbance heat gain, the state is predicted again. Figure 6 shows the two-day and four-day predictions for the last three weeks using the continuously updated disturbance heat gain. The predictions are improved significantly. However, if the disturbance heat gain changes dramatically during one prediction horizon, as in the last week (see Fig. 5), the accuracy drops. This effect is even more visible in the four-day prediction, as shown in Fig. 6.

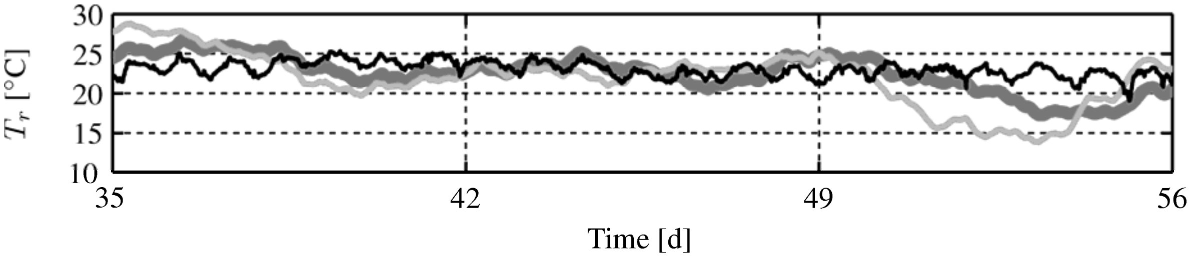

Figure 6: Comparison between two-day (dark-grey) and four-day (light-grey) temperature predictions and measured data (black) of the reference zone temperature during the occupied phase in summer considering the disturbance introduced by the occupants.

CONCLUSION

The aim of this paper was to provide a demand prediction for the HVAC system of a building, using a rather simple thermal model. The method uses an identification of relevant building parameters together with an estimation of disturbance heat gains caused due to the presence of people inside the building. The EKF approach used shows a robust convergence of the two thermal building model parameters. The adapted thermal building model demonstrates an accurate prediction of the indoor temperature for a few days. Based on the predicted system behavior, a Model Predictive Controller is able to generate the optimal inputs for the HVAC system. The self-adapting model guarantees an energy-optimal performance of the building services during various operating conditions, while the occupants' comfort is maintained at the highest possible level.

OUTLOOK

The same methodology can be applied to the energy management of commercial buildings. In those buildings a change in occupancy occurs between the workdays and weekends (or holidays). The two thermal building parameters would be predicted during the weekends, while the disturbance heat gains are estimated continuously during workdays.

ACKNOWLEDGMENTS

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SIMULATION MODELS OF REFURBISHED RESIDENTIAL HOUSING - VALIDATION THROUGH FIELD TEST DATA

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ABSTRACT

A significant number of buildings constructed in Germany in the second half of the twentieth century consume large amounts of energy due to out-dated insulation standards and inefficient heating systems. Through retrofit solutions the energy consumption and indoor comfort can be significantly improved and this work is based on such a refurbishment project, done in Karlsruhe, Germany.

In this work, a simulation model of one refurbishment solution for the buildings is presented along with its validation through field test data. The buildings analysed in the whole project are built in three blocks and the flats are disposed on five floors. Built in the fifties, they had no external insulation or only low-insulated walls, “single glass windows”, a single cackle stove per flat installed in each living room and an electrical circulatory type water heater. For each building a different retrofit scenario in terms of insulation, heat production and delivery, domestic hot water production and air-handling systems was implemented. Each block has insulation panels with different thermal conductivity: k = 0.035 W/(mK) and 0.021 W/(mK) for standard insulation panels and 0.006 W/(mK) for vacuum insulation panels. District heating, ground-source heat pumps and a solar plant provide heat and hot water. The heat is distributed by radiators, radiant surfaces (floor or ceiling) or ventilation systems. The air-handling systems work with exhaust fans or with different methods of waste heat recovery. For the three buildings of the first block one common retrofit solution was implemented, while each building of the other two blocks has a different refurbishment layout: all together there are seven different refurbishment versions.

Each building has been evaluated through the energy saving ordinance for buildings in Germany (EnEV). In order to assess the actual effect of the refurbishment solutions, an accurate high time resolution monitoring process started in February 2010. Additionally, a dynamic simulation model for each refurbishment version has been developed in the language Modelica. The model combines a thermal model for the building and models for the installed technical equipment with models for the users as heat and CO_2 sources. The validation of the model is done by comparing simulation results with the data from the monitoring system.

The preliminary analysis with EnEV has shown a potential for reducing the energy consumption up to 85%. However, first analyses of the monitoring data show that the heat consumption of the buildings is above the heat demand calculated following the EnEV procedure. As such the simulation models can be employed as a tool to elaborate new control strategies for the buildings' system engineering in order to maximise user comfort and energy efficiency. The models can further be used in conceptualising and testing of new virtual refurbishment versions.

Grateful acknowledgement is made for financial support by BMWi (German Federal Ministry of Economics and Technology), promotional reference 0327400G.

INTRODUCTION

A large number of buildings constructed in Germany in the second half of the twentieth century consume big amount of energy due to low insulation standards and obsolete heating systems. A detailed analysis of this consumption points out that over 78% of the energy consumption of private households is used for space heating [1]. Depending on the age classes and building typologies, the energy consumptions of buildings vary significantly. Some regions partially destroyed during the Second World War, have a high number of “more family houses” built between the 50’s and 60's. To a large extent these buildings were built and administered by building societies. Due to the restricted financial possibilities these buildings were built with qualitatively inferior materials. The housing society “Volkswohnung Karlsruhe” has 35 residential buildings in the area of Karlsruhe-Rintheim with more than 1.000 apartments built in the 1950s and 1960s. In this work one model of a specific retrofit solution implemented in a field test in Karlsruhe in cooperation with” the Volkswohnung” housing society is analysed and validated.

In Figure 1 the buildings orientation and the floor plan of the apartments are shown. Before the refurbishment process, the buildings had a primary energy demand (calculated following the EnEV monthly balance procedure [2]) of 347 kWh/(m²a). After the refurbishment process the first block has a primary energy demand of 55 kWh/(m²a), the second block of 45 kwh/(m²a), the third block of about 27 kwh/(m²a). More details on the static calculations, primary energy balances and CO_2 balances for this field test are presented in [3].

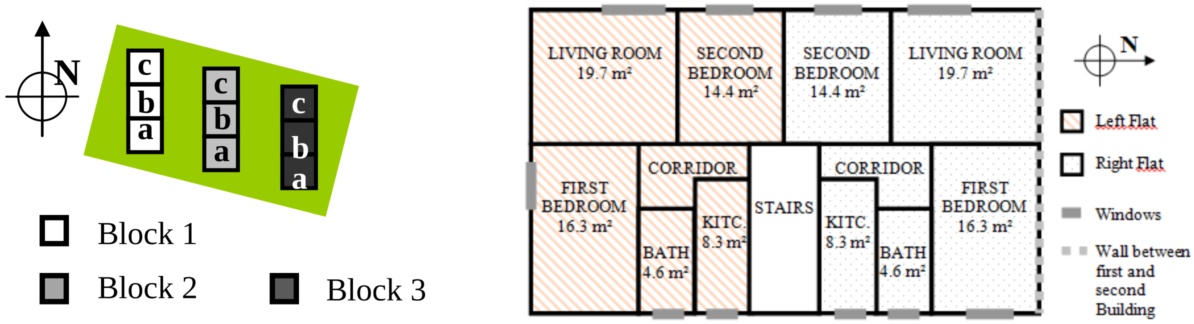


Figure 1: Left side: Buildings orientation. Right side: Floor plan of each floor, for each entrance.

While the whole project is taking into account the complete refurbishment of 3 buildings (for a total of 90 apartments, having the same floor plan, and 7 different refurbishment configuration) in this paper the validation of a Modelica model of one specific refurbishment configuration (block 2, entrance “a”) will be presented. The block two has been externally insulated with 16 cm insulation with conductivity k = 0.021 W/(mK). In the entrance “a” the windows are double glass insulated with a U-Value of 1.3 W/(m²K). The heat for the heating and for the domestic hot water comes from a district heating network. The rooms are heated by radiators. The ventilation of the sleeping rooms and of the living rooms is realised by small ventilation units with heat recovery system installed directly in each window.

A high time resolution monitoring system was installed in the buildings. In each room a monitoring module collects the relative humidity, window opening position, CO_2 and VOC concentrations, the temperatures of the air inside the room, and supplied to the room. In each apartment (of the second and of the third building) a volume flow meter measures the volume flow through the heating system, flow and return water temperatures are measured as well. The monitoring process delivers the data used for the model validation.

METHOD

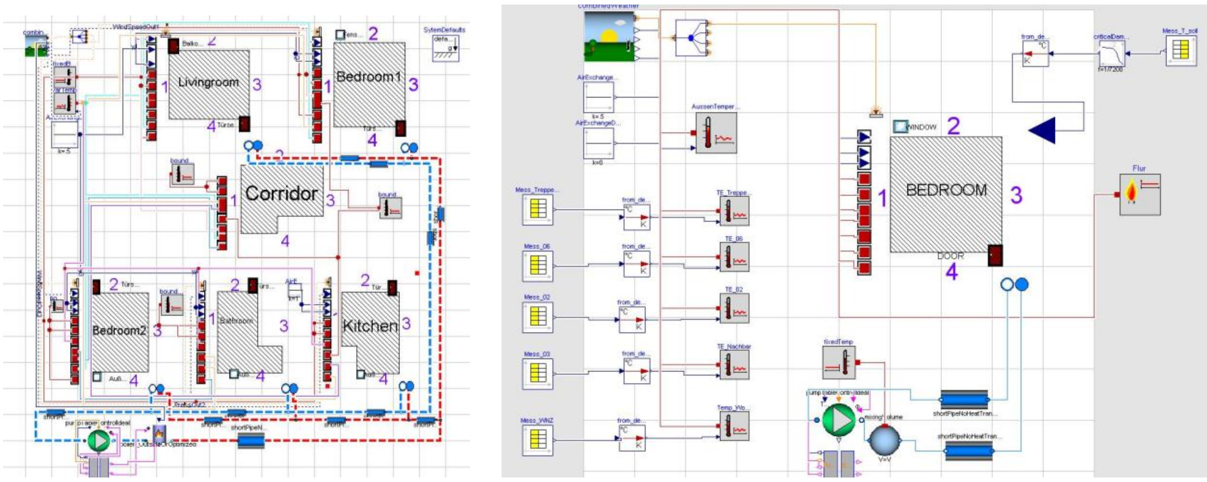
As opposed to static simulations, dynamic simulations include time as a system variable allowing for a detailed simulation of the interactions between ambient, building and users and as such for a better method of developing and testing control strategies.

For this project a coupled simulation model between the building's envelope and the installed technical equipment is developed. The model is constructed using the equation based, object-oriented programming language Modelica [4], together with the simulation environment Dymola [5]. The model validation is done by using the data provided by the extensive monitoring system. Once the model is validated it can be used to simulate different scenarios of control strategies and user behaviour.

The simulation of a whole block would be impractical as far as the simulation duration and stability are concerned. Since the apartments are very similar in layout, the simulation of only one apartment, under correct boundary conditions, allows for a higher degree of detail in the model and serves the same purpose.

The first step in building the models was the generation of a data base with all the relevant data. Modelica-records have been created for all the buildings' elements: walls, windows and doors which allow choosing the wall type for each wall from a drop down menu. The models for the technical equipment are developed gradually. The district heating is modelled by an ideal heat source and a pump. Models for a decentralised pump system, radiators, floor heating, and a window ventilation unit with adjustable heat recovery factor for the second block have been finalised.

Once an apartment (Figure 2a) or a room (Figure 2b) model with all its components is ready, it is coupled to a weather model and tested.



a b

Figure 2: Simulation set-up for an apartment (a), a bedroom (b)

The first test is done with weather data from a test reference year (TRY). Such data is commercially available from the German Meteorological Institute (DWD- Deutsche Wetter Dienst) for 12 meteorological areas in Germany, with Karlsruhe located in area 12. The data is provided in hourly values and for the simulation, data for direct and diffuse solar radiation, ambient temperature and wind speed have been used. The purpose of this test is to see if the model reacts appropriately to the influence of the ambient.

The next step in assessing the conformity of the model is a simulation with real measured weather data. A further purpose of this test is to provide a reference case when analysing the role of user behaviour, because this simulation uses an energy efficient control strategy: set temperature in rooms is 21°C, with the exception of the bathroom where there are 24°C. Unfortunately the measured weather data only provided the global solar radiation. In order to correctly calculate the solar radiation on an oriented surface both the direct and the diffuse solar radiation are needed. Three models were implemented and tested with weather data from TRY 12 for the estimation of direct solar radiation from global radiation. In order to evaluate the applicability of the model for the geographical region the difference was built between the direct radiation data from the TRY and the calculated data from the model. For this difference the mean value and the standard deviation were calculated. The results are presented in Table 1. The chosen model was Erbs, Klein & Duffie, because it has the lowest mean value and also one of the lower standard deviations.

Model	**Mean value (W/m²)**	**Standard deviation (W/m²)**
Erbs, Klein & Duffie [6]	0,9419	41,61
Skarveit & Olseth [7]	-5,298	41,21
Maxwell [8]	6,72	46,755

Table 1: Comparison between the three models for estimation of direct solar radiation from global solar radiation

The last step in validating the model is to set all the boundary conditions according to the measured data: temperatures of adjacent rooms, volume flows and flow and return temperatures for the water in the heating system. The simulation results for the free flowing air temperature are then compared against the measured data. Deviation in the results is then discussed, along two directions: improvements in the thermal simulation models, improvements in the monitoring concept.

RESULTS

The simulation results for the third previously described test, the validation through measured data, will be presented in this section for one room. The room is a sleeping room with a westwards orientation. It has an area of 14,55 m² with a window area of 1,84 m². The installed radiator has a nominal power of 835 W (45/35/20). A ventilation unit with heat recovery is installed in the room. The assumed infiltration rate is 0.5 h^{-1}. The adjacent rooms are a living room, another bedroom, the corridor and the staircase. Simulations were done for the month of December using minute values.

Two simulation set-ups were used for the validation. Both use real measured weather data and the measured temperature in the other rooms as boundary conditions for the walls to the adjacent rooms. In the first simulation set-up the measured flow temperature and the volume flow for the radiator are inputs in the model making the control strategy in the simulation through the thermostat valve obsolete. The thermostat valve is as such removed from the model. In the second simulation set-up (Figure 2b) the temperature set by the user for the room is given as an input in the model. The second simulation set-up allows as such for the additional validation of the thermostat valve model.

The measured free flowing air temperature in the room comes from a sensor integrated in the control panel of each room.

Figure 3 presents the free flowing air temperature as resulting from the simulation and as it is measured by the temperature for one day and one week.

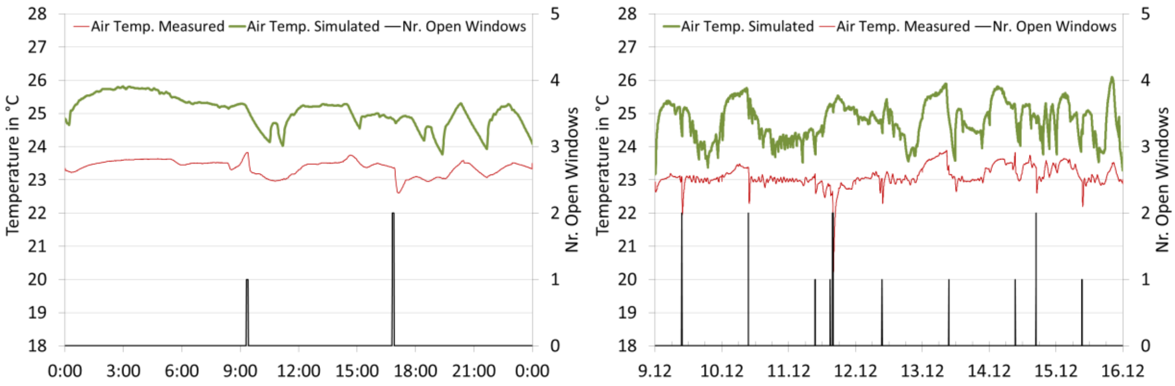


Figure 3: Comparison between the measured and simulated free flowing air temperature in the bedroom for the 19th of December (left) and for one week in December (right).

The average level of the temperature from the measured data is around 23,1 °C, which is higher than expected, when assuming a standard user. The explanation is that the users, when using an energy efficient system, tend to increase their consumption: this effect is known as rebound effect. In fact, the heat energy consumption (obtained from the high time resolution monitoring process) of this user for the month of December is 23% above the heat energy demand calculated following the EnEV [2].

The sudden drops in the measured temperature are probably by the opening of windows as shown in Figure 3. The opening of windows was not modelled at this time as there is no way of knowing what the opening angle of the window is, as the sensor only senses if the window is open or closed. The exact opening of the window can be obtained by trial and error simulations, but that was not the scope of the validation at this point. The simulated temperature profile, apart from the difference caused by the window opening follows the overall development of the measured temperature quite faithfully.

Figure 4 presents the free flowing air temperature as resulting from the simulation and as it is measured by the temperature sensor mounted in the corner of the room for one day and five days. The temperature set by the user, changing as expected twice or three times a day, is also shown. The measured air temperature follows the lead of the set room temperature.

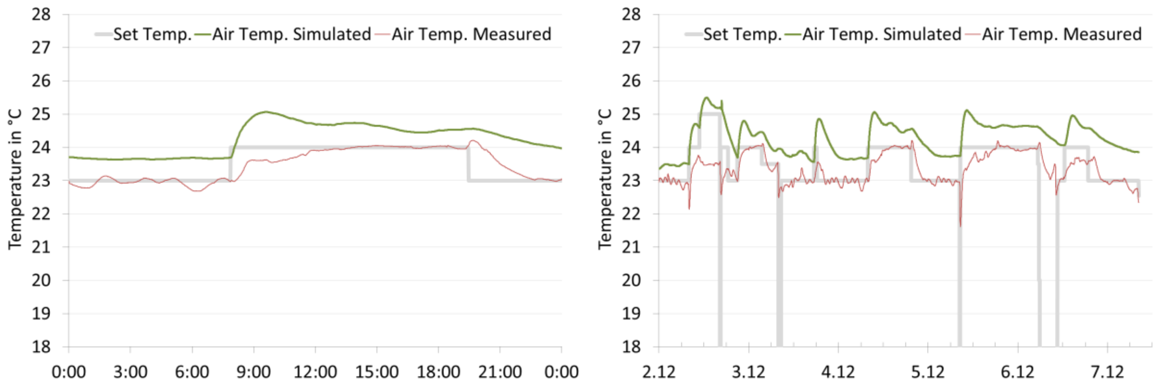


Figure 4: Comparison between the measured and simulated free flowing air temperature in room for the 4th of December (left) and five days of December (right).

The simulation results resemble the measured temperature with the distinction of an overall higher temperature level and overshot when the set temperature increases. This means that the models need a bit more fine tuning for an exact simulation. However they can be used when comparing models with one another because this errors work as offsets for all the models and should not influence relative comparisons between the models.

DISCUSSION

A method for validation the simulation models using data from the monitoring system has been presented.

The models once validated can be used to develop new control strategies and to analyse the user behaviour, particularly the rebound effect. Another realistic application of the model is in the development of new refurbishment solutions. The present model can be adapted to describe new refurbishment solutions and the new solutions can be compared to existing ones by analysing the results of simulations done under the same boundary conditions.

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The Application of Sensitivity Analysis in Building Energy Simulations

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Abstract

Sensitivity analysis plays an important role in the understanding of complex building simulations programs; it helps to identify important and non-important input parameters with respect to the output results, or it can be a tool to understand the program behavior itself, among other uses. The objective of this study is to discuss and evaluate the application of different sensitivity analysis into ESP-r; a well proven building energy modeling tool. Two types of buildings were evaluated. Sensitivity of simulations results were calculated by elementary effects methods (also known as Morris method), including an example of second order interactions between the input parameters.

Introduction

Building energy consumptions are estimated to be an important cause of total energy consumption. The growth in population, building services and comfort levels assure that this tendency will still increase for the following years. However, the comprehension of energy consumption in buildings still remains at low levels because the complexity of the problem and the unavailability or information concerning, first the building itself and its interactions with its environment.

In this study we propose the application of a sensitivity analysis technique in order to select the most influential parameters of a building energy model. This technique is the elementary effects methodology, or Morris Method, proposed by Max D. Morris in 1991 [1] The main objective of this analysis is to test the different Morris sensitivity measures and new measures proposed, in order to discuss how this is relevant for building energy modeling, using ESP-r, a well proven simulation tool. Two typical buildings are taken as examples for this analysis, one collective building (MDU-type), and one semi-detached single house.

The Morris Method

This screening method is a very effective methodology to identify the subsets of few important input factors among a large number of *k* inputs parameters in a model. This method is based on a methodology derived from OAT (One-factor-at-a-time) screenings methods. Using a fractional design input matrix where the points are sampled from a *p*-dimensional regular grid, different random trajectories are mapped into this design with the only condition that one trajectory differ from their precedent. This design allows representing a derivative-type equation, denoted by Morris as "elementary effect" from the change done in each trajectory (equation 1).

$$d_i(\vec{x}) = \frac{f(\vec{x} + \triangle_i \boldsymbol{e}_i) - f(\vec{x})}{\triangle_i}, i = 1...k \tag{1}$$

Using Morris experimental design [1] enables one elementary effect per parameter at a computational cost of *(k+1)* runs of the model, (*k:* the total number of parameters). A set of *r* independent "trajectories" enable estimating *r* different values of each elementary effects at a computational cost of *(k+1).r* simulations. The average value μ_i and standard-deviation σ_i of the elementary effects are computed for all parameters. The standard deviation of the elementary effects is a good indicator of non-linearity in the input parameter or interactions of upper-order levels with other parameters involved in the model. By plotting both statistics μ_i and σ_i, the Morris method main objective is to graphically identify within reasonable uncertainty which inputs may be considered to have effects which are:

1. Negligible (low average, low standard deviation)
2. Linear and additive (high average, low standard deviation)
3. Nonlinear or involved in interactions with other inputs parameters (high average, high SD).

In the case parameters fall into case 3, a subsequent detailed experiment with only those inputs is recommended. Campolongo and Braddock [3] proposed an extension of Morris method that permits the calculation of at least second-order effects with a reasonable computational cost by computing the equivalent of a second-order derivative of the model (eq. 2) and optimizing the computational experiment using the solution of the “handcuffed prisioner problem” so the number of runs required to have one elementary effect par pair of factor is optimized which is k^2.r.

$$d_{i,j}(\vec{x}) = \frac{f(\vec{x} + \triangle_i \boldsymbol{e}_i + \triangle_j \boldsymbol{e}_j) - f(\vec{x} + \triangle_i \boldsymbol{e}_i) - f(\vec{x} + \triangle_j \boldsymbol{e}_j) - f(\vec{x})}{\triangle_i \triangle_j} \tag{2}$$

APPLICATION CASE OF MORRIS SENSITIVITY ANALYSIS

The first building chosen is a seven-floor residential building of a population between 70-80 habitants. The building has 33.40 meters of length, 14 meters of width and 18 meters high adding to a small floor area in the last floor of 2.57 meters of high. It has a connection to a heating network and no cooling equipment was available, window-to-wall-area of 40% composed of mainly double glazing window type, an age of 10 years with external isolation.

The computer building model was split into 24 thermal zones; 16 for the apartments and the rest for the common non-heating zones. The temporal values of climate data: diffuse solar on the horizontal and direct normal solar identity were decreased by 60% to improve the results with available experimental measures. This can be explained by an error in the measurements of glazing ratios of each façades and an approximation of the weather in the zone.

With a validated energy model (5% of error compared to real measured values) we proceed to the analysis of different input parameters using Morris Sensitivity Analysis Method. Second building proposed was a house divided in two thermal zones with a roof including in one thermal zone. This house is neighboring of two houses of the same geometry representing one thermal zone each. The base case of this house was defined to be $120m^2$, and 7.5 mts of height. The thermal properties of this house were defined based in a building-age of 15 years with external insulation.

BUILDING MODEL

The annual energy consumption is then calculated using the energy calculation suite ESP-r[4]. The calculation method is based in the finite volume method which permits solve PDE’s by using approximation of their integrals. The fluid dynamics are solved using SIMPLE algorithm. A conversion program was developed in *bash/awk/sed* to prepare the ESP-r input files according to the changes of the Morris sampling experiments. The files are simulated in a batch process recovering hourly, daily and annual heating loads. And then Morris indices are processed in an octave-script. The input parameter configuration and space intervals where defined differently for the case A(MDU-type) and the case B(semi-detached house) (see tables in appendix).

The p-dimensional grid was defined as p=10 for all experiments [2]. First-order Morris sensitivity indices (defined as MM1) were calculated for cases A and B using Martigny (Switzerland) weather information (+ Nantes weather data in case B).

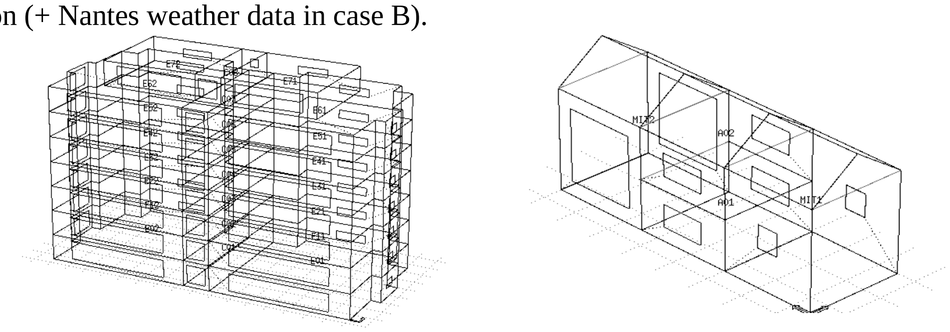

Fig. 1 Building types simulated with ESP-r. FLTR. (A) Collective (MDU), (B) Semi-detached house.

Second-order experiments (MM2) for both weather files were calculated only for case B, due to complexity and high computational cost of case “A”. An initial experiment involving 82 parameters for collective building “A” (using specific, Set-point temperatures, infiltration and occupant gains for each of the 16 heated zones) enabled to select a reduced set of 24 input parameters.

Experiment	Method	Building	p	r	K	weather	N	Time of analysis
1	MM1	A	10	10	82	Martigny	830	3.4 days
2	MM1	A	10	10	72	Martigny	730	3.0 days
3	MM1	A	10	10	24	Martigny	250	1.2 days
4	MM1	B	10	10	26	Martigny	270	1.25 hours
5	MM1	B	10	40	26	Martigny	1080	10 hours
6	MM1	B	10	10	26	Nantes	270	1.25 hours
7	MM2	B	10	4	26	Martigny	2704	1 day
8	MM2	B	10	4	26	Nantes	2704	1 day

Table.1. Numerical experiments performed

RESULTS

Several characteristics for output energy needs have been used. Preliminary analysis emphasized the 3 dimensional parameters as the most influencing for annual heating load. This obvious "size" effect may be reduced by using heat load/ m^2 or m^3 (figure 2). A logarithmic transformation may also be applied to the output, in order to identify interactions caused by multiplicative effects (low SD on Morris diagram for $\log_{10}$). Moreover, the coefficients can be interpreted as relative elementary effects or their variability.

Besides mu and sigma defined above, another post-processing has been used as suggested by [5] with μ^* and σ^*. The use of the absolute value of the average in Morris variables avoids the cancelation error when non-monotonic functions are used. Instead this value gives also valuable information about the model and their behaviour in an oscillatory response.

Results of experiment 3 (fig. 2) shows that even when the importance of geometry is reduced when the annual heating loads are taking in account per m^2, it remains among the major influences (with a high sigma, due to both negative and positive influences depending on interactions with other factors). Insulation and occupation-related parameters affects significantly the heating load as could be suspected. Because obvious parameters are at the top of the ranking (as expected), it is of critical importance to analyze the parameters that are not important but can have a negative effect on the demand.

The use of a logarithmic transformation emphasizes some (but only a few) factors with (partial) multiplicative effects (represented by low sigma) such as temperature related parameters (climate, internal set points) or ventilation and permits to distinguish better the effects of second-order non-linearity. This transformation also increases the differences between each Morris indices of the factors, increases the definition and could help in better decisions at design/renovation level.

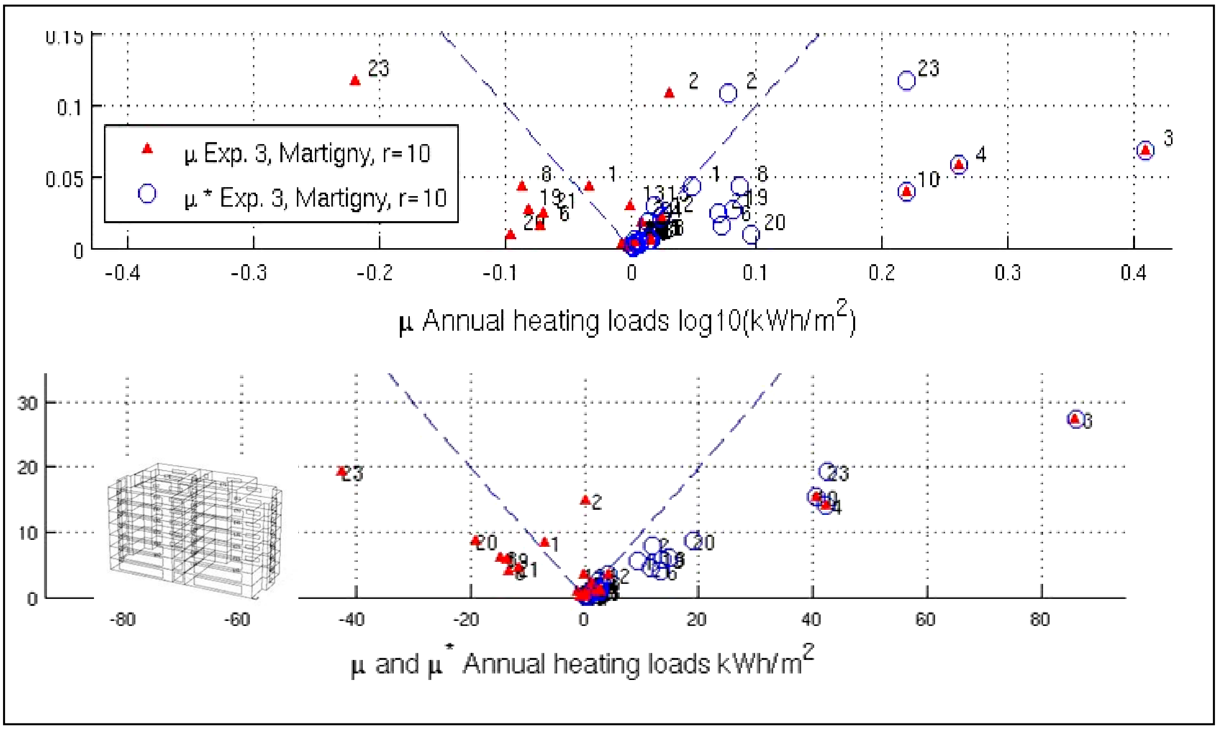

Fig. 3 Graphical results of numerical experiment 3.

In both building examples, the standard deviation of the effects are high which mean that most of this factors interacts with each other and have strong non-linearities. Experiments 4 and 5 (Fig. 3) show that increasing the number of simulations (through number of trajectories, *r*) greatly affects the final ranking of the parameters, because it affects a better definition of the variations and nonlinearities.

Despite that the facts of most literature recommends the use of 10 as the optimal r value in Morris algorithm, this result shows that increasing the r value beyond 10 improves considerably the distinction from important and non important parameters. Optimal r value for building energy simulation should be placed in at least a value of 50. But this also needs to be discussed since the high-time consuming of energy simulation and the range of parameters we chose in this study.

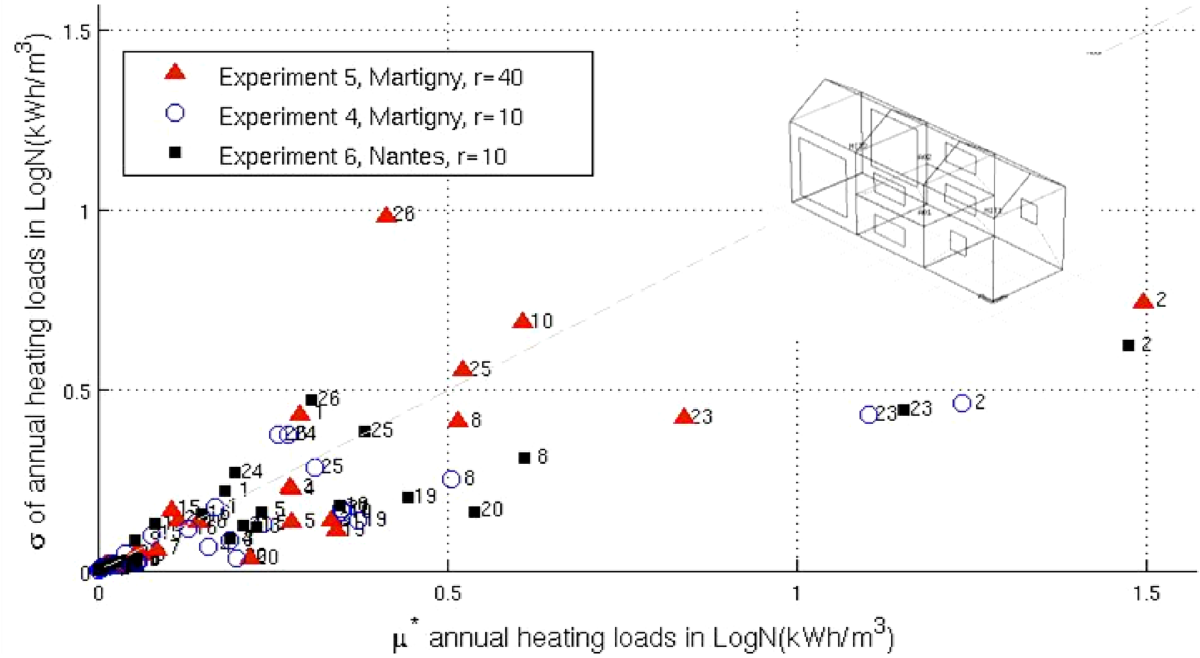

Fig. 4 Graphical results of numerical experiments 4, 5 and 6.

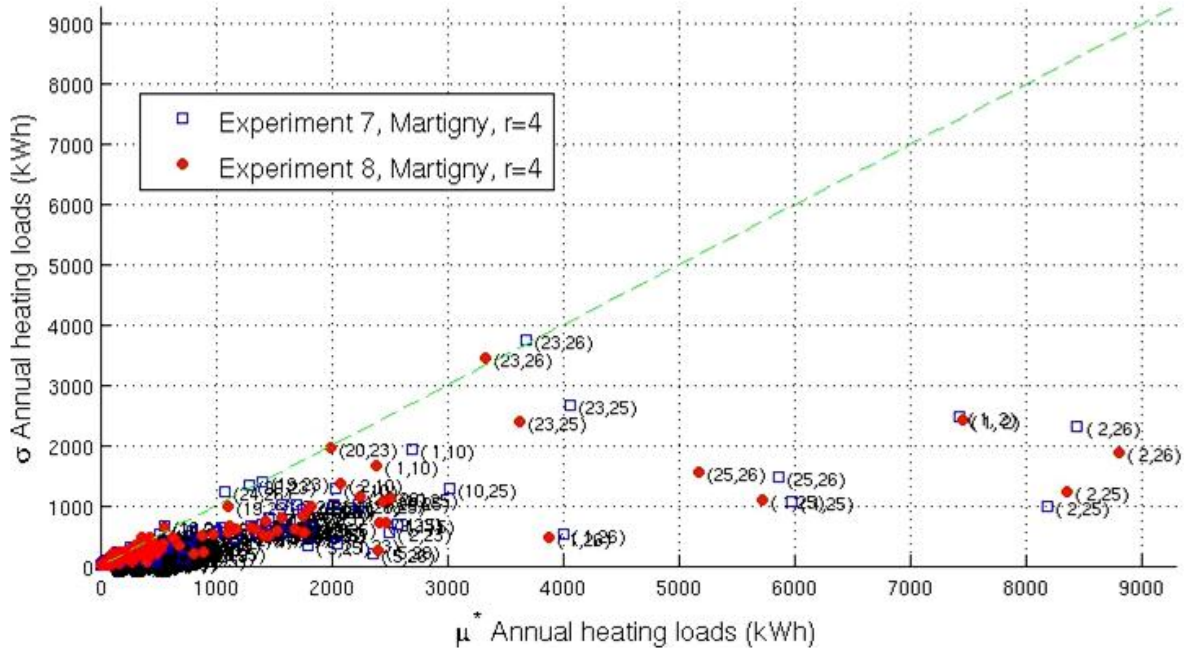

Fig. 4. Graphical results of experiments 7 and 8.

BUILDING TYPE A (COLLECTIVE)

No.	Parameter	Ranking 1	Ranking 2	Unit	Interval
1	Building size: correction for length	11	11	%	50 – 150
2	Building size: correction for width	9	8	%	50 – 150
3	Building size: correction for height	1	1	%	50 – 150
4	Setting point temperature of all apartments except apt.E42	3	2	°C	17 – 24
5	Setting point temperature of apt. E42	14	14	°C	17 – 24
6	Night-day setting point temperature diff. affecting all Apt. Except E42	8	9	°C	0 – 8
7	Night-day setting point temperature apartment E42	20	20	°C	0 – 8
8	Occupants affecting all apartments except apt. E42	6	6	Occ/app	1 - 8
9	Occupants apt. E42	21	21	Occ/app	1 – 8
10	Ventilation rate affecting all apartments except apt. E42	4	3	%	40-100
11	Ventilation rate apt. E42	13	16	%	40-100
12...15	Glazing ratio each facade (4)	12,15,23,22	12,13,23,22	%	5-50
16	Ground reflectivity	19	19	%	20- 30
17	Ground reflectivity in presence of snow (January-December)	24	24	%	30 – 50
18	View factor of ground	16	15	%	30 – 40
19	Climatic sensitivity: correction for horizontal diffuse solar radiation.	7	7	%	20 – 100
20	Climatic sensitivity: correction for external dry bulb temperature	5	5	%	50 – 100
21	Climatic sensitivity: correction for direct normal solar intensity	10	10	%	20 - 100
22	Climatic sensitivity: correction for wind speed	18	18	%	50 – 100
23	Insulation thickness of external walls	2	4	mm	5 – 100
24	Building rotation	17	17	degrees	0 – 180

Definitions**: (Ranking 1)** Ranking from experiment 3 based in Mu* values of annual heating loads in kWh/m^2, p=10. **(Ranking 2)** Experiment 3. based in Mu* values of $\log_{10}$(annual heating loads - kWh/m^2)

BUILDING TYPE B (SEMI DETACHED HOUSE)

No.	Parameter	R1	R2	R3	R4	Unit	Interval
1	Building size: correction for height	4	4	4	4	%	50 – 150
2	Setting point temp. of studied zone (house A01-A02)	2	3	2	3	°C	17-24
3	Setting point temperature of adjoining house (MIT1)	12	12	12	12	°C	17-24
4	Setting point temperature of adjoining house (MIT2)	13	13	13	13	°C	17 – 24
5	Night-day set point temp. diff. affecting house "A01-A02"	10	11	10	11	°C	0 – 8
6	Night-day set point temp. diff. affecting house "MIT1"	18	15	17	15	°C	0 – 8
7	Night-day set point temp. diff. affecting house "MIT2"	17	18	16	18	°C	0 – 8
8	Occupants house "A01-A02"	6	6	6	6	O/hous	1 - 8
9	Occupants affecting house "MIT2" and "MIT1"	19	19	18	19	O/hous	1 – 8
10	Ventilation rate "A01-A02"	7	8	7	8	%	10-60
11	Ventilation rate "MIT1"	25	26	23	26	%	10-60
12	Ventilation rate "MIT2"	26	25	24	23	%	10-60
13	Glazing ratio surface A "MIT1"	21	21	20	21	%	10- 60
14	Glazing ratio surface B "MIT1"	24	24	25	24	%	10 – 60
15	Glazing ratio surface A "A01-A02"	16	17	22	17	%	10 – 60
16	Glazing ratio surface B "A01-A02"	14	16	14	16	%	10 – 60
17	Glazing ratio surface A "MIT2"	20	22	19	22	%	10 –60
18	Glazing ratio surface B "MIT2"	23	23	26	25	%	10 - 60
19	Climatic sensitivity: corr. for horizontal diffuse solar radiation	9	7	9	7	%	20 – 100
20	Climatic sensitivity: corr. for external dry bulb temperature	11	9	11	9	%	50 – 100
21	Climatic sensitivity: corr. for direct normal solar intensity	8	10	8	10	%	20-100
22	Climatic sensitivity: correction for wind speed	22	20	21	20	%	50-100
23	Insulation thickness of external walls affecting all houses	5	5	5	5	mm	5-100
24	All 3 houses building rotation using as axis "MIT1"	15	14	15	14	degrees	0-180
25	Building size: correction for width	1	2	1	2	%	50 – 150
26	Building size: correction for length	3	1	3	1	%	50 – 150

Definitions: **(R1)** Ranking from experiment 5 based in Mu* values, p=40. **(R2)** Experiment 4, Mu* values, r=10. **(R3)** experiment 5, abs(Mu), r=40. **(R4)** experiment 4, abs(Mu), r=10. *All values are expressed in annual heating loads in kWh*

Table.2. Parameters of the experiments for building A and B, their intervals and results of some experiments.

Results of experiments 7 and 8 show clearly that weather conditions didn't affect interactions between the parameters. It's also clear that the parameter of most first-order influence (Setting point temp) is the parameter which most interacts. Insulation and geometrical parameters also has strongly third-upper order interaction effects which are not negligible. Unless the good information second-order interactions gives, an augmentation of r value is needed to make more conclusions about the design of the building since glazing ratio appears in the group of non influential second-order parameters.

CONCLUSIONS

Sensitivity analysis of building energy models with respect to input parameters is crucial, both for comprehension of these models and their practical application to building design and in the search of typologies. Morris method has been tested here for this purpose and demonstrates its usefulness for ranking main input parameters.

The most influencing parameters are geometrical building dimensions (size effect). Then a second group of factors have a major influence on heating loads: thermal characteristics (insulation; ventilation rate), and set-point temperature. Climate characteristics (temperature, solar radiation) and other behavior factors (day-night difference, free heat gains) are a third influencing group of factors.

No parameter can be considered as having a linear influence (standard-deviation of elementary effects are never negligible). The same factors are involved in the second order interaction analysis which pinpoints again the first two groups of influences: size parameters, insulation, ventilation, set-point temperature. High variability of main second-order effects might make suspect non-linearities (insulation thickness, e.g.) or higher-order interactions.

Dividing energy needs by m^2 or m^3 enables to limit the influence of size factors, with magnitude similar to third group, with small average elementary effects but a significant variability. The use of logarithm transformation of the energy needs also drastically increases the differences between each Morris indices of the factors. This increases the definition and could help in better decisions at design level or renovation level.

The present analysis was made with rather big intervals of each factor, in order to enlarge the space of possibilities. Of course, increasing intervals for input parameters increases simultaneously elementary effects and their variability. So local analysis with narrower intervals must be made in the future with specific aims such as optimising design of new buildings, retrofitting of existing ones, designing experimental validation or selecting building typologies.

Morris method is a screening method which provides only a rough analysis of influencing parameters and interactions. Other methods such as variance-based sensitivity indices (VBM) have been proposed [6]. They generally perform better, but the computational cost of VBM doesn't allow to make an extensive study in complex building such as building A (a VBM for 12 parameters requires at least 14,000 runs of the model for a standard analysis). This makes Morris methods (MM1 and MM2) very competitive for the analysis of building energy models.

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HOW IMPORTANT IS THE IMPLEMENTING OF STOCHASTIC AND VARIABLE INTERNAL BOUNDARY CONDITIONS IN DYNAMIC BUILDING SIMULATION?

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ABSTRACT

A comprehensive behavioural model for office buildings that can be coupled to any building simulation software has been developed, based on state-of-the-art empirical submodels from literature. It incorporates 4 aspects of user behaviour, i.e. the stochastic and adaptive nature, the individual variability and the variability amongst different buildings, depending amongst others on the building use. This model allows for simulation of the building's internal boundary conditions in a much more sophisticated manner than is common practice nowadays, i.e. the use of deterministic and constant daily schedules of occupancy and occupant behaviour. The latter comprises the use of lighting, shading device and appliances. In this study, the importance of using such a detailed behavioural model for energy demand simulations is assessed.

Three office building variants consisting of cellular offices are modelled. In a first step, a complete Monte Carlo analysis is performed using the detailed behavioural model. On a yearly basis, this results in standard deviations of about 10% for the net heating demand, 10% to 20% for the net cooling demand and 10% to 15% for the lighting energy use. These uncertainties are much more modest than those calculated in other studies, mainly because the evaluation is done at the building level instead of the room level. The results proved to be quite robust over the different building variants. The use of pre-defined deterministic schedules to represent the internal boundary conditions in building energy demand simulations is compared with the mean results of the Monte Carlo analysis. When several individual offices are lumped into a single thermal zone, the error on the yearly results when monthly schedules based on building specific pre-processing of the detailed behavioural model are applied, is limited to 5%. This indicates that for energy demand calculations the use of monthly 'diversity profiles' yields a satisfactory level of *precision*, although the *accuracy* of the results evidently depends on the selected schedules.

INTRODUCTION

In dynamic building energy simulation, numerous decisions on the modelling resolution need to be made, many of them built-in and thus unconsciously accepted by the average user. This issue is raised when it comes to the internal boundary conditions of the building, i.e. the occupancy and occupant behaviour influencing the building envelope (e.g. window operation or use of shading device) and producing internal heat gains (e.g. metabolism, lighting).

In current building simulation practice, the occupancy and occupant behaviour are commonly simplified to deterministic, constant and lumped schedules, either based on design values combined with engineering judgment, or on 'diversity profiles' [1], deduced from measurements. In reality however, the nature of human behaviour can be described by quoting

[2]: "*The use of controls is clearly influenced by physical conditions, but their use tends to be governed by a stochastic rather than a precise relationship*", to which it could be added that the threshold at which action is taken – or more precisely: at which the probability that action is taken rises – is different for every individual. User behaviour is thus *stochastic*, *adaptive* and *individual*. These last two features can be easily understood by the schematic representation of Figure 2, showing the probability that action is taken as a function of a certain environmental variable. Furthermore, differences exist on a building level too, due to many possible reasons, such as the building function (e.g. university vs. private companies).

Recent research developments in building simulation allow inclusion of some of those detailed aspects of occupancy and occupant behaviour. In [3] the uncertainty on the simulation results induced by integrating a detailed behavioural model [4] into the BES tool ESP-r is studied. Very large standard deviations (over 100%) were found for energy demand calculations, the exact magnitude depending on the building properties. It was concluded from a sensitivity analysis that the necessary resolution of indoor boundary conditions is higher than that currently applied. However, the analysis was done by imposing rather extreme behavioural profiles at room level, which is likely to result in an overestimation of the range of indoor boundary conditions for building energy simulations.

Integration of a detailed behavioural model incorporating the four aforementioned aspects into building simulation (Figure 1a) requires real-time coupling, which is time-consuming and computationally challenging. It is therefore studied in this paper if this high level of resolution is of significant importance in energy demand calculations. This requires assessing the uncertainty due to internal boundary conditions. At the same time, the results are compared with those of an intermediate modelling resolution, where the current practice of using simplified schedules is refined by defining building specific schedules based on pre-processing of the behavioural model (Figure 1b).

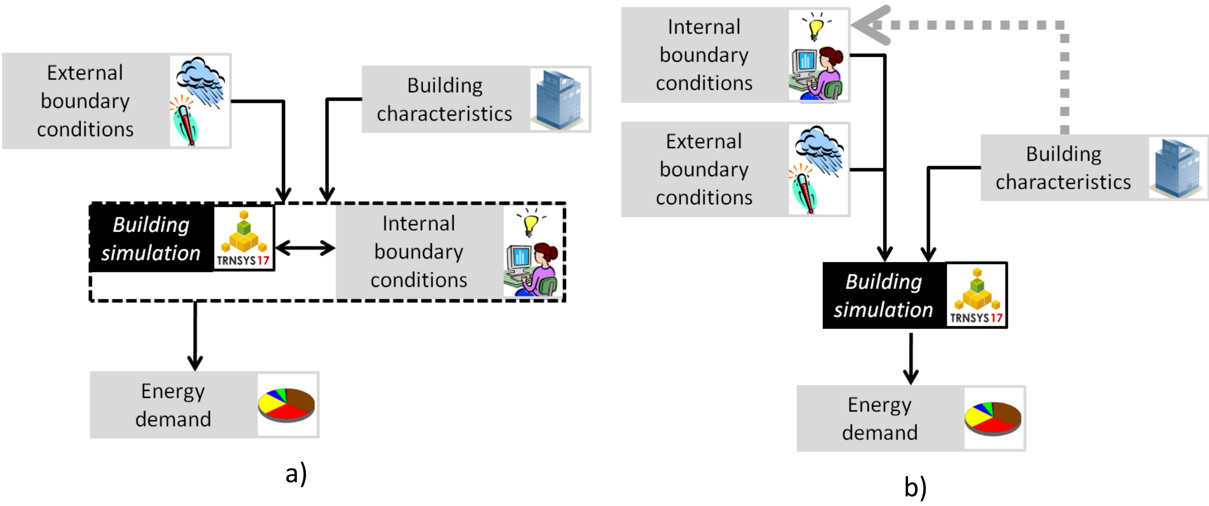

Figure 1: Schematic overview of dynamic building simulation data flow. a) Integration of detailed behavioural model. b) Current practice, refined by defining building specific schedules representing the internal boundary conditions (dotted arrow).

BEHAVIOURAL MODEL

A comprehensive modular model for occupancy, window operation, lighting control, shading control and heat gains by appliances for office buildings, designed to be used in uncertainty analysis of energy calculations was proposed in [5], based on an extensive literature study. All details of the model can be found in [5], here only the essential parts are discussed. The behavioural model is programmed in MATLAB with a 5 minutes time step. Its output is averaged over 1 hour so coupling to the energy simulations is possible.

The core of the model is the occupancy model. It is a Markov chain consisting of three empirical functions [6]: a cumulated probability of first arrival, a probability of intermediate absence and a cumulated probability of departure, all as a function of the time of the day. The cumulated probability of first arrival is multiplied by a parameter of turn-up T and the probability of intermediate absence is multiplied by a parameter of mobility M, which are introduced to account for the variability in building population (Table 2).

The heat gains due to office appliances are assumed to be constant from first arrival until last departure. No stochastic aspect, i.e. noise on the heat gains profile, is thus considered by lack of relevant probabilistic data on ranges, frequencies etc. The magnitude of the sensible gains is sampled from empirical data and is thus an input parameter for the uncertainty analysis (Table 2). After departure, a certain percentage of the appliances heat gains remains. This value is an uncertain input parameter too (Table 2).

The submodels for lighting and shading use incorporate the adaptive and stochastic features by calculating the action probabilities on every time step from the environmental conditions and deciding if action is taken by comparing the probability with a randomly generated number between 0 and 1 (i.e. Markov chain). Driving variables are illuminance levels and the occupancy status. Individual variability is included by defining representative active and passive users (Figure 2) and randomly distributing them over the building zones. Furthermore, the ratio of active over passive users in the building is varied in the uncertainty analysis (Table 2). The latter can be understood as taking into account the variability in building populations.

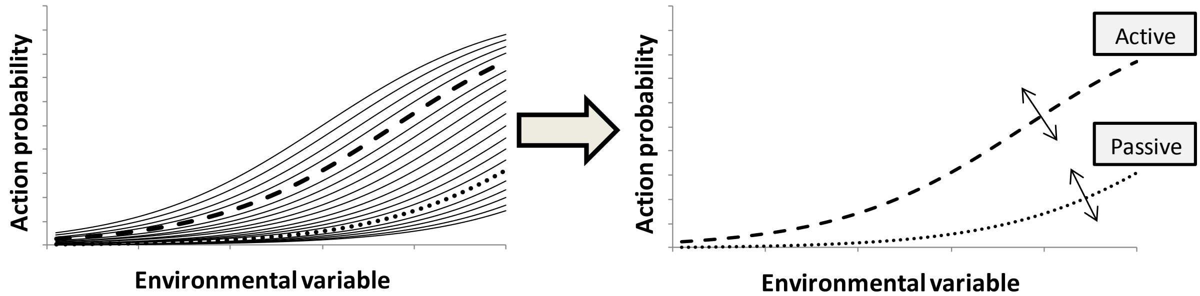

Figure 2: Schematic representation of user behaviour (left) and definition of active and passive users (the arrows indicate the stochastic character) (right).

SIMULATION MODEL AND TOOLS

The basic building model is shown in Figure 3. The dimensions of one room are 4.0 x 2.7 x 3.2 m^3 (L x W x H). Three variants of this building are selected (Table 1). The selection is made to represent a range in influence of the occupant on the energy balance.

The hygienic ventilation rate is 36 m^3/(h·person). Infiltration is assumed constant at 0.1 ach. The heating set point is 20°C, whereas the cooling set point is 25°C. Since active cooling is provided, no window operation is allowed. Heating, cooling and ventilation are operational during the nominal working hours, i.e. from 8 to 18 h. The installed lighting power is 11 W/m^2. The lighting is controlled manually by an on/off switch by the door, extended with automated daylight dimming for variant 2 (Table 1). Either a manually controlled external roller screen or a fixed external horizontal slat system is provided as solar shading device.

The office building is simulated as a multi-zone building in TRNSYS 17 with a one hour time step. The model zoning depends on the resolution of the internal boundary conditions modelling and is discussed further on. Dynamic daylight simulations are performed with Daysim. Simulations are done for a typical weather data set of Uccle, Belgium.

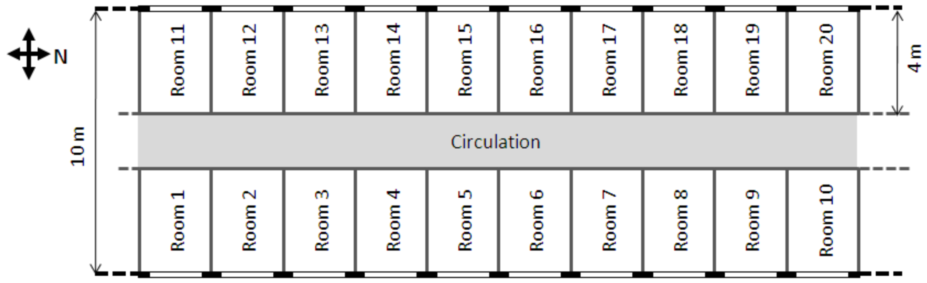

Figure 3: Model of office building.

	U_{opaque} [W/m²K]	glass% [%]	$U_{glazing}$ [W/m²K]	g-value [-]	τ_{vis} [-]	shading device	lighting control
1	0.4	43	1.1	0.59	0.77	manual ext. screen	manual on/off
2	0.2	21	0.6	0.48	0.72	manual ext. screen	manual on/off
3	0.4	43	1.1	0.59	0.77	fixed ext. slats	daylight dimming

Table 1: Selected building variants.

METHODOLOGY

In a first step, a complete uncertainty analysis is executed, coupling the detailed behavioural model as explained above to TRNSYS17, according to the integrated approach of the scheme of Figure 1a. A Monte Carlo analysis with 100 runs is performed. All inputs (Table 2) are assumed to be normally distributed. Each individual office of the building is modelled as a separate zone in the thermal multi-zone model, to allow for the individual variability to play its role.

Input parameter	Average	Standard deviation
Mobility [-]	0.4	0.12
Turn-up [-]	0.7	0.08
Level of internal heat gains [W/m²]	8.8	1
Remaining gains after departure [%]	35	10
Ratio of passive users of lights [%]	25	10
Ratio of passive users of blinds [%]	50	20

Table 2: Average value and standard deviation of the input parameters of the Monte Carlo analysis (from [5]*).*

Subsequently, averaged and deterministic behavioural schedules are defined (Figure 1b). The schedules used in this study are derived from the detailed behavioural model – using the average inputs of Table 2 -, by averaging daily profiles on a yearly or monthly basis (Figure 4). These schedules can be considered to be a type of ‘diversity profiles’, albeit building specific. Modelling each office as a separate zone is now no longer necessary. The building model is simplified to a 3-zone model (2 office zones and 1 circulation zone).

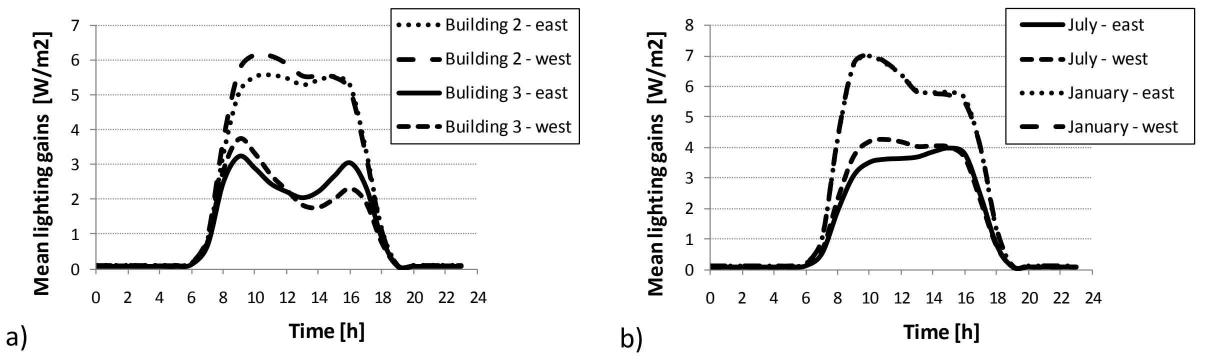

Figure 4: Illustrative building specific schedules. a) Yearly averaged lighting use profiles of building variants 2 and 3. b) Monthly averaged lighting use profiles of building variant 1.

RESULTS

The monthly standard deviations resulting from the complete Monte Carlo analysis for heating and cooling demand are modest (<15%) during winter and summer months respectively. In intermediate seasons, the relative uncertainty on heating and cooling demands becomes very large. On a yearly basis, the standard deviation of heating demand is about 10%, while for cooling demand it is between 10% and 20%. The standard deviation of the monthly lighting energy use, shown in Figure 5a, is between 10% and 20%, whereas this is between 10% and 15% on a yearly basis.

Although the absolute cooling and heating demands and lighting energy use differ substantially among the 3 building variants, the relative standard deviations are comparable. This indicates that these results may be generalized to other office building designs consisting mainly of individual offices. Since individual control options are fewer in landscape offices, it can be expected that the uncertainty range will not be larger.

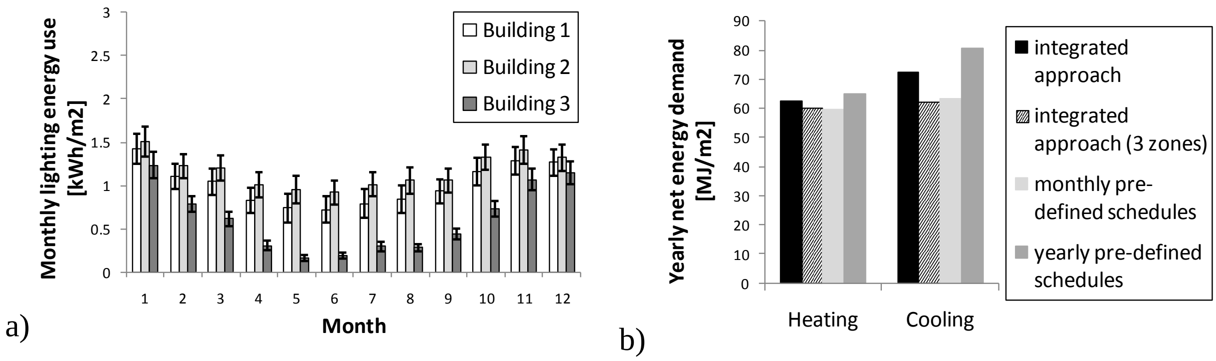

Figure 5: a) Results of the complete Monte Carlo analysis: average value and standard deviation of the monthly lighting energy use. b) Comparison of average results of MCA with integrated approach and results of approach with building specific pre-defined schedules.

The yearly average results of the Monte Carlo analysis using the integrated approach (Figure 1a) with a multi-zone and a 3-zone thermal model are compared with the results using pre-defined building specific behavioural schedules (Figure 1b) for the heating and cooling demands of building 1 in Figure 5b. Analogue trends are found for the other 2 building types. Comparing the first 2 data series, the zoning resolution of the thermal model shows to have a substantial influence of up to 20%. Comparing the 2^{nd} data series with the 3^{rd} and 4^{th}, the error induced by using deterministic pre-defined profiles compared to integrating the detailed behavioural model in a 3-zone thermal model is found to be limited to 30% using yearly schedules and 5% using monthly schedules. It must be emphasized that the deterministic profiles are derived from the detailed behavioural model and are thus building specific.

DISCUSSION

The necessary resolution of modelling internal boundary conditions (i.e. occupancy and occupant behaviour) in building simulation has been studied. The study has been performed for 3 office buildings consisting of individual offices, since behavioural research has been restricted to this type for non-residential buildings.

A Monte Carlo analysis assessing the uncertainty on the building energy demand for heating and cooling and the lighting energy use due to the internal boundary conditions yielded rather modest results. A maximum standard deviation of 20% on a yearly basis was found for cooling demand, while this was 10% for heating demand and 15% for lighting energy use.

The use of pre-defined deterministic schedules to represent the internal boundary conditions in building energy demand simulations is compared with the mean results of the Monte Carlo analysis. When several individual offices are lumped into a single thermal zone – thus decreasing the resolution of the thermal model to a common practice level -, the error on the yearly results when monthly schedules based on building specific pre-processing of the detailed behavioural model are applied, is limited to 5%. This indicates that for energy demand calculations the use of monthly 'diversity profiles' yields a satisfactory level of *precision*, although the *accuracy* of the results evidently depends on the selected schedules. The latter might be derived from measurement data or averaged from detailed hourly behavioural profiles (e.g. with the model of [5]).

In future work, analogue evaluations will be executed for building simulations assessing summer comfort and heating and cooling end energy consumption.

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ASSESSMENT OF MODELING APPROACHES FOR LOUVER SHADING DEVICES IN OFFICE BUILDINGS

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ABSTRACT

The presented paper focuses on the performance of exterior shading devices made of louvers. The analysis of the performance of these devices differs substantially from more traditional screens as their performance not only depends on the solar properties of the used materials but also on the position of the sun with respect to the louvers. In order to capture this complexity, models predicting the solar transmittance of louver shading devices have to be integrated into building energy simulation tools. A ray tracing method has been developed to describe the global solar transmittance of louver shading devices. Consecutively, this method is integrated in the dynamic building energy simulation program TRNSYS to assess the cooling demand and required cooling power in a south oriented office cell. The proposed integrated approach allows calculating the solar transmittance for each time step. The method however is also quite complex and requires an important computational effort. Therefore this research contrasts the results of this ray tracing method against the performance of other modelling approaches to assess the performance of louver shading devices in dynamic building energy simulation programs. It is shown that representing the shading device as a fixed reduction factor, independent of orientation, is an important simplification and is insufficient to incorporate the complexity of the performance and control of exterior louver systems. Deviations up to 102% were found for the cooling demand and up to 72% for the cooling power. The use of view factor models typically underestimate the cooling demand by up to 36% and the cooling power by up to 26%. The use of a simplified implementation of shading factors, however, is possible within acceptable margins if the results of a ray tracing calculation are implemented in a building energy simulation tool. Implementing the results of a ray tracing calculation of one representative average or sunny day reduces the deviations to 14% for the cooling demand and 18% for the cooling power. Performing additional ray tracing calculations for typical heating or cooling conditions or for every month further reduce the deviations to the order of 10% to 5% for the cooling demand and power respectively.

INTRODUCTION

Exterior shading devices are very well suited to provide good protection against excessive solar radiation. The need for this protection, however, depends on the actual energy demand of the building. When heating is required, the shading device should be retracted or allow a maximum of transmitted solar radiation. If cooling prevails, an efficient protection is required while allowing daylight inside the building. In order to capture this complexity, models predicting the solar transmittance of louver shading devices have to be integrated into building energy simulation tools (BES). Typically only simplified approaches are available for integrating shading devices in BES-tools. For all shading devices, solar properties depend amongst others on the position of the sun. While most BES-tools can include angle dependent solar properties for glazings and solar screens, this is often not the case for shading devices with fixed elements such as louvers. Here, more advanced modelling techniques are required.

In this work a ray tracing (RT) method has been developed to calculate the instantaneous solar transmittance of louver shading devices. This RT-method was integrated in the dynamic building energy simulation program TRNSYS to assess the cooling demand and required cooling power in an office cell. The RT-method is quite complex and requires an important computational effort. Therefore this research contrasts the results of this ray tracing method against the results of simplified implementations and other modelling approaches to assess the performance of fixed louver shading devices. The results are compared with simple implementations as can be typically found in less complex energy assessment tools based upon EN ISO 13790. In particular, the proposed method is compared with the implementation of the Flemish Energy Performance Regulation (EPR) [1].

METHODOLOGY

Shading device models

The solar radiation transmitted through vertical louver systems consists of two parts: direct solar transmittance (direct and reflected short-wave radiation) and secondary heat transfer (long-wave radiation, convection and conduction). In this work we will focus on the first part as it dominates the solar transmission of shading devices in buildings that have insulating glazing units. Two models are used to calculate this solar transmittance: (1) The first model uses a forward ray tracing method based on the work of Roofthooft [2]. This model calculates the net transmitted direct and diffuse fraction accounting for specular and diffuse reflection on the louvers. (2) The second model uses a view factor method (VF) similar as used in Safer [3] where the transmitted fraction of the direct solar radiation is calculated as the glazing area that is not shaded multiplied by the impinging direct solar radiation. The shaded fraction is determined by a geometrical calculation of the shading pattern on the window based on the position of the sun. The diffuse solar fraction is calculated as the amount of the sky that can be seen by the window multiplied by the incoming diffuse solar radiation. As this method does not take into account multiple diffuse or specular reflections it generally underestimates the transmitted solar radiation. The results are expressed as a Shading Factor (SF) which is defined as one minus the ratio of the net transmitted solar radiation on the receiver over the total incident solar radiation. Although the ratios for direct and diffuse radiation are calculated separately, it is chosen to express SF as a combination of both ratios as this suffices for the used BES-tool (see further).

In this paper an elliptic curved louver shading device is calculated (diffuse reflectance = 0.643, direct reflectance = 0.689). The louver width is 0.2 m, thickness is 0.04 m, louvers are separated 0.2 m from each other. The distance between the shading device and the outer glazing surface is 0.09 m. The results are calculated for two louver positions: one horizontal position (0 deg) and a louver inclination of 30 degrees compared against the horizontal position (30 deg).

Building simulation model

A thermal model of a typical office cell (H x W x L = 2.8 m x 2.7 m x 4.0 m) with south-facing façade (glazed area is 2.43 m²) has been implemented in the dynamical simulation program TRNSYS 16.1 [4]. The opaque parts of the façade have a U-value of 0.56 W/(m²K). The window consists of an insulating glazing (85%, U-value equals 1.21 W/(m²K), g-value equals 0.625) and a frame (15%, U-value equals 2.00 W/(m²K)). The "multi-zone building", TYPE 56 of TRNSYS is used to model the energy demand of the office zone. Simulations are done for a typical moderate Belgian climate. The hygienic ventilation rate equals 22 m^3/h per occupant (IDA 3 according to EN 13779) and is provided by a balanced mechanical ventilation system. The air supply temperature is 16°C throughout the year. The ventilation system as well as the heating and cooling system operate during office hours from 08:00 a.m. till 06:00 p.m. on workdays (from Monday till Friday). Set points for heating and cooling are 21 °C en 23 °C respectively. The internal heat gains for appliances and lighting are estimated at 260 W per occupant. The cooling demand and power are expressed as the net sensible cooling demand calculated for the considered office. It does not include the energy needed to condition the ventilation air.

In order to implement the solar properties of the shading device into the building simulation model, the previously defined SF is used. The SF reduces the solar radiation impinging on the window. In such a way, only the reduction due to a lower transmitted solar radiation is considered and indirect solar gains by the heating of the shading device are not accounted for. However the effect is estimated to be small for current highly insulating glazings. Different methods were used to implement the SF in the simulations.

(1) A first method uses the hourly values that are calculated with the above described RT-model and VF-model. This method takes into account the full variation of the transmission of solar radiation due to the changing solar position. The RT-model combined with the use of hourly SFs will be further referred to as reference results. (2) A second method uses a fixed SF for the entire simulation. Distinction is made between different approaches to obtain this fixed value. A first approach is to use a default value. In this paper the results are compared against a fixed SF of 0.50 as proposed by the Flemish EPR [1]. The following approaches use a yearly average of the SF as calculated with the RT-model. Both a simple arithmetic average (second approach) and a weighted average (third approach) are implemented. Weighting factor for the latter is the incoming solar radiation. Using a fixed value treats the heating and cooling season in the same way. As a result some important physical phenomena are disregarded: during heating season solar positions are low resulting in lower than average SFs. Using an average SF hence overestimates both the heating demand and the cooling demand. (3) Therefore, the third method makes distinction between the heating and cooling season. For both seasons an average and weighted average value is calculated. (4) The fourth method calculates an average and weighted average for each month. As most simplified energy calculation methods, such as the Flemish EPR, use a month as time-step, this represents the most accurate approach available for such methods.

In the above, the SF is determined for each hour of the year. As the hourly calculations and especially the RT- calculations require quite some computation time, it is further examined what the influence is of simulating only a limited number of days to determine the SF. The following approaches were used to specify these days: (1) an overcast day in midseason in an attempt to simulate the most average situation, (2) the sunniest day in winter and summer in an attempt to have the right characteristics when it matters most, and (3) the sunniest day of each month.

DISCUSSION

Figure 1 compares the results of the different methods and approaches to calculate the SFs based on the full set of calculations. It is shown that on average the louver inclination of 30 degrees offers 12% (VF-method) or 21% (RT-model) more protection than the horizontal position. Also the method used to calculate the SF shows similar ranges of variation: the VF-method predicts a 23% better protection than the RF method for horizontal louvers. For an inclination of 30 degrees this is 14%. The evaluated method to calculate the SF hence introduces errors of the same magnitude as the influence of the inclination angle. As a logical result of the lower solar position during winter, the SFs are higher than average for the cooling season and lower than average for the heating season. The results however depend on the inclination angle: the deviations are more pronounced for the horizontal louvers than for the louvers with a 30 degree inclination. Focussing on the differences between the averages calculated as arithmetic mean versus the solar radiation weighted averages reveals that the differences are smaller than 4%. Focussing on the influence of simulating only a limited number of days to determine the SF, Figure 2 shows for all three approaches the average (arithmetic mean) and solar radiation weighted average SF. Compared against the averages based on the full hourly values (see Figure 1), the difference are typically smaller than 5% if the corresponding values are compared. This suggests that the full hourly calculations of the SF may be replaced by calculations of a set of typical days.

Figure 3a shows the results for the annual cooling demand of the office. It is clear that using a fixed value (SF = 0.5) overestimates the cooling demand regardless of the louver inclination. Compared against the reference results, the annual cooling demand is overestimated with 53% (0 degrees) and 102% (30 degrees). Also the effect of the inclination angle is clearly visible. For the reference results, the louver shading with an inclination of 0 degrees yields a cooling demand that is 32% higher than that with an inclination of 30 degrees. Comparing the VF-model results against these of the RT-model shows that the former underestimates the cooling demand. As a result of not taking into account reflections, the cooling demand is underestimated by 33% (0 degrees) and 28% (30 degrees) compared against the RT-model.

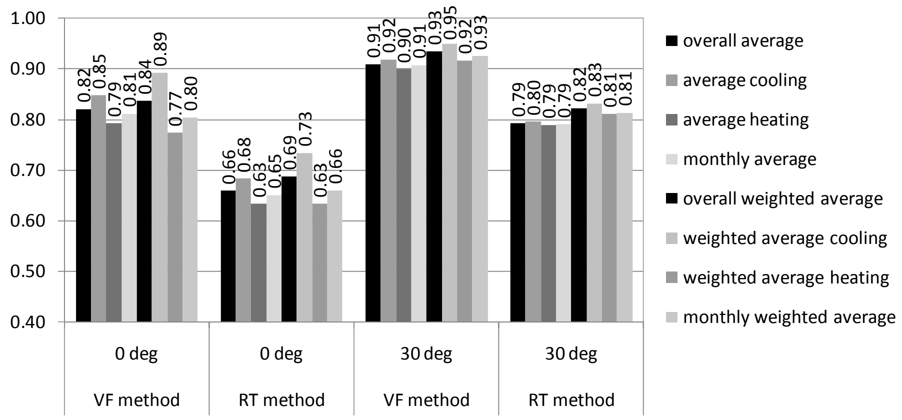


Figure 1: Yearly averages of the shading factor as a function of the calculation method and slat angle position, based on the full hourly set of SF calculations.

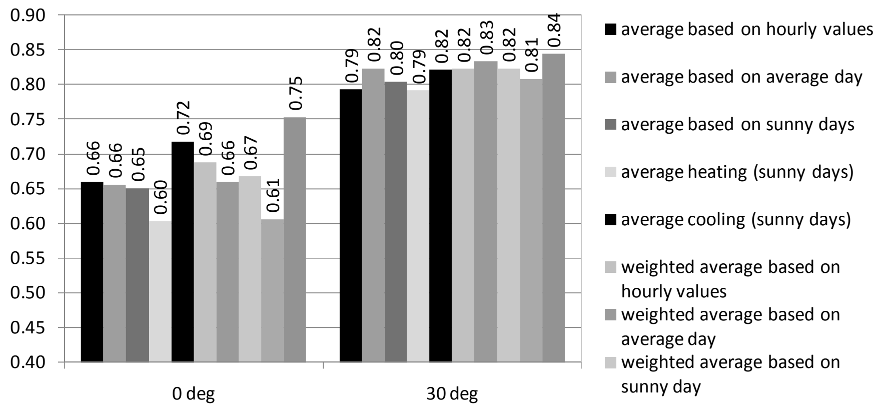


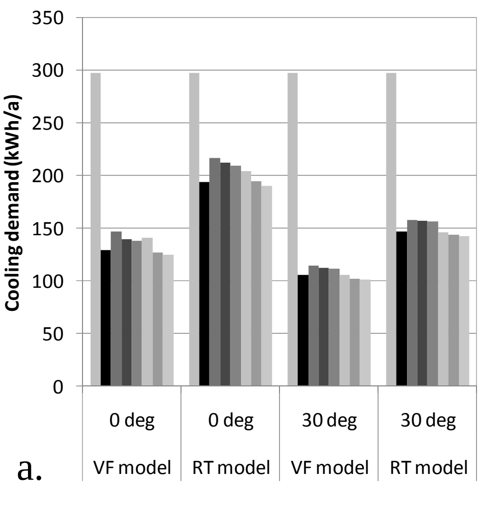
Figure 2: Yearly averages of the shading factor as a function of the calculation method and slat angle position based on specific days.

Focussing on the different methods to implement the SF into the BES-tool shows that, apart from the cooling demand calculated with the fixed EPR value, all results have a relative small deviation from the reference results for a given inclination. The deviation is smaller than 12% for an inclination of 0 degrees and smaller than 8% for the inclination of 30 degrees. Implementing the yearly average SF factor gives the highest deviations: an overestimation of the cooling demand with 12% (0 degrees) and 8% (30 degrees), indicating that the SF is underestimated during cooling season. Using a different average for heating and cooling season partly corrects this problem: the overestimation of the cooling demand is reduced to 9% (0 degrees) and 7% (30 degrees). Further refining the averaging period to one month reduces the deviations to 8% (0 degrees) and 6% (30 degrees).

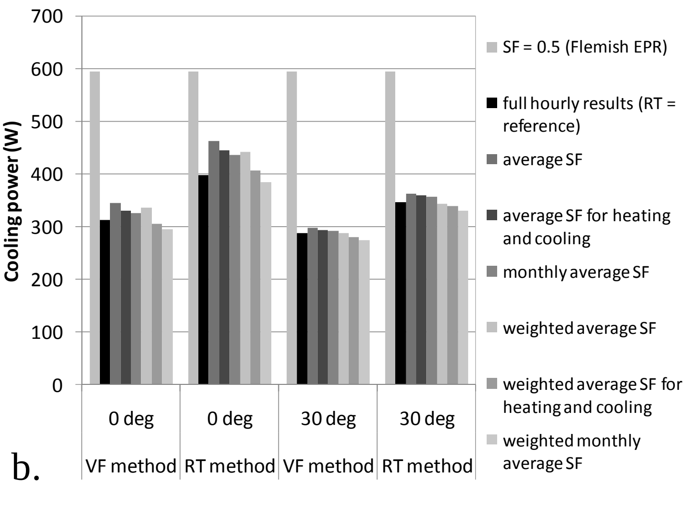
Using the arithmetic mean as the average has the disadvantage that all hourly SFs have the same weight. By calculating the solar radiation weighted average, SFs that are more relevant receive more weight. Implementing a weighted average SF factor results in an overestimation of the cooling demand with 5% (0 degrees) and an underestimation of 8% in case of an inclination of 30 degrees. Further refinement of the averaging period to heating and cooling season or months reduces the deviations to less than 3%.

Figure 3b shows comparable results for the maximum cooling power. The fixed EPR value (SF = 0.5) largely overestimates the cooling power with respectively 49% and 72% for an inclination of 0 and 30 degrees. The different methods to implement the SF into the BES-tool show a somewhat higher maximum deviation (16%) from the reference results in case of an inclination of 0 degrees but somewhat lower (5%) in case of an inclination of 30 degrees. As for the cooling demand, the VF-model underestimates the cooling power by up to 26% (0 degrees) and 21% (30 degrees) compared against the reference results of the RT-model.

Figure 4a compares the results for the annual cooling demand of the office in case of SFs determined based on daily sets of the RT-calculations with the full hourly reference results. The SF calculations based on the average day (average or sunny day) show the largest deviations for both cooling power and demand. The weighted averages perform better than the arithmetic averages. It is further shown that the results depend on the inclination angle of the louvers. Although the average SFs only show small differences (Figure 2), especially the cooling power and demand of the horizontal louvers has a more important variation. The cooling power has a deviation up to 18% and the cooling demand 14% compared against the full hourly reference results. For the inclination of 30 degrees this is 4% and 5% respectively.



a.



b.

Figure 3: Annual cooling demand (a) and cooling power (b) as a function of the SF calculation model and slat inclination. Results based on full set of hourly SF calculations.

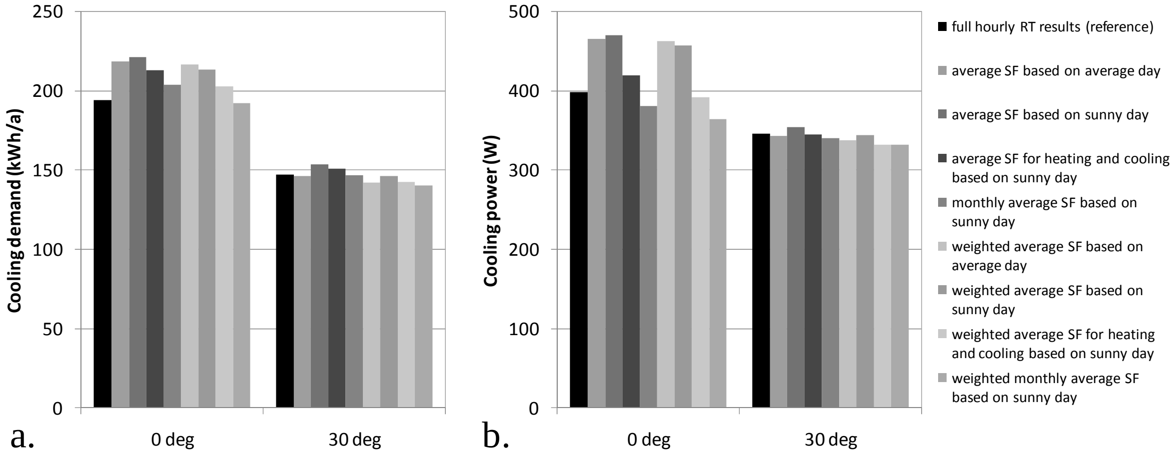


Figure 4: Annual cooling demand (a) and cooling power (b) as a function of the SF calculation model and slat inclination. Results based on daily set(s) of hourly SF calculations.

CONCLUSIONS

The presented paper assesses the influence of different models and approaches to simulate the performance of exterior louver shading devices on the cooling demand and power of a south oriented office cell. As a reference a full hourly forward ray tracing method is used. It is shown that representing the shading device as a fixed reduction factor, independent of orientation, is an important simplification and is insufficient to incorporate the complexity of the shading performance of exterior louver systems. Deviations up to 102% were found for the cooling demand and up to 72% for the cooling power. Also the use of view factor models cannot be defended as they underestimate the cooling demand by up to 36% and the cooling power by up to 26%. The use of a simplified implementation of SFs, however, is possible within acceptable margins if the results of a ray tracing calculation are implemented in a building energy simulation tool. Implementing the results of a ray tracing calculation of one representative average or sunny day reduces the deviations to 14% for the cooling demand and 18% for the cooling power. Performing additional ray tracing calculations for typical heating or cooling conditions or for every month further reduce the deviations to the order of 10% to 5% for the cooling demand and power respectively.

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STOCHASTIC ACTIVITY MODELING IN RESIDENTIAL BUILDINGS

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ABSTRACT

In this paper we present a method to simulate residential building occupants' activities, which can be used directly to predict occupants' presence and as an input to models of occupants' behaviour, to produce more coherent and accurate predictions of buildings' energy demands for heating, ventilating and air-conditioning as well as for lighting and electrical appliances. First we describe a stochastic model of the activity chains of residential building occupants and the calibration of this model using French time-use survey data (for the period 1998/1999). This model is based on three time-dependent quantities: (i) the probability to be at home, (ii) the conditional probability to start an activity whilst being at home, and (iii) the probability distribution function for the duration of that activity. We then present first results from the validation of this model based on the aggregated time use survey dataset as well as for disaggregations of the survey population; the objective here being to enable predictions of specific segments of a given population.

INTRODUCTION

Some of the activities of residential building occupants have a direct bearing on the behaviours of interest to the building simulation community: the use of lights and appliances (both water and electrical) as well as of windows and shading devices [1]. A robust way of handling this complexity is to model occupant' activities based on measured time-use survey (TUS) data.

In the next section of this article we present one such modeling methodology and give an overview of the data we use to calibrate the models used. Then, we present some initial simulation results and associated validation tests, based on comparing simulated outcomes with survey responses, for both the aggregate dataset and for disaggregatations of the survey population. We conclude with an outlook regarding future work to further refine this preliminary model.

METHOD

TIME USE SURVEY DATA

In order to calibrate our model, we use the data of a French time-use survey (TUS) that was conducted from February 1998 to February 1999 by the French National Institute of Statistics and Economic Studies. This information is included in electronic format in a data base containing the TUS data of many different countries [2]. The survey contains the information of 12000 households and over 15000 individuals. The respondents completed questionnaires (resolution 10 min) describing the chronological course of events of the activities (out of a list containing 41 different categories, see the legend of Fig. 2 for those of most interest to residential buildings) they performed during one particular calendar day starting and ending at midnight. Additional information that was recorded contains the date of the recording, the gender, the age, a household ID and the information in which type of place the person is present (at home, workplace, school, etc.).

The day the data was recorded is relatively uniformly distributed, ranging from 10.5 % for Mondays to 16.9 % on Thursdays. The months are also relatively uniformly covered, ranging from 7.6 to 11.0 %, apart from March, August and December which lie between 4.1 and 5.6 %. 47 % of the respondents are male. 24.6 % are retired.

In Fig. 1 we show a summary of median durations of residential activities of the TUS as a function of the hour of the day when they were started, indicated by the height of each single-colored area. The scarcity of events during the night time amplifies the weight of erroneous recordings in the data base leading to

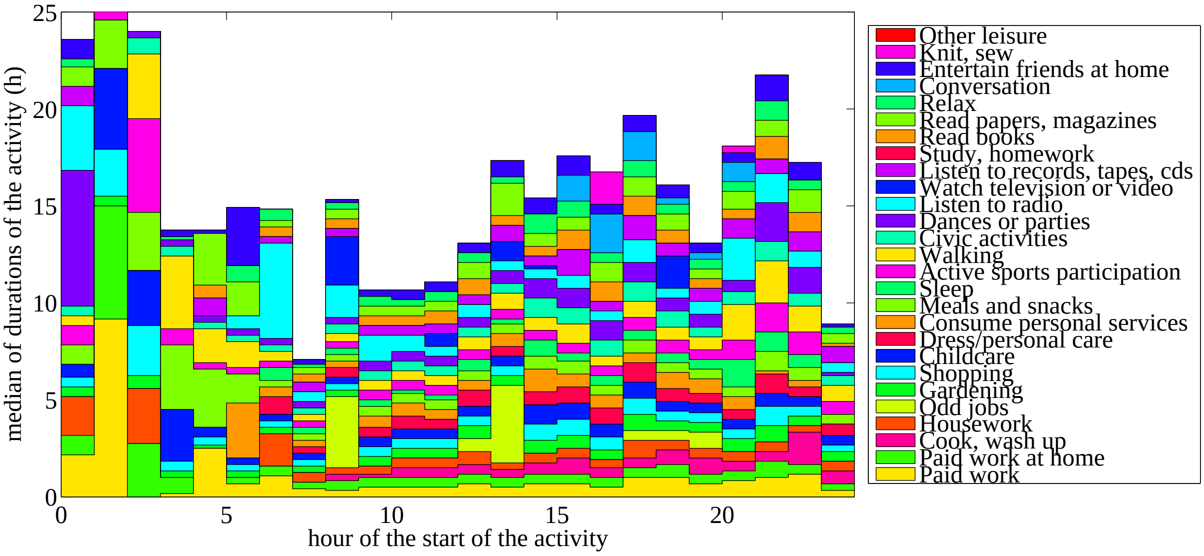

Figure 1: (color on-line) Stacked medians of the durations of residential activities of the TUS that were started during the hour interval given on the x-axis. Activities which are in average performed less than 0.1 % of the day are not shown. The y-axis is bounded to a maximal value of 25 h.

a much longer mean duration during the night time (we assume that the activity type in the data base has sometimes been mistaken for another one in the data base; during the night time this likely leads to a replacement of sleeping by another activity, which increases the mean duration of the other activity substantially). Therefore, we do not show the whole range of activities between 12 am and 6 am, to focus on the rest of the day which is more reliable. At the end of the day the means decrease because of the censoring of the questionnaires which stop recording after midnight.

METHODOLOGY

The basic quantity we are interested in is the probability to perform an activity j depending on the time t, which we will denote by $p_j(t)$. We apply a stochastic approach to model individuals'activity chains throughout their day. In our model, we use two basic quantities which describe whether a certain activity is performed whilst someone is at home. First, we consider the time-dependent conditional probabilities $p_{\mathrm{s},j}(t)$ to start a certain activity j whilst being at home, and second, the corresponding probability distribution functions (PDFs) $f_j(t)$ of the duration the activity j lasts. When the duration is drawn from the continuous PDF in the simulation, the value is rounded to the 10 min resolution of the simulation afterwards. To assign residential activities to an individual, we need to know whether that person is at home. Although the latter is to be modeled stochastically, we use the recorded occupancy data of the TUS in order to evaluate the performance of the activity model itself as a post-process of an occupancy model. In this approach, there are censored events at the beginning and the end of the calendar day of the questionnaire as well as when an individual leaves his residence. This is modeled in the simulation by forcing an activity to end as soon as the individual leaves his/her residence.

In general, the mentioned stochastic quantities can be strongly dependent on the time of the day. However, because some activities occur very rarely in the TUS during a certain period of time, there might not be enough data to calibrate a model meaningfully with a high time resolution. We have thus derived the conditional probability to start an activity j whilst being at home $p_{\mathrm{s},j}(t)$ at an hourly resolution from the according frequency distributions of the data. To get smooth results in the simulations we have defined the starting probability $p_{\mathrm{s},j}(t)$ to be equal to the linear interpolation of these values for the different time steps.The measured hourly values as well as the time values regarding the 10 min time step of the simulations are set to the center of the corresponding time intervals. However, at the end / the beginning of the day we have kept the derived value of the whole hour interval for the last / first three time steps afterwards and we did not interpolate with the values of the next / previous day, due to inconsistencies in the TUS, which will be described in more detail later. The PDF of activity durations has also been derived based

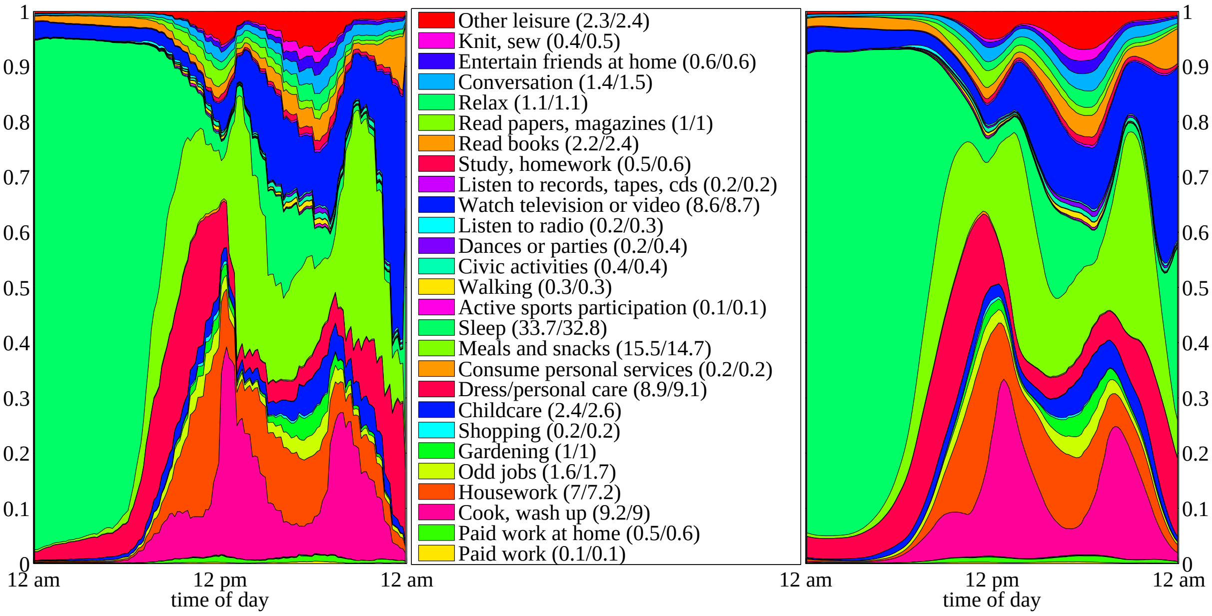

Figure 2: (color on-line) Activity profiles whilst being at home. On the y-axis the cumulative frequency distribution is shown. Left: Time use survey. Right: Simulated. The two values in parentheses show the overall percentage (rounded to one decimal place) that the corresponding activity has been performed throughout the whole day (in the TUS / in the simulation). Activities with mean percentages smaller than 0.1 % are not shown in the legend.

on the activities started at each hour interval. However, representing the PDF by the measured frequency distribution of the TUS implies the need of many input parameter values for the simulation program. Furthermore, there is very often a bias in the questionnaire as humans are not perfectly precise when recording the times of their activity chains. This implies that the rounded values (30 min time steps) occur more often, which is very unlikely to best reflect reality in general. Therefore, we have fitted the measured duration PDFs (of all occurrences in one hour time intervals) by Weibull distributions using maximum likelihood estimation. In this way we estimate the values and the confidence intervals of the two parameters determining the scale and the shape of the Weibull distribution. To determine whether these theoretical distributions differ in successive time intervals for a given activity j, we have performed a two sample z test checking whether the two values are significantly different. If they are not, the same has been done for all pairs of the set which also includes the parameters of the subsequent time interval. This procedure has been repeated, as long as we did not find at least one pair where the value of at least one of the scale / shape parameter was significantly different. Afterwards, we have again fitted the Weibull distributions based on all the occurrences which fall into these eventually extended time intervals. This procedure prevents the PDFs $f_j(t)$ from a non-assignment in intervals around t where there is no start of the activity j in the TUS data. The drawback of this procedure is that in case of a rare event where the average duration varies substantially in subsequent time periods but where no events where recorded in some hour intervals of the TUS, this can lead to a uniform PDF in all those time intervals. However, this is rather an error related to data scarcity than to a mis-specification of the methodology.

When evaluating the specifics of the sleeping activity there is one particularity in the French TUS: More than 98 % of all the events when this activity has been begun in the time interval between 11 pm and midnight fall on the last 10 min, which is clearly an artifact of the survey method. Either it could be due to an imprecision or misunderstanding when the questionnaires were filled out or to the uncommon character of the day such a questionnaire was completed. This information was of use to deduce a realistic way of modeling sleeping - the most time-consuming residential activity. The problem when one wants to fit a Weibull distribution is that most of the sleeping events at night are censored (because they start before midnight), thus yielding a very poor fit. Thus, we have considered the sleeping events after midnight as not being censored yielding a realistic mean of over 7 hours. We have also checked

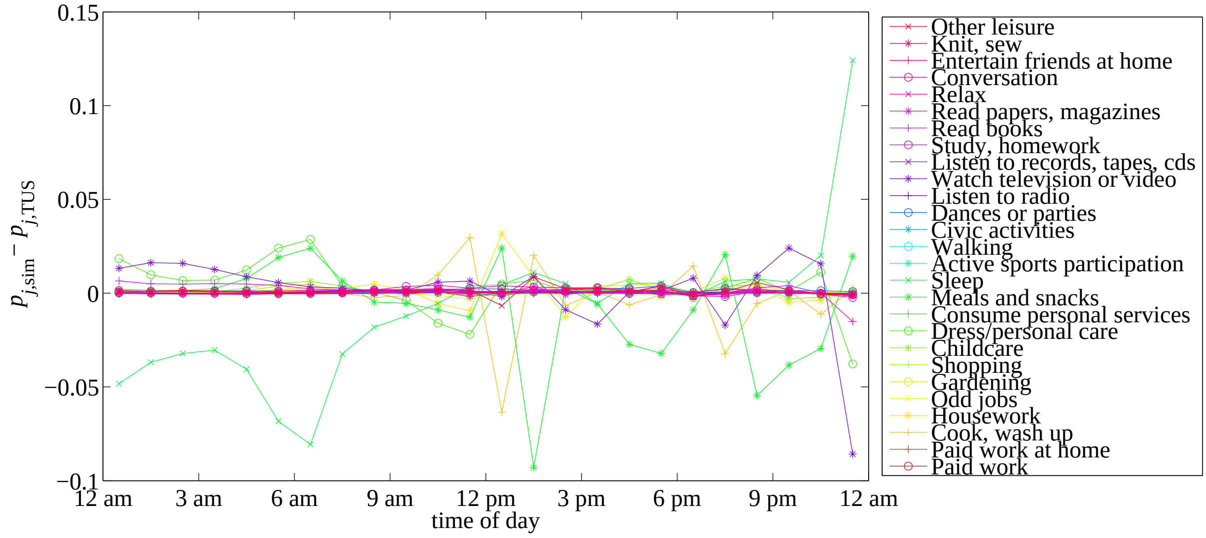

Figure 3: (color on-line) Differences of the shares of different activities of the simulation results $p_{j,\mathrm{sim}}$ and the TUS $p_{j,\mathrm{TUS}}$ on an hourly aggregated basis. The lines are drawn to guide the eyes.

for the non-zero percentage of sleeping events before midnight being censored in all hourly intervals, yielding 98 %, 40 %, 25 % and 7 % for the last, the second, the third and the fourth last hour interval, respectively. In the simulation, this leads to the peculiarity that as soon as the activity sleeping starts we choose a long sleep duration from the last mentioned distribution with a probability being equal to the above-mentioned ratio of censored events in the corresponding interval.

When one wants to predict activity chains of individuals, the dependence of peoples' behavior on, *e.g.*, the individuals' characteristics or the weekday is of great interest. However, the calibration of a model of residential activity chains for sub-populations is problematic due to the scarcity of events as the sample size decreases. Regarding the fitting of the empirical frequency distributions of durations with Weibull PDFs, this can lead to a substantial decrease of the quality of the predictions. Therefore, we derive the Weibull fits of the activity durations of the sub-populations in the same manner as explained above. However, as soon as both of the fitted Weibull parameters are not significantly different from those of the entire sample population (according to the two-sample z-test; see above), we take the two values of the latter. In this way we prevent the simulations to be based on a set of events which is less representative of human behavior in general than the set of the whole sample, taking into account that the predictions are based on a sample which also includes individuals who are not in the corresponding sub-population.

RESULTS

We present a comparison of the activity profiles of the simulation and the data that has been measured in the TUS in Fig. 2. The simulation results have been generated by taking the average values of 100 simulation runs. These profiles show the shares of the different activities that are performed when the individuals are at home. On the left-hand side the measured data is shown and on the right there are the results of the simulations. The measured profiles of many activities show the peaks at the hours and the half-hours due to the rounding of the respondents which was mentioned in the previous section. Moreover, the previously mentioned strong increase of sleeping is visible at 11.50 pm. In the parentheses of the legend we show the mean percentages for which the corresponding activity occurred throughout the whole day, rounded to one decimal place.

The differences of the shares of different activities of the simulation results $p_{j,\mathrm{sim}}$ and the TUS $p_{j,\mathrm{TUS}}$ on an hourly aggregated basis (in this way the rounding artifacts in the time specifications are leveled out) are shown in Fig. 3. The largest difference of 10.5 % occurs for sleeping in the last time interval. However, this is due to the fact that the probability to start an activity has been derived on an hourly basis, whereas in the TUS strong increases during the last 10 min of the day (cf. Fig. 2). This increase has a strong weight when the starting probability is derived and thus the model overestimates the percentage of sleeping people in this interval. Furthermore, the number of people who are sleeping during the night is underestimated by the simulations. This is due to the fact that the simulation duration is set to 24 h, implying that the individuals who began their sleep before midnight are not accounted for in the simulation (an easily resolved artifact of this particular simulation). There are also quite large underestimations of the share of people having meals and snacks between 1 and 2 pm of 8.6 % and up to 5.8 % in the evening hours. We still have to study in detail for which reasons these aberrations occur. The activity "watching TV" is highly underestimated by the simulations (-8.1 %) during the last hour interval of the day. This underestimation is caused by the overestimation of sleeping in this interval, which suppresses the likelihood of performing other activities, as it can also be observed in the underestimation of the activities Dress/Personal care or Read books within this interval. Furthermore, this is also observable in the first time intervals of the night, where the lack of the proportion of people who started sleeping before midnight (because of the simulation duration which was set to 24 h and starting at midnight) amplifies the occurrence of other activities.

We present an evaluation of the performance of prediction of different versions of algorithms in Table 1. These algorithms have been tested for different disaggregations of the sample population. The criterion according to which the disaggregation was chosen is shown in the first column. The different criteria in these lines specify whether the respondent was retired, living in an urban area or belonging to a specific income class. These sub-populations were then simulated as is described above. The results of the whole sample population were then evaluated. These values are shown for three different types, corresponding to three different ways how we have calibrated the PDFs of the algorithm: (i) when the Weibull parameter values of the sub-populations are not tested for significant difference to the ones of the whole sample, (ii) the case where the PDF is derived independently of the starting time, and (iii) when the Weibull parameter values are derived as described in the previous section (having a time-dependent PDF which is afterwards tested for significant difference to the corresponding PDF of the whole sample population and if necessary replaced).

On the left-hand side of Table 1 we show the overall share of the time steps where the activity is correctly predicted for the individual activity chains. The best performing is the one where the Weibull distribution are not tested for statistical significance to the ones of the entire sample population. There, the best result is obtained for the disaggregation according to different income classes. This is probably due to the fact that in this case there is the largest number of different categories and thus, the PDFs could be adapted more closely to the behavior of different people. The simulations of type (iii) with a time-independent PDF of durations are those with the worst performance. On the right-hand side of Table 1 we show the share of the activity profiles which is correctly predicted for the different algorithms. The fact that the differences between (i) and (iii) are small is an indicator that the calibration with a larger data set would be of great increase the differences of individuals' behavior. Furthermore, it is evident that the time-dependence of the PDFs is crucial for accurate predictions. The fact that the values do not differ significantly amongst the different chosen disaggregations is a sign that criteria were chosen, that do not imply a strong difference in residential behavior.

Table 1: Mean correctly predicted share of the activty profile (left) and correctly predicted activities of all activity chains (right) of different versions of the algorithm (in %).

	activity chains correct			profiles correct		
disagg. criterion	(i) no stat. sign. test	(ii) t-indep. PDF	(iii) t-dep. PDF; stat. sign. test	(i) no stat. sign. test	(ii) t-indep. PDF	(iii) t-dep. PDF; stat. sign. test
retired	53.14 ± 0.13	52.35 ± 0.28	53.14 ± 0.13	85.5	23.8	85.4
urban	53.07 ± 0.13	52.08 ± 0.28	52.99 ± 0.13	85.6	23.8	85.5
incorig	53.32 ± 0.15	52.18 ± 0.28	53.00 ± 0.13	84.9	23.8	78.5

DISCUSSION

There are types of behavior which are not captured by the model, e.g. the consecutiveness of activities, which could be taken into account by describing the probabilities to start an activity as transition probabilities from one activity to another. One example would be the increased probability to start eating when the cooking is finished.

Nevertheless, the results of the simulations are satisfying. The general trend of activity profiles of the aggregate population is well reproduced. We have made considerable progress towards a better matching, after defining the PDFs of activity durations as being time-dependent. However, the biggest difficulty in modeling this behavior is that the questionnaire data does not perfectly represent reality, as is evident at the beginning and the end of the day, when the shares of different activities in TUS profile are often very different (cf. Fig. 2, right/left) although they should be equal in reality (as soon as all different weekdays are represented with the same share in the TUS, as is approximately the case). This is why we have also set the simulation duration to 24 h, in order to make the results comparable to the TUS. When one wants to use this model, e.g. in building simulations it will produce more realistic results when the simulation duration is extended. Clearly we would like to avoid these kinds of artifacts, making it necessary to estimate which particular behavior is real and which one is due to systematic errors of the experiment. Nevertheless, the simulations based on the time-use surveys are a powerful tool to derive detailed statistical information about activities that occur at a given time of the day in residential buildings.

Moreover, the methodology which is shown here to derive the specific behavior of individuals with specific characteristics seems to be a good compromise between parsimony and statistical significant explanatory power. If the data set for the calibration of the model can be expanded, this will extend the applicability of the model as a tool to predict individuals' behavior in residential buildings.

CONCLUSION

The purpose of this work is to develop of a time-dependent model to predict residential occupants' activities. We used time-use survey data to calibrate the model. In this our aim is to have a structure which is sophisticated enough to capture the peculiarities of individuals' behavior.

We are planning to use this model as a pre-process for a model predicting the use of electrical appliances, as the probabilities of the latter is clearly strongly dependent on the activities that are performed [3]. The interest in this is the possibility of predicting the time-dependent distribution of the electric power demands of entire districts. As the socio-demographic characteristics of districts are likely to vary strongly, the whole modeling methodology could make it possible to adapt the electricity supply infrastructure of small scale power plants more adequately. However, more progress is still needed to achieve these goals. Regarding data scarcity, we are also planning to test the probabilities to start an activity of subpopulations for statistical significant difference to the entire population mean. In this our quest would be helped if it is proven to be viable to combine complementary TUS datasets, either from other years or from adjacent countries.

ACKNOWLEDGEMENT

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DIFFERENTIAL SENSITIVITY OF THE ENERGY DEMAND FOR AN OFFICE BUILDING TO SELECTED ARCHITECTURAL DESIGN PARAMETERS

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ABSTRACT

Conceptual architectural design requires the fast evaluation of design alternatives. Building performance simulation is increasingly used to assess the impact of important design parameters. However, uncertainty exists with regards to (1) the level of modeling detail required for the early energy assessment of design alternatives, and (2) which values to choose for the parametric sensitivity analysis. In the presented study the impact of ten architectural design parameters on an urban office design was assessed.

The dominant performance indicator for the optimization of architectural design alternatives is the energy demand for heating. Still, the systemic perspective in building design requires extending the view at least towards energy demand for cooling and lighting. That is why the authors establish the parameter impact on the individual and summed up (total) energy demand for heating, cooling and lighting.

To establish the parameter impact on the selected performance indicators the differential sensitivity analysis (DSA) technique was applied. The sensitivity analysis requires knowledge about the range of the model input parameters.

For conducting the study a review of the architectural design for sixteen European office buildings was undertaken. The aim was to establish realistic minimum and maximum values for the architectural design parameters such as ratio net office floor area to gross floor area. It was found that the parameter varies between 0.55 and 0.79.

With respect to the required modeling level for predicting the annual building energy demand for heating, cooling and lighting, the most abstract level - one office zone for each floor - is sufficient. The findings apply when the diversification of the final office use and thermal capacity of the internal partitions are accounted for.

The results of the sensitivity analysis confirmed the high influence of glazing performance and architectural room layout. Of the 10 parameters considered, the 2 most influential are g-value and ratio office to gross floor area. The least influential parameter is the window to wall ratio. The surprising observation can be attributed to two reasons: (1) a narrow but realistic parameter range and (2) the operation of the external shading devices.

INTRODUCTION

Conceptual architectural and building physics and system design requires the evaluation of a great number of design alternatives. Building performance simulation is increasingly used to assess the impact of important design parameters. However, uncertainty exists with regards to

(1) the level of modeling detail required for the early energy assessment of design alternatives and (2) which values to choose for the parametric sensitivity analysis.

The dominant performance indicator for the optimization of architectural design alternatives is the energy demand for heating. However, the integrated perspective in building design requires extending the view at least towards energy demand for cooling and lighting. That is why the authors establish the parameter impact on the individual and summed up (total) energy demand for heating-, cooling- and lighting energy for an urban office development.

The sensitivity analysis is necessary to identify the design parameters that have the highest impacts on the selected performance indicator. The knowledge about those parameters and their impact provides designers a basis for decision making to achieve the design requirements. The three questions addressed in the paper are:

1. Which modeling resolution level is suitable for the prediction of the annual building energy demand for heating, cooling and lighting (total energy demand).
2. What is the parameter range for the architectural design parameter ratio of office to gross floor area?
3. Which parameter rank highest and lowest with respect to their impact on the total energy demand?

METHOD

The presented study is concerned with establishing the required modeling abstraction level and parameter sensitivities of selected performance indicators. For identifying the parameter impact the building simulation tool IDA-ICE was used [1].

To establish a suitable modeling abstraction level for the conceptual design stage, three different levels were analyzed: abstract, medium and detailed. There are different approaches to validating simulation results: analytically, empirically and comparative [2]. In this study the authors apply inter-model comparison, whereby the detailed model is used as reference.

To quantify architectural design parameters, a review of architectural designs for 16 European office buildings was undertaken. The architectural design parameters considered are: ratio of net office floor area to gross floor area and window to wall ratio among others.

To establish the parameter impact on the selected performance indicators (output) the differential sensitivity analysis (DSA) technique was applied. DSA uses the difference of the output relative to a reference case as sensitivity measure, which is the result of varying one input parameter at the time. The DSA allows to rank-order the considered design parameters from most to least influential. However, it does not allow assessing parameter interactions or the combined impact of design parameter on the output.

OFFICE BUILDING PERFORMANCE - CASE STUDY

The abstraction level and parameter sensitivity were analyzed for a five-story office building. The building is located in Zürich/Switzerland and orientated East/West, see Figure 1. The building complies with the local building regulations. The performance indicator considered is the energy demand for heating cooling and lighting. The set points for heating and cooling are 21^{o}C and 26.5^{o}C, respectively. The building is equipped with external shading devices which operate based on two parameters: solar incident angle and level of solar radiation on the inside of the glazing.

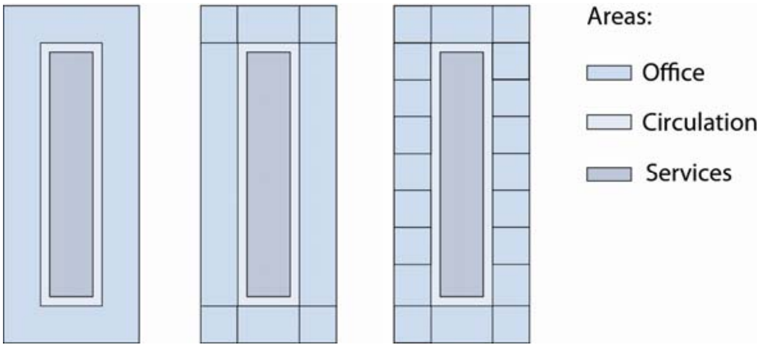

Figure 1: Case study office floor layout, three abstraction levels simple, medium and detailed.

A first performance assessment indicated an energy demand for heating, cooling and lighting of 43.2kWh/a. The energy demand for lighting dominates the overall demand with 56%. Space heating requires 33% and comfort cooling 11%.

IMPACT OF THE MODELING LEVEL

The influence of the modeling abstraction on the performance indicator energy demand was considered on three levels: abstract, medium and detailed. The detail of the zoning was chosen for representing the abstraction level. The abstract building model made use of one thermal zone for each office area on each floor. The medium abstraction level differentiates the zones specific to their orientation adjacent to the building façade. The detailed abstraction level differentiates between the individual office spaces. The resultant number of office zones modeled for the medium and detailed abstraction level is 8 and 20, respectively. The office use pattern, defined by specific gains and use schedules, were differentiated between open plan offices, individual offices and meeting rooms.

It was found that the predicted energy demand for the detailed modeling levels lies between 0.8 and 2.4-times the energy demand predicted with the abstract building model, see Figure 2. The difference between abstract and detailed building modes for the sum of the energy demand for heating cooling and lighting is 27% (58MWh).

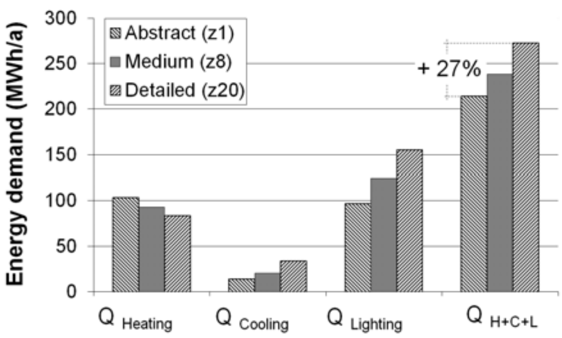

Figure 2: Annual energy demand for heating, cooling and lighting for three abstraction levels.

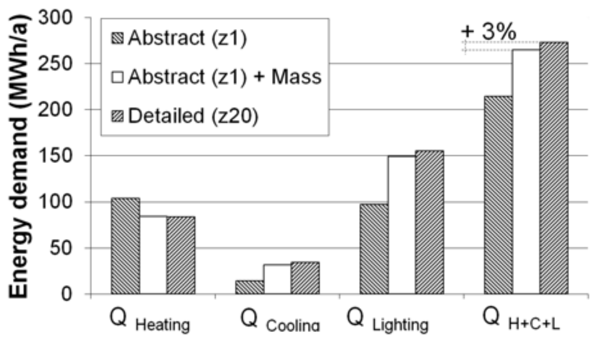

Figure 3: Internal mass correction - annual energy demand for heating, cooling and lighting.

The energy demand for the abstract compared to the detailed model was found high for heating and low for cooling. This observation was interpreted, resulting from a low internal mass due to the missing internal walls. To prove the impact of the thermal mass the abstract building model was adapted, numerically defining the internal mass corresponding to the mass of the internal walls in the detailed model. The results show (see Figure 3), that the differences in total energy are reduced to 3% (8MWh).

DIFFERENTIAL SENSITIVITY ANALYSIS

Differential sensitivity analysis (DSA) is the most commonly used sensitivity analysis technique in design practice. It is used complementary to intuition and design experience. The aim is to identify the impact of selected design parameters (model input) on performance indicators (model output) such as energy demand and comfort.

The parameter sensitivity is indicated by the difference of the model output to a reference, due to varying one input parameter at the time. The DSA allows to rank-order the considered design parameters from most to least influential. However, it does not allow assessing parameter interactions or the combined impact of design parameter on the output.

Parameter ranges for sensitivity analysis

To conduct a sensitivity analysis, knowledge about the parameter (model input) distribution is required. Whilst there are a number of publications available documenting the parameter distributions of physical properties of building material [3, 4], little knowledge is available with respect to the distribution of architectural design parameters such as ratio of areas as net office, circulation and services to gross floor area.

In an attempt to quantify the parameters, 16 European architectural designs were reviewed. It was found that the ratios vary widely, see Table 1. The percentage office area on the gross floor area ranges from 55% to 79%. The area allocated for circulation and access ranges from 5% to 26%. The floor area needed for services varies between 4% and 21%. An overview of the results can be found in Table 2.

	Ratio of specific floor area to gross floor area		
Areas	**Min.**	**Mean**	**Max.**
Office	0.55	0.69	0.79
Circulation	0.05	0.16	0.26
Services	0.04	0.15	0.21

Table 1: Area ratios for office, circulation and services areas relative to gross floor area.

Parameter Impact Assessment

In an interdisciplinary project workshop, building services engineers and architect identified 10 parameters, which were expected to have an impact on the energy demand of the building. The parameters are (1) g-value, (2) ratio of office to gross floor area, (3) room height, (4) window to wall ratio, (5) u-value glazing, (6) u-value façade, (7) orientation, (8) infiltration rate, (9) thermal active building mass and (10) internal gains. The parameter ranges were defined with three values: reference, min. and max. value, see Table 3. The resulting sensitivity of the energy demand for heating, cooling and lighting to the parameters is indicated in Figure 4.

The internal gains are modelled in accordance to SIA MB 2024 [5] and are 14 W/m^2, 32 W/m^2 and 50 W/m^2: The thermal active building mass is differentiated by the availability of building elements with high thermal storage capacity. For the reference case the external wall and concrete floor are available for heat exchange. For the case with high thermal mass the internal walls and ceiling are also exposed. For the case with low thermal mass, the high capacity building elements are blocked off by plasterboard and carpet.

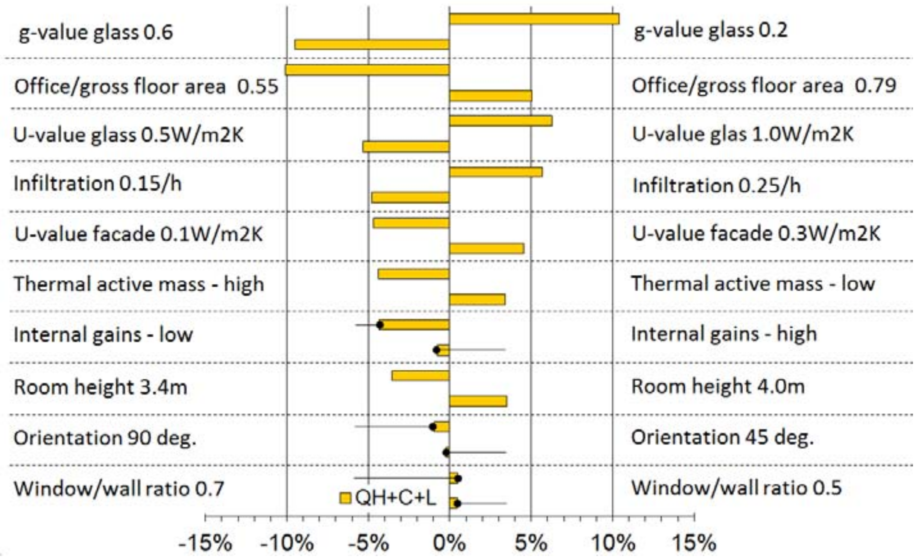

Figure 4: Sensitivity of total energy demand to 10 design parameters

The parameter ranking, see Figure 4, indicates that from the 10 considered parameters, g-value of the glazing und ratio of office to gross floor area are the two most important. The least important parameters are building orientation and window to wall ratio.

It surprises that the commonly highly regarded parameter window to wall ratio finishes as the least important parameter. The result is caused by two facts: (1) the total energy demand is dominated by the energy demand for lighting, which in turn is influenced by the automated external shading and (2) by the narrow but realistic parameter range.

CONCLUSIONS

The paper reports a multidisciplinary effort to establish and rank-order the importance of 10 design parameters. The domains covered are building physics and systems as well as architecture. To identify the parameter impact a sensitivity analysis using the building simulation tool IDA-ICE was undertaken. The following three questions were addressed:

1. Which modeling resolution level is suitable for the prediction of the annual building energy demand for heating, cooling and lighting (total energy demand).
2. What is the parameter range for the architectural design parameter ratio of office to gross floor area?
3. Which parameter rank highest and lowest with respect to their impact on the total energy demand?

It was found that from the three resolution levels considered the most abstract is suitable. That is, when the different office use pattern and thermal capacity of the internal partitions are accounted for. The abstract resolution level represents the office space on one floor as one zone.

As limited knowledge is available with regards to the parameter range for architectural design parameters a design survey was undertaken reviewing typical floor layout for 16 European office buildings. It was found that the parameter ratio of office to gross floor area can range from 55% to 79%.

The ranking of the design parameters as a result of the differential sensitivity analysis gave surprising results. Of the 10 parameters considered, the 2 most important are g-value and ratio office to gross floor area. That confirms the importance of the performance of the façade glazing and the architectural layout on the energy consumption during building operation. It did surprise that the commonly highly regarded parameter window to wall ratio finished as least important parameter. That is for two reasons: (1) the range of the glazed façade area is assumed narrow but realistic and (2) the operation of the external shading.

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Appendix 1

Areas:	**Netto office**		**Services**		**Access/ Circulation**		**Voids**		**Gross floor**
Pos.	[m^2]	[%]	[m^2]	[%]	[m^2]	[%]	[m^2]	[%]	[m^2]
1	1399	71.7	270	13.8	283	14.5	0	0.0	1952
2	1779	68.4	358	13.8	463	17.8	286	11.0	2600
3	1286	55.5	434	18.7	598	25.8	1772	76.4	2318
4	976	73.9	282	21.3	63	4.8	819	62.0	1321
5	474	71.9	92	14.0	93	14.1	0	0.0	659
6	250	62.2	62	15.4	90	22.4	0	0.0	402
7	372	69.4	67	12.5	97	18.1	82	15.3	536
8	887	68.1	205	15.7	211	16.2	597	45.8	1303
9	736	67.8	138	12.7	211	19.4	170	15.7	1085
10	815	69.7	190	16.2	165	14.1	0	0.0	1170
11	778	72.0	140	13.0	163	15.1	104	9.6	1081
12	924	72.5	208	16.3	142	11.1	594	46.6	1274
13	1281	63.8	428	21.3	299	14.9	94	4.7	2008
14	1175	79.0	175	11.8	138	9.3	509	34.2	1488
15	618	75.9	37	4.5	159	19.5	117	14.4	814
16	644	70.3	128	14.0	144	15.7	16	1.7	916

Table 2: Data collection from 16 architectural design concepts for a typical floor plan.

Parameters	**Unit**	**Max.**	**Reference**	**Min.**	**Comment**
Office/gross floor area	[%]	79	67	55	/
Window to wall ratio	[%]	70	60	50	/
Room height	[m]	4	3.7	3.4	Floor to floor
g-value	n/a	0.6	0.35	0.23	Pilkington [6]
U-value glass	[W/m^{2}K]	1.0	0.75	0.5	/
U-value façade	[W/m^{2}K]	0.3	0.2	0.1	/
Orientation	[Degree cw]	90^O	45^O	0^O	North to south
Infiltration	[1/h]	0.25	0.2	0.15	Element 29
Thermal active masse	/	high	moderate	low	/
Internal gains	[W/m^2]	50	32	14	SIA MB 2024

Table 3: Differential sensitivity analysis - parameter ranges.

MODELLING SYSTEM FLOWS IN BUILDING AND CITY DESIGN

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ABSTRACT

Buildings and cities have major part in global energy consumption. This calls for a performance-oriented approach of the design of buildings and cities to reduce their environmental impact. Therefore, the paper proposes Parametric Systems Modelling (PSM) as a tool for supporting a multidisciplinary performance-oriented design process of building and cities. The method is based on the Systems Modelling Language (SysML), which is a diagram-based modelling tool universally serving in systems engineering and which has its roots in software engineering. The transfer to the building domain is intended for design, evaluation and optimization of buildings and cities as systems. The approach exceeds the approach of geometric parametric modelling, extends it by physical and technological information. Thus, it provides a basis for multidisciplinary analyses and simulations. Its application aims at the generation and exploration of innovative sustainable design solutions at system level.

The first part introduces the PSM method that bases on the Systems Modelling Language (SysML) and illustrates it by a simple example from the building domain. The PSM method includes at its current development state seven model types represented in form of different diagrams: (1) use case diagrams, (2) requirement diagrams, (3) block definition diagrams, (4) activity diagrams, (5) internal block diagrams, (6) simple parametric diagrams and (7) parametric diagrams extended by measures of effectiveness (moe). These types serve for a design-oriented and requirement-driven generation of the system.

The next part reports from the development of an innovative sustainable build-city system, which was supported by PSM. An emphasis is set on the modelling of energy, water and biomass flows. On the one hand, this illustrates the capabilities of the method for performance-oriented design modelling of buildings and cities; on the other hand, it serves to present an innovative design solution and to show the use of renewable energy, water and biomass recycling in the local urban environment.

To sum it up, the application of Parametric Systems Modelling is intended for supplementing the geometry-based CAD / CAAD to provide a modelling environment that allows the multidisciplinary parametric system-based description of the design artefact. The aim is to provide an environment that allows the modelling of multidisciplinary interdependencies for performance-oriented design simultaneously with geometric modelling. The developed PSM method is basis for this environment. Further development of the research includes prototypical implementation of a PSM editor integrated with a parametric CAD environment.

INTRODUCTION

The demand of sustainable, energy-efficient, and resource-saving solutions in the design of buildings and cities requires new methods of modelling. Geometry-focused modelling as being state-of-the-art in building design needs a complementation in terms of the modelling of engineering aspects of energy and material flows. For this purpose, the research project described in the paper establishes the method of Parametric Systems Modelling on the basis of the industry standard Systems Modelling Language [5]. The first part proposes a sequence of diagram-based model types in order to provide means for modelling buildings and cities as systems starting from requirements and use cases to item flows and parametric interdependencies. The second part reports from the application of the methodology to an innovative building-city system, which focuses on the flows of energy, biological materials, and water. Two exemplary diagrams represent stages in the development of a systems model for a sustainable urban configuration.

METHOD OF PARAMETRIC SYSTEMS MODELLING

The method of Parametric Systems Modelling (PSM) aims at complementing geometry-focused parametric modelling as used in today's architectural design by considering non-geometric performance relevant aspects, by supporting a requirement-driven setup of the system, by analysing its behaviour and performance and by assisting the designer in the exploration of the design space. The approach adapts the Systems Modelling Language (SysML) [5] for the use in building design and urban planning. The SysML bases on the Unified Modelling Language (UML) [6], which is an important standard for object-oriented software development; this eases the implementation of the system in computer-aided design environments. The developed PSM methodology includes a set of seven diagram types, which are illustrated by a simple example form building services in Figure 1:

- *(1) Use case diagrams (uc)* describe the system’s context. They usually deal with external prerequisites for a building that are not part artefacts to be designed.
- *(2) Requirement diagrams (req)* derive requirements from use cases and refine the prerequisites of the design. Systems or system parts can directly satisfy requirements.
- *(3) Block definition diagrams (bdd)* serve to define the structure of the system. As an extension by the PSM method, they include requirements as association blocks to enable a requirement-driven design process.
- *(4) Activity diagrams (act)* model the generic processes taking place in the design including the exchanged items such as energy or material. An allocation of processes to system parts is possible and leads to the next diagram type.
- *(5) Internal block diagrams (ibd)* describe the item flows between blocks. They may include current flows as well as sums of flows. These diagrams provide together with activity diagrams an important basis for analysis and simulation e.g. of energy flows in the building.
- *(6) Parametric diagrams (par)* capture calculations for analysis and represent analysis models e.g. for dimensioning. The constraint blocks of these diagrams may also embed subordinate simulations.
- *(7) Measures of effectives (moe)* extend parametric diagrams for evaluation purposes and, thus, provide an important tool for performance-oriented design.

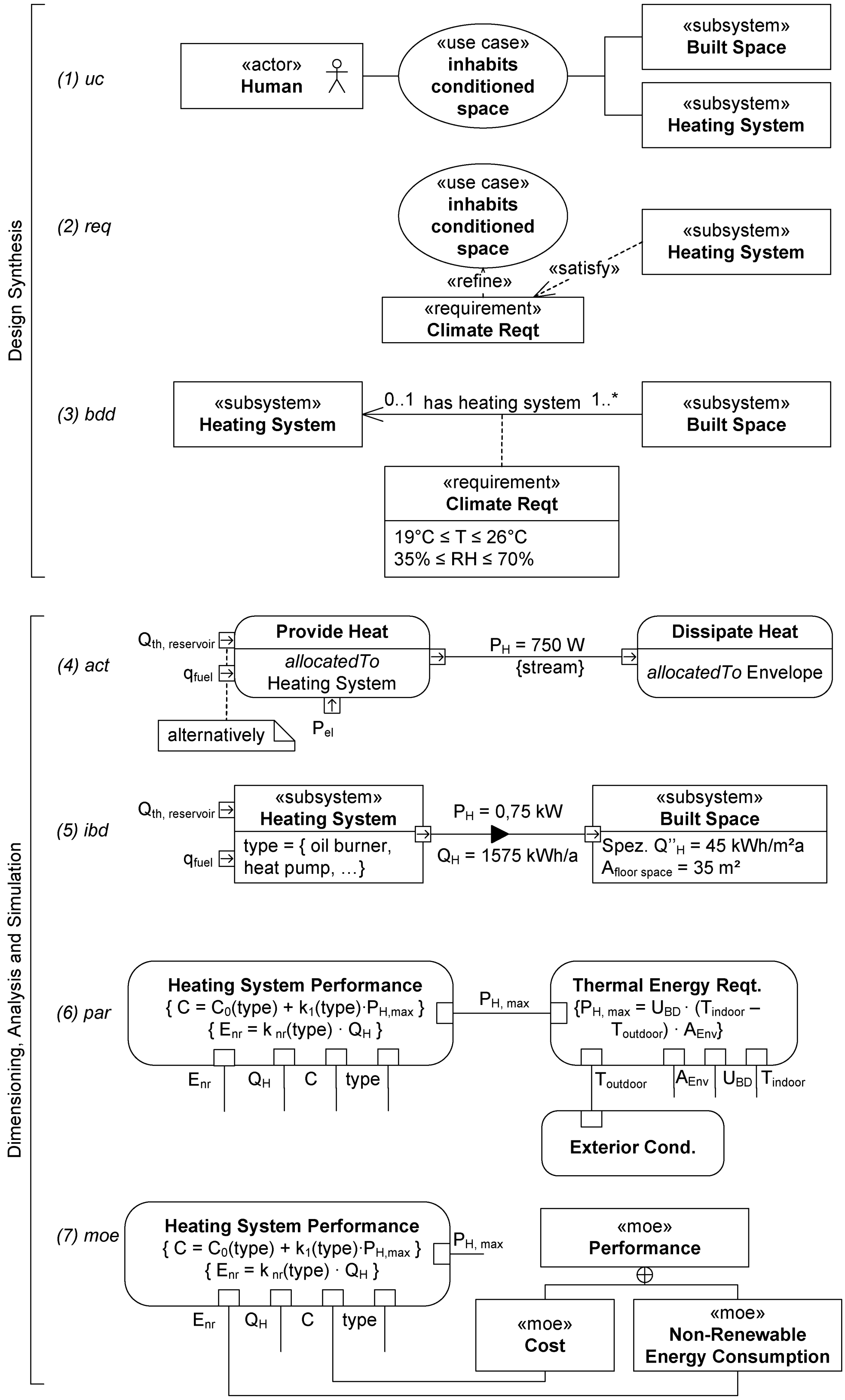


Figure 1: Parametric Systems Modelling (PSM) contains a set of seven diagrams-based model types using the Systems Modelling Language (SysML): (1) use cases, (2) requirements, (3) block definition diagrams, (4) activity diagrams, (5) internal block diagrams, (6) parametric diagrams, and (7) parametric diagrams with measures of effectiveness (moe).

AN INNOVATIVE BUILDING-CITY SYSTEM

In this part, two diagrams from the development and modelling process of an innovative building-city system provide illustration of the application of the PSM method. The process aimed at the development of a sustainable system of buildings and its urban environment in terms of energy, water and bio mass. The resulting system features a productive greenhouse, a desiccant heating and cooling system, and a pyrolysis system. The system design founds on research done by the Watergy research group [7], documented by Buchholz [3]. Geyer and Buchholz [4] describe the development process in detail.

Figure 2 displays the requirements on the building and its urban environment made by the inhabitants. These requirements concern four different types of item flows: energy, water, food, and area. Energy is needed as electric energy for transport in the city, for operating devices and lights, and as heating and cooling energy for providing conditioned living and working space. From the requirement of conditioned space, the need for an enclosed space derives, which is satisfied by the building. Furthermore, the water requirement splits up into two different types: drinking water and process water. This allows intelligent recycling and regeneration of water. At the bottom row, general system types are attached in order to satisfy the requirements. The further development deals with the realisation of these systems.

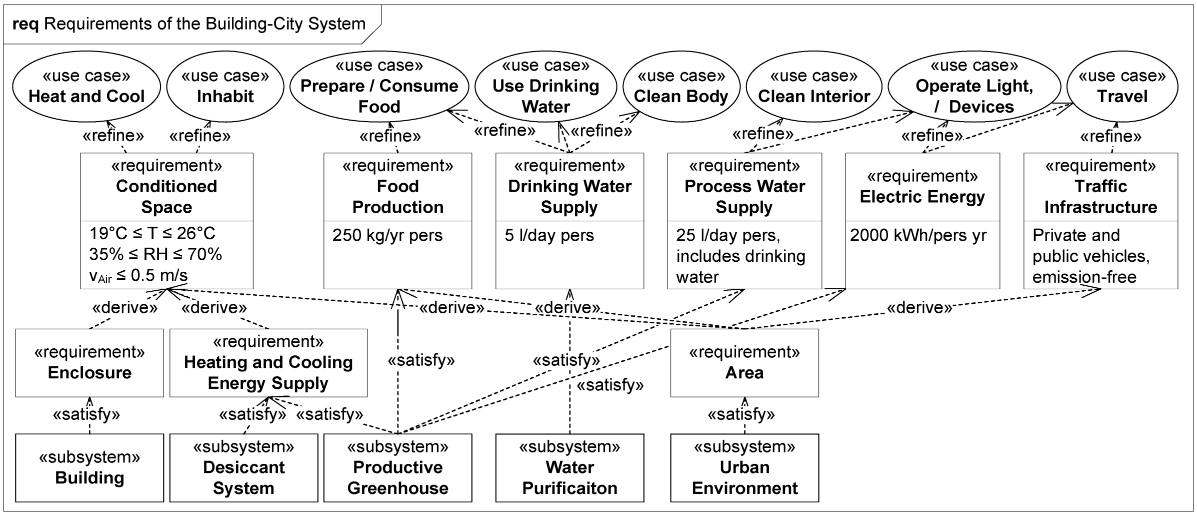


Figure 2: Requirements of the innovative building-city system.

The figures 3 and 4 show a design solution of the innovative building-city system and model the item flows. The productive greenhouse (Fig. 3 and 4, top left) is probably the most important component of the system. It provides process water (process water by biological treatment; drinking water by combined evapo-condensation), which is cleaned by the plants and is used for washing and cleaning processes. Furthermore, the greenhouse contains plants for food production with high effectiveness (especially CO2 accumulation) and integrates solar energy generation. For energy generation, selective reflectors (Concentrated Solar Power, CSP) in the greenhouse concentrate the near-infrared and infrared radiation (NIR), which does not support the growth of the plants. The heat gained by this concentration serves, first, for producing electric energy by means of a gas turbine, Stirling engine or PV, and, second, for regeneration (drying) of the diluted desiccant with the waste heat at a lower temperature level. The second process stores energy by loading the desiccant (e.g. a brine) with hygroscopic potential. Within the building with its heating and cooling system, this potential serves to transport energy by forcing absorption leading to a process equivalent to a solar-driven heat pump. This heat pump provides heating and cooling energy for the building. The process of absorption has been examined for building heating (Buchholz et al. [2]). By absorbing humidity and transporting heat in this process, the desiccant solution is diluted and needs regeneration.

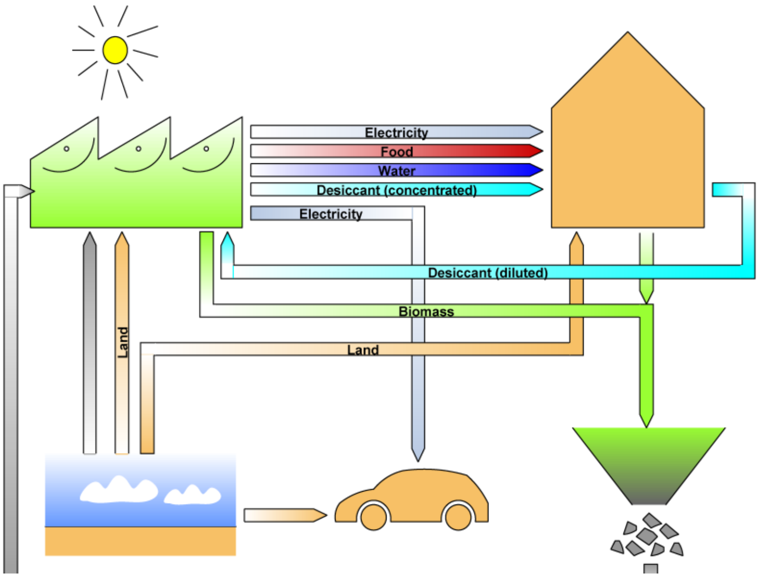
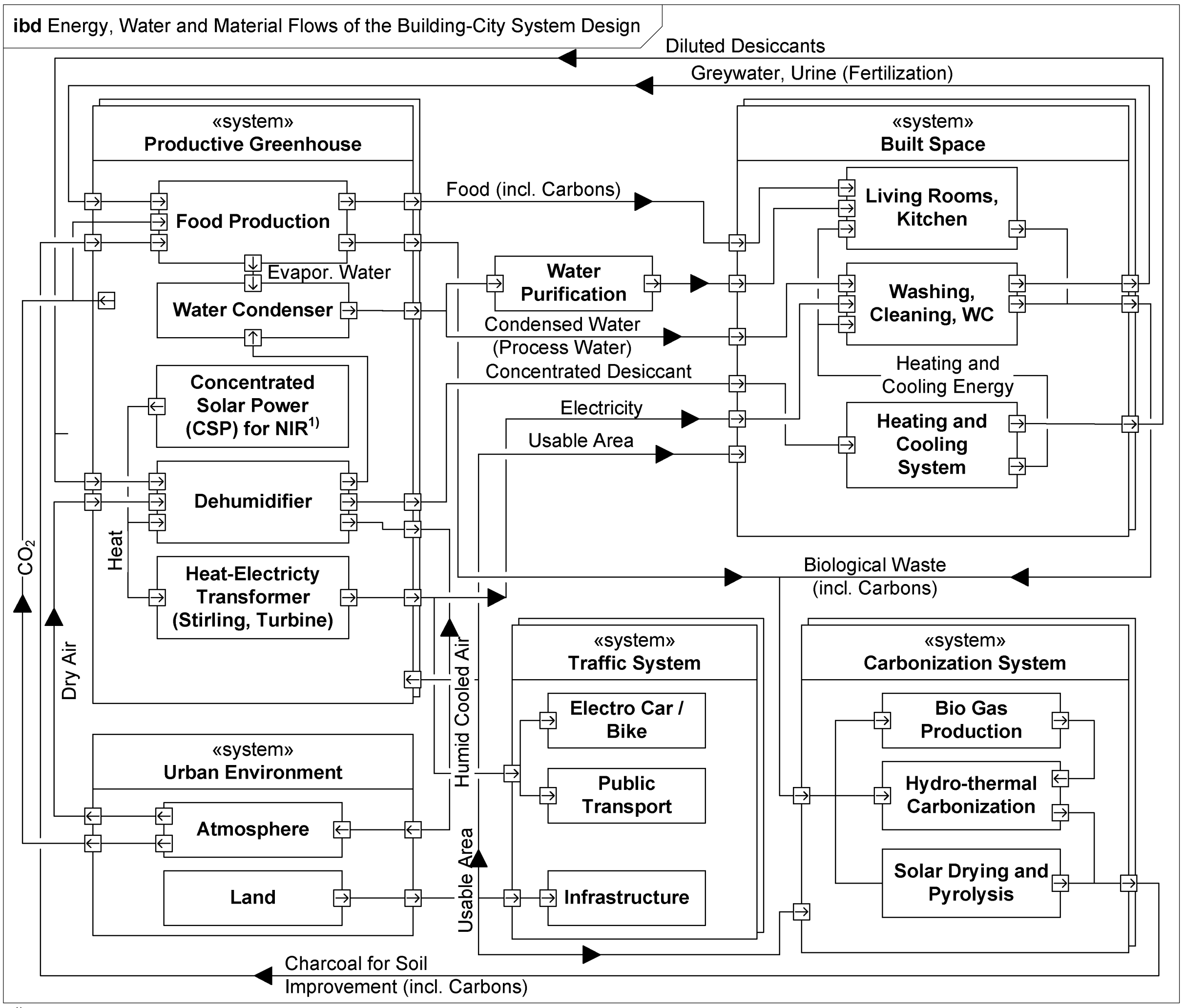


Figure 3: Graphic illustration of the flows in the sustainable building-city system.



[1] NIR = Near Infrared Light

Figure 4: Item flows of the innovative sustainable solution for the building-city system.

For process water gaining, a condenser integrated in the envelope of the greenhouse (Fig. 4, top left) collects water from evaporation processes of the plants and from the dehumidification process of the desiccant system. A further important feature of the water cycle is the separation of greywater and urine from solid biological waste. The liquid parts are recycled in the greenhouse whereas the solid parts undergo solar drying and pyrolysis, a process that produces heat and charcoal. The charcoal is used for soil improvement in the green house leading to a fertile soil called terra preta. This utilization process provides a constantly growing soil volume with increased water storage and heat accumulation property, contributing to an also constantly growing area of improved climate in terms of heat retention and evaporative cooling. Moreover, the constant accumulation of carbon absorbs more CO_2 than the construction and the operation of such a city system produces. Thus, the system is a CO_2-absorbing city. The “cycler support” guide [1] describes the processes in more detail and a further publication [4] contains the detailed performance analysis.

CONCLUDING REMARKS

In summary, the approach of Parametric Systems Modelling (PSM) serves to model multidisciplinary physical, chemical, technical, or economical interdependencies as a system model based on the industry standard Systems Modelling Language (SysML). This model type provides a base for

- Requirement-driven modelling of the design capturing the interdisciplinary dependencies, the behaviour, and the interaction of the components of the design,
- Observation and simulation of the system’s behaviour in order to learn more about the design artefact’s overall performance,
- The application of assisting search methods such as parameter studies and optimization,
- Decision-making support by design space exploration, by search methods, and by presenting alternative well-performing solutions or solution regions to the designer.

By these features, the approach complements the geometry-based parametric methods currently practiced in architectural design and bridges the gaps between parametric modelling, performance-oriented design, and Building Information Modelling (BIM) by a modelling method adding non-geometric information and multidisciplinary interdependencies in a formalized way to the building model.

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MODELLING THE UPTAKE OF LOW CARBON TECHNOLOGIES IN THE UK RESIDENTIAL BUILDING SECTOR

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ABSTRACT

Residential scale low carbon technologies can include micro-distributed renewable energy solutions and technologies that reduce the energy demand while maintaining lifestyle, health and comfort. Modelling the uptake of these integrated renewable energy systems and thermal upgrade measures at the building stock level is necessary in order to identify the most energy efficient and cost effective solutions. The outcome of such modelling work can inform policies to help achieve national CO_2 emissions reduction targets.

In recent years, several UK physics-based residential stock energy models have been developed to estimate the baseline energy consumption of the existing stock as well as to provide insight on the future of its energy demand. The aim of this paper is to analyse existing approaches to modelling the future integration and uptake of low carbon technologies in existing UK residential building stock models leading to the proposal of an overarching structure of an uptake module to be embedded in future building stock energy models.

The S-curve methodology, which is based on logistic functions, provides a simplified method that has been widely used to model uptake. However, in many cases this approach does not take into account or offers limited understanding with regard to factors such as domestic decision maker behaviour, leading to a large discrepancy between modelled (predicted uptake) and the observed outcome (actual uptake). A trend in more recently developed models involves the use of increasingly sophisticated algorithms. These consider such factors as building-specific technical eligibility and customer decision making algorithms and are therefore thought to provide a more realistic modelling approach.

Based on the analysis of existing approaches, a set of recommendations for the development of an 'uptake module' for a residential building stock model currently under development are formulated. The scope, framework and functionality of the proposed module are highlighted and the envisaged structure and components are illustrated. In addition, existing data sources that could be used to populate the underlying databases of this model are discussed.

INTRODUCTION: UPTAKE OF LOW CARBON TECHNOLOGIES IN THE RESIDENTIAL SECTOR

The EU Renewables Energy Directive 2009/28/EC set an overall target of at least 20% of total energy in EU member countries coming from renewables by 2020, as renewable energy is considered vital for the transition towards a low carbon economy [1,2]. In the residential sector, these solutions encompass integrated local power generation and technologies that reduce the net electrical demand of end-users, while maintaining comfort levels [3].

In the UK, the technical potential for relatively low cost energy efficiency measures in the residential sector has been estimated to be 40 $MtCO_2$ savings, with 9-18 $MtCO_2$ per annum considered achievable by 2020 from existing buildings [4]. Significant savings can also be achieved by more expensive interventions, such as small-scale micro-distributed renewable technologies which have the potential to reduce CO_2 from heat and electricity production. They can also help to create a more diverse and secure energy supply and reduce fuel poverty, particularly in hard-to-treat homes and off-gas areas [5]. In recognition of this, the 2007 UK

Government policy statement set out a definition for 'zero carbon homes' which among its various other objectives, aimed to increase the uptake of distributed renewable energy technologies (both at a building and community scale) [6].

Various reports have found that in the residential sector, a number of factors influence the uptake of energy efficiency measures [3,7,8]. These can be categorised as:

Physical factors such as building type, location, orientation and accessibility.

Technological factors which are operational factors that can be attributed to the renewable technologies themselves.

Economic factors such as market-based supply-demand, basic financial barriers, existing financial incentives and economic uncertainty.

Regulatory factors which relate to the regulatory framework within a country that makes it more difficult or easier for certain households to benefit from low energy measures.

Social factors such as acceptability, lack of information and various psychological/sociological barriers.

By taking account of all these factors *the technical limit of the stock (*the portion of the total stock suitable for the installation or upgrade) and *the realistic maximum uptake* (the proportion of the technical limit representing what could be achieved during a given period) can be determined [6].

REVIEW OF EXISTING APPROACHES TO MODELLING UPTAKE

In recent years, a range of physics-based residential stock energy models have been developed to help answer policy questions by estimating the baseline energy demand of the existing stock as well as by providing insight on its future demand [9]. In the UK, two distinct approaches to modelling the uptake of energy efficiency measures, including renewable energy technologies, have been developed. These approaches are summarised below:

The S-curve approach

This approach is based on logistic functions that project the likely uptake rate, ownership and eventual saturation level of new technologies. The S-curve represents three stages: an initial slow uptake, followed by a much faster rate as the technology is widely implemented and finally another slow uptake as the product approaches saturation in the market. S-curves have been applied by the Building Research Establishment (BRE) in domestic stock models to project the integration levels of low energy technologies in particular [10,11]. These curves were developed using historic data for the uptake of energy efficiency measures and are based on the assumption that the rate of uptake is proportional to time and the remaining size of the market. The key limitation of this approach arises from the fact that the low carbon technology market is characterised by significantly more complex drivers than other markets (such as the physical/technological, regulatory and social factors discussed above).

Uptake modules using advanced consumer decision making process algorithms

Recently developed models such as DEMScot and Element Energy [7,12] have adopted a more advanced approach towards the estimation of the potential uptake of technologies that take account of human influence and behavioural change. The common algorithm structure of the two models divides the uptake estimation procedure into a number of stages and aims to determine three important parameters:

The identification of technically eligible dwellings: eligible archetypes in the stock are determined based on constraints that affect the physical uptake and deployment of technologies. These include both *building specific constraints* such as building type, location, orientation, accessibility and *technological constraints* attributed to the measures themselves.

The identification of trigger points for customer decision making: the key 'triggers' or 'intervention points' are moments over the course of a dwelling's lifetime where there is an opportunity to integrate low-carbon works into other concurrent building works [13].

The prediction of the homeowner (or landlord) likelihood to adopt a technology: this 'final decision' is a function of different attitudinal and socioeconomic variables which may either be related to cost or other factors such as aesthetics, disruption and perceptions on energy efficiency. The likelihood for an average household to adopt a technology can be accounted for by applying techniques such as binary or multinomial Logit (MNL) models [14], random assignment or Net Present Value (NPV) calculation. The Logit model, in particular, adopts a quantitative approach that makes use of Discrete Choice Modelling to explore domestic decision maker behaviour and predict the market shares of low carbon technologies [7].

	S-Curve approach	**Advanced consumer decision making process algorithms**
Description	Logistic functions that project the likely uptake rate, ownership and eventual saturation level of measures	Advanced algorithms that take account of human influence/ behavioural change. May use logit algorithms/NPV calculations.
Models	BREHOMES, Johnston, Fawcett, UKDCM and DECarb models [9,15]	DEMScot and Element Energy models [7,12]
Advantages	•Simplified approach •Applicable to a wide range of models with varying degree of sophistication	•More realistic estimation of uptake and understanding of various socioeconomic drivers
Limitations	•Limited understanding of the drivers of domestic decision maker behaviour •Inaccurate estimation of hidden costs •Lack of distinction between 'early adopters' and 'laggards' in population	•Involves complicated procedures •May involve compilation of extensive databases

Table 1: Comparison of uptake modelling approaches

DEVELOPMENT OF AN UPTAKE MODULE

Based on the review of existing approaches, a set of recommendations for the possible future development of an 'uptake module' for a UK residential building stock model currently under development can be formulated. This stock model is based on a core BREDEM (BRE Domestic Energy Model) algorithm structure building model [16] and a number of modules that undertake specific functions. The uptake module aims to determine the uptake and physical deployment potential of particular technologies for the residential stock as a whole. From the review of the various modelling approaches and the consideration of associated concepts, the following aspects of the module's functionality are therefore proposed:

- An approach that allows for the consideration of the various factors such as physical constraints, economic feasibility and social factors such as customer/occupant acceptance would provide a more realistic estimate of uptake and deployment. Accordingly, the more detailed approach to modelling utilising an advanced consumer decision making process algorithms will be used.

- The module will involve the creation of a database of inputs concerning a range of renewable energy technology characteristics and costs.
- Input from a “future scenarios” module will be used to account for predicted changes in fuel prices and regulation.

Overarching algorithm structure

Ideally, the module framework should incorporate the following seven stage approach, which is based on the approach embedded in the DEMScot and Element Energy uptake modules. The envisaged module structure and components (Figure 1) are discussed in detail below.

1-List of technological improvements and occupant behaviour change scenarios
The first stage will involve the creation of a list of all potential renewable technology options in conjunction with various occupancy behaviour scenarios. A particular issue that needs to be considered at this point is the option to model multiple technologies. It will need to be ensured that the core model will allow for any synergies and diminishing effects resulting from the installation of more than one technology and the identification of ‘competing’ technologies. For example, the co-existence of mCHP and a solar thermal system may not be an efficient option, as they will be both producing hot water.

2-Definition of dwelling stock
The segmentation of the residential stock is essential in the estimation procedure. A series of building characteristics that are deemed of particular relevance will be allocated to a set of archetypes. These include such aspects as frequency of occurrence in the stock, current notional CO_2 emissions, floor area, roof area and type. Additional attributes may need to be assigned to these archetypes to allow for a sub-sample selection functionality for scenario testing where, for instance, dwellings of a particular tenure type may be targeted.

3-Identification of technically eligible dwellings
The available upgrade options will be matched to eligible archetypes in the stock, based on a defined set of building-specific and technological constraints. It is proposed that this process be undertaken through the use of geographic information system (GIS) methods to create a database of dwelling information that can be accessed for this purpose [3].

4-Identification of trigger points for customer decision making
Existing research in this field provides an overview of such triggers in the existing UK housing market. However for this module, it is proposed that an expanded set of trigger points be developed to account for potential trigger variability in different tenure types. In addition, the approach will also potentially attempt to account for other non-financial drivers.

5-Estimation of overall costs of technological improvements
A key step in the uptake potential estimation is the costing methodology selected. Each upgrade needs to be classified according to how its sizing and costing will be calculated. Total cost will be broken down by a) survey/initial measure identification costs, b) installation costs, c) hidden costs, d) maintenance costs and e) replacement costs. Additional algorithms need to be generated in order to account for price variation as a function of both scale and time, where future costs are likely to fall as technologies become more mainstream.

6-Estimation of customers’ willingness to pay
An additional component will estimate the percentage of homeowners/landlords *actually making a decision.* Its development is to be informed by the more sophisticated MNL algorithm modelling approach [14].

7-Other constraints

Finally, other constraints affecting uptake will need to be factored in the calculation. These may include practical supply chain constraints, data for which will be provided from ongoing research in that field.

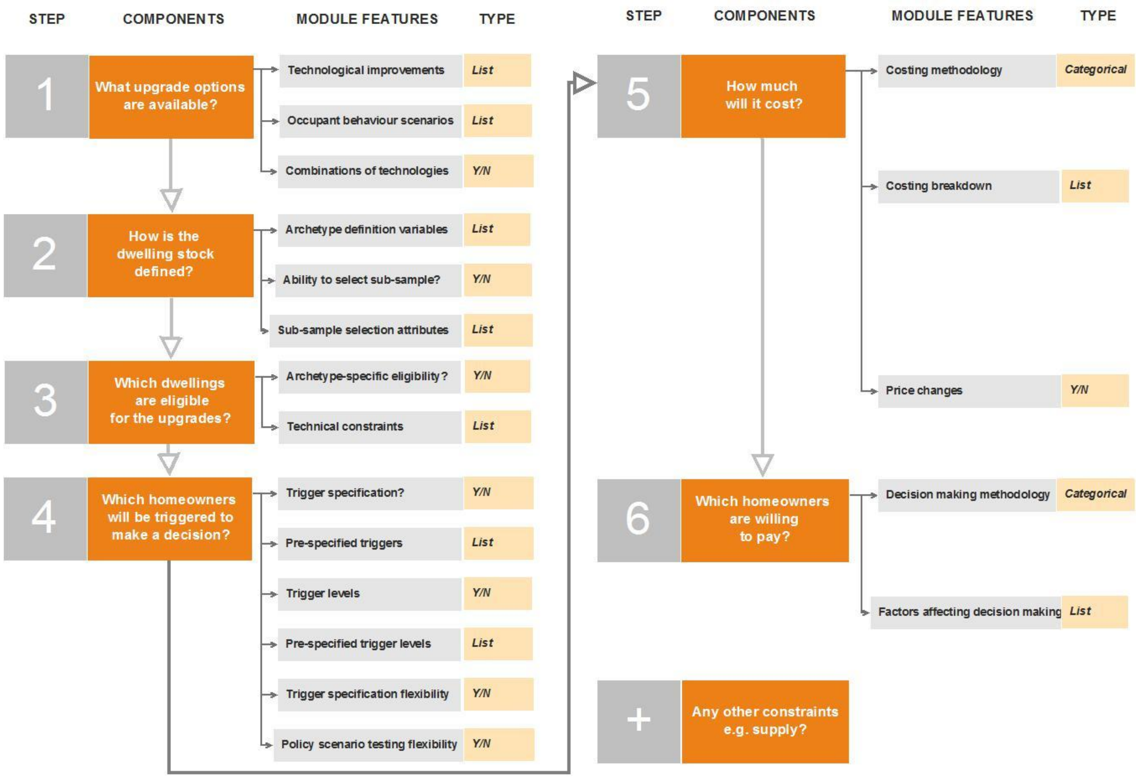

Figure 1: Schematic of Module Structure

CONCLUSIONS AND AREAS OF FURTHER RESEARCH

This paper has concluded that a more detailed approach to modelling utilising a consumer decision making process algorithm allows a more realistic approach to modelling uptake since it takes into consideration the various socio-economic factors that ultimately contribute to consumer decisions. In formulating the set of recommendations for the development of an uptake module for a residential building stock model, the work has outlined gaps in existing knowledge; hence, further work is planned in the following areas:

- Additional data is required for the development of an improved methodology for the identification of technically eligible dwellings that attempts to strike a balance between level of detail and broad assumptions. For example, the technical potential of a dwelling for the installation of a ground source heat pump may be assessed as a function of only the presence of a garden or by examining additional details, such as accessibility and size.
- Further research is required to build on the currently defined set of 'trigger points' with the aim of covering a wider scope of tenure types and it is also essential to gather the more detailed data required to populate the costs database for the model.

ACKNOWLEDGMENTS

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TOWARDS FORMULATING AN URBAN CLIMATIC MAP FOR HIGH DENSITY CITIES – AN EXPERIENCE FROM HONG KONG

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ABSTRACT

High density and compact city design is a topical issue. There are needs to deal with the scarcity of land, to design for a viable public transport system, and to re-build the community of our inner cities. High density living is increasing an issue that planners around the world have to deal with. Hong Kong is a high density city with a population of 8 millions living on a piece of land of around 1,000 square kilometres. In a nutshell, it means that there are a lot of people, and therefore activities happening per square metre of land and its air space in a high density city. Moreover, urban Hong Kong has been multi-zoned. That is to say, commercial, amenity, residential, and sometimes industrial buildings are mixed and co-exist in close proximity. Recently, the general public of Hong Kong is increasing aware of "over development" and "poor designs" of recently completed estates and projects. With lower air mass transport through the city, the dynamic potentials to mitigate urban heat island are seriously reduced; thermal stresses in the summer months are increased; and air pollutions dispersion is reduced. All in all, an unfavourable outdoor urban condition has resulted. Finding ways to strategically plan a city environmentally requires climatic information that is scientifically based. Hong Kong is a high density city with a sub-tropical climate and a hilly topography. The government of Hong Kong has recently commissioned studies towards producing an urban climatic map (UCMap). The extraordinary urban morphology of Hong Kong and the complex wind environment makes the task a unique scientific challenge. Using planning and land use data, a GIS based UCMap has been created. This has been classified and coded. Land use, ground coverage, building bulk, greenery intensities and so on have been incorporated. Overlaying it is the climatic data available from the Observatory. Based on the UCMap, the government of Hong Kong is re-working their urban zoning plans and planning strategies to take into account the urban climatic issues. Some of the scientific workings, as well as the implementation strategies of working with the UCMap are reported in this paper.

INTRODUCTION

To address the urban climatic problem, in 2006, subsequent to an Air Ventilation Assessment study [1], the government promulgated two guidelines. Firstly, there is the joint bureau Technical Guideline (TC 1/06) on the methodology of assessing how a development affects the air ventilation conditions of its surroundings [2]. Secondly, the Planning Department revised and published the Hong Kong Planning Standards and Guidelines (HKPSG) with a chapter on "Qualitative Guidelines on Air Ventilation" [3]. This document is referenced by the Town Planning Board when making decisions as to whether or not a development should be permitted. To further the two published guidelines, the government of Hong Kong in 2006 commissioned stage 2 of the study titled "Urban Climatic Map and Standards for Wind Environment" (UC-Map) [4]. The study includes many sub-modules (Figure 1). The works of one of the sub-modules (Urban Climatic Map and Planning Function Map – boxes in yellow in Figure 4) will be reported below.

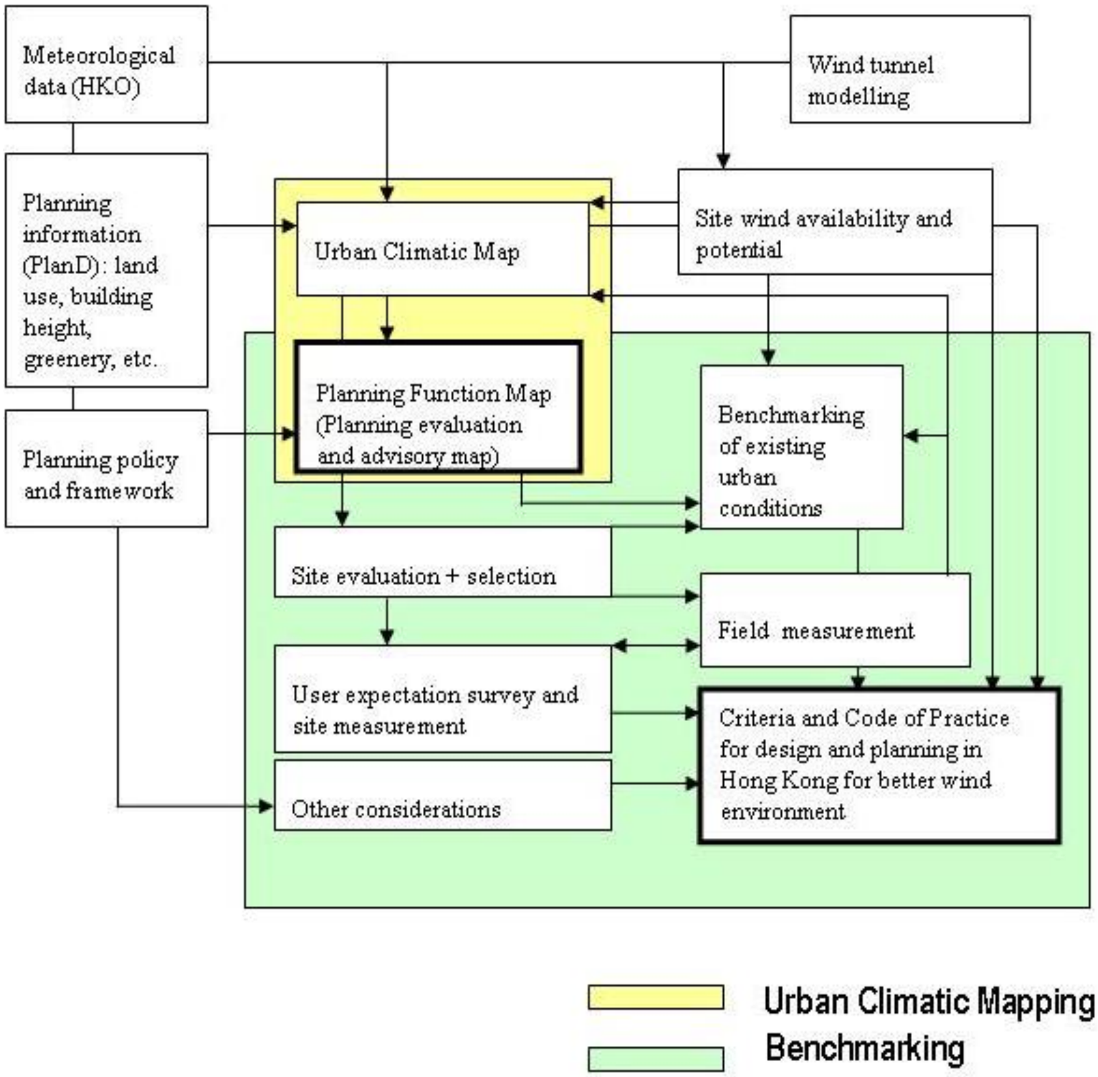

Figure 1: The research framework of the UC-Map study (2006-2009).

REVIEWS

Since the 80s, researchers in the field of urban climatology from Europe, North America, and South America have tried to develop the idea of urban climate assessment and analysis [5] [6]. Among them, Germany is a leading country in conducting urban climate analysis. After the re-unification of Germany, several cities in the former German Democratic Republic were analyzed in terms of urban climate using remote sensing (especially thermal imaging) and synthetic climate function maps were constructed. By introducing the concept of Urban Climatic Map, key urban climatic factors including meteorological data for climate assessment are mapped on to the base map of land use, topography and urban geometry. This Urban Climatic Map makes available the necessary climatic information to planners. The information is otherwise only known by scientists and climate experts. In Germany, there is a strong emphasis of urban climate research that also includes human-biometeorology. This is partly because of the legal requirement that “climate and air pollution” issues have to be considered in regional and urban planning projects. Guidelines VDI 3787 (Part 1), regarding the urban climate mapping details have been published by the German Engineering Society in

1997 [7]. The Guideline contains expert recommendations on methods and symbols to be used for drawing up urban climatic maps and the air pollution maps.

Apart from Germany, researchers in Japan have also produced urban climatic maps [8]. The Thermal Environmental Map for Tokyo promulgated by the Tokyo Metropolitan Government (TMG).

STUDY METHODOLOGY OF UC-MAP

Data Structure of UC-Map

A key problem of urbanization is the urban heat island (UHI) it generates [9]. For Hong Kong's hot and humid sub-tropical climatic conditions, urban heat island adds to human thermal stress in the summer months [10] [11] [12]. Field measurements indicate that at a typical mid-day in the summer of Hong Kong, UHI is about 2-4 degree C. Inhabitants of the city are less likely to be comfortable outdoor [13] [14] [15] [16] [17] [18]. In addition, buildings' energy consumption also increases. The urban climate of the city could be characterized with a balanced consideration of "negative" urban heat island effects (e.g. building bulks and building layouts) and "positive" effects. For the positive effects, two aspects are considered: Mitigation potentials (e.g. green open spaces) and Dynamic potentials (e.g. air ventilation). Scientifically, for urban climatic understanding, the positive and negative could be understood as in Figure 2.

Positive climate effects:	Negative climate effects:
Ventilation paths Downhill air movement Air mass exchange Bioclimatic effects from vegetation Neighborhood effects Altitude and Elevation	Heat island (building bulk) Anthropogenic heat Reduced ventilation Lack of air path effect

Figure 2: Positive and negative effects to urban climate.

Meteorological data in terms of air temperature, wind directions, speeds and frequencies, solar radiation, relative humidity of the last 10 years are collated from the Hong Kong Observatory. In addition, land and planning data in GIS digital format: land use, buildings, digital elevations, roads, landscape are collated from Planning and Lands Department HKSAR. Based on the information, a GIS based map of Hong Kong is structured. 9 separate layers have been constructed forming the basis of the map. Data are input at 10x10m.

Layer 1 – Building Volume Map

A principal cause of Urban Heat Island is the blocking of sky view by building bulks during cooling periods in the night time. Buildings built close together block each others in terms of the amount of heat energy that they could release back to the atmosphere.

Layer 2 – Land Use Map

Land use understanding and activities of buildings can be used to signal the anthropogenic heat contribution to the environment.

Layer 3 – Topographical Height Map

Changes in altitude in general change the air temperature, this moderate the sensible urban heat island intensity.

Layer 4 – Urban Green Space Map

Urban green area can affect the ground air temperature. Vegetation has a cooling potential to the city and thus mitigate the adverse effects of urban heat island.

Layer 5 – Ground Coverage Map

The amount of land that is occupied by buildings is known to be directly related to the air ventilation potential (wind permeability) of the location. In general, a neighbourhood with higher ground coverage (by buildings) has a lower air ventilation potential.

Layer 6 – Natural Landscape Map

Natural vegetation (together with slopes of the hill (Layer 6) creates cool air movement. This has a cooling potential to the city and thus mitigate the adverse effects of urban heat island.

Layer 7 – Slope Map

Cooler air moves downhill and in general along the valleys. This cooler air is beneficial.

Layer 8 – Ventilation (roughness length) Map

The Ventilation Map is created through the classification of surface roughness; in general, higher the roughness, lower the air ventilation potential. Roughness is in general related to the building density and building heights.

Layer 9 – Sea Breeze Map

The dynamic movement of air ventilation can mitigate the adverse effects of Urban Heat Island. Land and sea breeze is a consideration for coastal cities. In general, the benefits of sea breeze depend on the location's distance from the sea.

RESULTS

The layers are combined with their positive and negative effects collated. Three maps are produced based on a schema as presented in Figure 3.

The negative effects are summated to become the Urban Heat Island Analysis Map. The positive effects in terms of evapotranspiration and air mass exchange are summated to become the Dynamical Potentials Analysis Map. Combining the two maps becomes the initial Urban Climatic Analysis Map (UC-AnMap) of Hong Kong (Figure 4).

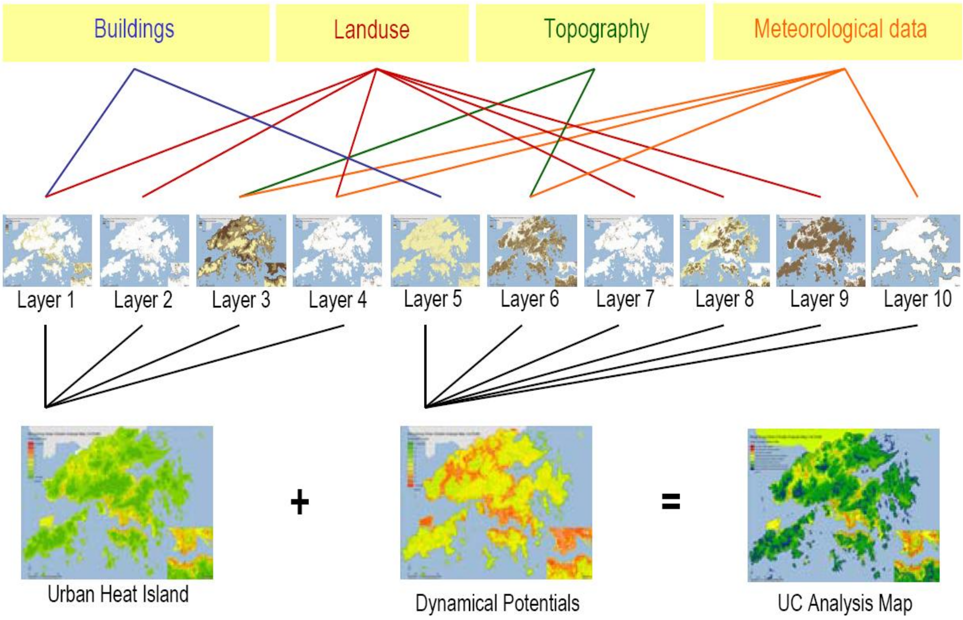

Figure 3: Schema of the UC-Map

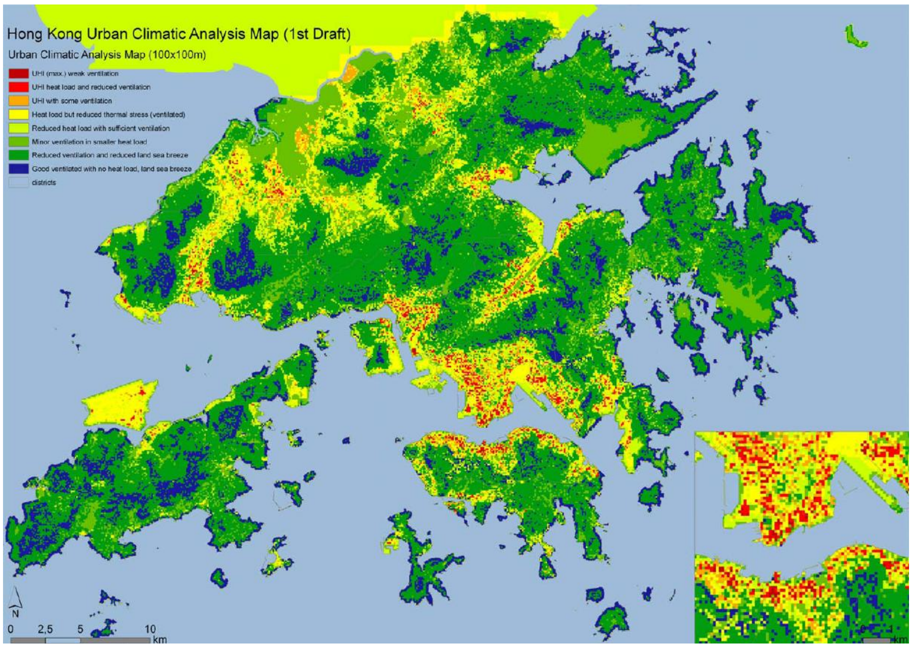

Figure 4: The draft UC-AnMap of Hong Kong.

Referring to Figure 6, one can immediately see the combined effects of buildings, open spaces, the natural landscape and topography. The UC-Map illustrates a strategic and holistic approach towards understanding the urban climate of Hong Kong. When the UC-Map is further examined at 100x100m grid resolution, the wall like effects of buildings along the coastline is apparent. There are small gaps, and those might need some protection. The downhill katabatic wind from the south over the ridges of the hill on the Hong Kong Island can be detected. This, perhaps more important than the already diminished coastline sea breezes, contributes positively to the urban climate.

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ESTIMATING RESOURCE CONSUMPTION USING URBAN TYPOLOGIES

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ABSTRACT

This paper describes an approach developed to estimate the resource consumption of cities using urban typologies. Urban typologies are identified at the neighbourhood scale using parameters that describe the physical environment. These typologies are then used to estimate the resource consumption of neighbourhoods. The objective of this methodology is to identify relationships between parameters describing urban form and resource consumption. In this paper, the focus is on measuring the material required to construct the infrastructure and buildings required for each typology.

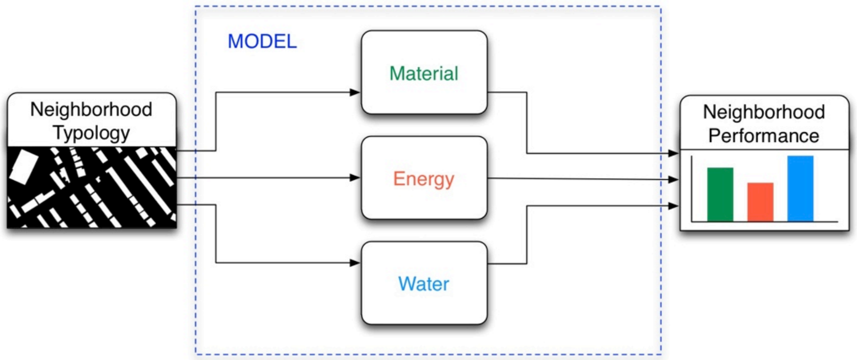

Figure 1: Neighbourhood typology analysis: this paper focuses on material usage.

INTRODUCTION

Typologies are identified from the existing building stock of London, and their material intensity is analysed. Material intensity is calculated based on construction materials used in residential buildings and urban infrastructure. Future work will examine the energy consumption of typologies (considering heating, cooling and transportation), as well as water consumption (*Figure 1*).

BACKGROUND

This work draws upon the research area of urban metabolism to consider the resource demand of urban areas at the micro-scale. The analysis seeks to identify mechanisms of behaviour that consume resources and to develop a rigorous method to estimate resource demands. The focus on an explanatory mechanism is an important aspect of this work, as it can inform policy makers about strategic targets for resource efficiency.

Although global urbanization is rapidly occurring, most economic and resource-use data is collected at the national, or regional scale. Therefore, the development of standardized methods to calculate resource consumption at the neighbourhood scale has global relevance, as it can fill these systematic data gaps and help estimate the resource consumption of cities.

Urban Typologies

Developing an approach for urban typology identification and assessment is motivated by a holistic view of urban systems where trade-offs between material, energy and water consumption are explored. Through the development of a repeatable methodology for identifying urban typologies, the performance of urban forms can be compared throughout a city and across cities. Typologies can be analysed in detail, considering renewable energy potential [1], as well as urban heat island calculations, or urban air-flow patterns.

Characterizing urban form using typologies has previously been done using several different approaches. Some examples of typology analysis from US cities have considered land-use [2] and socio-economic factors [3], but physical criteria were not considered. Other work has examined the influence of neighbourhood-scale urban form on travel behaviour [4]. Detailed neighbourhood measurements were used to measure the policy effectiveness of an urban growth boundary, to identify if it had reduced urban sprawl [5]. Neighbourhood typologies have also been used to examine energy use. Yamaguchi [6] divided Osaka city into representative districts depending on their land-use, and created typologies using urban form measures. These typologies were then used to predict the energy used for heating and cooling.

METHODOLOGY AND DATA

This analysis is structured in two parts. The first part describes the process of identifying typologies through grouping of urban form measurements; the second part describes how these physical characteristics are converted into material units. This analysis is applied to the greater London area at the *Lower Layer Super Output Area*[1] (LLSOA) scale. In the greater London area there are approximately 5600 LLSOA units. Average values for the number of people, buildings and area, per LLSOA, are summarized in Table 1.

Measure	Count (St. Dev.)
Population	1500 (11)
Buildings	178 (113)
Area [km^2]	0.49 (1.4)

Table 1: Average characteristics of LLSOAs used in this analysis

Typology Identification

Physical parameters were identified that describe the urban form (Table 2) and these measures were used to identify clusters. The data sources used for clustering in this analysis were a 3D building model [9] and a 3D building model with land-use categorizations [10]. After calculating urban form measures for each LLSOA, a statistical clustering technique was used to identify groupings in the data.

Category	Description
Plot Ratio	Total floor space / LLSOA area
Green Space Fraction	Total green space / LLSOA area
Built Area Fraction	Total built footprint / LLSOA area
Average Building Height	Average height of buildings in LLSOA

Table 2: Measurements of urban form (both residential and commercial buildings are included)

[1] The LLSOA is a spatial unit defined by the UK census bureau [8]

The k-means algorithm was used to identify the clusters. This algorithm partitions data into k number of clusters (where k is chosen based on graphical observation), using n observations. In this case, three cluster groups were chosen (k=3, n=5625) and the statistical language R [11] was used for the calculations. The implementation of k-means in R was the default McQueen implementation, which functions by iteratively partitioning the data until it reaches convergence. The resulting clusters were then used to identify building typologies.

Material Conversion Factors

Several data sources were used to estimate the amount of material required to construct infrastructure and residential buildings. These data sources came from guidelines for road construction [12-16], aggregated surveys of existing buildings [17], and typical construction methods [18].

Infrastructure: Using UK road construction guidelines, values to convert geometric measurements of various road types into kilograms of materials were calculated by examining UK local council guidelines [12-16]. The data from these sources are summarized in Table 3.

	Asphalt	**Gravel**
Thickness *[m]*	0.15	0.34

Table 3: Local or minor road construction specifications

Linear vector layer road data with road-type categorization was used [19], in addition to polygons representing roads [10]. These polygons, which represented the street network [10], accurately measured the varying street widths using remote sensing data.

Residential Buildings: Residential buildings were identified from the UK building dataset [10] and analysed at the LLSOA level. In the study area, over 92% of houses in the English Condition Housing Survey (EHCS) [17] were constructed of masonry (masonry cavity 64.7%, solid masonry 27.2%). A typical masonry cavity house (the average glazed area was 37% of the wall area) was used to estimate the material requirements for an average house. Based on typical construction methods, conversion factors for wall, floor and roofs were calculated (Table 4). These conversion factors were then used to convert the geometric measurements of residential buildings into kilograms of materials.

Element	**Masonry** [kg/m^2]	**Glazing** [kg/m^2]	**Timber** [kg/m^2]
Wall	480	10	-
Roof	-	-	21
Floor	-	-	32

Table 4: Typical material requirements for the shell of an average masonry cavity wall.

RESULTS

The typologies shown in Figure 2, were identified using the urban form measures described in Table 2. These boxplots summarize the distributions of the input measurements by cluster. The boxplots exhibit a reasonable separation for each of the three groups (the mid-range of the quartiles do not overlap for three of the four variables). The results from the clustering process are used to categorize each LLSOA into one of the three typologies. The spatial distribution of the clusters is shown in a map of the greater London area in Figure 3. A representative example of each of these clusters is shown in Figure 4 where the differences in the urban form can be understood intuitively.

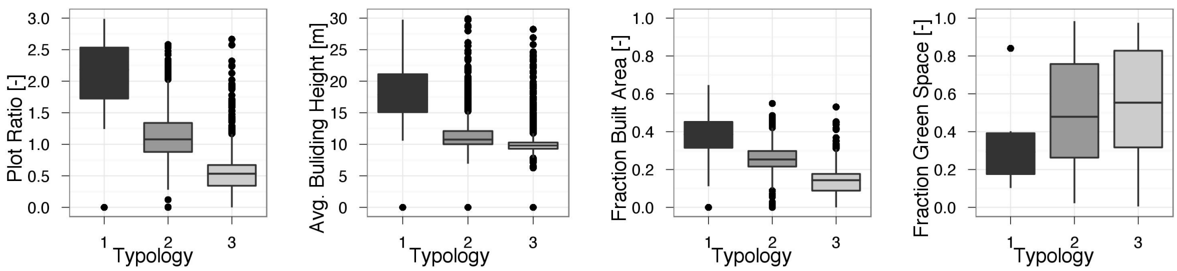

Figure 2: Typologies identified from clustering using urban form measures

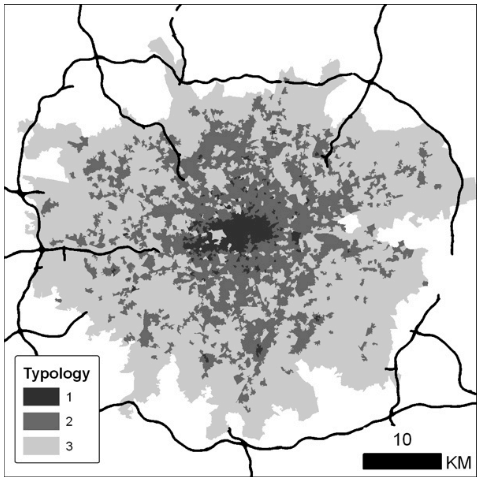

Figure 3: Map of London showing the grouping of the LLSOA divisions in three clusters. The black line represents the motorway around London.

These typologies are distributed radially (Figure 3) and reflect the population density of London. As a measure of population density is not used as an input, the typologies are considered to be an appropriate characterisation of the urban form.

Figure 4: Examples of a representative LLSOA unit from each typology

Although the material conversion factors used have several simplifications regarding residential construction (see section on Material Conversion Factors); the envelope area of residential buildings has a more significant impact on material consumption, than the road area of local infrastructure (Figure 5). Although typologies 2 and 3 have comparable amounts of green space (Figure 2) and similar material requirements per household, the variation in urban form can be explained through a difference in plot ratio (Figure 4) and infrastructure per household.

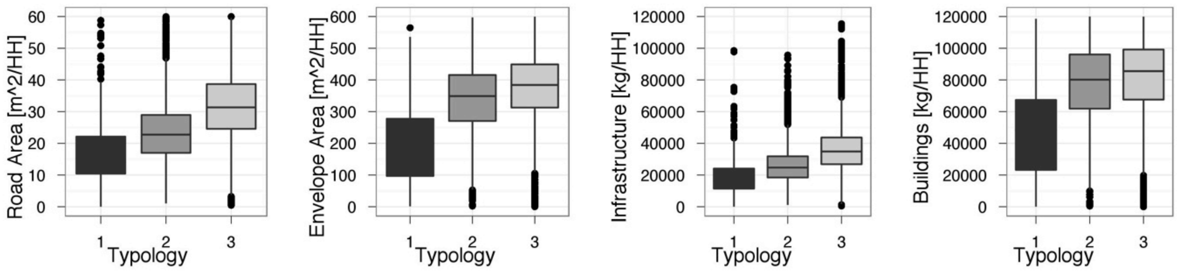

Figure 5: Area of infrastructure and residential envelope; material required for infrastructure and residential buildings. All measures are per household and typology.

DISCUSSION

Through the calculation of material required for the built environment of the three different typologies, a spatially resolved resource intensity measure has been obtained. This measure can be used to develop an efficiency metric, where the resources required for a certain typology, are attributed to the residents of that neighbourhood[2]. However, the fabric of the urban form is not homogeneous as there is usually a mixture of land-use types, where residential and commercial areas are mixed. Adequately attributing the physical infrastructure to residents requires measurements of the relevant part of the built environment that is used by residents. In this study, only the residential aspect of urban form was considered and a distinction between road infrastructure and buildings was made. In the case of roads, only local and minor roads were considered to be directly attributable to each LLSOA; motorways and major arteries have been excluded from the calculation of material required for the road infrastructure per LLSOA.

Using these assumptions the road are and envelope area are shown in Figure 5. Using the material conversion factors previously described, estimates of the material required for infrastructure and buildings are also shown in Figure 5. In a future phase of this work, a more comprehensive measure will consider the amount of business activity so that non-residential material intensity can also be calculated.

CONCLUSION

The goal of this work was to develop a repeatable methodology for estimating typology performance based on resource consumption; an approach that can be applied to different cities around the world. Formalizing how to identify typologies and how urban typologies perform with regard to material intensity is the first step in this approach. This analysis has shown that urban typologies can be identified using simple neighbourhood scale measures of the urban form. Comparing the material intensity of each typology has shown significant differences in the material quantities in the case of the greater London area.

The potential practical impacts of this work are two-fold: (1) the knowledge acquired can be used in urban design by helping improve design guidelines for new sustainable neighbourhoods; (2) this analysis can contribute to policy development, by identifying areas relevant for regulation so that improved urban resource efficiency can be achieved.

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[2] Such an efficiency measure assumes that both neighborhoods are providing the same unit of service which could be measured using a 'quality of life' metric. However, this is a subjective measure.

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PASSIVE COOLING OPERATION BY ACTIVATED OUTER SURFACES - FEASIBILITY STUDY FOR SWITZERLAND

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ABSTRACT

In modern highly-insulated office buildings the summer operation is getting more important. Different passive cooling techniques have established as cooling option mainly for office buildings and offer an energy-efficient way to increase the overall performance of the cooling operation. However, each of the established heat sinks, e.g. the ground or outside air, has particular limitations. On the other hand, space cooling by nighttime convection and radiation of an activated outer surface has rarely been considered or validated in practical operation for Swiss climate conditions, yet. A feasibility study by simulations of an activated outer surface delivered the results, that for the Swiss weather conditions the method is suited for nighttime passive cooling operation. It is capable of reaching considerable degrees of coverage of 60% even in an extreme summer climate of the Swiss weather data set "Lugano warm". In normal summer climate of the Swiss midland "Zurich normal", more than 90% of the cooling needs of an individual office room can be met. Cooling capacities in the range of 50-100 $W/m^2_{surface}$ are reached. In the "Zurich normal" summer climate 50 $W/m^2_{surface}$ are exceeded for more than 70% of the nighttime hours, while this value is diminished to 35% of the nighttime hours in the extreme summer climate "Lugano warm". The most important feature of the outer surface is long-wave emittance while the most important operation parameter is the average surface temperature. Regarding the electrical energy expenditure for the cooling operation, the typical high performance factors for passive cooling systems of 10 - 35 are reached, mainly depending on the pump efficiency. The main restrictions of the passive cooling by activated outer surfaces are the strong dependency on the weather conditions which implies a night-time-only cooling operation and thus the necessity of storage systems. Due to area restrictions of the building envelope the method is most suited to low-rise buildings with moderate cooling loads. However, in particular in connection to a heat generation during daytime, the method may hold interesting integration opportunities.

INTRODUCTION

Summer comfort has become a major issue in the design of office buildings due to high internal loads. Recently, passive cooling techniques - also known as free, direct or natural cooling - using a natural heat sink are increasingly applied. Every natural heat sink, though, has its limitations. High nighttime summer outdoor air temperatures, for instance, limit the heat rejection by nighttime ventilation. A passive cooling technique seldom evaluated for Swiss climate, yet, is the heat rejection by convection and in particular nighttime radiation to the sky by activated outer surfaces.

In this paper, results of a feasibility study for Swiss climate conditions are discussed regarding the features of the outer surface, the operation characteristic and the use profile of an individual office room pair in different orientations. Results on different use profiles of an open plan office and a single family house equipped with floor heating are described in [1].

METHOD

The feasibility of the space cooling concept has been evaluated using coupled building and system simulation in the simulation environment MATLAB-Simulink with the CARNOT-Toolbox [2], which contains a 2-star room model according to Feist [3] and Beuken models [4] for the wall components.

Room model

A pair of individual office rooms in north and south orientation shown in Figure 1 has been evaluated based on a type room defined in VDI 2078 [5]. The main features of the type rooms are given in Figure 1. Only the south-oriented zone is shaded. A mechanical ventilation guarantees an air exchange rate of 1.33 h^{-1} during working hours, infiltration adds 0.1 h^{-1}. Internal load profiles are based on DIN V 18599-10 [6] and SIA 2024 [7], which basically define the same values. Office working hours are assumed from 7 a.m. to 6 p.m., the ventilation system starts 2 hours earlier at 5 a.m.. Façade components have been chosen to comply with typical values of low energy houses. Thereby, cooling loads can be entirely covered by the thermally activated building systems (TABS).

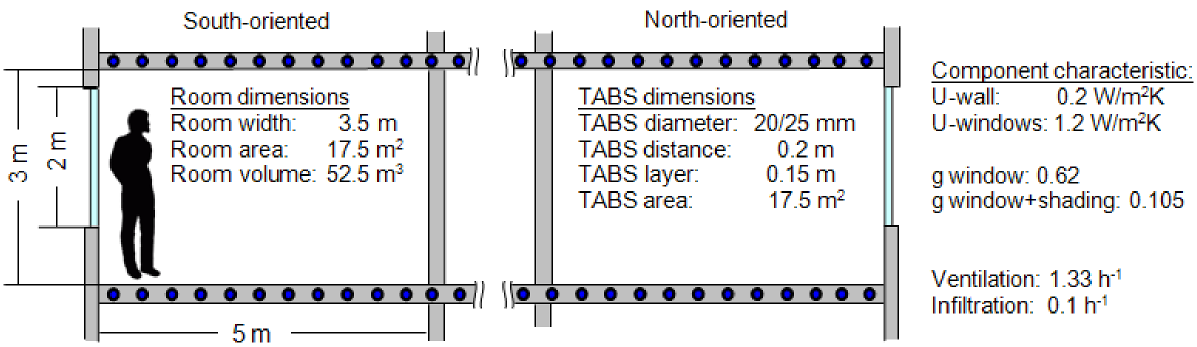

Figure 1: Room configuration and parameters

The TABS are integrated in the mid of the 30 cm strong concrete ceiling over the whole room area. The TABS inner/outer diameters are 20/25 mm, respectively, with a distance of 0.2 m. Concerning the site, a normal summer climate for the Swiss midland represented by the weather data set Zurich MeteoSchweiz normal year (denoted "Zurich normal") and an extreme summer climate in Ticino, represented by the weather data set Lugano warm year (denoted as "Lugano warm") according to SIA 2028 [8] have been considered.

Model of the outer surface of the building envelope

The outer surface has been modelled as unglazed collector by a differential node model for the absorber temperature T_A and the fluid temperature T_f with the respective capacities c_A and c_f according to equation (1) similar to Soltau [9]. Variables are explained in the following paragraphs.

$$\begin{aligned} c_A \frac{dT_A}{dt} &= \dot{q}_{sol} + \dot{q}_{cond} - \dot{q}_r - \dot{q}_c - \dot{q}_b - \dot{q}_f \\ c_f \frac{dT_f}{dt} &= \dot{q}_f - \Delta h_f \end{aligned} \tag{1}$$

Solar heat flux q_{sol} is modelled by the absorption of the incoming radiation on the inclined surface differentiated into the direct and diffuse component each multiplied by a distinct Incidence Angle Modifier (IAM). Condensation heat flux q_{cond} is modelled based on a convective heat transfer coefficient (see below) according the analogon between the heat and mass transfer (Le-number of 0.845) and the vapour pressure difference between the ambient air and the surface. Since only the nighttime operation in the summer half of the year and closed circuits without water spraying have been considered in the simulations, both terms do not contribute to the cooling power in nighttime operation.

The one main heat flux for the cooling operation is the nighttime radiation heat flux q_r, which is modelled by Stefan-Boltzmann law dependent on the view factors to the ambient air at temperature T_a and the sky for the inclination angle of the surface β

$$\dot{q}_r = \sigma \cdot \varepsilon \cdot [\frac{1+\cos\beta}{2}(T_A{}^4 - T_{sky}{}^4) + \frac{1-\cos\beta}{2}(T_A{}^4 - T_a{}^4)] \quad (2)$$

The sky temperature T_{sky} is derived from Swiss standard meteo data sets according to SIA 2028 by the equation of Martin and Berdahl [10], taking into account the dew point and ambient air temperature for clear sky conditions and the cloud index (available in six hour resolution in the data sets) to account for cloudy skies.

The second important heat flux by convection q_c is modelled by a wind dependent heat transfer coefficient

$$\dot{q}_c = h_c \cdot (T_A - T_a) \quad (3)$$

Wind data are recalculated from the meteo data for urban built environment at 10 m altitude according to SIA 2028. The convective heat transfer coefficient h_c is calculated for mixed convection as superposition of forced and free convection. It is derived by the respective Nusselt correlations, where the Nu-number for forced convection is evaluated for a flow on a flat plate and the Nu-number for natural convection is differentiated between heat flow upwards and heat flow downwards, depending on the actual absorber node and ambient air temperature.

Heat flux between absorber and fluid q_f is evaluated for the heat conduction in the absorber depending on geometry and the convective heat transfer in the absorber pipes depending on the internal flow velocity.

Backside heat flux q_b has been modelled by taking into account an insulated backside of 5 cm at heat conductivity of λ=0.036 W/m/K in order to accomplish a conservative estimation of heat losses for a roof-integrated component, since in this case the front losses to the ambient and the sky are dominating.

Δh_f describes the enthalpy change of the fluid.

Evaluation

The feasibility of the activated outer surface is evaluated in terms of the specific cooling power of the surface and the degree of coverage of the cooling energy needs. In the case that not the entire cooling need can be covered by the passive cooling operation of the outer surface an additional conventional back-up cooling is operated to maintain operative temperature within the limits according to SIA 382/1 [11], which defines an upper temperature limit between 24.5 °C and 26.5 °C depending on the daily maximum of 1 h average outdoor air temperatures.

RESULTS

The significance of the operating conditions in terms of the average temperature of the activated surface is depicted as cumulative frequencies of the cooling power at different constant inlet temperatures in Figure 2. Figure 2 left shows the cooling power for the weather data set "Zurich normal" during the nighttime hours 8 p.m. to 5 a.m.. For a constant inlet temperature of 24 °C, which reflects an upper temperature limit for the operation of a TABS system, a cooling power of 50 $W/m^2_{surface}$ is exceeded in more than 70% of the nighttime hours, while 100 $W/m^2_{surface}$ are exceeded in 30% of the nighttime hours. For a constant inlet temperature of 16 °C reflecting a lower temperature limit for the operation of a cooling ceiling, the cumulative frequencies are significantly reduced to about 30% above 50 $W/m^2_{surface}$ and only about 10% above 100 $W/m^2_{surface}$. Figure 2 right presents the results for the extreme summer conditions of "Lugano warm", where cooling power is further reduced due to the higher outdoor air temperatures. At 24 °C inlet temperature to the activated surface, cooling power still exceeds 50 $W/m^2_{surface}$ in about 40% of the nighttime hours and 100 $W/m^2_{surface}$ in about 10%. However, at inlet temperatures of 16 °C only 25% of the nighttime hours reach 50 $W/m^2_{surface}$ and only 3% go beyond 100 $W/m^2_{surface}$.

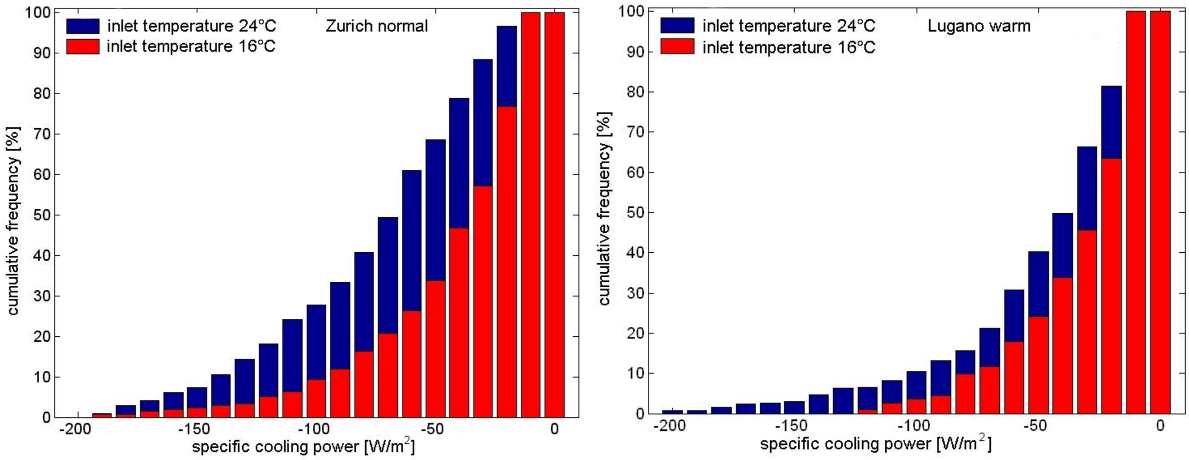

Figure 2: Cumulative frequency of the cooling power of the outer surfaces at inlet temperature of 24 °C (blue) and 16 °C (red) for the weather data sets "Zurich normal" (left) and "Lugano warm" (right).

While the cooling power is a useful design parameter, a more meaningful value for the energy evaluation is the degree of coverage in the whole summer period from the beginning of April (day 91) to the end of September (day 273).

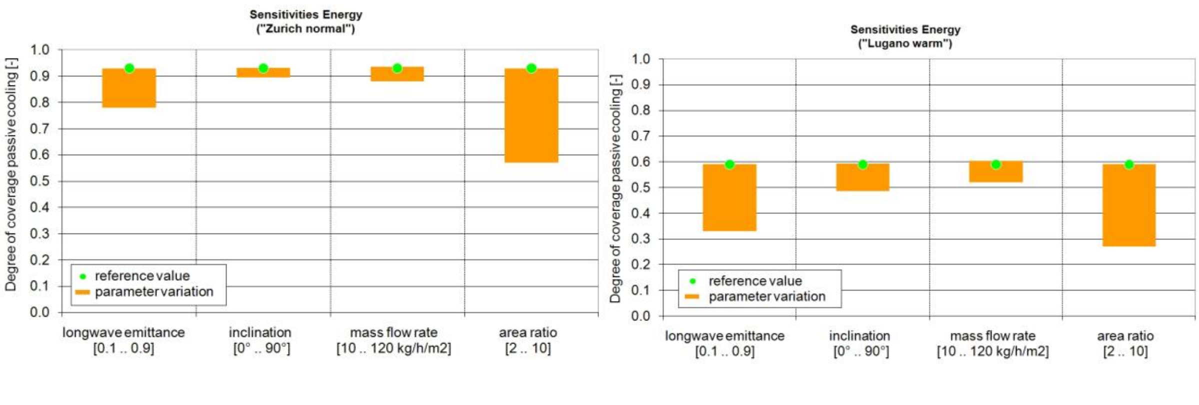

Figure 3: Degree of coverage and sensitivities for the "Zurich normal" (left) and "Lugano warm" (right)

Figure 3 summarises the results of parameter variation of the characteristics long-wave emittance, inclination of the surface, mass flow rate and area ratio between the net zone area and the activated outer surface for the two weather data sets "Zurich normal" and "Lugano warm" for the above mentioned 6-month summer period. For "Zurich normal", depicted in Figure 3 left, a high degree of coverage above 90% is confirmed for the reference conditions, referring to an emittance of 0.9, an inclination of 30°, a mass flow rate of 50 $kg/m^2/h$ and an area ratio between zone area and outer surface of 2. As for the cooling power the main impact is the emittance in the long-wave spectrum. The inclination of the surface and the mass flow rate have only little impact, but a higher area ratio decreases the degree of coverage.

In the extreme summer "Lugano warm" depicted in Figure 3 right, convective heat rejection to the ambient is limited due to the higher nighttime outdoor air temperatures. Therefore, the total degree of coverage is reduced to about 60% under reference conditions. Different to "Zurich normal" the degree of coverage is more affected by the inclination angle with a decrease of about 10% for vertical surface inclination.

Efficiency	**very high**	**average**	**poor**
Electrical power circulation pump outer surface	20 W	40 W	60 W
Efficiency back-up cooling	5.2	4.1	3.3
Running time (ZH normal / LUG warm)	843 / 1314 h		
Heat rejection passive	668 / 731 kWh		
Heat rejection back-up	43 / 535 kWh		
Total heat rejection	711 / 1266 kWh/a		
Electrical energy passive cooling	17 / 26 kWh/a	34 / 53 kWh/a	51 / 79 kWh/a
Electrical energy back-up cooling	8 / 103 kWh/a	10 / 130 kWh/a	13 / 162 kWh/a
$SPF_{c,passive}$	**39.6 / 27.8**	**19.8 / 13.9**	**13.2 / 9.3**
$SPF_{c,combi}$	**28.3 / 9.8**	**16.1 / 6.9**	**11.2 / 5.3**

Table 1: Sensitivities of the generator performance factors for the passive and combined cooling operation

Table 1 summarises evaluations of the generator seasonal performance factor for the passive and combined cooling operation. It is confirmed that the performance factor reaches high values both for passive cooling and combined cooling including a back-up operation. The importance of the pump efficiency is obvious. At high pump efficiency (20 W in Table 1) seasonal performance factors of the passive cooling ($SPF_{c,passive}$) above 30 are reached. The performance factor decreases to around 10 for the application of less efficient components (40-60 W in Table 1). However, even in "Lugano warm" a combined performance factor ($SPF_{c,combi}$) including back-up cooling above 5 is reached in this case.

DISCUSSION

The simulation results confirm that under Swiss weather conditions a passive cooling operation by activated outer surface is a feasible option to reduce the electrical energy expenditure for space cooling. In normal summer climate in the Swiss midland more than 90% of the cooling need of an individual office room can be covered by passive cooling operation. Cooling capacities range between 50-100 $W/m^2_{surface}$. Thus, about 500-1000 $Wh/m^2_{surface}$ can be extracted from 8 p.m. until 6 a.m. Even in extreme summers in Lugano, 50 $W/m^2_{surface}$ are exceeded in 40% of the nighttime hours in case of high inlet temperatures of 24 °C to the activated outer surface. With efficient pumps, e.g. of EU A label, high generator performance factors of more than 30, which are typical for passive cooling operation, can be achieved.

Parameter variations confirm that main design parameters of the system configuration are the surface long-wave emittance, since the heat rejection is dominated by the radiative heat transfer to the sky, and supply temperatures to the surface, i. e. the design temperatures for the heat rejection in the room. Thus, most materials are suited for the passive cooling by outer surfaces except for blank metals and selectively coated surfaces with limited radiative heat transfer.

The main restriction is caused by the distinct diurnal temperature and irradiation variations limiting the cooling operation to nighttime hours and implying the integration of a storage into the system. Moreover, high nighttime outdoor air temperatures may limit the performance.

ACKNOWLEDGEMENTS

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QUANTIFICATION OF RETROFIT MEASURES ON A MULTI-FAMILY RESIDENTIAL BUILDING FOR DIFFERENT EUROPEAN CLIMATES WITH DETAILED AND SIMPLIFIED CALCULATION TOOLS

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ABSTRACT

In the frame of the IEA project Annex 50 “Prefabricated Systems for Low Energy Renovation of Residential Buildings”, a simulation study was executed to show the order of magnitude of the measures to be taken with an example retrofit building at different locations in order to reach the energy demand goal of 30 to 50 kWh/a per m^2 gross heated area of primary energy for heating, ventilation and domestic hot water production. The measures to be taken included improved building insulation, including window replacements; the application of a ventilation system with heat recovery; the use of solar energy for domestic hot water production; and an improved energy production (by replacement of the heat generation).

An example building was chosen, being considered as typical enough for all participant countries. A three step procedure was applied to involve the different project partners with different calculation tools in the study:

- In a first step, the building was calculated “as is” at its original location, in order to compare the results achieved by the different partners with different tools.
- In a second step, the same building was calculated at a location of the participant’s country, in order to show the influence of the location on the same building.
- In the third step, the building had to be calculated at the location of the participant, and the respective measures had to be defined and quantified.

The step 1 calculations showed a systematic difference between the results for the useful energy demand for space heating (without domestic hot water) from the simplified calculation tools and from the detailed simulation programs. It could be confirmed that this difference originates to a large extent by the different treatment of losses through or against unheated spaces like staircases, basements and unheated attic spaces. This also showed that there is a considerable reserve in the energy demand calculated by the simplified calculations for the buildings considered here due to this fact.

From the step 2 calculations it could be seen that the energy demand of the building reacts as expected to the different climates for the locations considered.

For the step 3 calculations, being the main step of this study, a retrofit strategy was applied, which includes an extension of the heated space in the attic and basement floors, the enclosure of the balconies and an additional elevator tower with access balconies. For the three climates of Lucerne (Switzerland), Stockholm (Sweden) and Guimarães (Portugal), the necessary measures, such as U-values, glazing properties and solar collector area were identified to reach the goal. For the Swiss climate, the measures were identified in dependence of the heat generation system.

INTRODUCTION

General

The work reported in this paper was done in the frame of the project IEA ECBCS Annex 50 “Prefabricated Systems for Low Energy Renovation of Residential Buildings” [1]. The objectives of this Annex have been the development and demonstration of an innovative whole building renovation concept for typical apartment buildings. The concept is based on largely standardised façade and roof systems that are suitable for prefabrication. The highly insulated new building envelope includes the integration of a ventilation system.

Participating countries were: Austria, Czech Republic, France, Netherlands, Portugal, Sweden and Switzerland.

Calculation Exercise

The goal of the calculation exercise, which is described in full detail in [2], was, to show the order of magnitude of the measures to be taken at different locations in the countries represented in the task on typical retrofit cases, in order to reach the energy demand goal defined in the project definition, i.e. the amount of 30 to 50 kWh/(m^2•a) of primary energy for heating, ventilation domestic hot water production and possibly cooling (if needed). With one or more example retrofit buildings, the measures to be taken to reach this goal should be specified and quantified. Measures include

- Improved building insulation, including window replacements and additional insulation of opaque surfaces;
- the application of a ventilation system with heat recovery;
- the use of renewable energy sources, especially solar energy for domestic hot water production;
- improved energy production (by replacement of the heat generation), possibly including electricity production;

METHOD

Object Choice

Figure 1: Main façades of the Elfenau building (photos: Robert Fischer, HSLU)

The Swiss potential demonstration building “Elfenau”, located in Lucerne (see figure 1), was chosen as the example building. The building is one half of a multi-family house with three regular floors with 2 flats each, an unheated basement with garages, cellar rooms and a heating central, and an attic floor with two small single room flats and unheated attic space. The construction is rendered double brick masonry with concrete floor slabs and a concrete basement. The sloped roof is tile covered. Windows are double glazed with a wood frame. The radiator heating system is served by an oil fired boiler, which also provides domestic hot water. Ventilation is purely natural through open windows.

The building, erected 1958, was considered by all project group members representative for a considerable part of their building stock.

Calculation Procedure

The calculations were performed in different steps as summarised in table 1.

Calculation Step	Description	Location	Climate	Building use
1	Building as is	Lucerne, Switzerland	Lucerne	According to specifications
2	Building as is	Chosen by contri-buting country	According to location	According to common prac-tise in contributing country
3	Retrofit case	As for step 2	As for step 2	As for step 2

Table 1: Calculation steps

The goal of step 1 was, to compare the results from the different tools used by the different countries, in order to get an indication of the accuracy of the results obtained. The use of different level tools led to the expectation, that there would be differences in the results, which would have to be explained.

The building use data were derived from the Swiss standard for heating energy performance of buildings. The global values for occupancy, lighting and equipment were translated into schedules, considering seasonal variations like day length for lighting etc., in order to provide enough detailed information for the detailed tools. This way it was made sure, that there was at least no difference between the detailed and simplified tools from this side.

In step 2, the influence of the different locations was to be shown. The calculations were made based on the same specification as step 1. Instead of the provided climate and use information, the contributor's own information was used.

In step 3, the retrofit measures were applied, specified and quantified. The base of this calculation was, in respect of building geometry, a retrofit strategy in form of a set of new plans, provided by the Swiss retrofit team. This strategy considers the situation that retrofit measures often not only consist of an energy related improvement, but include building enhancements in form of additional space, added elements needed for compliance with current standards and regulations (not only energy, but security, handicapped accessibility etc.). The strategy includes an added lift tower and attached balconies, an extension of usable area in the attic and basement floors and the inclusion of former balconies in the heated area.

Overview of the Calculations Performed

For the different steps, different project partners contributed results, using different programs. Both simplified calculation tools (on a monthly or even seasonal basis) and detailed simulation programs were used. An overview of the contributions is given in table 2.

Calculation Step	Contributing country	Tool	Tool Category
1 and 2	Belgium	PEB - CALE2 [3]	Simplified
	Portugal	RCCTE [4]	Simplified
	Portugal	Energy+ [5]	Detailed
	Czech republic	Bsim 2000 [6]	Detailed
	Switzerland	IDA-ICE 4.0 [7]	Detailed
3	Portugal	RCCTE	Simplified
	Portugal	Energy+	Detailed
	Switzerland	IDA-ICE 4.0	Detailed

Table 2: Calculation contributions

RESULTS

The results from the different contributors for steps 1 and 2 are shown in table 3.

The values for the primary energy demand were derived from the contributed values for the useful energy demands for space heating. The assumptions for the calculation of these values are: useful energy demand for domestic hot water: Q_w = 75 MJ/(m^2 a); distribution efficiency for domestic hot water: $\eta_{d,W}$ = 0.7; heat generation efficiency (heating and domestic hot water): η_g = 0.8; primary energy factor: f_{PE} = 1.24 (oil). With this, the following calculation formula results, and the values can directly be compared.

$$E_p = (Q_h + Q_W / \eta_{d,W}) / \eta_g \cdot f_{PE} = (Q_h + \frac{75}{36 \cdot 0.7}) / 0.8 \cdot 1.24 \quad (1)$$

		Step 1: as is, Lucerne climate		Step 2: as is, local climate		
		Useful energy demand for space heating	Primary energy		Useful energy demand for space heating	Primary energy
Contributor	**Program**	kWh/m^2	kWh/m^2	Location	kWh/m^2	kWh/m^2
Belgium	PEB-CALE2	137	259	Liège	125	239
Portugal	RCCTE	147	274	Guimarães	60	139
Portugal	Energy+	98	198	Guimarães	18	74
Czech Rep.	Bsim 2000	105	209	Brno	139	261
Switzerland	IDA-ICE 4.0	94	192	Lucerne		
Switzerland	IDA-ICE 4.0 with Simplifications	136	257	Lucerne		

Table 3: Calculation results from steps 1 and 2

The step 1 calculations showed a systematic difference between the results for the useful energy demand for space heating (without domestic hot water) from the simplified calculation tools (137-147 kWh/(m^2•a)) and from the detailed simulation programs (94-105 kWh/(m^2•a)). By an additional calculation with a detailed simulation tool (IDA-ICE, last line in table 3) it could be confirmed that this difference originates to a large extent by the different treatment of losses through or against unheated spaces like staircases, basements and unheated attic spaces. The accordingly simplified model lead to a value of 136 kWh/(m^2•a).

From the step 2 calculations it could be seen that the energy demand of the building reacts as expected to the different climates for the locations considered.

The result of step 3 show the necessary building modifications to be applied at the different locations in order to reach the goal of a primary energy consumption for heating, ventilation and domestic hot water consumption of 30 to 50 kWh/(m^2•a). An annual heat recovery efficiency of 0.8 had to be considered. As the results strongly depend on the goal to be reached, they are shown separately in tables 4 and 5 for the lower and upper boundaries of the target.

		Lucerne	**Stockholm**	**Guimarães**
Exterior walls – new parts - retrofitted existing walls	W/(m^2·K)	0.15 0.2	0.15 <0.1*	0.23 0.23
Basement interior walls to non-heated zone	W/(m^2·K)	0.55	0.55	0.73
Balcony floor	W/(m^2·K)	0.15	0.15	0.67
Interior roof in contact with attic non-heated zone	W/(m^2·K)	0.55	0.55	0.34
Window frame	W/(m^2·K)	1.60	1.60	1.50
Glazing, U-value g-value	W/(m^2·K) -	0.8 0.5	0.8 0.5	1.1 0.45
Collector area	m^2	22.7	22.7	19.80

*or a different set of measures

Table 4: Calculation results from step 3 to reach the goal of 30 kWh/(m^2•a)

		Lucerne	**Stockholm**	**Guimarães**
Exterior walls – new parts - retrofitted existing walls	W/(m^2·K)	0.15 0.4	0.15 0.2	0.44 0.44
Basement interior walls to non-heated zone	W/(m^2·K)	0.55	0.55	2.43
Balcony floor	W/(m^2·K)	0.15	0.15	0.67
Interior roof in contact with attic non-heated zone	W/(m^2·K)	0.55	0.55	0.50
Window frame	W/(m^2·K)	1.60	1.60	2.35
Glazing, U-value g-value	W/(m^2·K) -	0.8 0.5	0.8 0.5	2.1 0.45
Collector area	m^2	22.7	22.7	15.84

Table 5: Calculation results from step 3 to reach the goal of 50 kWh/(m^2•a)

For the Swiss climate – assuming that the elements added new to the building such as balcony enclosures, new elements in the attic floor and the roof are made according to Swiss 2010 standard target quality, i.e. having a U-Value of 0.15 W/(m^2•K) – the value of 50 kWh/(m^2•K) is not really a challenge. To reach the value of 30 kWh/(m^2•a), measures were identified in dependence of the heat generation system. While the CHP according to the specifications and a gas boiler lead to nearly equal results given in table 3, the use of a heat pump allows for U-values for the existing building elements of 0.4 W/(m^2•K), the limit being defined by the comfort and damage prevention requirements rather than by the energy target.

For the northern climate of Stockholm, the same measures are sufficient to get under the value of 50 kWh/(m^2•a). To reach 30 kWh/(m^2•a), considerably lower U-values would be needed.

DISCUSSION

The results lead to insights in two areas:

- The systematic difference between the simplified and detailed calculation methods, leading to 42 % higher values for the useful energy demand for space heating given by the simplified tools, could be explained to a large extent by the different treatment of losses through or against unheated spaces like staircases, basements and unheated attic spaces. This also shows that there is a considerable reserve in the energy demand calculated by the simplified calculations for the buildings considered here due to this fact. Care must be taken when applying different classes of tools for the same target. The boundary conditions, including simplified assumptions for e.g. the treatment of unheated spaces, must be carefully set and clearly stated to ensure comparable results.
- The step 3 results show that the given span of the goal of 30 to 50 kWh/(m^2•a) is quite large. The upper boundary not really being a challenge, except for the northern climate, it is possible with a reasonable technical effort to achieve a target of 30 kWh/(m^2•a) for a wide range of European climates. Setting targets on the level of primary energy for space heating, ventilation and domestic hot water leads to a strong dependency on the type of heat generation. It must be decided whether this higher degree of freedom is wanted.

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INFLUENCE OF THE URBAN MICROCLIMATE ON THE ENERGY DEMAND OF OFFICE BUILDINGS

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ABSTRACT

A significant part of the world's energy consumption is used for heating and cooling of buildings. Because of the global trend towards urbanization, the minimization of the energy consumption of buildings in urban areas has a great energy-saving potential. Due to the urban heat island (UHI) effect a building in an urban area needs more energy for cooling and less energy for heating than the same building in a rural area. An important part of the energy exchange of a building with the ambient surrounding is the radiative and convective flow of heat. In this study detailed building energy simulations (BES) were used to analyze the effect of the neighbouring buildings on the radiative and convective flow of heat and their influence on the space cooling and heating demand of buildings in urban areas. Further a model based on measured data from Basel was used to account for the higher ambient air temperatures in cities due to the UHI effect. BES were conducted for a stand-alone building and buildings surrounded by street canyons with different aspect ratios. In the street canyons more solar and thermal radiation is absorbed at the façades and entrapped in the street canyon than at the façades of the stand-alone building due to multiple reflections. This effect causes higher surface temperatures in street canyons. During the night the surface temperatures decrease slower inside the street canyons due to neighbouring buildings that block the thermal radiation to the cold sky. These higher temperatures of the building mass cause higher space cooling and lower space heating demands for buildings in urban areas compared to rural areas. This trend is further increased by the UHI effect. The results of this study show, that it is important to take the urban microclimate into account for the prediction of the energy demand of buildings in urban areas, and moreover for peak cooling and heating load determination. With the here proposed model all the important effects of the urban microclimate can be captured and quantified on street canyon scale.

INTRODUCTION

Minimizing the energy demand of buildings in urban areas has a great energy-saving potential [7]. To predict the energy demand of a building in an urban area, it is important to account for heat fluxes at several scales: UHI effects at meso- and microscale as well interactions with the surrounding buildings at local scale [5]. Besides the air temperatures that are increased compared to rural areas due to UHI effects, the microclimate around a building is also affected by (1) the lower wind speeds due to wind-sheltering by other buildings, (2) reduced energy losses during the nights due to buildings that block the exchange of thermal radiation to the cold sky, (3) changed solar heat gains due to shadowing and thermal and solar radiation exchange between buildings. All these effects have an important impact on the energy demand of buildings [4], in relation to heat transmission at the envelope, but also to ventilation [3], and especially to the potential of passive cooling by night time ventilation.

Most BES codes used today do not account for the interactions of neighbouring buildings, except perhaps for shadowing. The purpose of this study is to demonstrate an approach for combined building energy and heat-air flow analysis of a street canyon case with adjacent three-storey buildings. Similar studies have already been done on larger (city quarter) scale (e.g. [2] and [5]), but with simplified approaches for convective heat transfer and long-wave radiation on the street canyon scale. Here, the 3D radiation model within the BES code TRNSYS 17 [9] was used for studying the thermal und solar radiation distribution in detail. Different correlations for the convective heat transfer coefficients (CHTC) at the façades, based on CFD (Computational Fluid Dynamics) simulations, were used to account for the different flow fields around the studied buildings [1]. In addition a model for the UHI intensities was developed based on measured data.

NUMERICAL MODEL

The space cooling and heating demand of the studied buildings is determined using TRNSYS 16 and 17 [9], for a one year period with time steps of one hour. As the 3D radiation model within TRNSYS 17 so far can only be used for interior rooms, the street canyon spaces between the different buildings are modelled inside TRNSYS 17 as “atria” with open ceilings. In this way, not only the shadowing by the neighbouring building is considered, but also the exchange of thermal and solar radiation between the different buildings. A modern three-storey office building with different surroundings is analysed. BESs are performed first for a stand-alone building in an open field, then for the same building with street canyons in front and behind the building. Street canyon aspect ratios of 0.5, 1 and 2 are considered (aspect ratio H/W with H: height of the building, W: street canyon width). Figure 1 shows the building studied, surrounded by streets canyon with aspect ratios of 1.

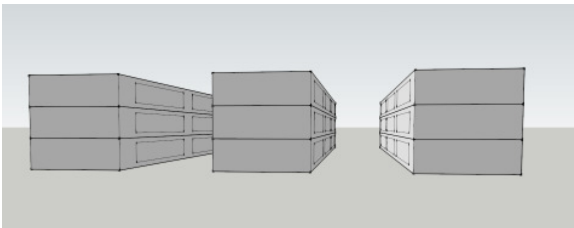


Figure 1: Studied building surrounded by street canyons with aspect ratios of 1. The building of interest is the middle building.

The studied building has a length of 110.5m (to minimize lateral boundary effects in the radiation model) and a total height and width of 13.5m. The building is well external insulated with a U-value for the walls of $0.25W/m^2K$, roof $0.15W/m^2K$ and ground floor $0.29W/m^2K$ (no basement is considered). The glazing fraction is 50% and windows with double glazing (U-value $1.4W/m^2K$, g-value 0.589) are used. Internal gains caused by lights, devices and persons and occupancies are set according to [8]. Light control is as follows: lights are on when the building is occupied and the solar radiation on the corresponding façades < $70W/m^2$. External shading devices are closed when solar radiation on the corresponding façades > $120W/m^2$. The building has an orientation showing a north and south façade, lateral façades are modelled as adiabatic. For the neighbouring buildings all walls are modelled as adiabatic except the one adjacent to the street canyon. To get realistic wall surface temperatures, the room air temperatures are controlled to be between 21°C and 26°C. A mechanical ventilation system is used (Day: airflow rate $30m^3$/h.person, heat recovery with 80% efficiency, ambient air is not heated to temperatures above 21°C; Night: air change of $1h^{-1}$ if building needs to be cooled). As the convective flow of heat at façades is smaller for buildings in street canyons than for stand-alone buildings, due to lower local air speeds, CHTC correlations from [1] are used in this study. These CHTC correlations are derived for infinite long stand-alone buildings and street canyons. Note that the CHTCs for the stand-alone building are rather low, due to the fact, that the air speeds at surfaces of an infinite long building are rather low. This is due to the fact that the air flow in this 2D configuration shows a standing vortex in the street canyon, without air flow to other street canyons, which would accelerate the air flow. A model for UHI intensity was developed, based on measured data in the city of Basel in the frame of the BUBBLE project [6]. Therefore the climatic data for Basel are used as input for the BES. The idea of this model is to get a schedule of the temperature difference between the rural (here Basel-Binningen) and the urban (here Spalenring) air temperature for one fictive day for each month. For each time of day the temperature difference are averaged for a time period from 1.9.1994-31.12.2001. The profiles can be seen in figure 2.

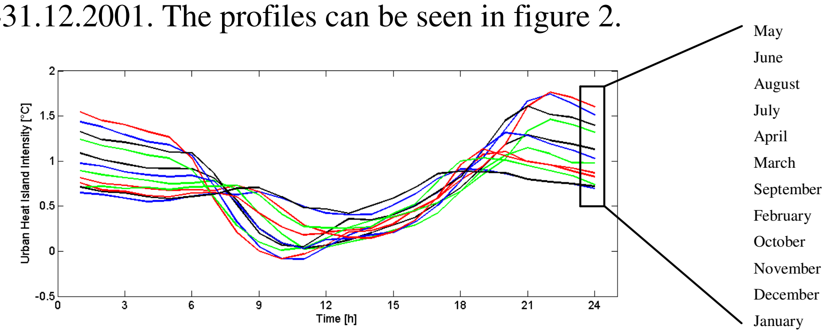


Figure 2: Schedule of the UHI intensity for fictive days for each month of a year.

RESULTS AND DISCUSSION

First the influence of neighbouring buildings on the radiation balances of the building façades was studied, with data of 48 hours (23rd and 25th June) extracted of the one year BES. This is a time period with high temperatures and low wind speeds, what is critical for space cooling. The BES are run for a stand-alone building and 3 street canyons with aspect ratios of 0.5, 1 and 2, with the same ambient temperatures (no UHI considered) and CHTC correlations (for a stand-alone building from [1]) for all cases. In figure 3 the wall surface temperature of the north and south façade, of the ground and the second floor are given for the stand-alone building and the same building surrounded by street canyons with different aspect ratios. The wall surface temperatures are higher for all the buildings surrounded by street canyons than for the stand alone building. These higher temperatures are caused by the multiple reflection of solar and thermal radiation inside the street canyons. This effect is stronger for the north than for the south façades, because in the street canyons direct solar radiation is reflected from the south façades onto the north façades. This reflected solar radiation is a significant part of the, on the north façade absorbed, solar radiation (see also figure 4). On the south façade, the absorbed direct solar radiation is the most important part. Besides the solar radiation also the thermal radiation exchange between the buildings further increases the façade temperatures. During the day the highest surface temperatures can be found for the street canyon with an aspect ratio of 0.5 and the surface temperatures are lower for higher aspect ratios, because more solar energy enters the wider street canyons. After sunset the surface temperatures of the buildings surrounded by street canyons decreases slower, because the thermal radiation to the cold sky is partially block by the neighbouring buildings. This effect is slightly stronger for narrower street. For both façades of the second floor the above described effects are lower than for the ground floor, because the interaction for the second floor facades with the sky gets more important than the interaction with the neighbouring buildings. As a result we observe that during the night the surface temperatures of the second floor facades are similar for all the studied cases. During the day the surfaces temperatures in the street canyons are still significantly higher than the ones of the stand-alone building, because the interactions with the neighbouring buildings are still important, but the temperatures differences between the street canyons with different aspect ratios are lower.

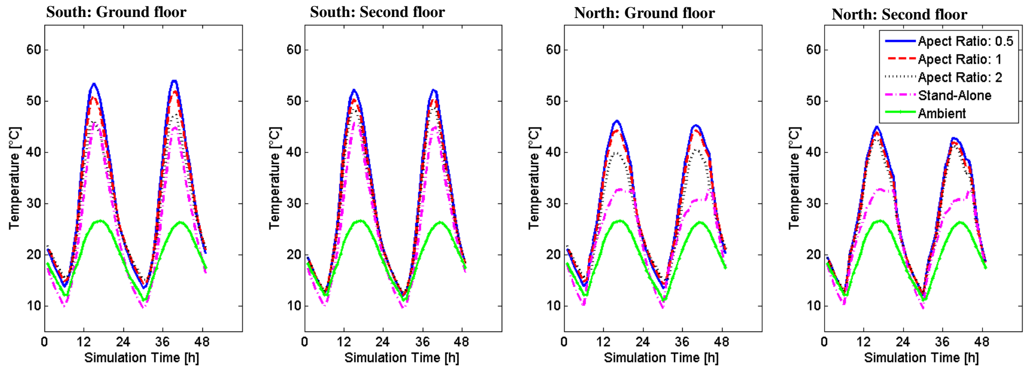


Figure 3: Wall surface temperatures and ambient air temperatures for the south and north façades of the ground floor and second floor (left to right) for a stand-alone building and buildings surrounded by street canyons with different aspect ratios (0.5, 1 and 2).

Figure 4 shows the absorbed solar radiation on the north and south façades of the ground and second floor for a stand-alone building and buildings surrounded by street canyons with different aspect ratios. The amount of absorbed solar radiation on the south façade is similar for all cases. In the street canyons more solar radiation is absorbed than on the stand-alone building because of the multiple reflections and more solar radiation is absorbed in wider street canyons. The profiles of the absorbed solar radiation on the north façade of the stand-alone building has three similar peaks in the morning, at noon and in the evening, while for the street canyons the peak at noon is the highest. This higher peak at noon is due to the reflected solar radiation from the south façade, were the (only) peak is at noon. For the ground floor more solar radiation is absorbed in the wider street canyons because more solar radiation can enter the street canyon. For an aspect ratio of 2 even with the multiple reflections less solar energy is absorbed than for the stand-alone building. For the second floor the differences between the different geometries are much lower but the differences between the stand-alone building and the street canyons are still significant.

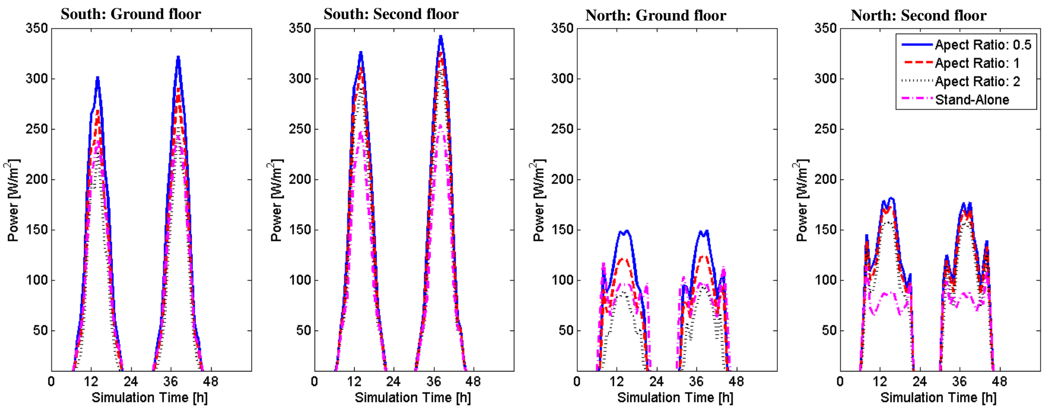


Figure 4: Absorbed solar radiation on the south and north façades of the ground floor and second floor (left to right) for a stand-alone building and buildings surrounded by street canyons with different aspect ratios (0.5, 1 and 2).

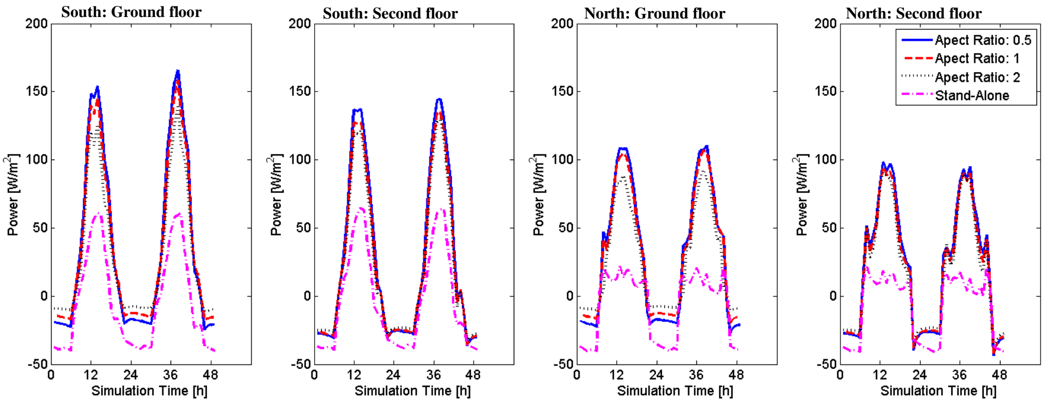
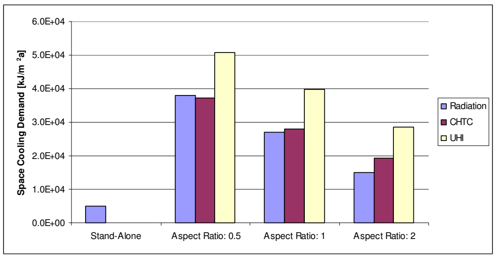


Figure 5: Radiation balances of the south and north façades of the ground floor and second floor (left to right) for a stand-alone building and buildings surrounded by street canyons with different aspect ratios (0.5, 1 and 2).

In figure 5 the radiation balances for north and south façades of the ground and second floor for a stand-alone building and buildings surrounded by street canyon with different aspect ratios can be seen. The radiation during the day is mainly influenced by the solar radiation that was already discussed above. During the nights the stand-alone building can radiate more thermal energy to the cold sky than the buildings surrounded by street canyons, where the thermal radiation is partially blocked by neighbouring buildings. The differences are again higher for narrower street canyons and higher for the ground than for the second floor.

In a second part of this study the influence of the urban microclimate on the energy demand for space cooling and heating were analysed in three steps. In the first step the space cooling and heating demand is determined for the cases considered above (case: "Radiation"). For the second step corresponding sets of CHTC correlations are used for each street canyon, as determined in [1] (case: "CHTC"). For the last step the above described UHI intensity model is used for street canyon cases (case: "UHI").

(a) 

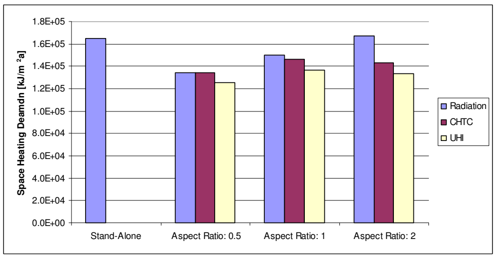
(b) 

Figure 6: Annual energy demand for space cooling (a) and space heating (b).

In figure 6a the energy demand for space cooling is given for the above described cases. It can be seen, that the space cooling demand for the stand-alone building is much lower than for the building situated in the street canyon. The cooling demand is highest for the wide street canyon (aspect ratios of 0.5) and is decreasing again for narrower street canyons. The high cooling demand for wide street canyons can be explained by the highest solar radiation entrapped in the street canyon, mainly due multiple reflections. The lower cooling demand in the narrow street canyon is due to less solar radiation entering the street. The different CHTC correlations become only important for narrow street canyons. The UHI effect increases the space cooling demand for all cases significantly. That means that for the determination of the space cooling demand the urban microclimate has to be taken into account. In figure 6b the results for space heating demand are shown. For the heating demand the differences between the different cases are much lower than for the cooling. In general, higher surface and air temperatures cause a decrease of the energy demand, and as such also the UHI has a positive effect. The UHI effect however has a lower impact on the heating demand, because it is less strong during winter than during summer (see also figure 2).

CONCLUSION

Important differences in space cooling demands were found between stand-alone buildings and buildings in street canyons. During the day radiative gains on the façades of buildings in street canyons become very high due to multiple reflections (entrapment of the radiation) and cause higher surface temperatures. During the night these temperatures decrease slower due to lower energy losses to the sky because of smaller sky view factors. In narrow street canyons the surface temperatures are further increased due to lower CHTCs due to lower air movement in the street canyon. These higher temperatures of the building mass directly cause higher space cooling and lower space heating demands for buildings in urban areas compared to rural areas. Additionally the UHI effect increases the space cooling importantly and to a lesser degree decreases the space heating demand. The impact of all these effects is stronger on the space cooling than on the space heating. This enhanced BES model can be used to predict the energy demands of buildings in street canyons accounting for the UHI effect, radiative entrapment by multiple reflections and the lower CHTCs. In future work, the CHTCs will be considered by conducting CFD simulations for each time step of the BES.

ACKNOWLEDGEMENTS

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OEIRAS MASTERPLAN: A METHODOLOGY TO APPROACH URBAN DESIGN TO SUSTAINABLE DEVELOPMENT

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ABSTRACT

This paper describes a new methodology for the conception of urban plans in order for them to fit the principles of Sustainable Development. The methodology herein presented makes use of different software for designing, calculations and dynamic modelling of buildings and urban spaces. The results from these assessments are then interpreted and incorporated in the urban design solutions.

This methodology was applied in a case study in Oeiras, Portugal, in the conception phases of the Oeiras Master Plan. The overall objective of the implementation of this process in this case study was to be able to foresee the area's final makeover and predict the impacts of the plan on the context through the integrated use of environmental analysis (ArcGIS), simulations of future scenarios (3dsMax) and 3d modelling studies (Revit, Ecotect).

Factors such as geomorphology, solar exposure, prevailing winds and rail and road traffic noise provided information on how to capitalize all favourable conditions of the site, which is a fundamental base for an appropriate land use transformation.

This methodology contributes to the control of urban design solutions and outcomes, and promotes the creation of an interface between urban planning, landscape and architecture projects. The development of a "City Information Modelling", similar to BIM, which has been successfully applied to Architecture and Engineering projects, is therefore seen as an answer to the new challenges presented by the present and future cities.

This strategy delivers the maximum benefits at all spatial scales by embracing the logic of sustainability so that urban design can be the first tool to optimize future building and infrastructure projects.

KEYWORDS: SUSTAINABLE DEVELOPMENT, METHODOLOGY, SIMULATION, MASTER PLAN

INTRODUCTION

The disarticulation of the urban planning process with the principle of Sustainable Development has led to the construction of urban spaces with low quality and without functionality [1]. The inadequacy of the current planned urban spaces and buildings regarding the use of solar energy, wind and ground use requires that the future interventions be developed with more skill and more concern with the use of natural resources.

In the 1960's all designers had the intention to develop themselves a methodology supported in problem-solving techniques, such as systematic analysis and operational research. In 1970 Christophe Alexander et al. published a new tool for building and planning: "A Pattern Language", which provides a new theory supported in the analysis and application of patterns related to town planning and building. To ensure a successful result of his methodology, considering the great number of patterns identified, he divided all of the patterns into three themes: towns, buildings and construction [2]. Yet all these approaches break down when the problem to solve is too complex.

In the 1980's, with the introduction of environmental concerns in urban planning, the requirements of the design process underwent a transformation towards the use of design directed methods that combined artistic and scientific processes to resolve problems. At the same time, Nicholas Negroponte from MIT Media Lab published an article about the possibilities of CAD and the "New Architecture Machine", which resulted from the partnership between architect and computer [3]. The new capacity provided by the use of CAD systems had a major role in the beginning of the 2000's when the sustainable movement earned a determinant place in all urban planning actions.

In this framework it appears to be necessary to develop a new methodology that provides for effectiveness in the result and that allows for different options to be simulated and evaluated without compromising the duration of the project.

The use of software for design and simulation seems to be the more accurate way to ensure the efficiency of the simulations and evaluations, especially when combined with the technical ability of the team to interpret the results and reflect on their consequent spatial distribution, which will invariably produce different solutions from one architect to another.

METHOD

In 2005 a new process emerged by the name of Sustainable Urban Planning [1], which introduces social, ecological, and solar concerns in all actions related to the territory. This process intends to assume an important role in the stage of land use transformation by ensuring that all actions do not have destructive impacts on the environment. It's a design process that infuses all stages of the planning process with a detailed understanding of the ecological system, the possibilities of solar power use and the concern to ensure public safety in all public spaces.

A dynamic support for these important aspects of the urban planning process can be found in the simulation stage through the modelling of the different scenarios. The plan design simulation is a tool for having control over the proposals and their impacts, especially if associated with the environmental and climatic conditions occurring in the project area.

During the last few years, simulation and analysis software solutions have been continuously developed and improved with notable repercussions on the approach of the design process at different spatial scales. In a few decades we went from hand-drawn blueprints to CAD drawings and since the invention of virtual 3D modelling in the 1980's the design process has changed to catch on with these technologies. Project design is now based on a wide scope of "know-how", obtained either from research or personal experience, and the use of these technologies has become essential for the creation of scenarios and immediate rendering of the solutions.

For this reason it is useful to choose a set of suitable and efficient tools to test all the urban planning parameters and interventions before they come into existence. An innovative contribution to sustainable development could be obtained with the virtual simulation process by defining and adapting it to a list of sustainable principles that take into consideration aspects such as renewable resources, transportation-traffic urban systems, noise emissions and air pollution.

Regarding urban planning, the first goal concerns the interaction between a Master Plan proposal with the urban morphology and future buildings and infrastructure projects. In this way, for instance, it is possible to take advantage of daylight and natural ventilation or to preserve views by simulation of the interplay between the architectural structures and the landscape [5, 6]. The second aim is to get a response that is both an environmental response to each particular climate as well as a cultural, social and economic one.

Having ascertained these basic principles, the next step is to analyse their practical application, which was the objective of the implementation of the Sustainable Urban Planning Process in the Oeiras Master Plan case study. This Master Plan entails a great range of urban transformations including: parks, cycling routes, mixed-use buildings and a recreational harbour on the Tagus river. The site has a large green surrounding area and is crossed by a road with intense traffic that creates problems to the pedestrians crossing and, most of all, breaks the link between the city and the shore.

The proposed methodological approach for the Sustainable Urban Planning Process [1, 5] is supported by five steps, and with a continuous virtual simulation and monitoring at every scale level (Figure 1). These stages of the process were sequentially applied to the area of the project and depend on each other, since each stage only begins after the evaluation or validation of the previous one.

Many different pieces of software were included in all stages of the Sustainable Urban Planning Process [7], allowing to perform a detailed analysis of the Oeiras Master Plan site, taking into account the achievement of the prerequisite environmental, economic and social goals. For a better understanding of the proposed operative process and how the BIM concepts have been included, each stage is described as follows:

Step 1 – Definition of the intervention goals – The first step requires the determination of the strategic goals for urban sustainability that are to be included in the planning process. These goals must take into account the protection and appreciation of the natural environment, the promotion and stimulation of economic activities, and the fulfilment of the needs of the population.

Step 2 – Reference situation analysis – Elaboration of a complete data survey regarding all the process features for Sustainable Development, handling both local data and information concerning to the surrounding area. Thus, environmental, economic, social and urban analysis are part of this stage, as well as the recognition of pertinent restrictions, potentialities and the definition of criteria for the urban planning process, which constitutes the basis for the plan design stage.

In this stage three main software programs were used: ArcGIS, for the precise analysis of the site, including topography and riverbeds, ecological structure, existing buildings, and solar exposure, biotopes; Excel, to transpose the results of the surveys conducted on site and with the population into tables and graphs, easier to read and compare and therefore more practical; and AutoCAD 2D, to draw the preliminary Master Plan.

Step 3 – Plan design – This step seeks to achieve an urban plan proposal that satisfies the previously defined goals and that, at the same time, assures that the project will help to promote a Sustainable Development.

This step includes seven actions: *Action 1* – survey and review the urban/rural property limits (ArcGIS, AutoCAD 2D); *Action 2* – selection of the restraining elements (geomorphology, solar exposure, indigenous species, existing road networks, public spaces, urban morphology, economic activities, cultural traditions, collective mobility and equipment); *Action 3* – definition of strategic and sustainability factors; *Action 4* – road design (AutoCAD Civil 3D); *Action 5* – buildings plan (AutoCAD 2D-3D); *Action 6* – location of pubic spaces and facilities (AutoCAD 2D); *Action 7* – conclusion of the plan design proposal.

Step 4 – Plan design proposal simulation – The plan design simulation is made through the modelling of scenarios, which enables to foresee the territorial changes brought by the design implementation. The two-dimensional design proposal developed in step 3 was translated into a precise and complete three-dimensional parametric model. This model gave an updated view of the whole project and the possibility to export individual parts to other simulation software. 3d Studio Max was chosen to create the model and organize the wide range of file formats while Revit was used to make volumetric simulations for the preliminary study of the buildings proposed and to generate elevation sections and terrain profiles working with mass groups imported from 3d Studio Max. Ecotect and Winair were used for lighting and energy analysis and to simulate the shadows and the wind potential of the site for important times of the year. The comparison of the different scenarios formed an information dossier used by all the team members as a technical support for their work (Figures 2, 3, 4 & 5).

Step 5 – Implementation – This step aims to ensure that the urban proposal is efficiently implemented, that its strategic goals are met and that the sustainability principles are respected. The entire implementation process is evaluated in order to make sure that the complete set of measures is correctly executed. The evaluation is detailed with the assistance of implementation technical sheets, formulated for each action, stating the desired goals and defining the priority of different actions.

RESULUTS AND DISCUSSION

The results achieved with this new urban planning process, having already been applied in different case studies, have been very positive and, at the moment, it is possible to guarantee not only the efficiency of the whole process but also the good level of the results in every major component of the project.

In this way the results obtained with this methodology also seem to validate the efficiency of advanced virtual technologies, such as the "BIM" systems, when applied to complex urban design problems and their contribution to the sustainable development of the project's site. As this methodology can be supported by a reduced group of dynamic software it also provides a better integration of all teams/information/domains resulting in a correct project without conflicts between specialities.

The main critical aspect to point out is related to the interpretation of the results of the simulation analysis. To overcome this critical point a high level of experience and specialization of the project's team coordinator is highly recommended.

Nonetheless, the implementation of this new methodology has proven to be a powerful tool for urban planning. It provides the architect or urban planner with the opportunity to anticipate the effects of the proposal in a wider scope and helps to reduce the impacts on the environment and in the future urban spaces, by allowing to run systematic simulations that enable quick retrofitting and evaluation of all solutions. Likewise it benefits not only from the possibility to speed up the whole process of urban planning by combining different software efficiently, but also by making the results easier to read and thus easier to work with.

In this way, this methodology also contributes to approach urban planning to the Sustainable Development principles because, even though it is a faster method, the rigor and consistency of the outcome is not only assured but also increased due to the use of BIM-like solutions adapted to urban planning during the various phases and with the continuous integration of all information gathered and developed.

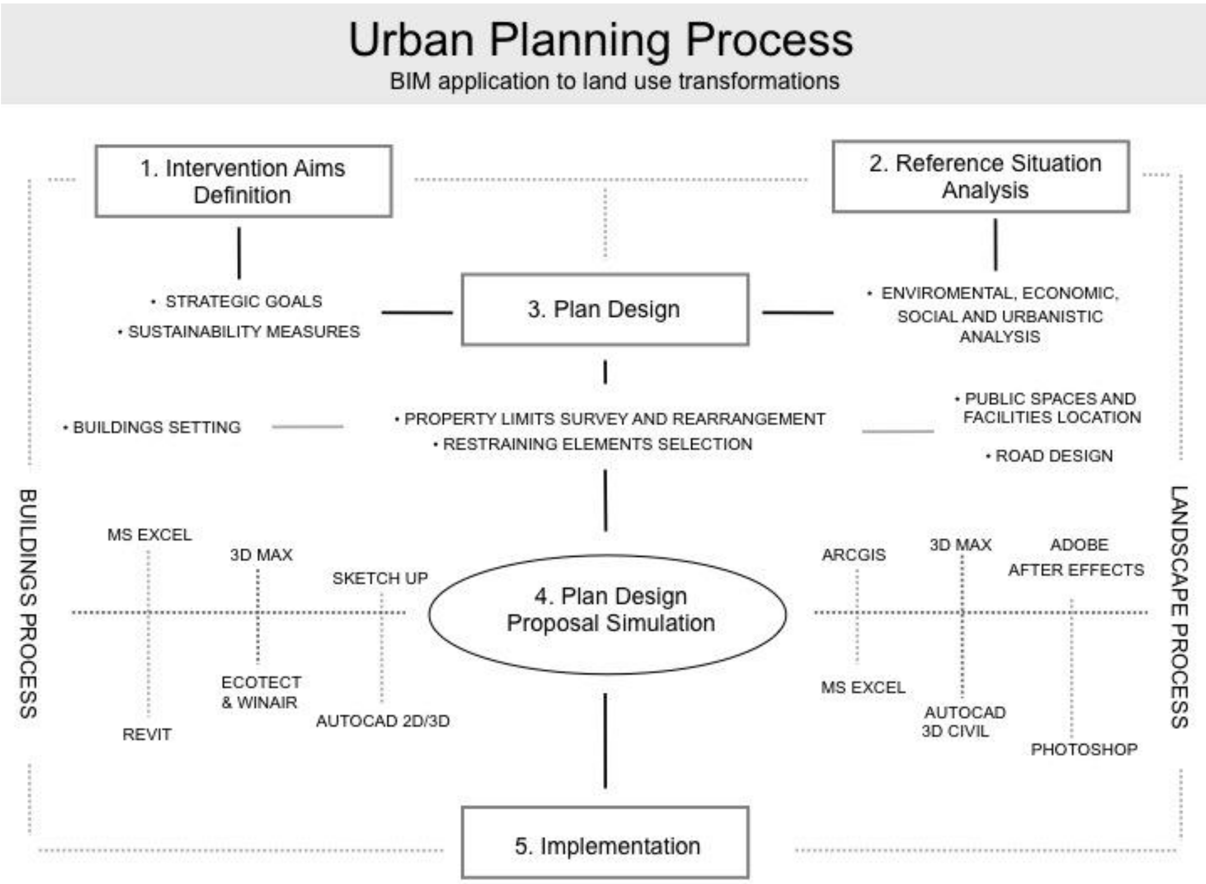

Figure 1: Structure of the Urban Planning Process Methodology

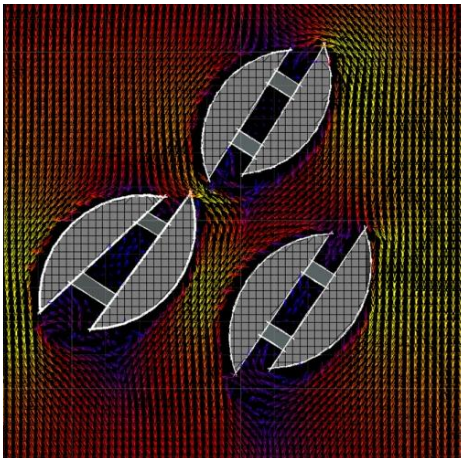

Figure 2: Wind simulation: Ecotect, Winair.

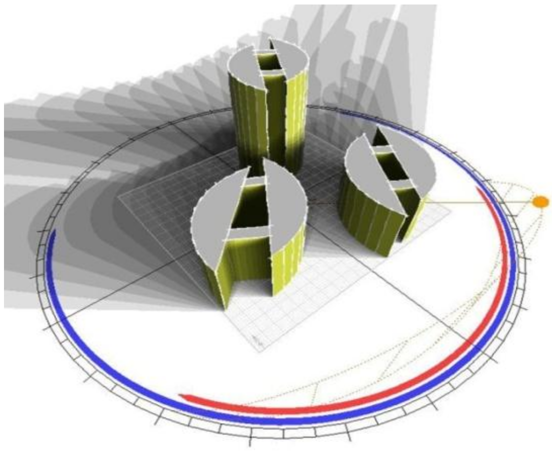

Figure 3: Shadow Study: Ecotect.

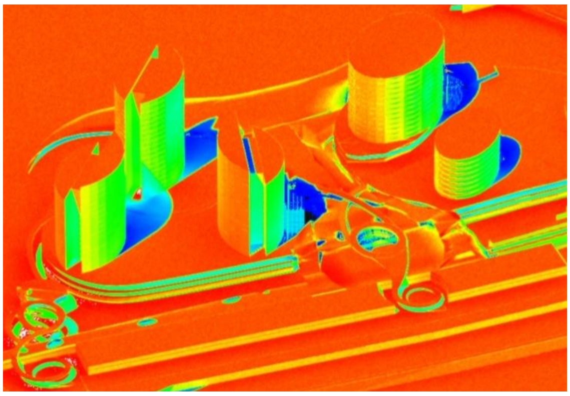

Figure 4: Illuminance Analysis lux_3d Max

Figure 5: Luminance Analysis cd/m2_3d Max

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URBAN OUTLINES 2D ABSTRACTION FOR FLEXIBLE AND COMPREHENSIVE ANALYSIS OF THERMAL EXCHANGES

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ABSTRACT

Thermal transfer modelling in the city involves several aspects: short waves radiative heat transfers related to the solar beam, short waves and long waves radiative transfers between the urban area and the sky, diffuse exchanges between buildings, conductive phenomena in the constructions, convective exchanges with ambient atmosphere and capacity of the objects to store energy. Strong difficulties have to be overcome to achieve this kind of simulation: complexity and dimension of the geometrical model, specification of initial and boundary conditions and heaviness of non lineal unsteady computations. The management of this problem needs discretizations error evaluation for the control of the solution.

In the development of the rendering techniques, some aspects have already been successfully addressed for a long time. In the radiosity problem, for example, the use of importance – the quantity dual to radiosity obtained by the solution of the adjoint problem – allows not only to speed up the solution, but also to introduce a control of its quality.

The radiosity method is valid for instantaneous exchanges of light, when most elements of the scene are pure diffuse reflectors. The incident energy is stored in the material and brought back to the exterior as long wave radiation. In this case, the elements behave as blackbody's emitters. This second problem cannot be considered as a steady radiative exchange; it needs to introduce additional terms that make the variables of the model time dependent.

Fortunately, as the short waves problem is independent of surfaces temperatures, it can be solved first, and the resulting irradiances are then considered as simple thermal loads in the long waves balance.

Assuming that convenient software is available, we still need to train the potential users to ensure the correctness of their results with an acceptable cost. It is then necessary to give them good skills to interpret the different situations they will meet. In the University, it is also convenient to educate the students in the management of the different techniques or algorithms.

We propose a simplified 2D program where most situations of thermal exchanges in the city can be easily reproduced and clearly exhibited. This software allows evaluating a wide variety of situations in an interactive way and with easy modifications of both the geometrical and physical data.

INTRODUCTION

This paper is devoted to the presentation of the radiosity method in 2D. This kind of presentation was already performed several years ago in in order to make the radiosity concept easier to understand [1]. The second idea is to propose to the students a software tool to help them to understand and experiment the methods and algorithms of global illumination and thermal exchanges.

FORM FACTORS

The view factor, also called form factor, is a pure geometric quantity even if its definition is based on energetic theory. It specifies the fraction of energy leaving a surface Q_i that reaches another surface Q_j [2].

$$F_{ij} = \frac{1}{A_i} \int_{x \in Q_i} \int_{y \in Q_j} \frac{\cos\theta_x \cos\theta_y}{\pi r^2} V_{ij}(x, y)\, dydx \tag{1}$$

The factor F_{ij} connects two patches: Q_i with area A_i and Q_j with area A_j (figure 1). The angle between the ray r and the normal to patch Q_i is denoted θ_x while the angle between the ray and the normal to patch Q_j is denoted θ_y. The symmetry of the integral yields to the property of reciprocity discovered by Lambert in 1760 [3]:

$$A_i F_{ij} = A_j F_{ji} \tag{2}$$

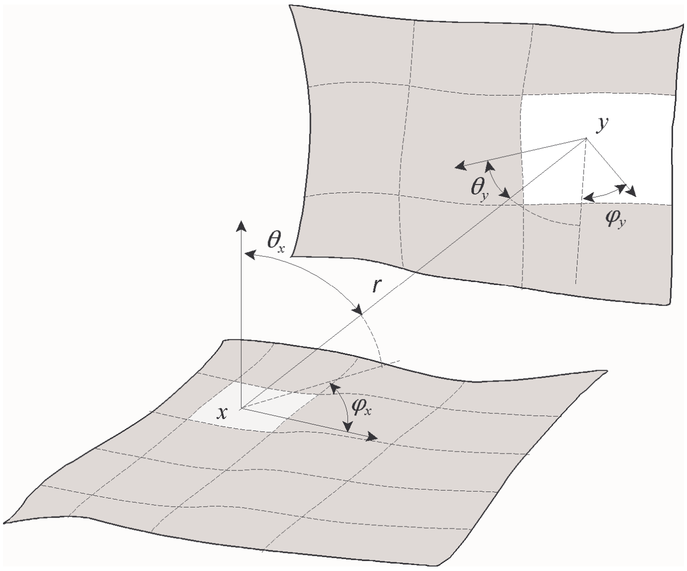

Figure 1: Definition of the form factor, after [2, 4]

The coefficient $V_{ij}(x, y)$ is the visibility function between the points x and y located on Q_i and Q_j; it takes only the values 1 (visible) or 0 (occluded). Explicit solutions of the view factor exist for a few number of particular configurations [2, 5] but computing the differential form represented by the inner integral is rather simple, at least if it is not necessary to solve a visibility problem.

The inner integral represents the point to area form factor. In 2D it is given by a formula:

$$F_{dL-j} = \int_{y \in L_j} \frac{\cos\theta_{dL} \cos\theta_j}{2r^2}\, dy \tag{3}$$

According to figure 2, it is simplified in:

$$F_{dL-j} = \frac{1}{2}\left(\frac{x_1}{r_1}\cos\vartheta_1 - \frac{x_0}{r_0}\cos\vartheta_0 \right) \tag{4}$$

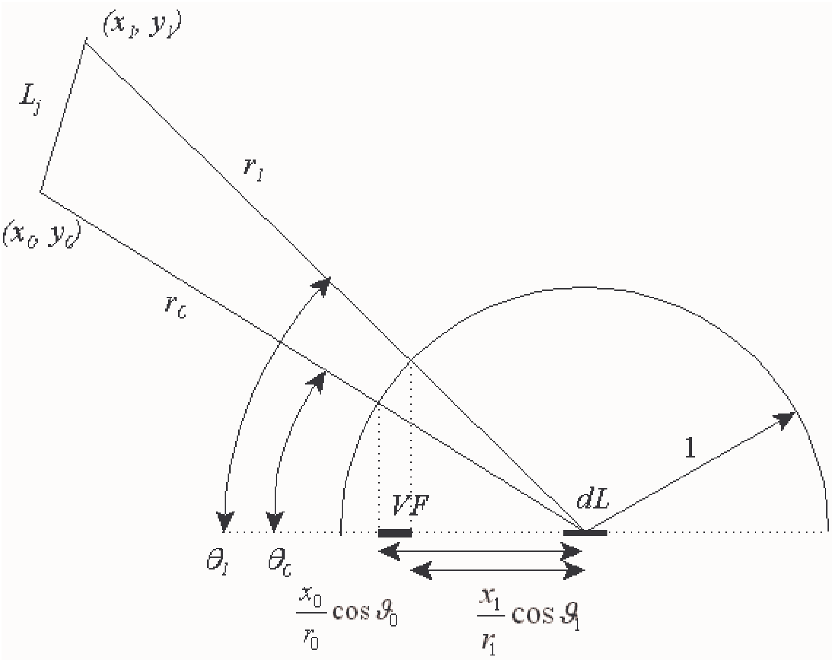

Figure 2: Computation of the point to area form factors

RADIOSITY EQUATION

The discrete formulation of the global illumination problem is given by the radiosity equations:

$$\begin{pmatrix} B_1 \\ B_2 \\ \vdots \\ B_N \end{pmatrix} = \begin{pmatrix} E_1 \\ E_2 \\ \vdots \\ E_N \end{pmatrix} + \begin{pmatrix} \rho_1 F_{11} & \rho_1 F_{12} & \cdots & \rho_1 F_{1N} \\ \rho_2 F_{21} & \rho_2 F_{22} & & \vdots \\ \vdots & & & \vdots \\ \rho_N F_{N1} & \cdots & \cdots & \rho_N F_{NN} \end{pmatrix} \begin{pmatrix} B_1 \\ B_2 \\ \vdots \\ B_N \end{pmatrix} \tag{5}$$

The B_i ,E_i and ρ_i terms represent respectively, the radiosity, the exitance and the reflectance of the element i,. The radiosity equation can be written as a system of N linear equations easy to solve with standard methods because the matrix M is well conditioned.

$$MB = E \quad ; \quad M_{ij} = \delta_{ij} - \rho_i F_{ij} \tag{6}$$

GEOMETRIC MODEL

The geometry is described by simple straight lines segments. These entities are supporting the finite element mesh. The mesh can be uniform or variable. Radiosity, exitance and reflectance are assumed to be constant on each finite element. Instead of computing the true form factor, the point to area form factor is computed in the Gauss points of the elements and then integrated. It can be shown that in most situations a single Gauss point per element is sufficient. The number N of finite elements is determining the size of the system of equations. Different geometric models are shown in figures 3, 5 and 6.

CLOSURE AND RECIPROCITY

To be consistent, the radiosity equations have to fulfill two important properties. The closure property specifies that the sum of the form factors relative to a single patch must be equal to 1 in a closed space. This condition is easily fulfilled in 2D. The reciprocity condition presented in equation (2), is satisfied only if the number of Gauss points is sufficient. In the particular situation where all the elements have the same size, the radiosity matrix is symmetric. It is shown below for a problem of 12 variables where the lack of symmetry indicates the approximation of the reciprocity condition.

0	0	0	0.0358	0.0738	0.0703	0.0965	0.1414	0.1644	0.0391	0.1023	0.2764
0	0	0	0.0840	0.1160	0.0764	0.1414	0.1644	0.1414	0.0764	0.1160	0.0840
0	0	0	0.2764	0.1023	0.0391	0.1644	0.1414	0.0965	0.0703	0.0738	0.0358
0.0391	0.1023	0.2764	0	0	0	0.0358	0.0738	0.0703	0.0965	0.1414	0.1644
0.0764	0.1160	0.0840	0	0	0	0.0840	0.1160	0.0764	0.1414	0.1644	0.1414
0.0703	0.0738	0.0358	0	0	0	0.2764	0.1023	0.0391	0.1644	0.1414	0.0965
0.0965	0.1414	0.1644	0.0391	0.1023	0.2764	0	0	0	0.0358	0.0738	0.0703
0.1414	0.1644	0.1414	0.0764	0.1160	0.0840	0	0	0	0.0840	0.1160	0.0764
0.1644	0.1414	0.0965	0.0703	0.0738	0.0358	0	0	0	0.2764	0.1023	0.0391
0.0358	0.0738	0.0703	0.0965	0.1414	0.1644	0.0391	0.1023	0.2764	0	0	0
0.0840	0.1160	0.0764	0.1414	0.1644	0.1414	0.0764	0.1160	0.0840	0	0	0
0.2764	0.1023	0.0391	0.1644	0.1414	0.0965	0.0703	0.0738	0.0358	0	0	0

Table 1: Form factors matrix for the mesh of figure 3 involving 12 elements

CONVERGENCE

We consider the different n orders of reflections. For the first one, we obtain ρE, with E, the total exitance. For the second one, we obtain $\rho^2 E$, and, then, $\rho^3 E$ …

When the equilibrium is achieved, the total power P emitted by all the walls and boundaries is equal to the sum of the initial exitance and the infinite number of reflections

$$P = \left(1 + \rho + \rho^2 + \rho^2 + \ldots\right) E \tag{7}$$

The limit of the previous series leads to a simple formula

$$\forall \rho \in [0,1] \ , \ \sum_{n=0}^{\infty} \rho^n = \frac{1}{1-\rho} \quad \rightarrow \quad P = \frac{E}{1-\rho} \tag{8}$$

This relation is valid if the domain is closed and if all the reflection coefficients are the same.

APPLICATIONS

In all the examples, we will consider a square box (3m x 3m) as shown in figure 3. The same figure shows the boundary conditions. The exitance is defined on the centre of the top (roof) side and set equal to 1 Wm^{-1}. In all the tests, the finite element mesh is uniform. The reflexion coefficients are all equal to 0.5. The radiosity is assumed to be constant. The results are displayed showing the evolution of the radiosity along the boundary, from the bottom left vertex. The function abscise varies from zero to the perimeter of the domain (12 m).

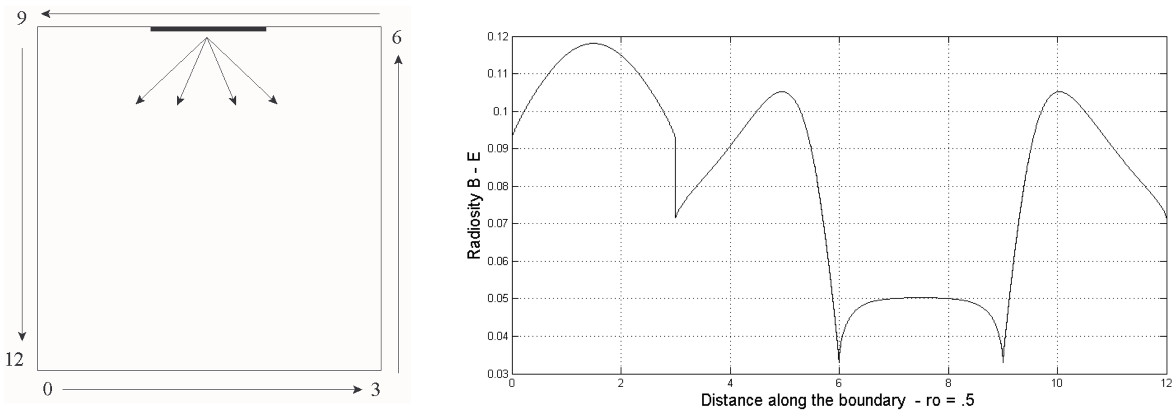

Figure 3: Mesh, boundary conditions, radiosity: 2400 elements, P = 2 W, CPU = 84 (59+25) seconds

A coarse mesh is built with 12 elements (3 per side). The coarse mesh results displayed in dashed line (figure 4) are compared to the exact solution. The imprecision of the result is reflected by the error on the total power.

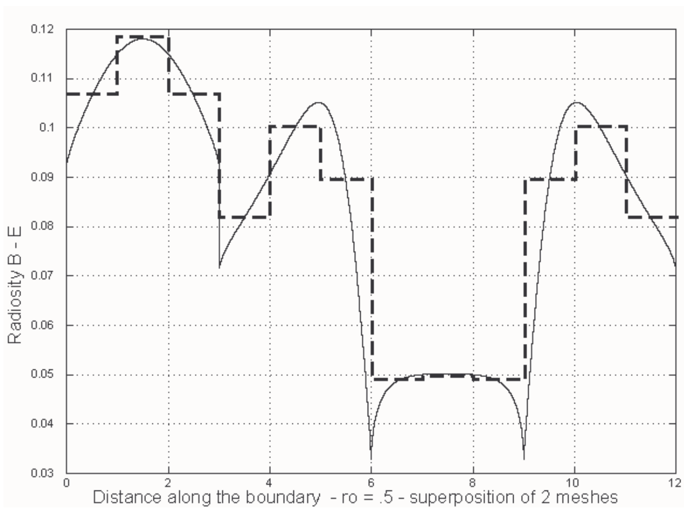

Figure 4: Radiosity for the coarse mesh, 12 elements (dashed line) versus exact solution, total emitted power: 2.0328 W.

This kind of simulation helps to understand the distribution of radiosity along the boundary of the domain. We observe that there is no difficulty to take into account the discontinuities of the solution. In the two following examples, the total exitance is equal to 1. The power is then converging to the same value of 2 *W*.

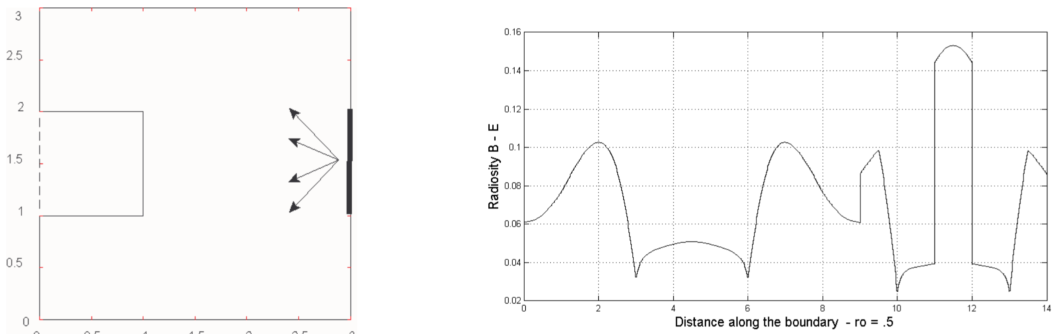

Figure 5: 840 elements, P=2.000 W, CPU 7 seconds

We also observe that the CPU time is very acceptable. This kind of simulation helps to understand the distribution of radiosity along the boundary of the domain. We observe that there is no difficulty to take into account the discontinuities of the solution.

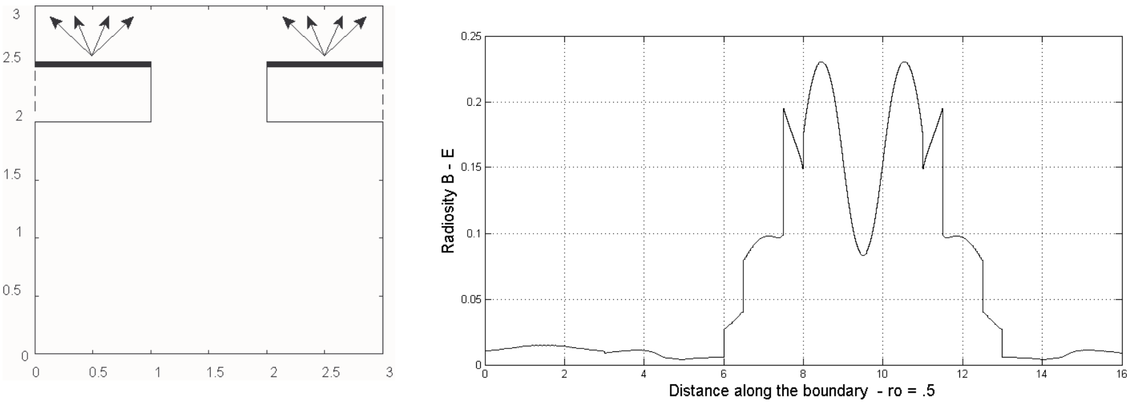

Figure 6: 800 elements, P=1.9997 W, CPU 8 seconds

CONCLUSION

The software developed to perform 2D radiosity analyses helps to understand the properties of the methods used to compute global illumination and the behavior of the algorithms used to obtain the solution. The cost of the solution is very low and allows then to compare many results. The convergence test performed on the total power in a close domain is very reliable and easy to use. Consequently, complicated geometric configurations can be handled. An important advantage of the 2D study is that we can represent any solution on graphics easy to interpret, for teaching purposes, but also to better design complex algorithms that will subsequently be implemented in 3D.

PERSPECTIVES

Due to the easiness to develop this 2D software, the program will be soon extended to take into account the long wave effects and to solve the non steady radiative exchanges. The importance equations have not been used in this paper, but preliminary tests have shown that they will be useful to compute the power for each exitance source.

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SIMULATING PHYSICAL REBOUND IN RETROFITTED DWELLINGS

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ABSTRACT

When predicting energy savings in existing dwellings, quasi steady-state calculation tools with fixed boundary conditions are often used. However, they may result in an overestimation of the energy savings. One of the reasons is the physical rebound effect that typically occurs when insulating the building envelope, a phenomenon seldom taken into account. Apart from the well-known behavioural rebound effect –when inhabitants offset part of the energy saving by increasing their comfort level– the physical rebound accounts for the fact that average indoor temperatures unintentionally rise after retrofit, even if the inhabitants do not change their heating pattern. This is due to the (unwanted) temperature rise in unheated zones and the lower temperature drop between two heating periods. Dwelling and time mean indoor temperatures are therefore higher after retrofit, leading to less energy savings than predicted with the simplified tools.

By using simulations it is possible to eliminate the behavioural rebound and focus on the physical rebound. Given a fictitious building stock, retrofit measures can be simulated and the impact on indoor temperature and energy demand can be analysed statistically. To do so, an existing dwelling is modelled in TRNSYS as a dynamic multi-zone building for which indoor temperatures and energy demands are calculated. To cover a sufficiently wide variation of building characteristics and building use, a pragmatic approach is used. Dwelling variants are generated by stepwise improving the insulation levels and a number of predetermined occupancy patterns are imposed to simulate differences in dwelling use (identical before and after retrofit).

As could be expected, the analysis shows that, even with the given variation of input parameters like temperature set points, heating patterns, ventilation/infiltration rates, a global correlation between indoor temperature and energetic quality exists. Good insulated dwellings give higher mean indoor temperatures than badly insulated dwellings. As a result, when insulating a dwelling in a retrofitting project, the indoor condition will change after retrofit, resulting in a physical rebound. When for comparison a fixed indoor temperature is assumed for the whole building stock –as is commonly done in many standard calculation tools, thereby neglecting physical rebound– the simulations show that the potential energy savings are easily overestimated.

INTRODUCTION

In the past, several energy efficient renovation projects have revealed that the predicted energy savings are not always achieved e.g. [1]. One of the reasons is the well-know (behavioural) rebound effect where inhabitants take back part of the energy saving in enhanced comfort by e.g. raising the thermostat setting. However, apart from the inhabitants, another ‘rebound’ can be detected. When the building envelope is insulated, the temperature in the unheated zones rises and the dwelling cools down less between two heating periods –

even if the inhabitants do not change their heating pattern. This effect leads to higher indoor temperatures after retrofit and is called the *physical rebound*. Since the indoor temperature has proven to be one of the main determinants in the energy consumption of dwellings, it is important to assess the size of this temperature rise and whether or not it is overruled by other factors when calculating energy savings.

In this paper, the physical rebound is investigated by dynamic simulations. Starting from a badly insulated case study, six new variants are modelled with increasing insulation level. The MonteCarlo technique is used to impose realistic occupancy patterns and the impact on net energy demand and indoor temperature is studied. The comparison is made with a commonly used calculation tool in Flanders, based on the EPBD-regulation [2], which does not incorporate this physical rebound.

METHOD

Building Model

An existing three storey terraced house is modelled in the dynamic building simulation program TRNSYS. The floor plan is given in Figure 1. The dwelling is divided in 3 thermal zones: living zone (kitchen, living room and bath room; 284 m^3), sleeping zone (310 m^3) and circulation zone (157 m^3). Each zone is considered as one node for which heat balances are solved every time step. Heat transfer between these zones is assumed to occur only by heat conduction through the internal walls and floors, thereby neglecting possible heat transfer via interzonal air flows.

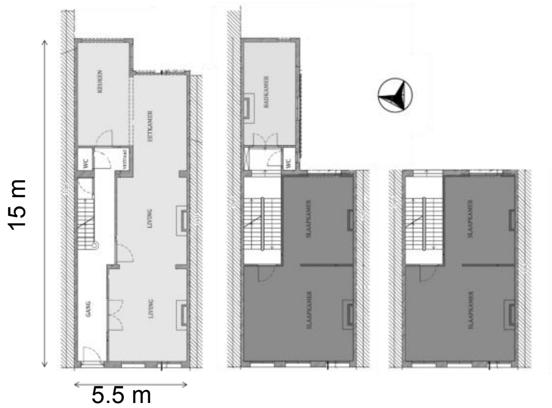

Figure 1: Floor plan of the three storey house with the ground floor (left), first floor (middle) and second floor (right). Light grey indicates the living zone, dark grey the sleeping zone and white the hallway. Basement floor is identical to ground floor.

The total heated volume V equals 751 m^3 while the heat loss surface A_T equals 312 m^2, leading to a compactness of $C = V/A_T = 2.41$ m. Outside and inside walls are heavy brick structures, while the internal floors are lightweight wooden structures. The least performing variant (mean U-value = 2.00 $W/(m^2K)$) is stepwise insulated in order to obtain 6 variants with increasing insulation levels – see Table 1.

Calculation methods

For each dwelling, two calculation methods are used to obtain the net energy demand and indoor temperatures. The first method is the reference method and treats the dwelling as a single zone at a fixed indoor temperature of 18 °C, as is done by a commonly used calculation tool in Flanders [2]. This temperature is lower than a typical thermostat set temperature in

Flat roof insulation – PU	[m]	**0.05**	0.05	0.05	0.05	0.1	0.05	0.15
Pitched roof insulation –mineral wool	[m]	**0.05**	0.05	0.1	0.1	0.15	0.15	0.3
Front facade (interior) – PU	[m]	**0**	0.05	0.05	0.05	0.05	0.05	0.15
Back facade (exterior) – EPS	[m]	**0**	0	0	0	0.1	0.05	0.15
Floor insulation (mineral wool)	[m]	**0**	0	0.05	0.05	0	0.05	0.15
U-value glazing	[W/(m^{2}K)]	**5.68**	5.68	5.68	2.83	2.83	1.3	0.86
g-value glazing	[-]	**0.86**	0.86	0.86	0.76	0.76	0.62	0.60
Mean U-value	**[W/(m^{2}K)]**	**2.00**	1.76	1.46	1.15	0.91	0.58	0.29

Table 1: Overview of the different insulation levels of the dwelling.

living rooms and therefore already incorporates some night setback and zonal heating. Since a fixed temperature is used for all insulation levels, physical rebound cannot be taken into account. The second method is a more realistic method and uses a multi-zone model of the dwelling. Different time schedules are then imposed to the different zones to simulate more realistic user behaviour (see further).

In order to compare the influence of these more realistic heating patterns, all other assumptions and boundary conditions are taken equal for both methods. For each building, the net energy demand for space heating and indoor temperatures are calculated for the month January. Hourly outside conditions are taken from the Meteonorm weather data file of Ukkel, Belgium. The internal gains and infiltration and ventilation rates are based on the legal energy performance calculation in Flanders [2]. The internal gains are only function of the heated volume, set constant throughout the year and uniformly distributed throughout the dwelling ($\Phi_{int} = 220 + 0.67\ V\ [W]$). Infiltration rates are expressed as a function of the heated volume and the air change rate at 50 Pa, n_{50} ($\dot{V}_{inf} = 0.04\ n_{50}\ V$ [m^3/h]). The n_{50}–value is assumed to be 3 h^{-1} for all dwelling variants. In a similar way are the ventilation rates fixed ($\dot{V}_{vent} = (0.2 + 0.5\ exp(-V/500))\ m\ V$ [m^3/h], with m a constant depending on the type of ventilation system and its performance, taken equal to 1.5 by default). Both air rates are set constant throughout the simulation period. The air capacity of the zones is multiplied by 10 to incorporate the thermal capacity of furniture. For this analysis, only net energy demand for space heating is considered, so no heating system is modelled.

In reality, inhabitants alter the thermostat settings depending on their comfort feeling, which is a complex combination of physiological factors (activity level, clothing) and physical factors (air temperature, mean radiant temperature, relativity humidity, air velocity). An indicator for thermal comfort that is often used for practical purposes, is the operative temperature T_{op} which is defined as the average of the zone air temperature T_a and the zone area weighted surface temperature T_{surf}. Therefore, the desired set temperature T_{set} is considered to be equal to the operative temperature T_{op}.

Generating heating patterns with Monte-Carlo technique

To generate realistic heating patterns, a quasi-stochastic approach is used. Based on mainstream lifestyles (full-time out to work, halftime out to work, continuously home), a number of predetermined time schedules are modelled for each zone (Table 2). In the absence of reliable statistical data, probabilities of occurrence are arbitrary allocated to each of the schedules. For each zone, a random number between 0 and 1 is generated and used –in combination with the probabilities- to pick the corresponding time schedule. Similarly, the set temperature in the living zone is randomly picked from a uniform distribution between [19-23] °C and the set temperature of the sleeping rooms between [14-16] °C. Between two heating periods, the living zone is kept at a minimum temperature of [15-19] °C. The hallway is never heated. The first day of the simulation (January 1st) is randomly chosen between Monday till Sunday.

So for the more realistic method, every simulation starts with the previous Monte Carlo algorithm to determine a realistic heating pattern. For each dwelling variant, multiple simulations are carried out to reach convergence in the results. Based on [3], 100 simulation runs per dwelling are performed.

Remark that this working method has no ambition to cover all possible heating scenarios or to obtain a reproduction of real-life inhabitants heating their homes. It is a pragmatic method of modelling more realistic behaviour in order to reveal the impact and spread on calculated energy savings.

	L1	**L2**	**L3**	**L4**	**S1**	**S2**	**S3**	**H1**
00:00 – 06:00	--	--	--	--	X	X	X	
06:00 – 09:00	X	X	X	X			X	
09:00 – 12:30	--	X	--	X				
12:30 – 17:00	--	--	X	X				
17:00 – 22:30	X	X	X	X		X		
22:30 – 00:00	--	--	--	--	X	X	X	
PROBABILITY	0.5	0.125	0.125	0.25	0.33	0.33	0.33	1

Table 2: Overview of the different deterministic time schedules in the living zone (L), sleeping zone (S) en hallway (H) All days of the week are identical except for the living zone, where during the weekend L4 is always used. 'X' = set temperature, '--' = minimum temperature.

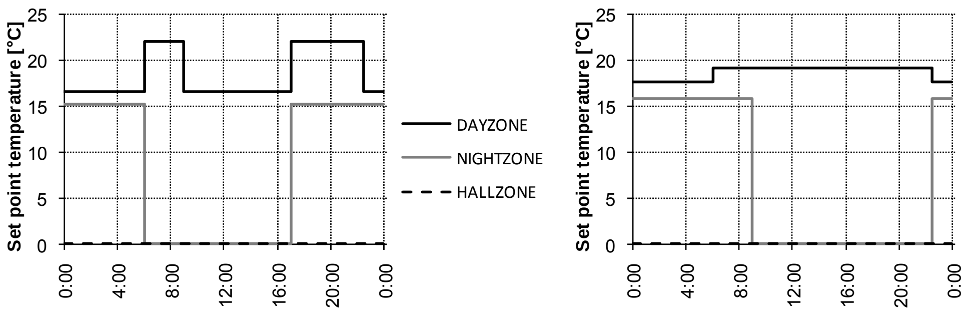

Figure 2: Example of two stochastic heating patterns, based on the predetermined time schedules of Table 2.

RESULTS

The zone volume weighted operative dwelling temperature and the dwelling net energy demand, respectively averaged and summed over the month January, are given in Figure 3 as a function of the mean U-value. The reference method –which treats the dwelling as 1 zone at a temperature of 18°C– gives one deterministic value per dwelling, while the quasi-stochastic method gives 100 values per dwelling (of which only the average, minimum and maximum values and 25% and 75%-quartiles values are shown).

When looking at the operative temperatures, one can clearly see the physical rebound: even with identical distribution of heating patterns, the dwelling temperature is not a constant but a function of the insulation level. For the badly insulated dwellings (U-value > 1.5 W/(m^{2}K)), indoor temperatures vary around 16°C, much lower than 18°C of the reference. Since the

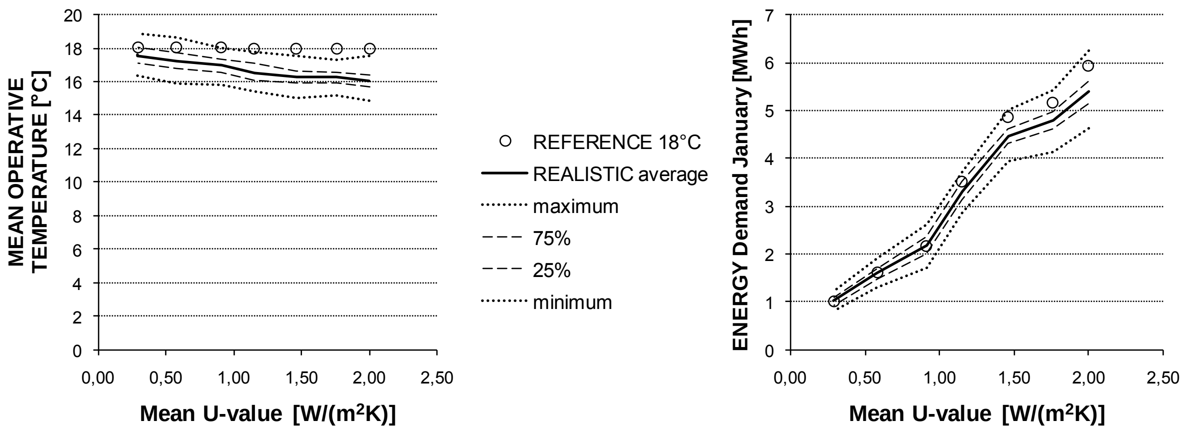

Figure 3: The zone weighted operative dwelling temperature (left) and the total energy demand (right) for the month January in function of the mean thermal transmittance U_m of the dwelling variant.

bandwidth nearly interferes with the 18°C-line, the 18° is probably too high to correctly assess energy consumption for existing, poorly insulated dwellings. This is also reflected in the total energy demand where, although the reference method is within the bandwidth of the realistic method, the 18°C still gives slightly higher energy demands. For the badly insulated dwellings the reference method gives energy demands that are almost 10% higher than the mean energy demands of the realistic method. For the best insulated dwelling however, temperatures vary around 18°C and the net energy demand of both methods corresponds very well.

The results of Figure 3 are based on the assumption that all other boundary conditions are constant for both methods e.g. internal gains, infiltration/ventilation rates. However, as well as with heating patterns, large variations exist in these parameters. In order to see whether their variability and uncertainty overrule the detected physical rebound, the above method is entirely repeated, but now the following parameters are allowed to vary as well within the same Monte Carlo algorithm: the previously defined internal gains Φ_{int}, the infiltration rates $\dot{V}_{inf}$ and the ventilation rates $\dot{V}_{vent}$ are randomly chosen between -10% until +10% of their reference value. Although a correlation might exist between mean U-value and these parameters (e.g. infiltration rates: new, well insulated buildings tend to be more airtight), all parameters are considered uncorrelated here. These simulations are performed for both the reference method and the more realistic method. Figure 4 shows the average, minimum and maximum values. The dwelling temperatures are not shown since these temperatures were found to be nearly affected by the additional stochastic parameters.

Figure 4 shows that adding uncertainty on internal gains, infiltration and ventilation rates, does not increase the uncertainty on the output of the Monte Carlo simulations: the bandwidth for the advanced calculation method remains almost the same. This suggests that the overall uncertainty is dominated by the variation in indoor temperature and heating pattern –a sensitivity analysis should quantify the separate effects. The bandwidth of the reference method entirely stays within the minimum and maximum values of the advanced method. Still, for the badly insulated variants, the reference method gives consistently higher energy demands than the realistic method. So, even with the additional uncertainty and for existing, poorly insulated dwellings, it is clear that energy demands calculated with a fixed inside temperature of 18°C are probably an overestimation.

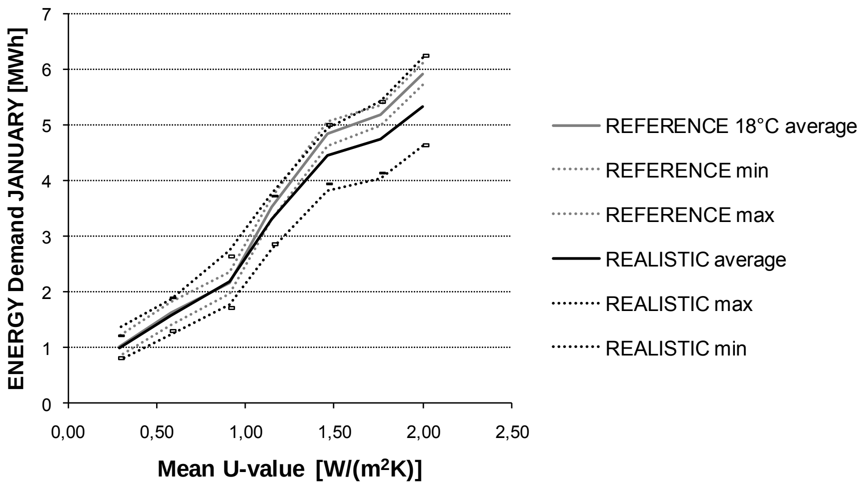

Figure 4: The total energy demand for the month January in function of the mean thermal transmittance U_m of the dwelling variant; the infiltration and ventilation rates and internal gains vary randomly between -10% until +10% of their reference value – the separate points depict the minimum and maximum values from the realistic method as shown in Figure 3.

DISCUSSION & CONCLUSION

The above analysis shows that, when heating patterns are randomly chosen between 'realistic' options, the physical rebound is clear: dwelling temperatures rise when insulation is added to the building envelope. The mean dwelling temperature increased from 16°C to 18°C when the mean U-value decreased from 2 W/(m^{2}K) to 0.3 W/(m^{2}K). This impacts the predicted energy demand, since calculating the energy demand with an inside temperature of 18°C for the initial, badly insulated dwelling, leads to a mean overestimation of about 10% for the presented case. This is of particular interest when the single-zone methodology of the EPBD-regulation is used for prediction energy savings of a building stock. Here, a consistent overestimation of initial energy consumption of 10% might lead to an important overestimation of potential energy savings and thus, the economical benefits of renovation measures. Nevertheless, due to their ease of use and limited calculation time, single zone models might still be of valuable use, but to attain more reliable results, it is suggested to make the indoor temperature a function of the insulation level.

ACKNOWLEDGEMENTS

The results fit in the framework of the OT-project (OnderzoeksToelage-project) KUL OT/09/23 "Towards a reliable application of interior insulation for the retrofit of existing buildings" at the Catholic University of Leuven, Belgium. This support is gratefully acknowledged.

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HEATING AND PASSIVE COOLING WITH HEAT PUMPS – COMPARISON OF SIMULATION, CALCULATION METHOD & FIELD MEASUREMENT RESULTS

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ABSTRACT

The energy demand for heating is decreasing significantly in modern highly-insulated dwellings. Comfort cooling of buildings in summer becomes even for residential dwellings more important due to higher thermal loads and rising demands for thermal comfort in summer. The project as a whole intends to point out how to increase the summer thermal comfort in residential buildings with heat pumps in an energy-efficient way. Therein, heat pumps can, besides space heating and domestic hot water, provide space cooling too. However the priority is always an effective reduction of heat loads by applying good thermal insulation and effective shading to get a high energy efficiency.

In a theoretical comparison, three heat pump concepts were simulated and evaluated including a multi-split air/air heat pump unit with variable refrigerant flow, an air/water- and a brine/water heat pump system. The ground coupled brine/water system reaches the highest efficiency with a generator seasonal performance factor taking into account all modes of 4.7. A variable refrigerant flow multi split air/air-conditioning unit achieved comparable high efficiency for active heat pump operation with 3.7 for heating and 4.1 for cooling operation. All systems achieve good thermal comfort conditions.

The solution with the highest efficiency, the ground source heat pump system with a passive cooling mode, has been evaluated in two field measurements. This system, applied in a low-energy house, showed a high efficiency and clean operation with a good thermal comfort. The measured overall seasonal performances have been 3.7 in a single family house and 3.9 for an ultra-low energy building with 5 flats.

The focus of this paper is the comparison of a simple model, called “24 h adiabatic heat storage”, with the detailed simulation and measurements to calculate for ground coupled heat pumps the influence of the passive space cooling on the space heating and domestic hot water generation. Both models achieve good coincidence for the borehole outlet temperature in periods of intense space cooling usage with an uncertainty of less than 0.4 K and over the entire cooling period of less than 0.2 K.

INTRODUCTION

In Switzerland, the highest energy demand is needed for space heating in wintertime to keep a comfortable room climate. Achieving a good thermal comfort with a low energy demand also with an increasing comfort demand in summertime requires energy efficient and economical system solutions. The main aim of the cooling function in dwellings is not a strict limitation to and complying with a maximum room temperature, but an increase of the thermal comfort in summer by avoiding high room temperature peaks and achieving a gentle decrease of the average room temperature. To reduce external thermal loads, a good thermal insulation, effective shading and night-time ventilation, if applicable, shall be applied rather than using active cooling systems.

METHOD

The effect of the passive ground coupled cooling with borehole heat exchanger on the domestic hot water and space heating operation of the heat pump system has been evaluated by on the one hand a comparison of three heat pump configurations in a theoretical study for the functions space heating (H), domestic hot water generation (W) and space cooling (C) and on the other hand two field measurements of passive ground coupled space cooling systems, which affirm the theoretical results and the calculation model. Some of the main findings of the project SEK [1] are summarized in this paper. The focus of this paper is passive cooling with borehole heat exchanger and the use of simulations for the validation of the calculation method.

PASSIVE COOLING IN SEASONAL PERFORMANCE CALCULATION

The Borehole Passive Cooling System

The passive cooling with borehole heat exchanger shows the highest efficiency in comparison to the two other systems; it is also the most popular space cooling system in Swiss dwellings. Passive cooling uses the ground temperature level to cool the building. Figure 1 shows a typical hydraulic scheme of a brine-to-water heat pump for low temperature, self-regulating floor heating, domestic hot water preparation and passive space cooling.

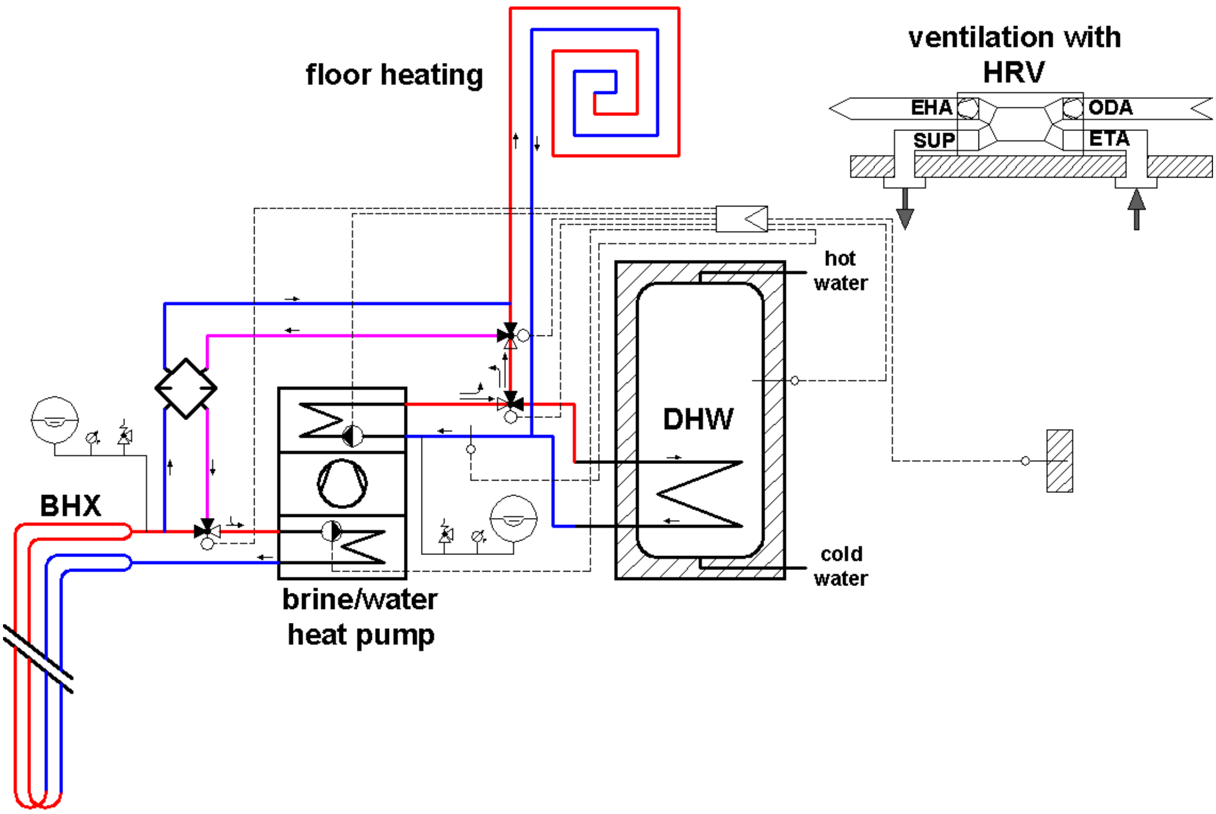

Figure 1: Hydraulic scheme for a brine/water-heat pump with passive cooling function (BHX = borehole heat exchanger; DHW = domestic hot water; HRV = heat recovery ventilation; EHA = exhaust air; ODA = outdoor air; ETA = extracted air; SUP = supply air)

Seasonal Performance Calculation Methods

The development of calculation methods for the annual seasonal performance of heat pump systems for space heating and domestic hot water in residential buildings made significant steps forward recently. The calculation method developed in the SFOE-project "Calculation method for the seasonal performance of heat pump compact units and validation" [2] has been implemented in the European standard EN 15316-4-2:2008. But there is up to now no standardized calculation method for passive cooling with borehole heat exchangers, likewise for the influence of the passive cooling on heating and hot water operation.

System Characteristics

Applying passive cooling with borehole heat exchanger means to connect emission system of the building and ground thermally. The two circulating fluids in the floor heating system and the ground loop are separated by a heat exchanger due to hydraulic reasons. It is called "passive cooling", since energy is only required to circulate the heat transfer media. However the temperature of these heat transfer media is not directly influenced actively like with a capacity controlled heat pump in reverse mode. Hence, the electric expenditure arises only from the transport of the heat transfer media. The amount of rejected heat from the room to the ground is influenced by several more effects like shading or internal loads of the room, which increase the room temperature and thereby augment the heat to be rejected. Calculating an SPF for passive cooling would require a thermal room balance.

Expenditure of the Passive Cooling

The electric expenditure for passive ground coupled cooling is basically calculated as integral of the electric consumption in all components used for the coupling of the cooled rooms to the ground. These components are here the two circulating pumps for the borehole heat exchanger and the heat emission system and in addition control devices. Because of the approximately constant electric power of these components the integral could be simplified to the product of average electric power and operation time. For the SPF-G the corresponding electric energy demand is calculated with equation (1).

$$E_{el,C,SPF-G} = (P_{el,ctr+aux} + P_{el,Pu,BHE})_C * t_C \qquad (1)$$

$E_{el,C,SPF\text{-}G}$	electric energy consumption for the system seasonal performance factor	[kWh]
$P_{el,ctr+aux}$	electric power consumption in control and auxiliaries	[kW]
$P_{el,Pu,BHE}$	electric power consumption in circulation pump of the borehole heat exchanger	[kW]
t_C	operation time of the passive cooling function	[h]

SPF-G is the ratio of produced heat and consumed electricity of the generation system.

Effect of the borehole heat exchanger recharging

The heat rejection to the ground improves the efficiency of the heat pump due to withdrawing heat from the ground with higher borehole outlet temperatures. This effect is mainly related to hot water preparation in summer showing an increase in the range of 3.0 to 3.5 K and is only observed, if the time span between cooling and domestic hot water generation is not too high. Figure 2 shows the seasonal devolution of the increase of the borehole heat exchanger outlet temperature referred to a variant without cooling mode. Only a small phase shift is visible compared to the rejected heat into the borehole heat exchanger from space cooling. The influence on the outlet temperature during wintertime is negligible. Hence, the following models take only domestic hot water operation into consideration.

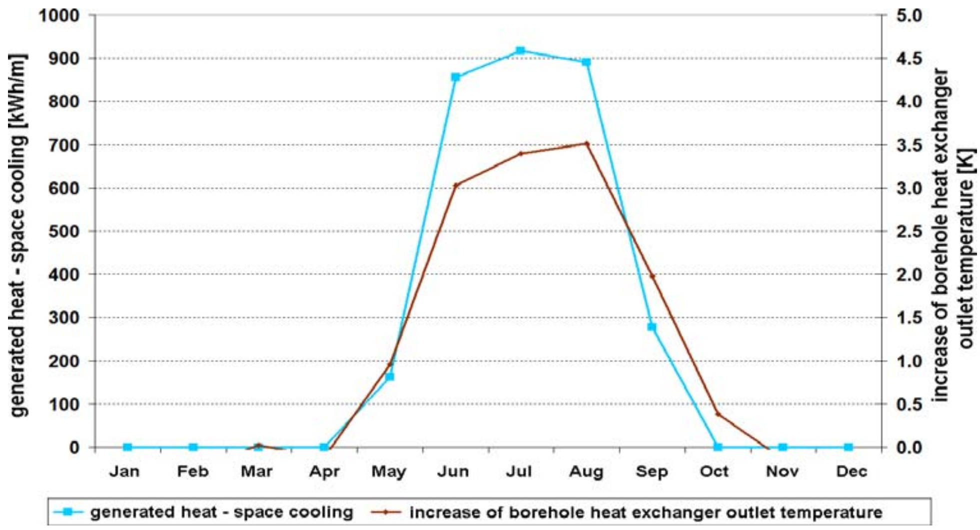

Figure 2: Seasonal correlation of heat rejected to the borehole and the increase of the borehole heat exchanger outlet temperature compared to operation without space cooling

Model – 24 h adiabatic heat storage model

The observations from the detailed simulations show an effect similar to short time heat storage in the borehole heat exchanger. The model assumes that the heat from passive cooling could be stored in the borehole heat exchanger only during one day (24 h) and is lost afterwards. This is a strong simplification, which is dedicated to a simple calculation. The dynamic heat injection based on a daily cyclic heat load pattern then defines the diameter of the active storage volume around the borehole where the outlet temperature increase is identical to the result of the detailed simulation. The temperature increase could on this basis be calculated with equation (3). The active storage volume based on a daily cyclic heat load pattern has been derived from several simulation variants. The equivalent heat capacity for the active ground heat storage equals 89 Wh/mK. This corresponds to a diameter of the active ground heat storage d_G of 0.4 m.

$$\Delta\Theta_{BHE,W,C,d} = \frac{Q_{C,d}}{C_{BHE}} = \frac{Q_{C,d}}{(c_{p,Bh} * \rho_{Bh} * \frac{d_{Bh}^{\ 2}}{4} + c_{p,G} * \rho_G * \frac{d_{G,d}^{\ 2} - d_{Bh}^{\ 2}}{4}) * \pi * l_{BHE}} \qquad (2)$$

$\Delta\Theta_{BHE,W,C,d}$	daily increase of the borehole heat exchanger outlet temperature in domestic hot water operation with heat injection into the borehole from ground coupled passive cooling	[K]	(2)
$Q_{C,d}$	daily rejected heat from space cooling	[kWh]	
C_{BHE}	activated borehole heat capacity for a daily cyclic heat load pattern	[kWh/K]	
$c_{p,Bh}$	specific heat capacity of borehole backfilling material	[J/kgK]	
ρ_{Bh}	density of borehole backfilling material	[kg/m^3]	
d_{Bh}	diameter of the borehole	[m]	
$c_{p,G}$	specific heat capacity of the ground	[J/kgK]	
ρ_G	density of the ground	[kg/m^3]	
d_G	diameter of the active ground heat storage for a daily cyclic heat load pattern	[m]	
l_{BHE}	length of borehole heat exchanger	[m]	

Ground coupled passive cooling in bin-method seasonal performance calculation

Comparing this simple model to the detailed simulation results shows a very good agreement of the results for the month June to August with high cooling demand, where the deviations are between 0 K and 0.4 K. The times in the begin and at the end of the cooling period show bigger deviations of up to 1 K, but have less influence on the seasonal performance calculation results because of the small cooling energy. The overall increase of the borehole heat exchanger outlet temperature in domestic hot water operation for the whole year furthermore shows a very good agreement with deviations in the range of 0.1 K to 0.2 K.

Ground coupled passive cooling in bin-method seasonal performance calculation

Implementing the above calculation methods for passive cooling into the bin-method according to the EN 15316-4-2 leads to very good agreement of the generator seasonal performance factors SPF-G compared to detailed simulation results as shown in Table 1. The negligence of the heat storage effect on the space heating operation in the calculation method leads to equal good agreement like without heat injection into the borehole and confirms the simplification to neglect the effect of heat injection into the borehole on the winter heat withdrawal. The increase of the domestic hot water seasonal performance factor by the heat injection from passive cooling could be reproduced by a very simple calculation model based on a short time adiabatic ground heat storage model. The performance factor of the passive cooling could be reproduced with good agreement also by a simplified calculation based on average electric power consumption if the assumption of full cooling need coverage is valid.

generator seasonal performance factors without passive cooling			
	simulation	bin-method	
SPF-G_H	4.4	4.6	5%
SPF-G_W	3.3	3.2	-3%
SPF-G_{HW}	4.0	4.1	2%
generator seasonal performance factors with passive cooling			
	simulation	bin-method	
SPF-G_H	4.4	4.6	5%
SPF-G_W	3.5	3.5	-1%
SPF-G_C	12.9	12.6	-2%
SPF-G_{HWC}	4.7	4.8	2%

Table 1: Comparison of SPF-G from simulation and calculation method

Thermal Behavior of Borehole Heat Exchanger in Field Measurement

Figure 3 exemplarily shows the correlation between the generated respectively rejected heat and the borehole heat exchanger inlet and outlet temperatures taken from the CosyPlace measurements in summer 2009 [3]. During winter the outlet temperatures are in a range of 0 °C to 7 °C. With a reduced heat withdrawal in spring the temperatures increase to about 10 °C in May/June. During periods with passive cooling and heat injection into the borehole, the borehole temperatures rise by 3…5 K up to maximum of 16 °C and fall back by the same amount after the cooling period to about 10 °C in September. A seasonal storage effect could not be observed. Before the control optimization the room air temperature stays at a maximum level around 25 °C, with the more intensive cooling after the control optimization the room air temperature even drops to a rather low level of 22…23 °C.

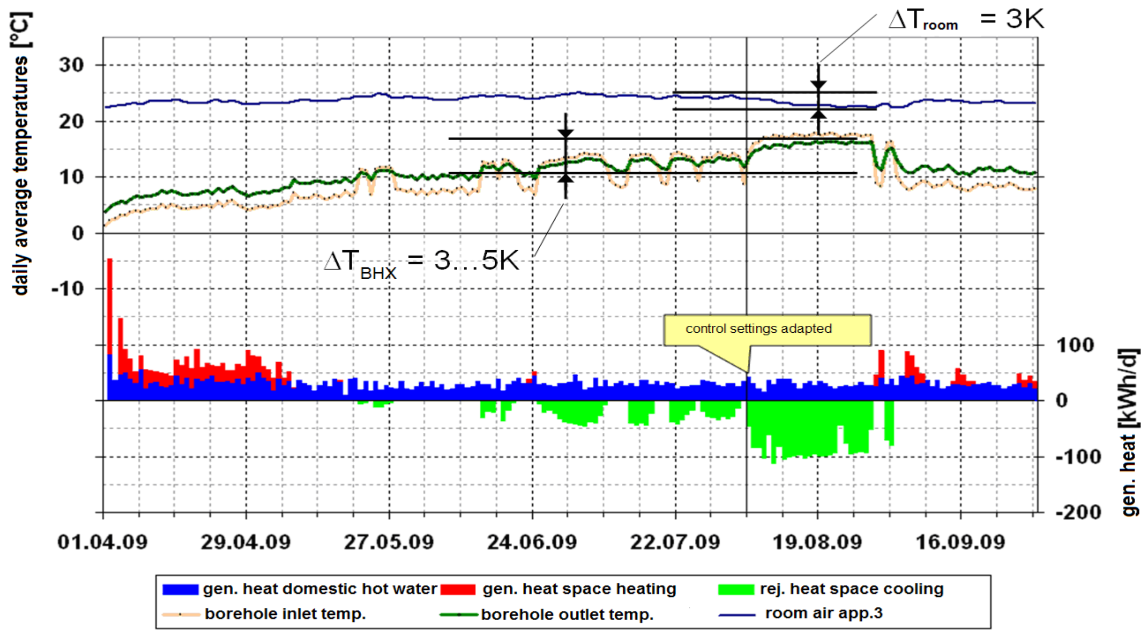

Figure 3: Generated heat correlated to borehole heat exchanger flow temperatures from field measurements

CONCLUSION

Space cooling in Swiss residential buildings is not a standard application up to now and in many cases also not necessary, but still more and more used. Hence energy efficient and robust solutions as shown in this paper are necessary to be available and implemented if required. Furthermore, space cooling, in particular passive cooling, is worth to be considered in calculation methods and legislative requirements. Especially in future ultra-low to plus energy buildings all consumptions and the potential energy savings of the integration of functionalities need to be considered.

ACKNOWLEDGEMENTS

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COMPARING CONTROL-ORIENTED THERMAL MODELS FOR A PASSIVE SOLAR HOUSE

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ABSTRACT

Solar heat gains through large window areas contribute significantly to lessen the heat demand of modern passive solar houses. Conventional heating controllers can fail to react in time to these uncontrollable heat gains, which leads to uncomfortable overheating periods. An alternative control technique to overcome this shortcoming is model predictive control (MPC), which allows the integration of weather forecasts and expected building thermal behaviour into the building energy management system. In order to be applied successfully, the MPC algorithm requires an accurate but also computationally efficient mathematical model of the building thermal behaviour and the HVAC components. Detailed building simulation tools like TRNSYS or EnergyPlus cannot be applied for this purpose since they are computationally too expensive. Instead, simple lumped-parameter models represented by resistance-capacitance networks are used. The parameters of these models are calibrated using measurement data.

The goal of this paper is to present a lumped-parameter building thermal model for a wooden test passive solar house with integrated photovoltaic system. The focus is on the identification of the relevant thermal dynamics of the building mass influencing the average room temperature in the test building. For this purpose, three lumped-parameter models with differently detailed modelling approaches for the outside walls and the building internal mass are evaluated. The individual parameters of the three models are identified using measurement data from an unoccupied period.

The results obtained for a training and a validation period show that a model where only the thermal dynamics of the internal construction are represented by two capacitances is able to estimate the average room temperature with an RMS error between the measured and simulated temperatures of around 0.5 °C. On the other hand, increasing the model complexity by treating the two different outside walls with two additional capacitances only slightly improves the accuracy. Therefore, in the test building considered the thermal dynamics of the outside walls with a thick insulation layer, but without brick veneer, are negligible compared to the thermal dynamics of the internal construction.

Thus, the two-capacitance model as a compromise between accuracy and complexity, together with an online state and parameter estimator, is proposed to be used in an MPC algorithm for heating and cooling control in the passive solar house considered.

INTRODUCTION

The design of a passive solar house is mainly characterized by a good thermal insulation, capturing passive solar gains through large window areas and a high internal thermal mass [1]. Conventional heating control is not adequate to control thermal comfort in this type of building because of its slow reaction to the passive solar gains, which increases the risk of overheating periods [2]. Furthermore, the high thermal mass can be used for load shifting in order to reduce peak heating demand and for damping temperature swings [3]. These circumstances raise the need for advanced control strategies anticipating the thermal building behaviour and the expected solar gains. Model predictive control (MPC) is a promising approach, since it allows the integration of weather forecasts and the expected building thermal behaviour into the energy management system. A prerequisite for MPC algorithms to improve the performance of the building control system is the availability of an accurate but also computationally efficient mathematical model. The model predicts the thermal behaviour of the building and its HVAC components in order to estimate the heating or cooling demand of the building for a time horizon of a few days. Detailed building simulation tools like TRNSYS or EnergyPlus are computationally too expensive for this purpose. Instead, simple lumped-parameter models represented by resistance-capacitance networks are used. The parameters of these models are calibrated using measurement data.

Although numerous publications deal with lumped-parameter building thermal models, only a few publications describe applications of lumped-parameter building thermal models on passive solar houses. Tindale [4] investigated the suitability of the popular 3R2C model (e.g. [5]) for buildings with thermally massive space as passive solar houses. He reported that adding a third virtual capacitance improves the dynamic response of the second-order model. Thron [2] compared different models up to fifth order with measurement data taken in a small residential solar building. She concluded that increasing the model order from second to third order only slightly improves the result for her test building.

Another approach is chosen by Kummert [6]. Since the building thermal behaviour is mostly dominated by heat transfer through walls, he shows that a second order model for a multi-layered wall is an acceptable compromise between accuracy and complexity. The model for a thermal zone is then constructed by using a capacitance for the room air and the derived wall representation for each wall of the zone. Therefore, the model for a simple test cell is already of 7^{th} order.

In this paper, the focus is on the identification of the relevant thermal dynamics of the building mass influencing the average room temperature in a passive solar house. For this purpose, three lumped-parameter models with differently detailed modelling approaches for the outside walls and the building internal mass are investigated. The models are calibrated and validated using measurement data from a test building.

TEST BUILDING

The test building considered in this paper is a six-storey timber construction located in the Swiss Alps at 2,883 meter above sea level. The building was built in 2009 by the Swiss Alpine Club (SAC) and is used as an alpine hut for mountaineers. It is a passive solar house with an envelope consisting of a wood frame structure with a 300 mm thick layer of glass wool covered outside by an aluminium shell. A building integrated photovoltaic (BIPV) system is mounted on the southern façade. The ground floor contains a restaurant, whereas the three upper floors are used for bedrooms and washrooms. The building services and house automation are located in the two basements. Up to 120 guests can be accommodated by the building. Figure 1 shows the east and south façades of the building. The building parameters are listed in Table 1.

This passive house is equipped with a ventilation system to control air quality. In addition, the ventilation system is used for heating and cooling the hut. The fresh air is blown into the restaurant and into the stairway located along the cascaded window front, which leads to the upper floors. The air is then extracted in the bedrooms, so that the solar gains through the wide window front are transported into the bedrooms.

Figure 1: East and south façades of the test building. The window front going from the bottom of the east façade to the top of the west façade belongs to the stairway leading to the upper floors.

Building volume	3699 m^3
Aluminium façade area	858 m^2
Photovoltaic façade area	122 m^2
Window front area	128 m^2
U-value building envelope	0.11 W/m^2K

Table 1: Building parameters [7].

The building is not occupied from October until March. During that time the building is fully remotely controllable. Therefore, the building is well suited to carry out tests during the winter months without having any human-induced disturbances.

Measurement setup

The building is equipped with a room temperature sensor in the restaurant and with duct temperature sensors in two reference rooms on each upper floor. The duct temperature sensors are located directly behind the air exhaust louvre. Therefore, these sensors are assumed to provide representative room temperature measurements when the ventilation is off. Additionally, the heating and cooling load are evaluated by measuring the flow rate of the supply air mass and the temperatures of the supply air and exhaust air ducts. The temperature of the building integrated PV façade is measured by two temperature sensors located at the rear of the PV panels. These building-related measurements are recorded with a sample time of a maximum of 15 minutes.

Weather conditions are measured by a weather station located directly next to the building. Measurement data of ambient temperature, wind speed, wind direction, global horizontal and diffuse horizontal solar radiation are provided every ten minutes.

THE LUMPED-PARAMETER THERMAL BUILDING MODELS

For the purpose of this investigation, all relevant rooms are lumped into only one thermal zone. In the case of the test building, this single zone includes the ground floor and the three upper floors, since only the comfort in this part of the building is relevant. The thermal behaviour of the two basements is not taken into account. No heat exchange is considered between the basement and the heated part of the building.

The electric analogies of the three lumped-parameter building thermal models investigated with increasing complexity are shown in Figure 2.

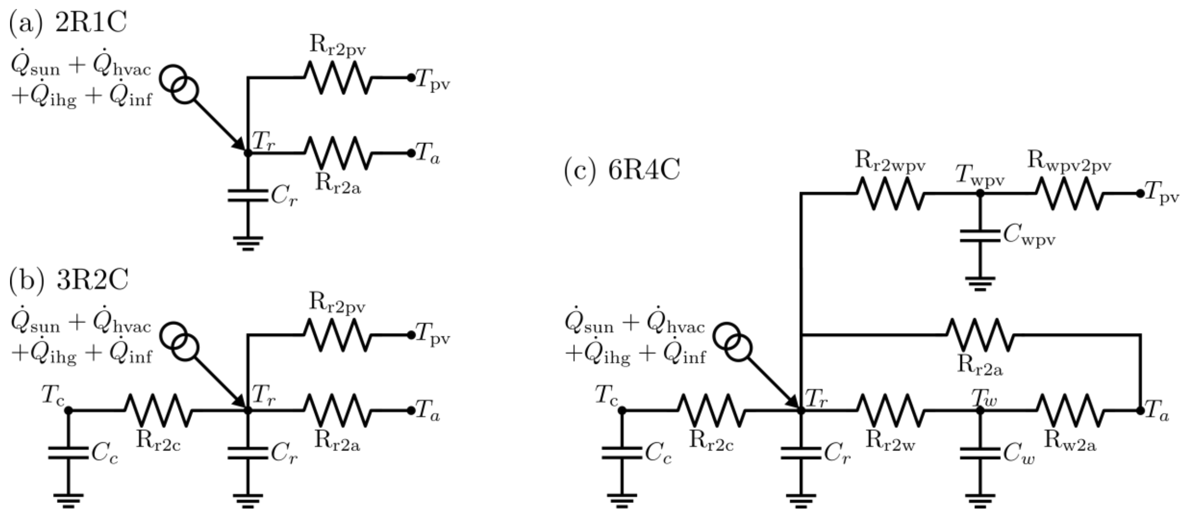

Figure 2: Electrical analogies of the lumped-parameter building thermal models investigated.

In the first model (2R1C) the thermal capacitances of the room air, furniture and internal constructions are lumped into one effective capacitance C_r with the average room temperature T_r. Because of the BIPV façade, the model distinguishes between the outside wall behind the BIPV air gap facing the medium temperature of the PV panels T_{pv} and the rest of the building envelope, which is linked to the outside air temperature T_a. In this model the two distinguished outside walls are represented only as resistances R_{r2pv} and R_{r2a}, respectively. Additional heat flows acting on the capacitance are solar heat gains through windows $\dot{Q}_{sun}$, heating and cooling load $\dot{Q}_{hvac}$, internal heat gains $\dot{Q}_{ihg}$ and heat flow by infiltration $\dot{Q}_{\inf}$.

The solar heat gains through windows depend on the total solar radiation on the windows and the angle-dependent total solar energy transmittance of the windows. In this work, the Perez model described in [8] is used to compute the beam, diffuse and ground reflected solar radiation on the sloped windows from the horizontally measured global and diffuse radiation data. The angle dependency of the total solar energy transmittance is evaluated using the relationship proposed by Karlsson and Roos [9].

In the second model (3R2C) only the room air, furniture and the mass of the outermost indoor wall surface layer, which define the building's daily behaviour, are lumped into the capacitance C_r. A second capacitance C_c is introduced, which is linked with the thermal resistance R_{r2c} to the capacitance C_r. The capacitance C_c represents the thermal dynamics of the mass of the internal construction having a time constant longer than 24 hours [10]. The walls are still modelled without any dynamics.

The third model (6R4C) is an extension of the second model where a capacitance for each of the two distinguished outside walls is added. Lightweight conductance, such as that added by windows, is modelled with the single resistance R_{r2a}.

Parameter identification

To compare the simulated average room temperature with the measurement data, a reference room temperature is defined. This temperature is calculated as a weighted average of all measured room air temperatures [11]. Because the storeys have different room heights, the volumes of the storeys are used to compute the weighting factors. Note that since not every room of the building is equipped with a temperature sensor, this calculated reference room temperature is only an approximation of the real average room temperature. This has to be taken into account in the interpretation of the results obtained.

The individual parameters of the three models are identified by minimizing with the Nelder-Mead simplex algorithm [12] the root mean square (RMS) error between the measured and simulated room temperatures using measurement data from an unoccupied period of 12 days. Figure 3 shows a comparison between the measured reference room temperature and the average room temperature estimated by the three different models for the training period and a validation period. The RMS error and the maximum absolute error of the three models and the two periods are listed in Table 2.

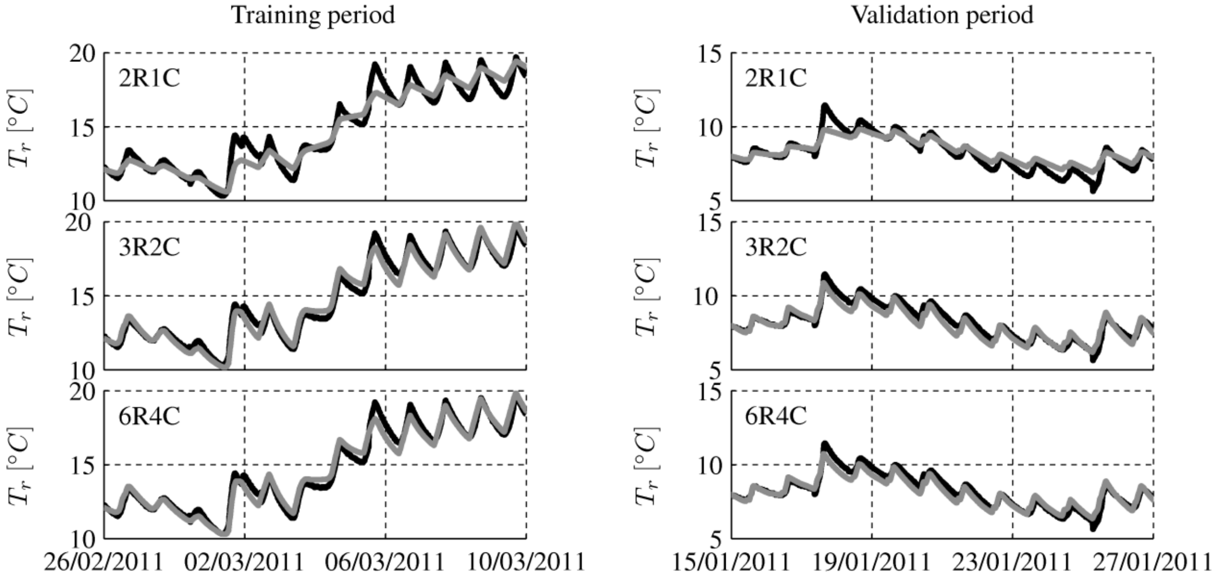

Figure 3: Comparison between the measured reference room temperature (black) and the simulated average room temperature (grey) of the three models for the training (left) and the validation (right) period.

Model version	**Training period**		**Validation period**	
	RMS error [°]	Max. abs. error [°]	RMS error [°]	Max. abs. error [°]
2R1C	0.623	2.11	0.443	1.68
3R2C	0.441	1.08	0.354	0.84
6R4C	0.437	1.14	0.348	0.97

Table 2: Characteristic numbers for the three models.

DISCUSSION OF THE RESULTS

Comparing the numbers in Table 2 shows that there is a substantial improvement from the 2R1C model to the 3R2C model. However, if the temperature levels in the building only change slightly, even the 2R1C model shows accurate results. On the other hand, increasing the model complexity by treating the two distinguished outside walls with two additional capacitances only slightly improves the accuracy. Therefore, in the test building considered the thermal dynamics of the outside walls with a thick insulation layer, but without brick veneer, are negligible compared to the thermal dynamics of the internal construction. Of course, this result may not be true in another passive solar house where the building envelope consists of a brick veneer.

CONCLUSION

In this paper, comparing three lumped-parameter thermal building models with increasing complexity with measurement data taken in a passive solar house, the relevant thermal dynamics of the building mass are identified. The results show that the dynamic response of the average room temperature in the considered test building is mainly influenced by the dynamic behaviour of the internal mass rather than by the temperature distribution in the outside walls. Therefore, a simple 3R2C model is able to estimate the average room temperature with an RMS error between the measured and simulated temperatures of around 0.5 °C. Thus, the 3R2C model is proposed to be used in an MPC algorithm for heating and cooling control in the test building presented.

Additionally, the small number of parameters of the proposed model makes it suitable to be used together with an online state and parameter estimator.

ACKNOWLEDGEMENTS

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SOLAR ENERGY QUANTIFICATION FOR THE WHOLE FRENCH URBAN AREA

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ABSTRACT

Renewable energies are a key component of French energy policies. In most of them, solar energy plays a central role. In 2010, 75% of French population is located in urban areas where the majority of building stock and energy demand are located. But renewable energies, especially solar energy (for electricity or heating), require space, this is problematic in urban areas. Moreover, the solar potential depends on building environment (tree shade effect, surrounding buildings…). Consequently, understanding of relationships between building environment characteristics of each specific area and its solar potential is critical.

This paper is focused on the quantitative impact of buildings' morphologies on the assessment of the solar potential of an urban area. It presents a method to quantify the energy potential received by facades and roofs located in urban areas for active solar energy. The method comes within the context of calculations divided into two categories. The most precise one calculates irradiation which reaches one building and the other one calculates the solar potential at the territorial level but does not include the urban morphology.

The first step of the proposed methodology combines a geographic information system, Corine Land Cover (CLC) which covers 38 countries and other regional databases. These regional databases provide several types of urban districts and the various types of buildings which make them up. Then, we dispatch those types in the CLC map on the basis of statistical data. The aim is to define the whole urban fabric of a country.

The second step aims at calculate the solar potential of the whole area previously described. We used the backwards ray tracing program RADIANCE including cumulative sky models for the computation of incident irradiation (Wh/m2) in a single simulation. In order to simplify the process, we also used the interface to RADIANCE that was developed specifically for urban radiation studies, PPF.

We will present the results of this study which give the total irradiation reaching the buildings facades and roofs in the whole French urban area. We will also discuss the influence in the calculation of the number of reflections on the walls and roofs.

INTRODUCTION

France increasingly seeks higher levels of optimization and rationalization of the use of its resources. One of the effects of this desire is the commitment to lower energy consumption and reduce greenhouse gas emissions which implies using renewable energy sources, with solar sources.

Numerous attempts to produce centralized solar heating networks have had little success due to significant losses[1]. Solar heating supply should therefore be installed closer to the consumption infrastructure, and more specifically, to the existing building stock. Given that the building stock evolves very slowly, the problems related to its energy consumption are long-standing. In addition, new buildings consume less energy than their older counterparts, and can utilize a larger spectrum of renewable energy potential, especially solar radiation, due to the fact that it is possible to choose certain parameters such as the orientation and inclination of the roofs.

Among the existing residential buildings, the vast majority is located in urban areas, where nearly 80% of French people reside [1]. Thus, a detailed estimation of the renewable energy potential in urban areas is necessary. The nature of their morphologies has a strong impact on both the types and quantities of locally recoverable renewable energy by the buildings and their infrastructures. However, studies exist at a national level but do not take into account – do so in an insufficiently precise manner- the impact of urban areas on solar potential. Other studies focus on specific buildings and cannot estimate the solar potential at a larger scale.

The purpose of this study is to evaluate the solar potential achievable in urban areas, an intermediate scale which takes into account urban geometry, and to apply it to the whole country.

Thereafter, we identify solar radiation by the term "solar potential". It is defined in this study as the amount of energy received by the facades and roofs of buildings. In this paper, the methodology and the results are presented.

RECONSTITUTION OF THE FRENCH BUILDING STOCK AND ESTIMATION OF ITS SOLAR POTENTIAL

To assess the solar potential, it is necessary to geometrically characterize urban areas throughout France. We therefore opted for a method which virtually reconstitutes the residential building stock with different computational steps on which it is possible to quickly intervene. It is divided into the following four stages:

• Crossing data between Corine Land Cover (CLC) [2] (a database which does not present a satisfactory level of accuracy for our study but is available throughout France) and the Mode of Land Use [3] (MLU; MOS in French), which is an additional source of information that we determine to be more accurate according to our criteria, but whose range of use is limited only to the Ile-de-France.

• Identification of types of buildings and ground plane (several types of buildings forming districts) which constitutes a new database. We identified 22 types of residential buildings and 30 types of ground plane for these buildings.

• Calculation of solar potential on different ground planes for the different climates in France.

• Aggregation of results at both a regional and a national level.

The difficulty lies in finding a source of information on the geometry of urban areas which is both relatively accurate and available throughout metropolitan France. The first database we chose to use is CLC 2006, since it is the most recent base that covers the entire territory. It

[1] In Denmark, for example, the Marstal District Heating Plant has significant heat losses in its heating network. It is mentioned in the Appendix 6 of the “Cahier du Clip 16”, available from the author.

was constructed from satellite images. The surface of the smallest spatial unit mapped is 25 hectares; however, this scale is too rough for our work at the district level.

The nomenclature of CLC is divided into categories or items. We are interested only in dense continuous and discontinuous fabric and industrial areas, which constitute the first three CLC categories. They cover the entire surface of the urban areas in France.

The Institute for Urban Planning and Development Ile de France (IAU) has created a more accurate database for public use across the Ile-de-France. The MLU consists of 83 categories at the scale of a few buildings which corresponds to the level of precision required for our study.

We divided classes of CLC into the 83 categories of the MOS using a Geographic Information System (GIS). It spatially decomposes the three varieties of CLC we study in those of the MOS and calculates their relative shares of the total surface of CLC treated. Only categories representing more than 1% in urban areas have been preserved which corresponds to approximately 80% of the surface of areas treated by CLC.

We assigned types of ground planes for residential [4] or non-residential buildings [5] to the categories of the MOS. The annual amount of solar energy received by the roofs and facades is calculated in the eight climatic zones defined in the RT2005 (French thermal regulations published in 2005). We chose the computer program RADIANCE enriched with the interface PPF [6]. This ray tracer is commonly used for such calculations and results have benefited from validation in the literature [7]. Moreover, ray tracers model the reflections with high accuracy and with excellent visual results.

However, the inherent difficulty in the use of such a tool is the extremely long process time, which varies exponentially with the number of reflections reaching the solar walls. The number of reflections is set at "2" by default in PPF. Compared to a calculation without reflections, the observed difference in the calculated potential is about 20% for facades and 5% for roofs. This result is a consequence of the reflection coefficient which is correspond to a value of 0.2 (part of the incident beam reflected) commonly chosen for the walls of buildings. We also observed that the difference of the solar potential with two reflections as opposed to one is extremely limited, being less than 2% for both roofs and facades.

RESULTS AND DISCUSSION

Logically, the southern regions have the highest values (Figure 1); however, some areas further north have relatively high potentials as well. Two important parameters were identified: the amount of solar energy received by each region, shown in Figure 2, and urban density, which determines the number of buildings per unit area and thus, the amount of surface that receives solar radiation per unit area.

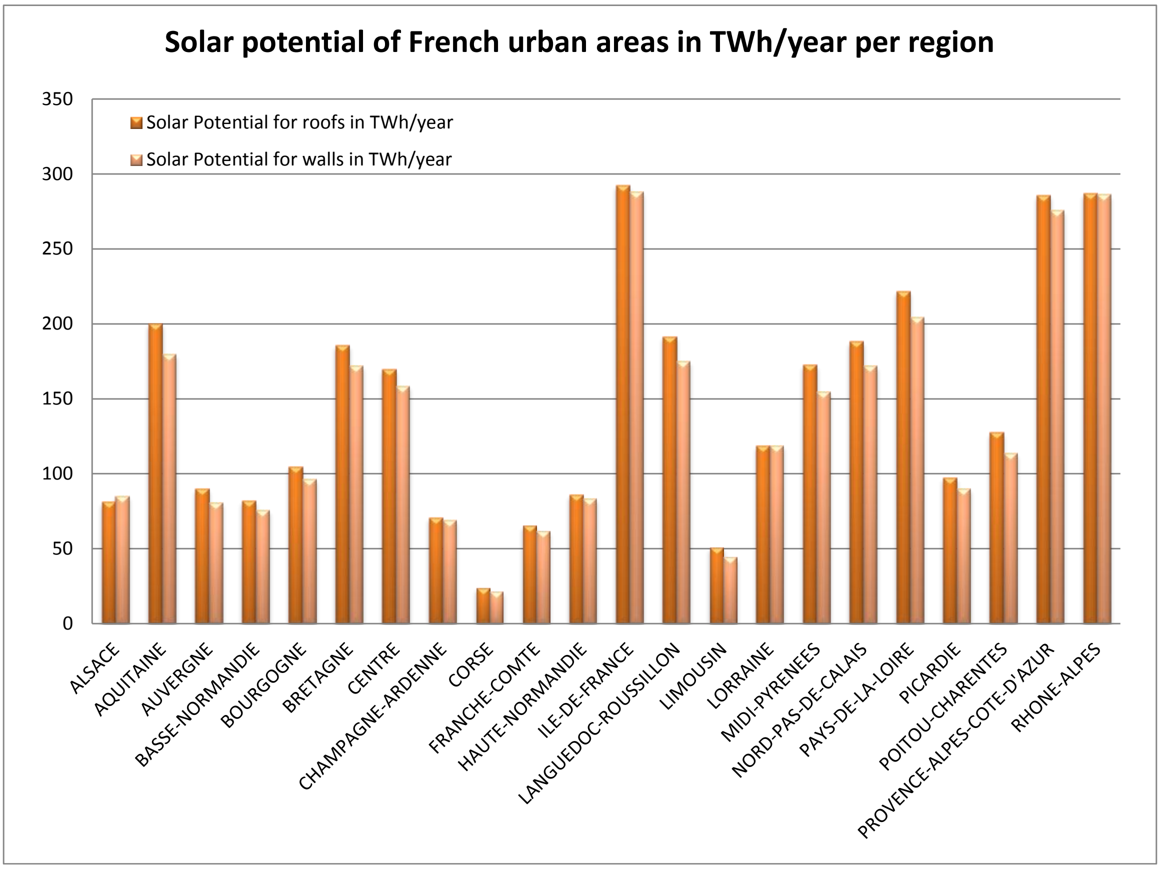

Figure 1: Solar potential of French urban areas

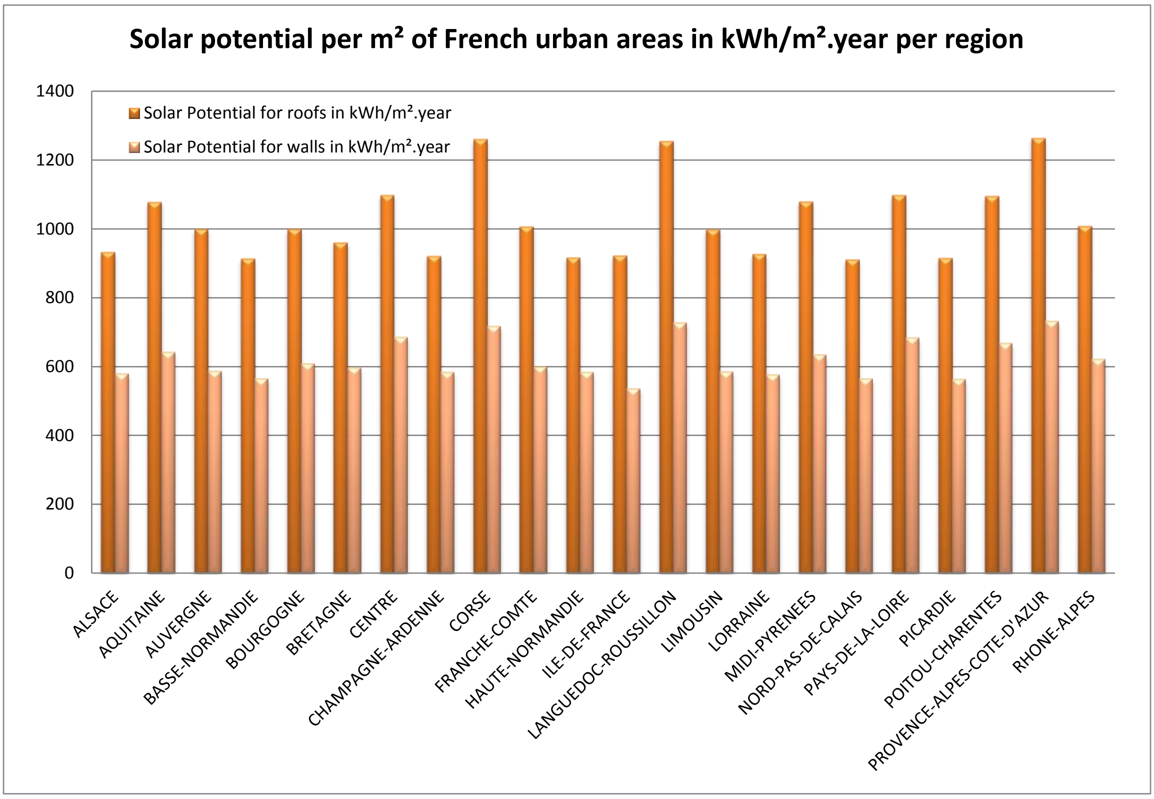

Figure 2: Solar potential per surface area of French urban areas

Indeed, regions such as PACA and Languedoc-Roussillon receive significant solar gain while others such as the Ile-de-France or even the Nord Pas de Calais compensate for lower solar gain by a higher density of buildings.

The total solar potential in French urban areas is approximately 3200 TWh / year for roofs and 2700 TWh / year for façades. These figures provide an upper bound to the amount of energy available to buildings located in urban areas. However, the installation cost of solar panels and surface constraints are not taken into account. In comparison, the energy consumption for heating in France is less than 400 TWh [8], or 6.4 % of the total solar potential.

One study of the INES (the National Institute of Solar Energy) estimated the magnitude of the potential closer to 10,000 TWh [9], but it is based on an area of 10,600 km² of roof. This value is given by IFEN (French Institute for the Environment) and, in reality, corresponds to build artificial surfaces whose scope is not clearly defined by the SOeS (formerly IFEN).

Our study assessed approximately 3100 km² of roof area and after numerous calculations using the number of buildings and the average area of the covered area, the value we obtained is slightly greater than 3000 km² of built area, which corresponds accurately to that of our study.

CONCLUSION AND OUTLOOK

The work presented in this paper aims to assess the solar potential received by the built infrastructure in urban areas. A validation of this method based on indicators such as number of buildings identified by the General Census of Population in France has been realized. It gives an error of less than 5% for the whole country but has regional disparities. The most credible explanation is that the distributions of the categories of the MOS in CLC are not exactly the same in all regions. Thus, recalibrations using indicators such as number of listed buildings in the census allows for a more realistic decomposition of the regions.

The next step is the calculation of this potential taking into consideration various efficiencies of several technologies such as photovoltaic solar panels or thermal solar collectors. The aim is to assess the potential energy supply by this type of technology. The results will be presented in the poster during the conference.

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LIFE CYCLE ASSESSMENT APPLIED TO URBAN SETTLEMENTS AND URBAN MORPHOLOGY STUDIES

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ABSTRACT

Life Cycle Assessment (LCA) is increasingly used to improve the environmental performance of products, and its application in the building sector seems promising. Several tools have been developed and compared in the frame of the European Thematic Network PRESCO (Practical recommendations for sustainable construction). An LCA model has been developed for Settlements, in order to help the decision making process during their design or renovation.

The system considered includes buildings, public spaces (streets, parks…) and networks (drinking water, sewage, district heating). All phases of the life cycle are modelled: fabrication of products, transport, construction, operation, renovation, dismantling and waste treatment with possible recycling. This model allows an evaluation of different impact indicators (e.g. resource depletion, energy and water consumption, global warming, waste generation, toxicity…), and the comparison between different design alternatives to be performed. The aim is to assess the influence of buildings and urban morphology on the environmental impacts of a settlement project.

The operation phase is long lasting, so that processes like heating/cooling play an important role in the global environmental balance. Decisions made at the level of the settlement (orientation of streets, compactness and urban density) have a large impact on heating/cooling loads. Therefore the LCA tool is linked to thermal simulation. Some development is on-going regarding dynamic-LCA aspects, particularly accounting for the temporal evolution of the electricity production mix. This communication presents an application of the model on case studies inspired by Quartier Vauban in Freiburg. The aim is to define a best practice reference to which other projects can be compared.

INTRODUCTION

Buildings and urban settlements are complex systems. Knowledge is still missing regarding the links between decisions, particularly design choices, and environmental impacts. Such knowledge and derived tools is needed by professionals in order to progress in their practice of eco-design.

This communication presents a model developed at the settlement's scale, on a cradle to grave basis, in order to compare design alternatives on an environmental point of view, addressing impacts from a regional to a global scale. When evaluating a project using such a model, it is useful to compare performances using a benchmark. In order to identify best practice references, the model has been applied to case studies inspired from Quartier Vauban in Freiburg.

METHOD

As we consider here that in the case of a settlement, most impacts are related to the production of energy, water, materials etc, which occurs out of the settlement, Life Cycle Assessment (LCA) has been used rather than impact evaluation focussing a local system. Impacts can occur on a global scale, like in the case of climate change, or the depletion of the ozone layer, at a regional scale, with the acidification or eutrophication problems, or at a local scale, as with smog or waste production. We choose here to use the LCA methodology, in order to get the most comprehensive information about the consequences of settlement on the environment. This methodology permits the calculation of various indicators, e.g. damage-oriented, regarding the human health, the biodiversity or resource depletion.

LCA is a standardized assessment methodology [1], permitting the study of a system from its production to its end of life. LCA is composed of four main steps: after the definition of the goal and the scope of the study, the system is clearly defined (principally its functional unit and boundaries) and the hypothesis of the study specified, then the inventory analysis is performed. This inventory is an account of all substances taken and emitted in the environment, during the whole life cycle of the system. From this account, indicators corresponding to impacts are calculated. All those steps are directly linked with an interpretation phase, which may imply a new definition of the system or the goal and scope of the study (for example if a lack of data appears during the inventory phase).

The model developed for the settlements' study take into account four stages in the life cycle: construction, operation, renovation and dismantling of the settlement [2][3]. The calculation of the inventory is based on two different aspects: first on the production, the renovation and the elimination of what is included in a physical boundary, then on the assessment of all that is included in the flows boundary defined in our model, which include transport, water, energy, materials and settlement's components and waste. The settlement is composed of different types of buildings, open spaces, networks and optional district heating production infrastructure. Because energy consumption represents a large part of the environmental burden, heating and cooling loads are evaluated for the different buildings using a dynamic multi-zonal simulation [4]. A graphical interface simplifies data input, making possible to study a large number of buildings within the time constraints of professional practice.

PRESENTATION OF THE CASE STUDY

The model presented above has been applied on two settlements inspired from the eco-district Vauban in Freiburg (Germany) [5]. The first one named "low energy neighbourhood" (LEN) is representative of the major part of the whole eco-district. The second one, named "plus-energy neighbourhood" (PEN) is similar to the Solar-City designed by Rolph Disch, but adapted in order to harmonize the number of inhabitants in the two cases.
Both include dwellings, a tertiary building, an elementary school and a parking lot of four levels including a supermarket in its ground floor and a photovoltaic system on the roof.
In order to use these models as references for a comparison with projects in Greater Paris area, the two settlements are contextualized in the model, e.g. using climatic data for Paris and the French electricity mix.
The surfaces of the open-spaces and the number of buildings of the plus-energy neighbourhood represented above have been adapted so that the two settlements include the same number of inhabitants.

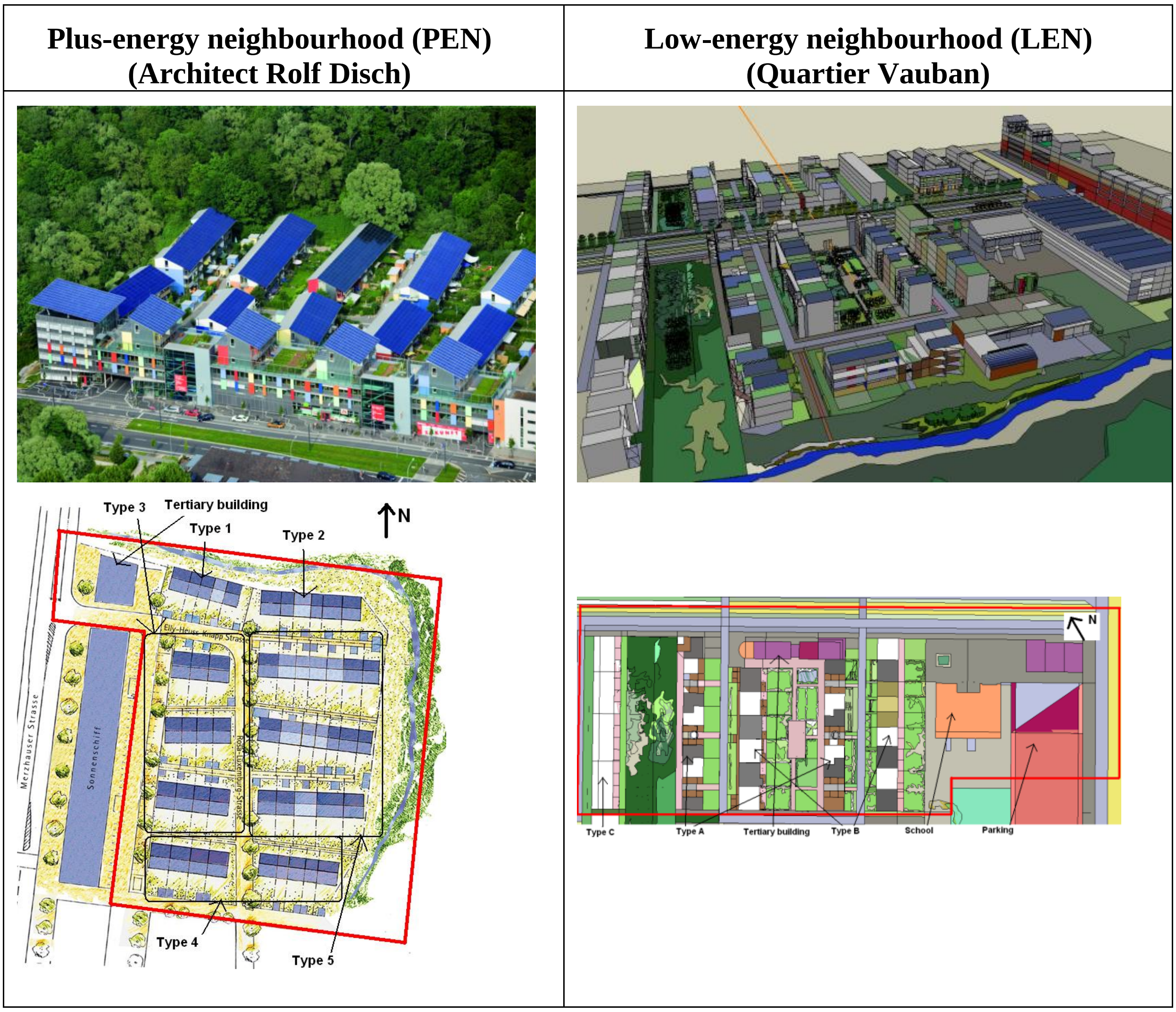

Figure 1 : overview of the two settlements

Settlements characteristics	**PEN**	**LEN**
Settlement area	39,000 m²	24,000 m²
Built area	7,000 m²	6,000 m²
Area of street and pavement	9,000 m²	9,000 m²
Area of green spaces and garden	23,000 m²	9,000 m²
Number of inhabitants	394	394
Average area of the dwellings	138 m²	87 m²
Number of employees – offices	100	100
Number of employees - school	10	10
Number of employees - supermarket	15	15
Number of pupils - school	110	110

Table 1: Characteristics of both settlements

Building models include different thermal zones according to their orientation and function (dwelling, offices…). The functions are modelled using weekly and hourly scenarios regarding occupancy (in number of occupants per zone or per m²), ventilation (in m3 per hour, taking into account the infiltrations), internal gains (W/m²), heating and cooling set points (°C). Building characteristics are indicated in Table 2.

Thermal performances	Plus-energy neighbourhood	Low-energy neighbourhood
Glazing, U in W/(m².K)	0,70 (triple glazing)	0,87 (triple glazing)
Outer walls, U in W/(m².K)	0,12 (exterior insulation)	0,16 (exterior insulation)
Ground floor slab, U in W/(m².K)	0,16	0,16
Roof, U in W/(m².K)	0,11	0,11
Thermal bridges around the slab W/(m.K)	0,05	0,10
Average heating load of the buildings	17 kWh/m².year	23 kWh/m².year

Table 2: Thermal performances of the building

We also define the cold and hot water consumption in litter per day per person, as well as the characteristics of the public spaces (type, composition, surface, needs of lighting and water, imperviousness), and of the heating, drinking water and sewage networks (length, composition, maintenance…).
Because the objective is to compare urban and architectural choices, aspects related primarily to occupants' behaviour, e.g. domestic waste sorting, choice of home-work transport mode etc. are not accounted for, but they are included in the model.
Buildings are heated by district heating, the source being a cogeneration plant using 20% of natural gas and 80% of wood with an efficiency of 26% for electric production and 61% for heat production. The domestic hot water is produced 50% by this plant and 50% by solar panels (410 m² of south oriented collectors for both settlements). The French electricity production mix is considered (78% nuclear, 14% hydroelectric or renewable, 4% gas and 4% coal) with 9% losses in the network. 5 440 m² of photovoltaic panels are integrated on roofs for the plus-energy neighbourhood and 1 650 m² for the low-energy neighbourhood.
The life cycle assessment is performed considering a 80 years life span, but this parameter can be varied in sensitivity studies. Demolition waste is considered treated as inert waste, except metals that are recycled. Impact indicators are normalized in equivalent inhabitants-year, using French references (e.g. 8.7 t eq. CO_2 emissions per person and per year).

RESULTS

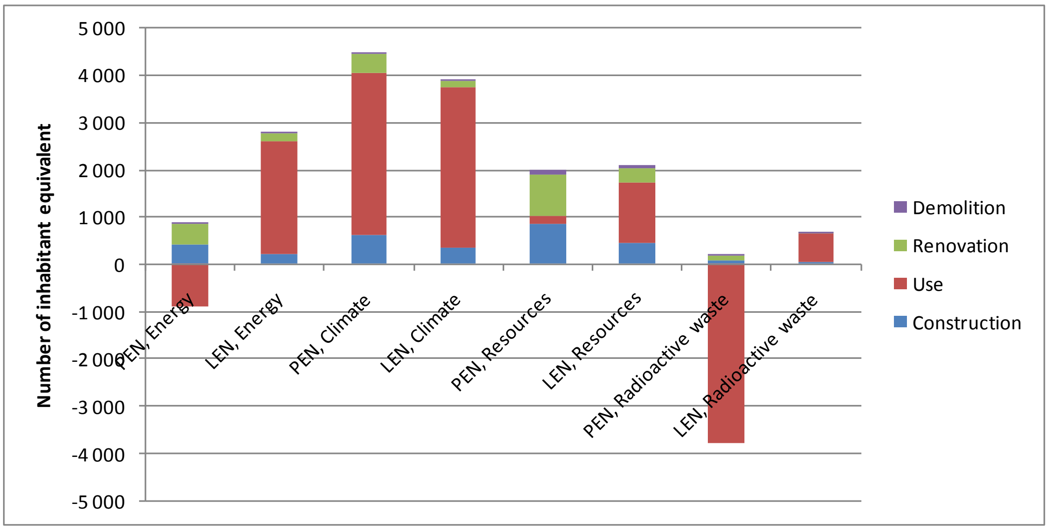

Figure 2: Comparative total life cycle impacts on four indicators

The histogram above presents the results of the LCA for the two settlements, on four indicators (of the twelve existing), decomposed into four life cycle phases.
The first indicator is the primary energy consumption. More energy is consumed in the PEN for construction and renovation, due to the fabrication of PV modules, but the renewable electricity production (combined with solar hot water and co-generation systems) compensates this consumption so that the overall performance is higher than for the LEN (see Table 3).

	PEN		LEN	
	Use phase	**Life cycle**	**Use Phase**	**Life cycle**
Photovoltaic	-100%	-85%	-29%	-25%
Cogeneration	-9%	-8%	-10%	-9%
Thermal solar	-8%	-7%	-9%	-8%
Total	-117%	-100%	-47%	-42%

Table 3: primary energy balance compared to a reference without photovoltaic, cogeneration and thermal solar

The trend is similar regarding resource depletion, but PV production does not allow a zero impact to be achieved. In this indicator, the use of gas has a large effect than the uranium saved by renewable electricity production. The balance would probably be different if probable instead of ultimate reserves are considered in the impact assessment, and further research is still needed on such topics.

The French electric mix consists in 78% of nuclear power. Avoiding a standard production, the electricity produced by the cogeneration and the photovoltaic systems reduce heavily the generation of radioactive waste.
The climate change indicator (t CO2 equiv) presents an impact 15% higher for the PEN than for the LEN. The difference appears principally during the phases of construction, renovation and demolition, due to the fabrication of photovoltaic panels, whereas the impacts of the use phase are very close for the two settlements. This result can be explained by the electric mix, which includes only 4% of gas and 4% of coal thermal plants. Therefore solar electricity production doesn't influence significantly the greenhouse effect indicator (-8% for the PEN and -2% for the LEN).
On the other hand, the impact is higher for the PEN because the dwelling area per occupant is higher in this settlement. In fact, by m² of heated surface, the impact on greenhouse effect is lower by 18% for the PEN than for the LEN.

DISCUSSION

Comparing the energy performance of different urban forms leads to different conclusions, e.g. regarding appropriate glazing ratio and solar exposure. One main reason for such variability is related to assumptions regarding occupant's behaviour, particularly the management of solar protection and window opening. Applying LCA extends the problematic, accounting for the use of materials and addressing various environmental impacts. For instance compactness may reduce material quantities, which may displace the optimum evaluated using only energy assessment. But environmental performance is greatly influenced by occupants' behaviour. Standard scenarios have been used in the present study, but sensitivity analysis would be useful to complement the comparison of alternatives.

Comparing urban morphologies requires harmonization of the functional unit considered. This is complex for a settlement including various types of buildings (dwellings, tertiary buildings, shops…), infrastructures (parking loan, roads…), of different size, capacities, characteristics... It is therefore difficult to define a universal benchmark and best practice reference that can be used to assess the performance of projects, e.g. for labelling purposes. Perspectives for methodological improvement are discussed e.g. in the frame of the European LORE-LCA research coordination action, aiming at identifying good practice and knowledge gaps regarding the application of LCA in the building sector. For instance, some elements are neglected when modelling large systems like urban districts, inducing the question of the validity of such cut off rules.

CONCLUSION

Sustainability is on the agenda of most organisations, and particularly cities. Accounting for environmental issues in the building and urban sectors is presently based upon rather subjective approaches. Yet the severity and planetary extent, long duration and possible irreversibility of environmental impacts like global warming, nuclear risk, dispersion of toxic substances, biodiversity loss and resource depletion, justifies more precise tools to be used in the decision making process. Developing such tools therefore corresponds to the needs of professionals, and can be based upon experience gained in the industry, using methods like LCA. The example comparison presented here illustrates the possibility to compare alternatives on a multi-criteria basis, showing advantages and draw-backs of the different solutions. Further activities are planned to improve the methodology and perform sensitivity studies, e.g. regarding life span and occupants' behaviour.

ACKNOWLEDGEMENTS

CEP takes part in the European research coordination action LORE LCA (Low Resource consumption buildings and constructions by use of LCA in design and decision making) coordinated by SINTEF (Norway). Some work is also performed with the help of national projects (ANR) and a Chair "Eco-design of buildings and infrastructure" has been created by ParisTech with the support of VINCI.

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ENHANCING RESULTS OF A HEAT PUMP FIELD TEST BY MEANS OF DYNAMIC SIMULATIONS

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ABSTRACT

A comprehensive field test with heat pump systems in existing buildings all over Germany is analysed. Each building and each heat pump system is unique because local technical companies installed them. Thus the field test represents an "as built in practice" state (year of installation 2007). Due to the inhomogeneity of the field test objects and unknown parameters it is not possible to extract the influence of every component on the system's efficiency. In addition, the performance of heat pump systems depends sensitively on weather (air-to water heat pumps) or geological effects (ground coupled heat pumps) as well as on building and user behaviour.

Models of the heat pump system's components are tested with the field test data. The model components are subjected to time series of the field test and their behaviour is compared to the behaviour of the real components. The single models can be combined to models of the complete system. The Modelica (see www.modelica.org) libraries developed at the Institute for Energy Efficient Buildings and Indoor Climate allow a detailed modelling of the whole thermo-hydraulic system including the heat source, the heat pump, water storages and the heat sink - the building. The models of a complete system allow detailed parameter studies.

Outcomes of the field test show, that under the corresponding circumstances (existing one-family homes in Germany) certain heat pump systems are less efficient regarding primary energy demand than standard boiler systems. The influence of the heat source and heat sink are clearly identifiable. Other effects are less distinct but can be verified and quantified by simulation results.

The object orientated modelling also allows the composition of new system set-ups such as hybrid heat pump systems that consist of heat pumps and boilers. A simple hybrid system is proposed for the retrofit of buildings. A small air-to-water heat pump is added to an existing boiler and only works within conditions that guarantee a high efficiency. The hybrid system achieves savings both in insulated and non-insulated existing buildings.

Keywords: building simulation; heat pump; hybrid heat pump system

INTRODUCTION

Modern heat pump systems offer a high potential for energy savings compared to standard heating systems. Their actual performance particularly depends on weather conditions and geological effects as well as on building design parameters and user behavior. Therefore, an energetic optimization requires an intelligent coupling of all system components. In this paper a field test serves as data basis to estimate realistic heat pump performances in existing buildings and to test models. The models are used to simulate optimized heat pump systems.

THE DATA BASIS

The field test presented within this paper was conducted through the Fraunhofer Institute for Solar Energy Systems in Freiburg. It contains heat pump systems all over Germany and started in 2007. Air-to-water heat pump (AWHP) systems as well as brine-to-water heat pump (BWHP) systems are analysed. All test objects were formerly heated with oil boilers. Heat pumps of different manufacturers were installed by local companies in 2007. The field test objects are very inhomogeneous with respect to system layout, which complicates the analysis and makes it difficult to extract single effects from the data.

Finally 43 objects had a sufficient data basis whereof 21 are AWHPs, 17 are BWHPs with vertical ground source heat exchangers (GSHX) and 5 are BWHP with horizontal GSHXs. Fig. 1 shows the construction years of the buildings within the field test and the according specific heat demands. Insulation standards according to the building construction year can't be identified. Even some of the newest buildings achieve high values probably generated through a corresponding user behavior.

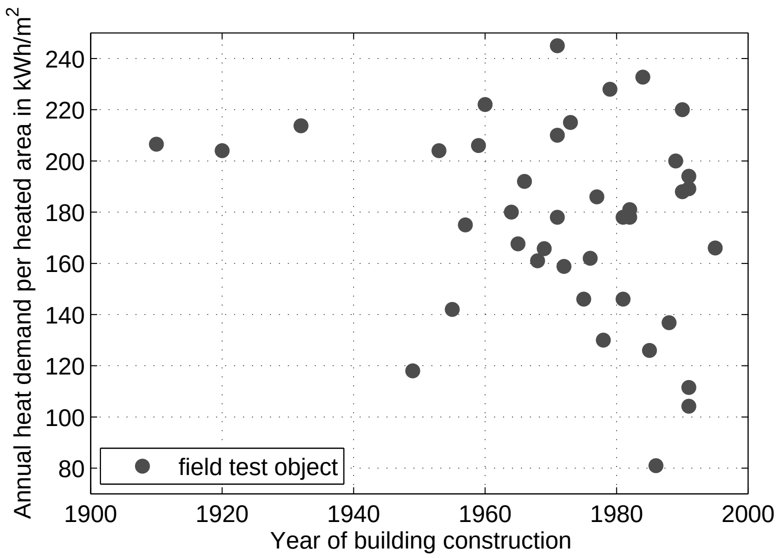

Figure 1: Construction years of the field test objects analysed and the according specific heat demands.

PERFORMANCE OF HEAT PUMP SYSTEMS

In this paper, the system boundary for the calculation of the heat pump system efficiency is chosen in a way that makes the heat pump system comparable to other heating systems (see fig. 2). That means that for example the energy used for loading pumps (which are not necessary in boiler systems) is included. This system boundary assumes the storage being located outside of the thermal building shell which means that all storage losses are heat losses for the system. All calculations concerning primary energy demand are done using this system boundary, allowing a comparison to a boiler system. All calculations are based on the data of the years 2008 and 2009.

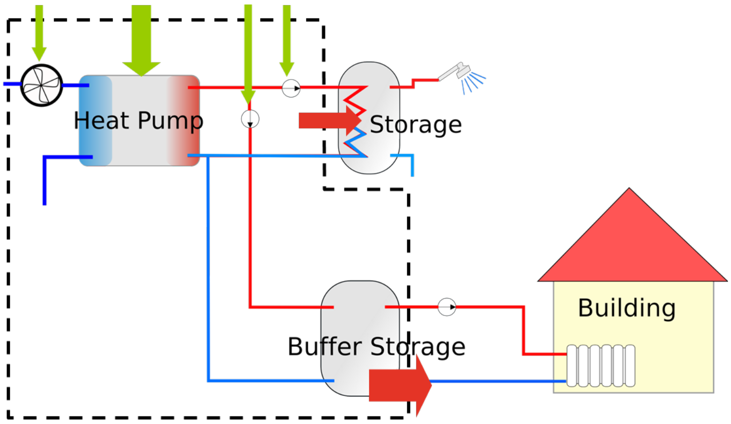

Figure 2: System boundary used for analysis.

In fig. 3 relative savings in primary energy are shown compared to a hypothetical new condensing boiler that produces the same amount of heat as the heat pumps with a fixed efficiency of 0.96 (primary energy factors according to (1), non-renewable part). Each field test object is indicated through its number on the abscissa. It shows, that only BWHPs achieve savings in primary energy in the field test. The majority of AWHP systems uses more primary energy than condensing boilers would (2.4 % more). Whereas BWHP systems merely achieve savings of primary energy, on average 18.8 %. Only three of 21 ground coupled systems are less efficient than a new boiler.

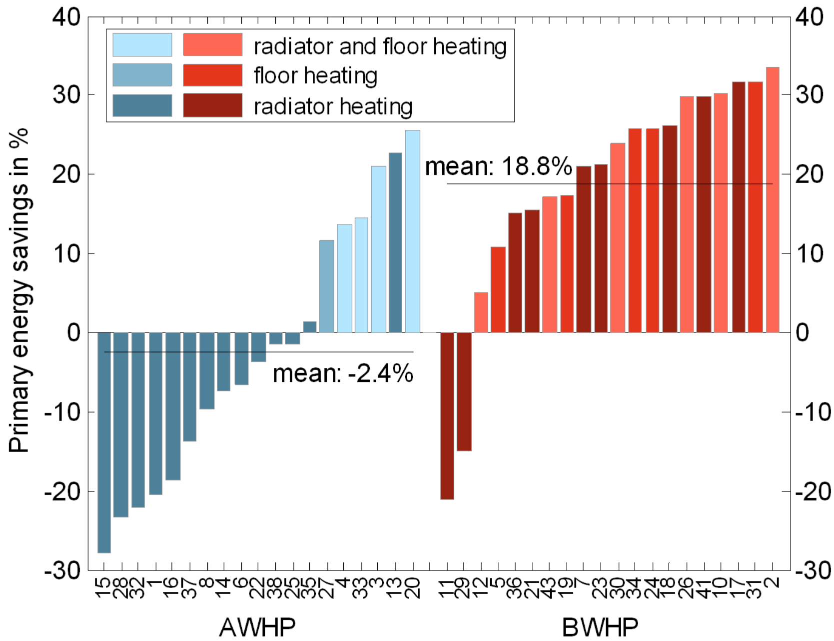

Figure 3: Relative savings in primary energy compared to a new gas boiler.

Heat Pump System Models

The Modelica (3) model libraries developed at the Institute for Energy Efficient Buildings and Indoor Climate allow a detailed modelling of the whole thermo-hydraulic system of a building. New models have been developed for heat pump systems. The Modelica language allows an acausal modelling and thus it allows to consider the interaction of all system components. Simulations are done using the software Dymola for the graphical connection and for the compilation and simulation.

The building models represent structural effects, weather and user influences (4), (6). They are compatible with the building services installation models described below.

The building services installation library contains basic components of building services installations, such as pumps, pipes, boilers, heaters and valves. It uses medium models of the Modelica.Media and components of the Modelica_Fluid libraries. Simple components calculate state changes of fluid by look-up tables, more complex models use finite volume methods and empiric correlations (4), (6).

Heat pumps are modeled table-based with manufacturer data (see (7)). Storages are modeled with multiple layers allowing the modelling of stratification. Buoyancy effects within the water volume are taken into account by an effective heat conductance depending on the temperature differences between the layers (see (7)).

Validation of models

A validation of library components is done using the data from the field test.This data is taken as input to the components or combined components. This way the model's reaction can be compared to the behavior of the real component. This is done for the table-based heat pump model in the set-up shown in fig. 4. Generally the heat pump behavior can be simulated well by the manufacturers' data. Other components are validated analogously. For the validation of ground source heat exchanger models the field test data is complemented by thermal response test data (see (2)).

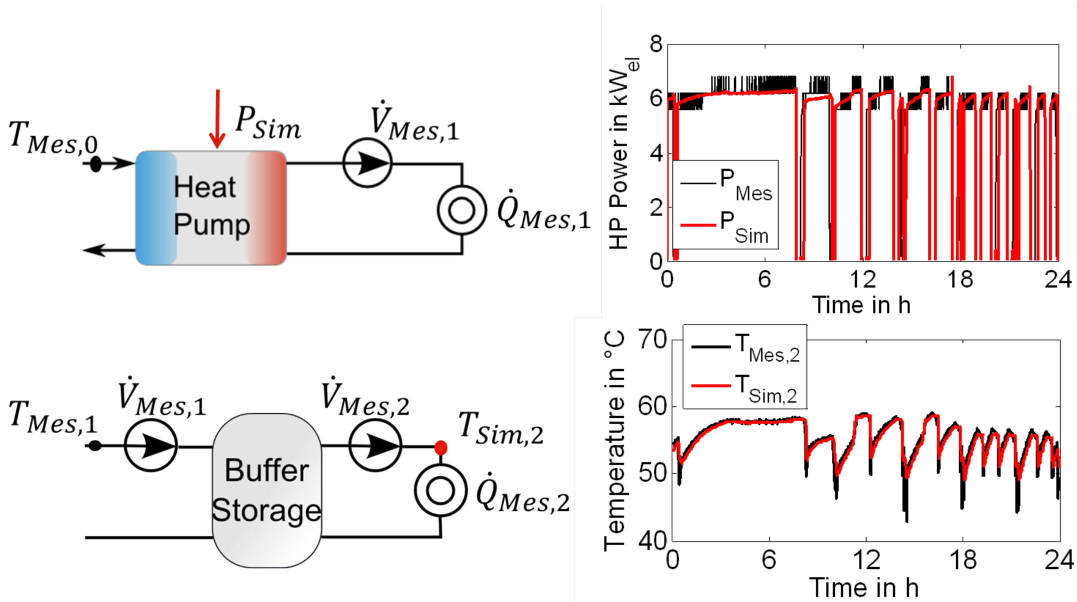

Figure 4: Validation of models and comparison of simulated values to field test data.

Numerical study on hybrid heat pump systems

The AWHP system presented here is a possible solution to the problems of standard systems in existing buildings described above. Its idea derives from some observations: AWHPs are less efficient at low ambient temperatures. Most heating systems in Germany are over-dimensioned due to design conditions at very low ambient temperatures. Existing boiler systems are often quite efficient. But future policies require the use of a certain amount of renewable energy in buildings.

The numerically analysed hybrid system tries to cope with these facts (see scheme in fig. 5). The heat pump condenser is located in a water storage of 750 l volume. The storage is connected to the heating system's flow and return. The heat pump heating output shall be low enough to avoid overheating at the condenser. The bivalent temperature is chosen to 0 °C and the nominal heat pump power is chosen to 3.5 kW and a CoP of 3,6 at A2W35. The heat load of the building is 2.4 kW (insulated) and 10.2 kW (non-insulated), the boiler nominal power matches the building's heat load. The simulations were done using the test reference year number 4 for Potsdam, Germany (cf. (8))

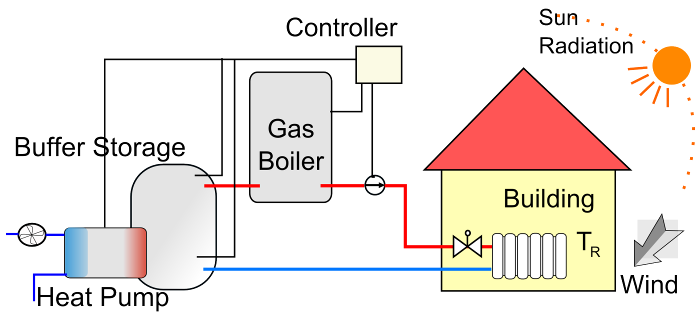

Figure 5: Scheme of the hybrid heat pump system.

Fig. 6 shows the simulated primary energy demand for the insulated (a) and non-insulated (b) building. For the insulated building we see that the AWHP system has low savings in primary energy compared to the boiler system. The hybrid system achieves savings of 19 %. For the non-insulated building the AWHP has a higher demand of primary energy than the boiler system. The savings of the hybrid system are 9 %.

Summary and Outlook

Heat pumps in existing buildings can be economically and energetically advantageous compared to boilers, nevertheless in the field test a lot of them that are not.

A possibility for savings in primary energy are hybrid heat pump systems. Numerical studies presented above showed that they can save primary energy compared to simple gas boiler systems (here: 9 to 19 %, depending on insulation standard) and AWHP systems. The results of dynamic simulations show that savings depend on the system arrangement and the ratios of heat load, boiler and heat pump. Every building and heating system type needs its own adjustment. Optimal sizes of each component (among other the storage size) and controller settings have to be found for different insulation standards and heating systems in further research.

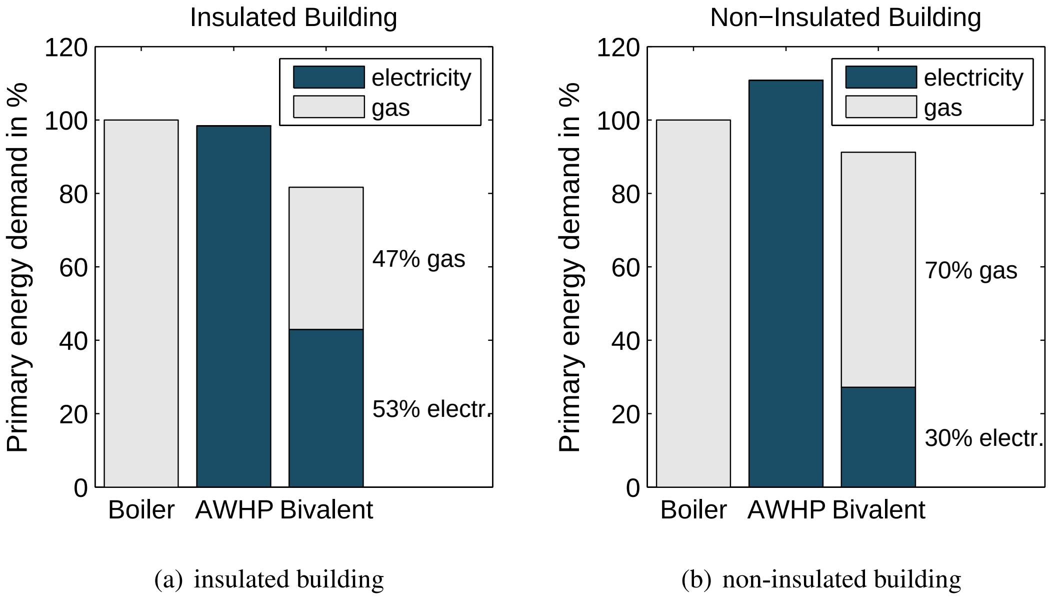

Figure 6: Primary energy demand for the variants within the study of hybrid systems.

ACKNOWLEDGEMENT

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BALANCING DIVERSITY AND EVALUATION TIME IN BUILDING ENERGY SYSTEM EVOLUTIONARY ALGORITHMS

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ABSTRACT

Modern building design encompasses multiple domains and disciplines, from physical, to functional, to aesthetic. With advances in technology and increasing demand for functional buildings with improved energy performance and uncompromising comfort, the task of the design team is a challenging one. Building performance simulation tools with ever wider scopes are being employed, developed, and integrated to meet these challenges. For this complex design landscape, with a large number of interacting design variables and a multitude of often conflicting objectives, evolutionary algorithms are recognized as an efficient method in searching the design space and arriving at optimal solutions. In previous work, the simulation software TRNSYS 17 was coupled to the Matlab genetic algorithm toolbox in a proof of concept using a single objective evolutionary algorithm [1,2]. The present paper continues development towards a customized, robust, and flexible optimization platform for building energy performance simulation.

In this paper, an implemented optimization method is presented, where a multi-objective evolutionary algorithm is applied to a simple building design case study. The case study is a simple shoe-box building, with glazing areas, orientation, and construction build-ups as design variables. The objectives are to minimize both annual heating and cooling load.

The simulation software used is TRNSYS 17 [3]. The algorithm and processing are done using code written by the author in Python 2.6 [4]. The algorithm is first described, followed by the details of the problem domain including parameters, variables, and objectives. Results of several evolutionary algorithm runs are presented. Each run represents between 2,000 and 10,000 individual TRNSYS runs. The aim of the present paper is to investigate population diversity through mutation and population size, as well as to provide a solid foundation for future more complex design problems.

Results show that the algorithm succeeds in finding solutions to the design problem representing three strategies; one strategy focuses on minimizing cooling, another heating, and a more balanced approach. These results are discussed along with challenges in the approach used. Finally, a roadmap for future research is presented.

MULTI-OBJECTIVE EVOLUTIONARY OPTIMIZATION

Evolutionary algorithms have been applied to diverse engineering design problems and have been proven to derive high quality and often unintuitive solutions [5].

De Jong identifies the challenges associated with the still-maturing field of multi-objective evolutionary computation [6]. Many evolutionary algorithms are designed to optimize a single objective, and if multiple objectives are combined, such as in a weighted sum, these approaches can yield useful results. However, many building design objectives are difficult to quantify, and it is important for designers to understand the trade-off between, for instance, comfort and cost. In one approach, solutions are presented as vectors of fitness values in the solution space. Pareto-optimal points represent points that are not dominated by any other points in the population.

A well known multi-objective evolutionary algorithm, NSGA-II, is selected for its proven speed and ability to find Pareto-optimal solutions in an N-dimensional solution space [7]. NSGA-II identifies successive dominance fronts in the population, as shown in Figure 1 where the first three fronts, F1-F3 are labelled. Figure 1 plots each solution in the design space for a single generation. In this case, two objectives are present, one per axis. The fronts are therefore trade-off curves.

The next generation is made up by randomly selecting two individuals in a scheme called binary tournament selection, where the winner of the tournament is the individual with a better dominance front, and in the case of a tie, the individual in the least-crowded region of the front. This technique helps preserve diversity across the solutions.

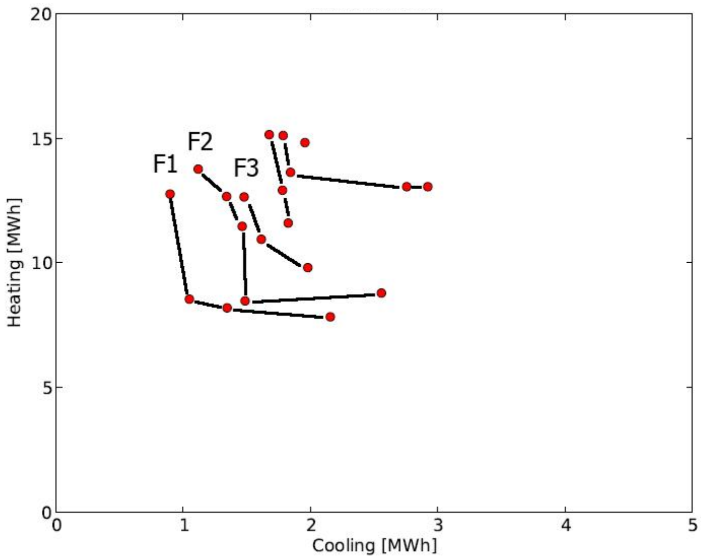

Figure 1 – Standard starting population and ranked Pareto-fronts

The NSGA-II algorithm is implemented with minor changes, such as adding capability to deal with discrete list variables which represent different wall constructions.

BUILDING DESIGN PROBLEM DOMAIN

A test case problem was prepared based loosely on the building test cases of ASHRAE Standard 140-2001, "Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs". This shoebox geometry shown in Figure 2 allows for a fast simulation time, and serves as a test case and proof-of-concept before a more complex building and system are attempted. Infiltration is modelled according to the standard at 0.5 ach/hr. The weather file used was a TMY2 file for Genève-Cointrin Airport.

Table 1 provides more details on the design variables which define the design space to be explored by the evolutionary algorithm. 7 variables were chosen. Table 2 summarizes the two objectives, to simultaneously minimize annual heating and cooling loads.

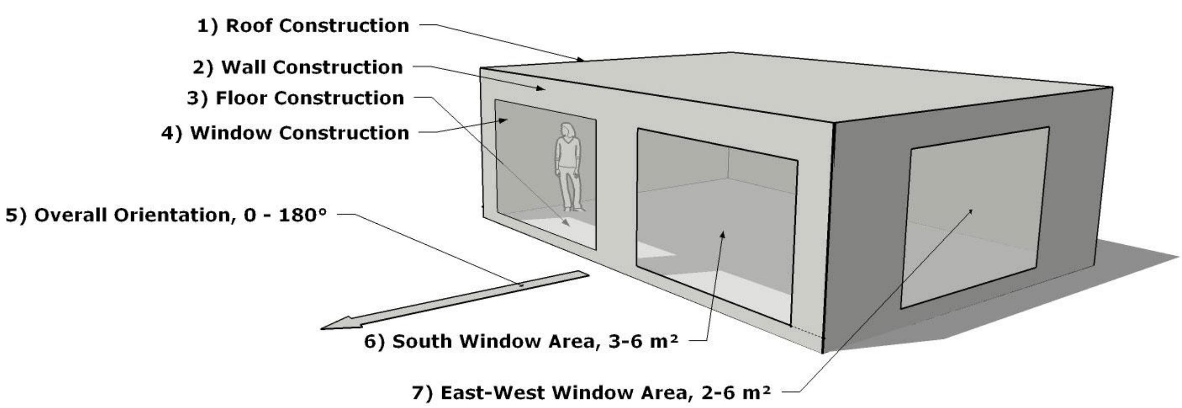

Figure 2 - Test case building

Table 1- Design variables

<table>
<tr><th></th><th>Variable</th><th>Range and description</th></tr>
<tr><td>1-3</td><td>Constructions</td><td>Floors, and walls, can all independently vary between 3 ASHRAE BESTEST defined constructions;
<table>
<tr><td>Lightweight</td><td>Plaster Board, Insulation, Siding / Roofdeck U-0.50</td></tr>
<tr><td>Heavy</td><td>Concrete, Insulation, Siding / Roofdeck U-0.51</td></tr>
<tr><td>Medium</td><td>Same as heavy, but ½ concrete thickness U-0.92</td></tr>
</table>
<table>
<tr><td>U-Values</td><td>Walls</td><td>Floor</td><td>Roof</td></tr>
<tr><td>Lightweight</td><td>0.500</td><td>0.039</td><td>0.316</td></tr>
<tr><td>Heavy</td><td>0.511</td><td>0.040</td><td>0.511</td></tr>
<tr><td>Medium</td><td>0.924</td><td>0.040</td><td>0.924</td></tr>
</table></td></tr>
<tr><td>4</td><td>Glazing</td><td>South and East-West windows can independently vary between four ASHRAE defined window constructions;
<table>
<tr><td>#</td><td>Panes</td><td>U-Value</td><td>g-Value</td></tr>
<tr><td>1</td><td>Single glazed</td><td>5.5</td><td>0.89</td></tr>
<tr><td>2</td><td>Single glazed</td><td>5.4</td><td>0.82</td></tr>
<tr><td>3</td><td>Double glazed</td><td>3.2</td><td>0.70</td></tr>
<tr><td>4</td><td>Double glazed</td><td>2.9</td><td>0.79</td></tr>
</table></td></tr>
<tr><td>5</td><td>Orientation</td><td>Overall building orientation (azimuth) can vary between 0 (South) and 180 (North) degrees</td></tr>
<tr><td>6-7</td><td>South window areas</td><td>The South facing windows can each vary between 2 and 6 m^2 (therefore total area can vary between 4 and 12 m^2)</td></tr>
<tr><td>7</td><td>East-west window areas</td><td>The east and west windows can vary between 2 and 6 m^2</td></tr>
</table>

Table 2 – Optimization Objectives

	Objective	Description
1	Annual heating demand	Total thermal energy in MWh to maintain internal temperature above 20 °C
2	Annual cooling demand	Total thermal energy in MWh to maintain internal temperature below 23 °C

RESULTS

Table 3 below lists the important parameters used in three runs of the evolutionary algorithm NSGA-II applied to the simple case study building. In all runs, 100 generations were executed. In run number one, a population size of 20 was evaluated 100 times, with a low rate of mutation (which introduces randomness into the population). In run 2, mutation was significantly increased, by a factor of five. In run 3, the population size was increased by a factor of five with the original mutation rate.

Table 3 - Evolutionary algorithm runs

Run	Name	Population	Mutation	Generations
1	Standard	20	5%	100
2	High Mutation	20	25%	100
3	High Population	100	5%	100

Figure 3 shows the final population for run 1. Solutions show a clustering along the 6-7 MWh/a band for heating, with a wider distribution for cooling demand. Crowing is high, suggesting that the niching (Pareto-front diversity) mechanism in NSGA-II has not been properly implemented. Total execution time was approximately 2 hours for all 2,000 simulations, on a quad-core 2.8 GHz CPU, with 4 runs in parallel. Figure 4 displays the final population of run 2, using a much higher mutation rate. Clearly, this rate of mutation is too high, resulting in an increase in diversity at the cost of solution quality.

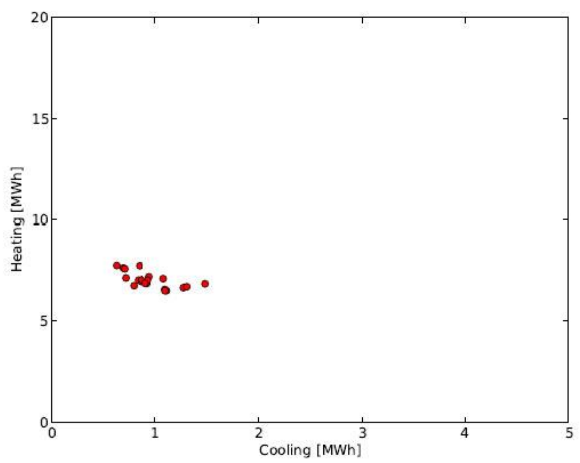

Figure 3 – Standard solution

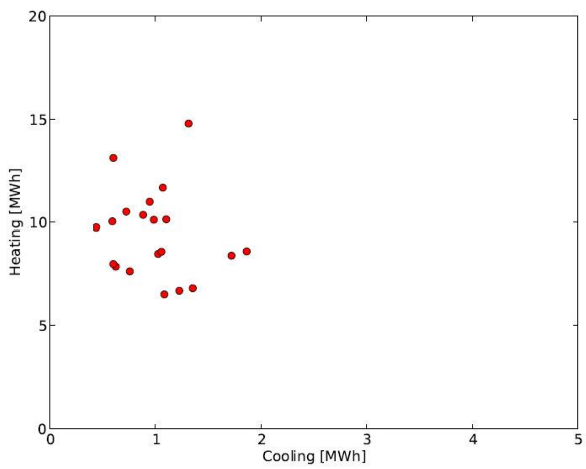

Figure 4 - Solution, high mutation

Figure 5 shows the results of a high-population evolutionary algorithm run. In this case, a broader Pareto-front is found, at the cost of 5 times more simulation time over the 10,000 simulations.

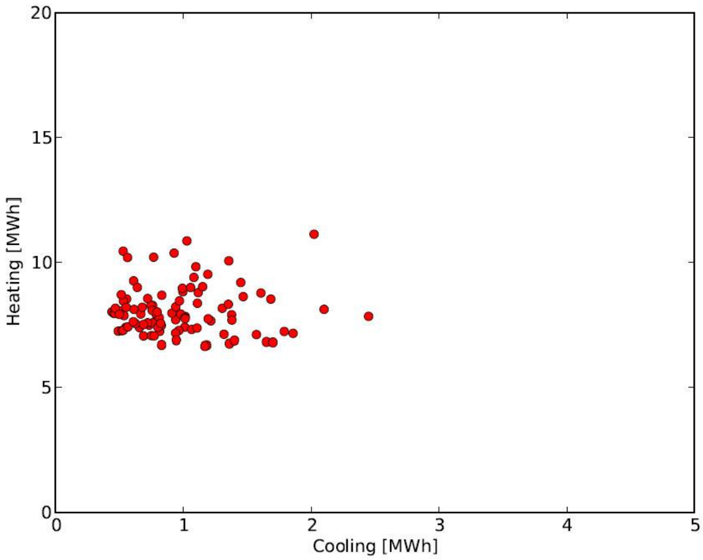

Figure 5 - Solution, high population

Table 1 lists three representative results from the “standard” run and the “high population” run. In general, three groups of results can be identified, representing three different design strategies and goals.

Table 4- Sample results

	Orientation	**"South" glazing**	**“East-West" glazing**	**Walls**	**Roof**	**Floor**	**Windows**	**Cooling**	**Heating**
	°	**m^2**	**m^2**	**-**	**-**	**-**	**-**	**MWh/a**	**MWh/a**
1	15	5.2	2.0	Heavy	Light	Heavy	Type 4	1.5	6.5
2	170	3.0	2.0	Heavy	Heavy	Heavy	Type 4	0.4	8
3	42.3	3.0	2.2	Heavy	Light	Heavy	Type 4	0.9	6.6

DISCUSSION

As can be seen in Figures 3-5, the algorithm generally finds good solutions to the design problem. The “high mutation” run notably does find some optimal points, but many solutions are of significantly poor quality. This highlights the sensitivity of evolutionary algorithms to parameters such as mutation rate. An optimum exists between a mutation rate of 0%, and 100%, which would essentially represent a random search. The high-population run predictably performs well in the goal of finding a broad range of quality solutions, simply due to an increased starting diversity and better exploration of the design space throughout the run. However, it does not significantly out-perform the standard run, and does not warrant the five-fold increase in simulation time. Once again, an optimum exists in the evolutionary algorithm parameter of population size.

Solutions found by the evolutionary algorithm generally fall into 3 categories, representing two extreme points on the Pareto-front and a more balanced approach. Line 1 of Table 4 shows a “minimize heating” approach, representing the right-most solutions in figures 3-5. In this strategy, a minor decrease in heating can be achieved by orienting the building south and maximizing the south-facing window area, thereby allowing a solar heat gain during the winter. This of course comes at the expense of an increased cooling load during the summer. The second strategy conversely tries to minimize the cooling at the expense of an increased heating demand. This strategy minimizes glazing areas and orients the building north, to minimize any solar heat gain during the summer. These solutions are on the upper left part of the Pareto front. Finally, the third strategy balances these two objectives by minimizing the glazing area to limit solar heat gain, but also keeping some window area with a view to the south to allow a heating demand offset in the winter.

It is also important to note that the algorithm successfully designs for higher-performance windows and massive insulating opaque constructions. Interestingly, the minimize-cooling strategy is a design with the heavy roof construction, while the other two strategies are designed with light construction roof. As seen in Table 1, the lightweight roof does have a higher U-Value, but less thermal inertia. The cooling priority strategy benefits more from thermal storage than insulation.

This research is an important step towards implementing a multi-objective optimization method for building energy performance design. Upcoming research will focus on re-factoring the code, and designing baseline search techniques to compare performance. For example, the evolutionary algorithm could be compared to a mesh search and a random search in terms of overall number of simulations. Further work will then continue in finding optimal parameters for NSGA-II and other evolutionary algorithms applied to more complex design problems.

This paper presented an implementation of the NSGA-II multi-objective evolutionary algorithm applied to a case study building energy design problem. Although diversity across the Pareto-front was low, results do show successful designs given the problem domain, showing progress in developing a software tool using artificial intelligence techniques. Such a tool should design successful buildings to the meet increasing demands in sustainable construction.

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SIMULATION OF THERMAL SOLAR COLLECTORS, LATENT HEAT STORAGE AND HEAT PUMP SYSTEM FOR SPACE HEATING

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ABSTRACT

In this paper the thermo- hydraulic behavior of a heat pump system together with thermal solar collectors and a latent heat storage is simulated and the effects of these components on the overall system performance are analyzed.

With the help of the storage system the time between energy supply and energy demand can be separated. Therefore it is very attractive to load the storage at times, when "free" energy can be used, for example solar radiation. Then this storage can be discharged, whenever heat is needed. An optimal case concerning the utilization of renewable energy would be that the supply and demand are equal. Modern heating systems for buildings need a supply temperature of approximately 35 °C. Standard heat storages do not work efficiently with small supply temperature differences, because of the low sensible heat storage capacity. In contrast to such storages a phase change material (PCM) storage device uses the phase change process to store energy at small temperature differences.

During the year solar energy is not constant. Analyses of the solar radiation over the year show that there is a potential to use solar radiation in spring and autumn just for low temperature storage systems. Therefore a solar collector model has been implemented in a coupled building and system simulation, so that overall systems analysis can be done, which can answer the question, if it is much more efficient to integrate a latent heat storage device in connection to a solar system than just use normal buffer storage instead.

The modeling of thermo-hydraulic heat pump systems is done with the building and HVAC model libraries developed at the Institute for Energy Efficient Buildings and Indoor Climate using the modeling language Modelica. With the numerical studies of a complete thermo-hydraulic heat pump system the effects of different components on the overall system performance are analysed.

Keywords: building simulation; PCM; latent heat storage; thermo hydraulic modeling; thermal solar collector

INTRODUCTION

Modern heating systems for buildings need a supply temperature of approximately 35 °C. In order to use such supply temperatures more efficiently, the standard heat storage systems must be redesigned. The integration of a latent heat storage system in a modern heating system ought to enhance the overall system performance. The new storage system can be linked to a heat pump or a thermal solar system supplying a typical residential building, e.g. floor and ceiling heating system.

In this work numerical studies of a complete thermo-hydraulic heat pump system are done and compared to a combination with solar and latent heat storage systems.

Latent Heat Storage Devices

Latent heat storage systems use a phase change process to store a large amount of energy at small temperature differences. If the phase changing is ideally, the temperature of the storage system will remain constant during the process.

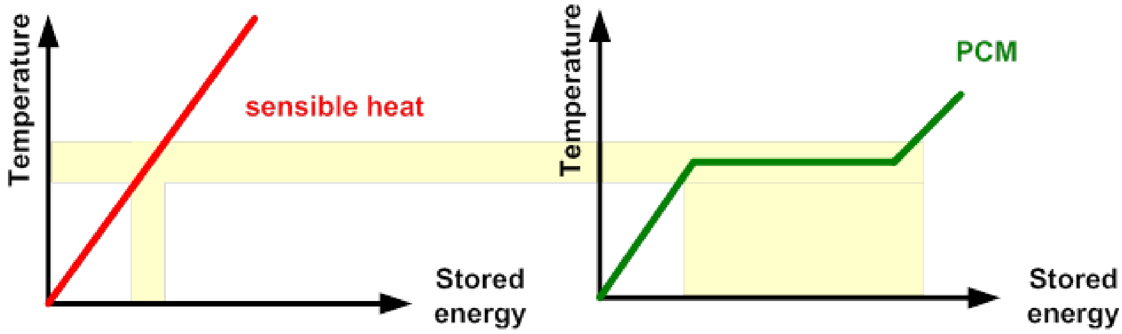

Figure 1: Sensible and latent heat storage.

For a heating application salt-hydrates or paraffins can be used as a PCM, because on the market there are materials, which have a phase change by approximately 35 °C.

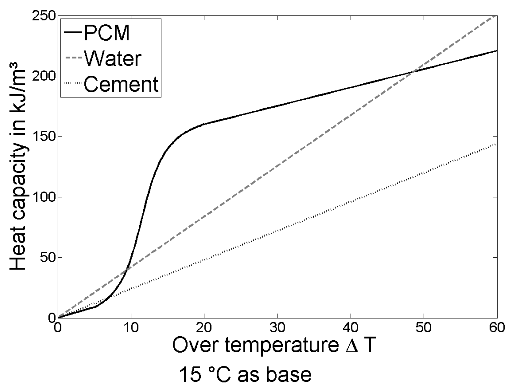

Figure 2: Specific heat capacity of different materials

Figure 2 shows a comparison of the specific heat capacity of water c_{water}, paraffin $c_{paraffin}$ and cement c_{cement}. All three materials have the same volume of one cubicmeter. The PCM- curve shows an ideal material with a melting temperature of about 25 °C. It can be seen that at the beginning the specific heat capacity of the PCM is the lowest and in the middle there is a region (phase change), where the PCM has the highest specific heat capacity. And at the end water has the highest c.

Model details of the storage system

A thermo hydraulic model of a latent heat storage device is developed. The PCM storage model consists of several PCM volumes in form of layers, which are combined to each other to create a whole storage. The complete PCM storage model exists of two base elements: PCM volume and a fluid component, here it is water, see Figure 3.

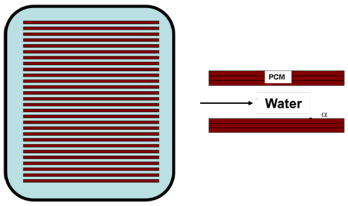

Figure 3: Sketch of the latent heat storage device.

The behaviour of each PCM volume is based on the energy balance, which is given by [2]:

$$\Sigma\dot{Q} = m \cdot c \frac{dT}{dt} \tag{1}$$

with $\dot{Q}$ as a heat flow, m as mass and c as specific heat capacity. The specific enthalpy is given by:

$$h = h_{trans} \cdot \left[\frac{\arctan((T - T_{trans}) \cdot r_{trans}}{\pi} + 0.5 \right] + c \cdot (T - T_0) \tag{2}$$

first term (latent heat part)

- h_{trans} specific enthalpy of transition
- T_{trans} temperature of transition
- r_{trans} width of transition

second term (sensible heat part)

- c specific heat capacity
- T_0 reference temperature

Using the equation above it is possible to build up a model of a PCM volume. Furthermore in this model several parameters like the mass of the PCM, the conductivity, design of the encapsulation and the ambient influence can be easily changed. At the same time each PCM volume layer can be discretized, so that it is possible to get a temperature profile of the material. The hydraulic model can be easily connected to other hydraulic components of a heating system such as heat pump or solar collectors.

THERMAL SOLAR COLLECTORS

For instance in spring and autumn it is possible to use the solar radiation for space heating applications. One efficient way of using thermal solar systems is to use them in combination with low temperature storage systems and for floor heating systems.

A solar collector model has been implemented, so that overall system analysis can be done, which can answer the question, if it is much more efficient to integrate a latent heat storage device in connection to a solar system than just use normal buffer storage instead.

The model is based on the performance factor, so that it is possible to simulate flat and pipe collectors [5].

Performance of a solar collector

$$\eta = K_\theta \cdot \eta_0 - a_1 \cdot \frac{t_m - t_a}{G} - a_2 \cdot \frac{(t_m - t_a)^2}{G} \tag{3}$$

with

- K_θ Incident Angle Modifier (IAM)
- η_0 optical losses
- t_m middle temperature
- t_a ambient temperature
- G solar radiation
- a_1 correction factor 1
- a_2 correction factor 2

The parameters can be found in data sheets and are stored in look- up tables. Up to now it is possible to choose ten different collector types, such as flat or pipe collectors. The model is connected to the weather model using data of the test reference year (TRY), so that it is possible to analyse different geographical areas in Germany.

In this study the collector is perfectly oriented for space heating systems, which means south orientation and an angle of 60°. The orientation for the preparation of a domestic hot water system would be an angle of 30°.

OVERALL SYSTEM

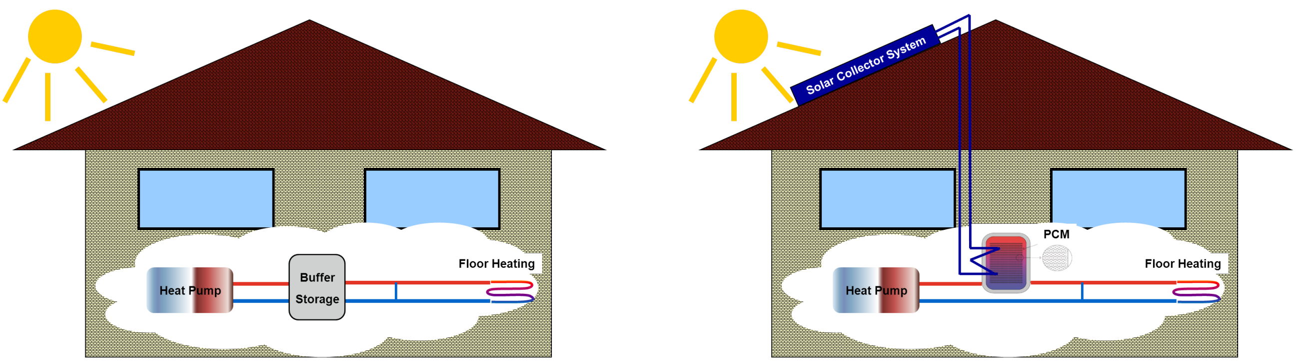

Figure 4: Left- Reference system. Right- Second system.

Two different overall systems are analyzed. The reference system consists of a heat pump, buffer storage, a building, the hydraulic and thermal connections and the weather model [1]. The building model has two floors and each floor has four rooms with an area of 24 m^2. Each room has a floor heating system. In one case the building is insulated and in the other case it is non insulated. The building is connected to the weather model (Test Reference Year (TRY) 4, Berlin). The heat pump used is an air to water heat pump. The buffer storage consists of several layers (for the reference case the number of layers is set to 5) and has a volume of 780 l.

The second system has a latent heat storage device instead of the buffer storage and a thermal solar collector system is combined with the heating system. The latent heat storage has a mass of 100 kg PCM inside, which means 0.52 kg_{PCM}/m^2 and a volume of 150 l of water, which surrounded the PCM. In this study an ideal PCM is implemented with a phase change temperature of about 35 °C and a melting enthalpy of $150\frac{kJ}{kgK}$.

The solar system has four collectors (two serial and two parallel), has an area of $A = 6.161\ m^2$ and is oriented for space heating systems (south orientation and an angle of 60 °).

The results of the simulation are shown in figure 5. The heat storage, the thermal solar collector systems and the building's insulation standard are varied in different simulations for a year. The comparison between an overall system with buffer storage and an overall system with latent heat storage and solar thermal collectors shows that it is possible to reduce the primary energy demand. Simulations show, if the building is insulated, the primary energy reduction is higher (nearly 30% reduction) than in the case in which the building is not insulated.

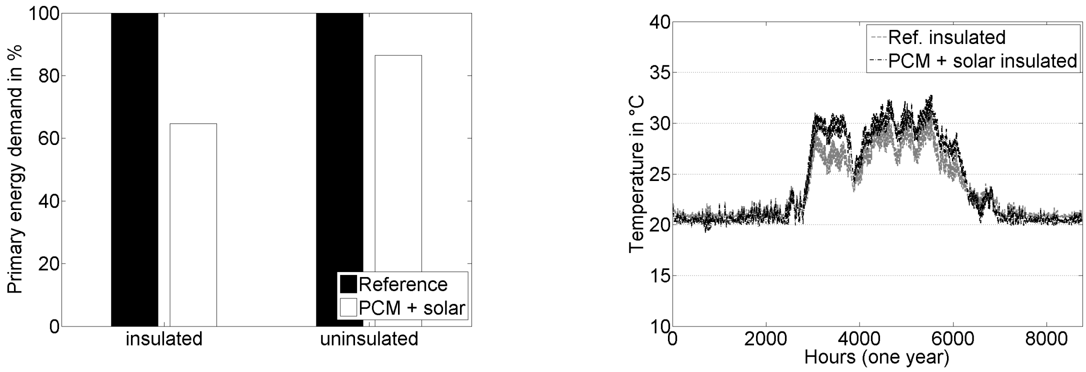

Figure 5: Left- Comparison of the primary energy demand. Right- Room temperatures for the insulated case.

Figure 5 shows the room temperatures for the insulated building over the year. Up to now all systems have the same heating curve, which is similar to the insulated building case, which means one heating curve for the reference system and one heating curve for the second system. A consequence of this is that the uninsulated building case has very often room temperatures above 20 °C. This means that it is not optimal in terms of thermal comfort. In the insulated building case the reference system has always a room temperature above 20 °C and for the case with PCM and solar collectors sometimes (less than 248 h per year or less than 2.8 % of a year) the room temperature is between 19 °C and 20 °C.

Another point is that the storage in the reference case has a very high volume of 780 l, whereas the latent heat storage has a mass of 100 kg PCM and around 150 litre of water, so that the storage volume is smaller than in the reference case. Figure 6 shows the operating interval of the heat pump for three cases, the reference case, the case with PCM and thermal collectors and a case, where only PCM is used. It can be seen that a smaller storage does not mean a higher number of operating intervals of the heat pump, which is better for the heat pump performance.

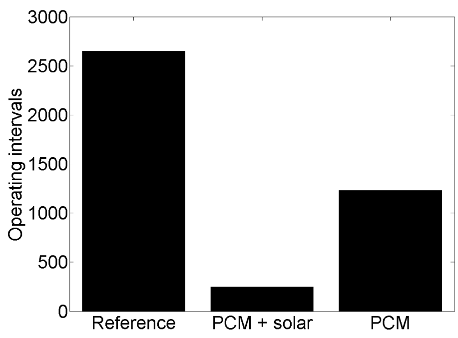

Figure 6: Number of turning on and off of the heat pump

SUMMARY AND OUTLOOK

A study has been done varying the heat storage, the thermal solar collector systems and the building's insulation standard for a year. It can be shown that the integration of a PCM (Phase Change Material) storage system and a thermal collector system can reduce the primary energy demand of the overall system.

Actual studies go on with optimization of the single components and at the same time more overall system analysis are done. First of all the control strategies will be optimised, so that the thermal comfort will be guaranteed in both cases and the mass of PCM in the storage will be increased. The validation of the PCM model with measurement data is in progress.

Additional numerical studies can analyze how the simulation results of an overall system will look like, if the clouding of the collectors because of other buildings or trees will be implemented in the solar thermal collector system model.

ACKNOWLEDGEMENT

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ENERGY REQUIREMENTS AND SOLAR AVAILABILITY IN SUBURBAN AREAS: THE INFLUENCE OF DENSITY IN AN EXISTING DISTRICT

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ABSTRACT

Urban sprawl is a major issue in terms of sustainable development. In fact, low-density suburban neighbourhoods represent a significant contribution to the overall energy consumption of a territory for energy needs in buildings and for transportation. But, although the environmental impacts of urban sprawl and their associated energy consumptions are now well documented, it remains a concern in many regions. This phenomenon is particularly familiar in Belgium, where 52% of the building stock is composed of detached and semi-detached houses, predominantly located in low-density suburban districts (contained in a range between five and twelve dwellings per hectare). In the current context of growing interest in environmental issues, local authorities become aware of this concern and are now trying to limit the development of new low-density suburban districts while households still continue to promote dispersed individual housing types located outside city centres.

In this context, the paper proposes to investigate the influence of an increase in built density, in existing suburban neighbourhoods. The idea is to favour a higher built density in existing neighbourhoods instead of building new low-density neighbourhoods on unbuilt areas. The impacts of four renewal strategies dealing with the density are assessed, at the neighbourhood scale, for three indicators: (1) the potential energy savings for heating houses, (2) the solar energy received by the facades and roofs, as dispersed individual housing types are known to be those that receive most solar gains and (3) the potential area of land savings. The influence of insulation, climate conditions and orientation is finally discussed. The chosen case study is a typical Belgian suburban neighbourhood. Research tools are numerical simulations tools and dynamic thermal modelling software.

The results of this exercise show that it is theoretically (land property is not take into account in our analyses) possible to increase built density in existing suburban neighbourhoods. Energy savings are significant while solar energy received by facades and roofs remain huge. Insulation is a critically important factor. Moreover, increasing the built density in existing neighbourhoods allows to preserve unbuilt areas and to limit the need for new infrastructures and networks, which should help suburban areas to become more sustainable.

INTRODUCTION

The process of urban sprawl, which commonly describes physically expanding urban areas, is a major issue for sustainable development [1]. For the same standard of insulation, detached houses need more energy for heating than terraced houses [2]. Moreover, suburban developments have created farther spatial separation of activities, which results in an increase in travel distances and transport energy consumption [3]. But, although the environmental impacts of urban sprawl and uncontrollable urbanization are now well known and may give rise to various issues, such as environmental pollution or large-scale climate change [4, 5] and despite the growing importance of the energy issues in public debate, low energy-efficient suburban developments are a reality in Belgium where many households and private developers still continue to promote dispersed housing types located outside city centres.

In this context, the paper aims at investigating the influence of a higher built density in existing suburban neighbourhoods. Four scenarios, in which the built density is increased, are defined and assessed. The idea is to promote a higher density in existing neighbourhoods as a solution to avoid building new neighbourhoods on unbuilt areas, which would increase urban sprawl and its undesirable effects on climate, landscapes and pollution.

METHODS

Methods and research tools

A method has been developed to assess energy requirements in Belgian suburban areas. It addresses the influences of individual buildings at the neighbourhood scale because, even if the urban context has been mostly neglected in building energy analyses so far, decisions made at the neighbourhood level have important consequences on the performance of individual buildings and on the transport habits of the inhabitants [6]. Moreover, the urban fabric determines the spatial configuration of building and hence solar energy received by the envelope. A typology of detached, semi-detached and terraced houses was established to classify the residential suburban building stock of Belgium. This typological approach is based on the common ownership, the area of the house in square meters (m²), the number of levels and the date of construction. Five age categories (pre-1950, 1951-1980, 1981-1995, 1996-2010, post-2010) are considered based on the evolution of regional policies concerning building energy performance and the evolution of construction techniques. Age categories are used to approximate a mean thermal conductivity of external façades from a "standard" composition of façades and glazing attributes for buildings in each category (Table 1).

	Pre-1950	**1951-1980**	**1981-1995**	**1996-2010**	**Post-2010**
Wall composition	Concrete blocks	Concrete blocks	Concrete blocks + 3cm PUR	Concrete blocks + 6cm PUR	Concrete blocks + 8cm PUR
Roof composition	Clay tiles	Clay tiles	Clay tiles + 8cm mineral wood	Clay tiles + 10cm mineral wood	Clay tiles + 13cm mineral wood
Slab composition	14cm concrete	14cm concrete	14cm concrete + 3cm PUR	14cm concrete + 6cm PUR	14cm concrete + 9cm PUR
Glazing type	Simple glazing	Double glazing	Double glazing	Double glazing	Double glazing
Windows U	4,08W/m².K	2,96W/m².K	2,76W/m².K	2,76W/m².K	1,8W/m².K

Table 1: Main characteristics of external facades and glazing by age category.

Using this classification, an energy consumption analysis was performed with TAS dynamic thermal analysis software to obtain the energy required to heat each type of building and solar energy on facades and roofs. The climate data are those of the Test Reference Year of Brussels (temperate climate). The maximum and minimum temperatures, for the considered year are 34.9 °C and -9,1°C. The inside temperature considered in the calculation is 20°C during the day and 16°C during the night.

The energy requirement for heating at the district scale was finally calculated by adding the results from the energy consumption analysis for each type of house according to their distribution in the district [2]. This total energy requirement is finally divided by the heated surface area of the whole district to give an indicator, in kWh/m².year, allowing the comparison between neighbourhoods and scenarios. This methodology was applied to each scenario discussed below (First line of Table 2).

The last indicators are the surface area and the length of networks saved if the density of the existing neighbourhood is increased and avoid the building of new individual detached houses and infrastructures on unbuilt land. The size of the plots (900m²) and of the houses (140 to 180 m²) used in this evaluation are based on the regional means for suburban territories and on the urban structure of the existing neighbourhood.

Case study

The chosen case study is a typical Belgian suburban neighbourhood located 6 kilometres east of a city centre (106.000 inhabitants). This kind of urban structure, made up individual detached houses built on large plots, represents about 11% of the regional built territory [7]. The neighbourhood is composed of 395 residential houses. 43,5% of the houses were built between 1951 and 1980, 49,1% between 1981 and 1995, 7,2% between 1996 and 2010. The neighbourhood has a surface area of 54 hectares, among which 2,4 hectares are dedicated to green spaces. The built density of the neighbourhood (number of dwellings / (total area – green spaces)) is worth 7,6 dwellings per hectare as things stand at present.

Figure 1: The chosen case study (Aerial view ©SPW-MRW and pictures of two houses ©de Meester) is a typical Belgian suburban neighbourhood located 6km east of a city centre.

Scenarios

Four scenarios have been designed and present different ways to increase built density in the studied neighbourhood. The first one consists in respecting the existing urban structure:

detached houses are built on remaining unbuilt plots. In the second scenario, the size of the plots is exploited to build new houses at the bottom of existing plots. In the third one, new detached houses are built between existing houses while in the fourth case, houses are built between existing houses to form a continuous facade made up terraced and semi-detached houses (Figure 2). In cases 2 to 4, the size of the new plots is smaller (around 400 m²) and the size of existing plots is reduced. In this last case, windows located on lateral facades are transferred to the roof to keep the same surface area of windows. In the four scenarios, new houses are assumed to be built according to the thermal regulations applicable in Belgium since the passing out of the European Energy Performance of Buildings Directive in 2010.

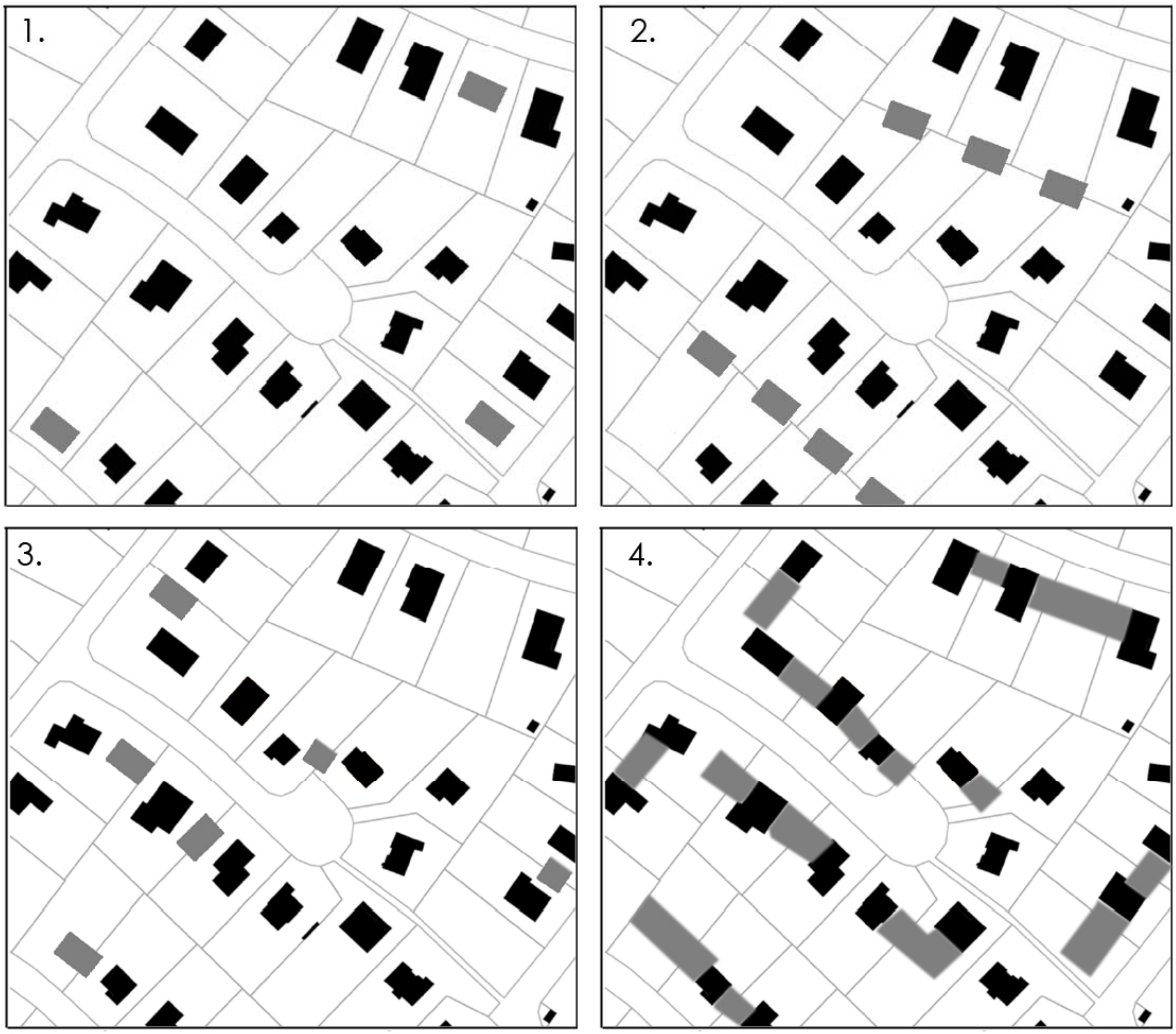

Figure 2: The four scenarios designed to increase built density in the studied neighbourhood – zoom. Existing houses are coloured in black, new houses are in grey.

RESULTS

Energy consumption for heating, solar gains and surface area of land saved

The first part of the assessment is a present-day inventory of the neighbourhood energy consumption for heating. It is calculated according to the above-presented method. Then, energy consumption for heating and energy savings, in comparison with the present-day inventory, are calculated, at the district scale, for the four scenarios designed to increase the built density. Solar gains on vertical facades and roofs are calculated for a reference house.

The new built density of the neighbourhood and an estimation of the surface area of land and of the length of collective networks saved are finally presented (Table 2).

	Present-day	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Mean energy consumption for heating [kWh/m².year]	146,9	139,4	121,3	128,0	102,2
Savings in comparison with present-day inventory	/	5,2%	17,4%	12,9%	30,4%
Solar energy received by façades [kWh/m².y]	398,6	398,6	398,2	394,6	382,6
Difference with present-day	/	0%	-0,1%	-1,0%	-4,0%
Solar energy received by roofs [kWh/m².y]	1005	1005	1005	1005	1005
Built density [houses per ha]	7,6	8,0	9,6	9,3	12,6
Surface area of land saved [ha]	/	2,07	9,27	8,10	23,4
Length of collective network saved[metre]	/	184	824	720	2080

Table 2: Present-day inventory and results for the four scenarios.

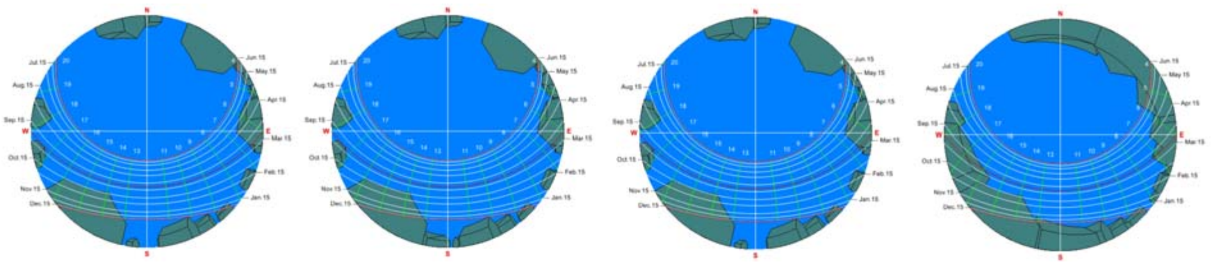

Figure 3: Solar paths and obstructions generated by each scenario, in the middle of the neighbourhood, on the ground, 15th June (Townscope software).

Significant energy savings can be obtained if the built density of the district is increased. The positive effects come from the building of new well-insulated houses, which makes the mean energy consumption decrease, at the district scale, even if houses are still detached (ex: -17,4% in scenario 2). As the present-day density is very low, adding new houses between existing ones allows to reduce energy consumption without reducing too much solar gains on facades and roofs (Figure 3). Note that vegetation was not taken into account. Scenario 4 combines the positive effect of an increase in built density and a more compact distribution of houses (detached houses require more energy for heating than terraced houses). Photovoltaic systems and solar thermal collectors mounted on roofs could be used according to the threshold values proposed by [8] and commonly used in practice.

On top of potential energy savings, increasing the built density of the neighbourhood allows above all to significantly protect unbuilt land from urbanization and to limit the need for new infrastructures and networks. However, even in scenario 4, the built density remains too low (12,6 dwellings / hectare) to organize a more efficient bus service.

Sensitivity analyses

Three sensitivity analyses were finally performed. These concerned insulation, climate conditions and orientation. Insulation offers a large potential for energy savings because the existing building stock is poorly or not insulated. If all the existing houses of the neighbourhood are retrofitted to reach the current standard required in the European Energy Performance of Buildings Directive and if new houses built in the neighbourhood reach the passive standard (<15kWh/m^2.year), which should constitute the standard for new buildings within the year 2020, energy savings, in comparison with present-day inventory, could reach 57,4% (62,6 kWh/m^2.year instead of 146,9 kWh/m^2.year). In this case, the influence of density could reach 6,6%, 18,6%, 16,4% and 37,5%, for the four scenarios described below.

As regard with climate, two representative cities were selected in Belgium (Brussels and Saint Hubert) to test the sensitivity of previous results with climate conditions. These cities are representative of climate variations within Belgium. Heating loads are higher in Saint Hubert (colder climate) but it has been demonstrated that the four scenarios tested are reacting in the same way to varying climate conditions. In terms of orientation, we determined that energy consumption in buildings varied only marginally (less than 4%) with the orientation of the neighbourhood and the solar energy effect on vertical facades and roofs, mainly because of a lack of optimisation for solar accessibility in existing houses and neighbourhoods.

DISCUSSION AND CONCLUSIONS

The analyses highlight that, for the studied existing suburban neighbourhood, the benefits of an increase in built density are significant in terms of both energy consumption and surface area of land saved. These findings are important because numerous similar suburban neighbourhoods are found in Belgium and abroad. Scenarios dealing with renovation versus demolition and reconstruction should now be compared and assessed to give a more complete image of energy consumption in existing suburban neighbourhoods and favour energy efficiency through efficient renewal strategies.

ACKNOWLEDGEMENTS

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QUALITY INDICATORS FOR DISTRICT HEATING NETWORKS

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ABSTRACT

District heating networks are very common energy systems all over the world but only few studies have been carried out to assess their performances through quality indicators. These indicators express district heating performances through different points of view. Four ones are developed in this study: energy sources, efficiencies, heat delivering equipments characteristics and environmental efficiency as a sum up.

First, the only energy indicator generally used is the primary energy factor (PEF), which quantifies the primary energy use of a device. However it does not give a complete insight of the whole energy use of district heating networks. Two other parameters have to be stated for this purpose: primary energy efficiency and the energy share.

Second, district heating efficiencies are generally not been taken into account unless sometimes the only amount of heat losses. A first indicator is defined to quantify networks heat losses relatively to the amount of heat delivered to customers. To take heat plant efficiencies into account, a more global indicator is defined. Its definition is close to a seasonal efficiency and it permits comparisons with other heating systems.

Third, indicators have been defined for heat plants equipments. Their aim is to permit stakeholders to check networks management of district heating companies. Two indicators are defined: one measures subscripted power relatively to network length and the other one represents the fictitious number of plants working hours while maximum plants power was delivered all the year.

Finally, environmental efficiency is stated. This analysis can include different aspects: green house gas emissions, water use and other pollutants emissions. For both design and management of district heating networks, an indicator representing CO2 emissions appears to be the most suitable one. Expressed relatively to delivered energy, it can be seen as a sum up of previous indicators because result of bad performances increases these emissions.

In this paper, these eight indicators are defined and their use is highlighted by a comparison of four different Finnish district heating networks.

INTRODUCTION

Although the district heating networks have been used as dwellings heating systems for millions of people in the world for many years, there is no method to optimize their design. However, they induce consequent investments and are not common at all in some European countries, like Belgium. Moreover, this energy medium is once again in the focus of European engineers and stakeholders. This upsurge in Europe is partly due to the objectives of the 3x20 [1] because District heating networks represent a great opportunity to carry out these objectives for large building stocks because they allow a wide range of energy sources for buildings heating including various renewable energy sources. These sources can be geothermal energy [2], Combined Heat and Power Plants [3], industrial waste heat [4], biomass [5], etc.

Only few studies have been carried out to assess heating district networks performances through quality indicators. First, a project lead by Euroheat&Power and finished in 2006 proposed a performance assessment of a district heating network based on only one parameter that was the primary energy factor (PEF) [6]. In 2007, the European norm CEN [7] proposed to use this parameter to manage a district heating or its design. But this indicator does not give a complete insight of the whole energy use of district heating networks.

Other quality parameters have been proposed to assess the performances of a district heating network by the French associations IGD and AMF [8]. They proposed 23 parameters that are important issues for existing networks but a lot of them cannot be stated at the design stage. Moreover, the only energy indicator used in this method is also the primary energy factor. van Lier [9] has developed a methodology related to a specific district heating, based on six indicators: heat loss, water replenishment, avoided CO_2 emissions, unplanned repairs, networks degradation and off-time replacement. These indicators have been developed to improve the management of old district heating networks and not to help investment decisions in new or old networks. Moreover, they neglect the energy point of view.

This paper will define eight key performance indicators for the environmental and technical design optimization of heating district networks. Then, the use of these energy indicators will be highlighted by a comparison between four Finnish cities.

DEFINITION OF QUALITY INDICATORS

The purpose of the indicators developed in this paper is to give a very complete overview of a district heating network for decision makers, project engineers, etc...

The primary energy factor, PEF

The first indicator, which is widely used, is the **primary energy factor** [6, 7]. It quantifies the primary energy use of a district heating network. Its definition is given by equation (1).

$$f_{p,DH} = \frac{\sum_j E_j \cdot f_{p,j} + E_{aux} \cdot f_{p,el} - E_{CHP} \cdot f_{p,el}}{E_{del}} \qquad (1)$$

where E_j is the amount of the jth primary energy consumed by the network, E_{aux} is the sum of auxiliary and pumping electric consumption, E_{CHP} is the amount of electricity provided by the combined heat and power plant (CHP) if any is installed, $f_{p,j}$ is the primary energy factor related to an energy source, $f_{p,el}$ is the primary energy factor for the power plants and E_{del} is the amount of energy delivered to the consumers.

This is a major factor allowing people to compare in an efficient manner two heating technologies e.g. district heating network and conventional boiler.

The relative importance of losses, RiL

Other important information is the amount of heat loss consumed by the network. These energies are compared to heat delivered to the consumers as shown in equation (2). Electricity from CHP plants is not considered.

$$RiL = \frac{E_{loss} + E_{aux}}{E_{del}} \qquad (2)$$

Where E_{loss} is the amount of energy lost in the district heating e.g. thermal loss through pipes, water replenishment, etc ... It can be stated by measuring energy leaving the heat plant and subtracting the sum of the energy at the customers’ substations.

The primary energy efficiency

As *Ril* does not take into account electricity delivered to the power grid by CHP plants, a third parameter is set. It compares all the net delivered energy (e.g. thermal to the district heating network and electric to the power grid) to the primary energy use and is given in equation (3). Delivered energies are thus no more weighted and electric production does not reduce primary energy consumption (as it does in *PEF*).

$$\varepsilon_{DH} = \frac{E_{del} + E_{CHP} - E_{aux}}{\sum_j E_j \cdot f_{p,j}} \tag{3}$$

The district heating global efficiency

Another parameter is defined closely to a seasonal efficiency: the ratio between all provided energies and all the necessary energies (see equation (4)). This global efficiency is defined to compare networks from a technical point of view because it will be affected by efficiencies of the network and the power plants. It also allows the comparisons of different heating systems for buildings e.g. the networks and a heat pump.

$$\eta_{DH} = \frac{E_{del} + E_{CHP}}{\sum_j E_j + E_{aux}} \tag{4}$$

Energy share

The last energy indicator expresses the energy share of the different district heating networks. It represents the relative importance of all the energy sources providing heat to the network and can be stated through the yearly energy consumption of these sources. It gives some keys to state the energy independency of networks.

Then an energetic analysis can be conducted thanks to these 5 first parameters. Some more parameters are needed to make sure district heating companies are able to fulfil customers' heat demands. For this purpose, IGD defined 7 parameters [8]. Four of them are related to network extension and heat delivery quality (outage) and cannot been stated in district heating design. Then the last three indicators, of which two are combined, will be highlighted.

Subscripted Heat Power by km (SHP)

This parameter was proposed by IGD [8]. It is expressed as the sum of all the maximum callable heat power divided by the length of the network. Its value gives an insight of the commercial profitability of a district heating network. The more this parameter, the more energy will be sold for a similar investment in piping equipments.

Equivalent to nominal power duration (Heq)

This indicator consists in the multiplication of two IGD defined indicators: rate of called power and equivalent to **full** power duration. As a result this new indicator is influenced by three parameters: weather, heat demand characteristics (e.g. dwellings or industrial customers) and networks heat losses. Its equation is given by (7).

$$H_{eq} = \frac{E_{del}}{P_{HP,tot}} \tag{7}$$

Where $P_{HP,tot}$ is the maximum heat plants power.

CO2 emissions

CO2 emissions can be seen as a summary indicator because it is a result of all the previous parameters: kind of energy sources, heat losses, efficiencies, etc. van Lier proposed to state avoided CO2 emissions. As this calculation asks assumption on conventional boilers use, CO2 emissions are expressed relatively to delivered energy (thermal and electric).

APPLICATION OF THESE INDICATORS AND DISCUSSION

These eight key performance indicators are able to give a complete view of the district heating and support decision making. This will be shown through the cases of four Finnish cities: Inari (Lapland), Helsinki (main city), Lahti and Juva (South Savo). They are derived from [10] which presents 175 district heating companies in Finland. In cases of Helsinki and Lahti, several companies are connected to the same network and data have been aggregated to allow criterion calculation at the city scale. The defined indicators are stated and results are shown in Table 1. Their analysis is conducted through four levels: Energy sources (through PEF, energetic efficiency and energy share), thermodynamics efficiency (through Global efficiency and RiL), heat plants and heat delivery characteristics (SHP and Heq) and environmental efficiency (CO2 emissions).

	Inari	**Helsinki**	**Lahti**	**Juva**
PEF, [-]	0.58	0.53	1.00	1.75
Energetic efficiency, [-]	1.71	0.75	0.69	0.57
RiL, [%]	11.90	7.96	11.59	19.37
Global efficiency, [%]	87.24	84.90	78.60	71.86
SHP, [kW/km]	766	2546	1146	1174
Heq, [h]	2695	1983	1756	1776
CO2 emissions, [TCO2/GWh]	119	171	251	437

Table 1: Key performance indicators for the four Finnish cities, results from data available in Finnish Energy Industries report: District heating in Finland 2009 [10]

Energy sources

Inari district heating network is characterised by a low PEF and a high energetic efficiency because more than 60% of its energy share come from renewable energies (biomass). Helsinki overall network presents a low PEF but also a low energetic efficiency. This is explained by its high use of Combined Heat and Power plants (CHP): 7389 GWh of electricity and 9839.3 Gwh of thermal energy. Lahti and Juva district heating show high PEF and low energetic efficiency. A look at their energy share highlights that more than 70% of Lathi’s energy comes from coal and 80% of Juva’s energy comes from peat. As the renewability of peat is not clear [11], this source has been considered as non-renewable.

Thermodynamics efficiency

First, RiL shows that Inari, Helsinki and Lahti cities have low heat losses through district heating networks. Helsinki network seems to have the lowest energy losses of the compared cities. Besides this network is the longest one (more than 2000km long). Big district heating can be managed in an efficient way and lead to high efficiency heat delivering. Finally, Table 1 shows that Juva networks have high heat losses through its networks. This appears to be a first important investment to enhance this network. Analysis of global efficiency shows that Lahti and Juva networks have low efficiency. For Lahti, an enhancement of the heat plant appears to be a very high efficiency measure because its network shows low relative losses.

Heat plant and heat delivering characteristics

Helsinki has the highest SHP. This statement can be explained by successive developments of district heating networks. Inari presents here very low value of SHP which might be a consequence of city rural characters. Lahti and Juva are bigger town than Inari but are not as big as Helsinki. They present similar value of SHP. Finally, high value of Heq for Inari might be due to the share of delivered energy and weather. Indeed colder weather involves higher heat demand and Figure 1 shows that more than 70% of total energy is delivered to non-residential customers. However Figure 2 also shows that Juva has a higher non-residential heat demand than Lathi and Helsinki but Heq is almost the same for these three cities. So, we cannot identify a clear link between buildings functions and Heq but it might be a key point.

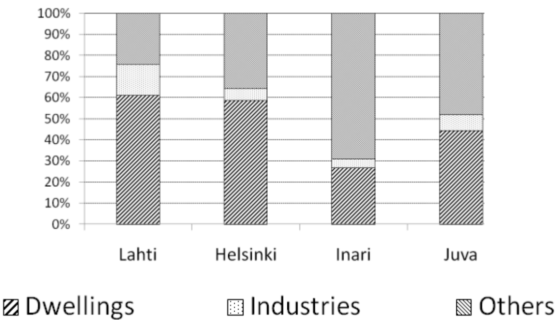

Figure 1: Delivered heat of district heating networks for different kind of customers expressed as a percentage of the whole delivered heat, source [10]

Environmental efficiency

This last step can be seen as a sum up of previous observations. Inari presents the lowest value as shown in Table 1. That means that 119T of CO2 are rejected to deliver 1 GWh of heat to customers. By comparison, if one GWh was produced by a sum of oil boiler which mean efficiency was about 85%, they will generate 331T of CO2. Helsinki and Lahti presents CO2 emissions by delivered energy lower than this value but it is not the case of Juva.

CONCLUSIONS

District heating networks are quite common systems in Europe and they are intended to have a great play in future energetic world. However few key performance indicators are defined. Especially, only one energy indicator is often used to assess their energy performances. In order to help engineers and decisions makers to assess the quality of district heating networks projects, new key energy indicators have been defined. They can be used either for new district heating networks either for investments in old district heating networks. They also allow a good energy management of existing district heating networks.

Literature generally considers only the primary energy factor but it has been shown that this parameter alone is not sufficient to help decision making even if it gives a good overview of the energy performances of a district heating network. Based on the same variables three parameters have been added to enhance this insight: relative importance of energy losses, primary energy efficiency and district heating global efficiency. Coupled with the primary energy factor and the energy share, they give a more detailed picture about network quality related to energy use.

Indicators related to heat plants and heat delivering characteristics underline weather and customers influences. Beyond these influences building stock influence is underlying: buildings age, mixing of customers’ functions (dwellings, industrial, services, ...), built density. The whole indicators are able to provide interesting details over district heating performances and can help decision making and energetic management for both new and old networks. Further developments are needed in order to establish clearly impacts of urban stock characteristics on these indicators.

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CitySim Simulation: The Case Study of Alt-Wiedikon, a Neighbourhood of Zürich City

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Abstract

As research in building energy demand simulation is reaching maturity, there is now a growing interest in the evaluation of the energy need of larger and/or pre-existing urban areas [1, 2, 3], to evaluate the energy performance associated with alternative development or improvement scenarios. These past years, the urban energy use simulator CitySim was developed at EPFL based on multiple physical models. CitySim can compute an estimation of the on-site energy use for heating, cooling and lighting; however for this it needs a complete physical description of the buildings in the form of an XML input file. To simulate just a few buildings, it is convenient to simply enter this information manually through a graphical user interface; but when buildings are counted in hundreds or thousands, a more efficient method is required: data handling in databases. This paper describes the methodology used to take best advantage of PostgreSQL and QuantumGIS to manage the inputs needed by CitySim and the large amount of results produced. It describes the database structure used for the case study and the working principle of the Java tool that links the database and CitySim. The methodology was successfully applied to simulate a case-study neighbourhood of Zürich City and produced useful energy demand graphs.

Introduction

The urban population is forecasted to increase to almost 70% by 2050, and the energy consumption in cities is likely to follow that trend if no remedial actions are taken. It is therefore necessary to identify solutions that lead to significant reductions of resource consumption whilst maintaining good quality of life standards for urban inhabitants. To this end, computer modelling at the urban scale is an invaluable decision support tool for urban planners and designers. However, with computer modelling tools, such as CitySim [1], the amount of data required for the simulation of an ensemble of buildings is proportional to the number of buildings involved, likewise for the results produced. At the urban scale, an efficient storage of the significant quantity of data needed and produced by the simulation of hundreds or thousands of shelters can only be realized by the use of databases (MySQL, PostgreSQL, Access or others). This article presents the creation of a database model for urban energy simulation using PostgreSQL, its link to the urban energy simulator CitySim and finally the case study of a zone of 123 buildings in the Alt-Wiedikon district of Zürich.

PostgreSQL database

Database management systems (DBMS) and geographical information systems (GIS) provide excellent tools for data management, and some start to integrate simulation modules [4, 5]. These modelling capabilities are limited, but we suggest that their usage in conjunction with urban energy use simulation programs is very promising. PostgreSQL is a complete and open-source DBMS, offering the wide range of usual SQL functionalities for data handling. It is also completed by the spatial data module PostGIS, which provides geometrical data types (such as points, lines, polygons and collections of these) and a multitude of related functions to access, edit and process spatial data. To these internal functionalities are added importation tools, APIs for access through self-written programs and various open source software offering for example graphical user interfaces. The open source GIS software QuantumGIS can be used to access, visualise and modify data in a PostgreSQL database, and to produce map representations of any parameter linked with a geometry.

CitySim

These past years, the urban energy use simulator CitySim was developed at EPFL [1]. Comprised of multiple physical models coupled together, CitySim can compute an estimation of the on-site energy use for heating, cooling and lighting with an hourly time step. A radiation model first computes the irradiation incident on each surface of the zone, direct from the sun, diffuse from the sky and reflected by other surfaces. The results of this model, together with predictions of longwave radiation exchange, are input to a thermal model determining the thermal exchange through buildings' envelopes and computing the heating or cooling energy needs to maintain predefined temperature conditions inside. Finally, energy systems providing heating, cooling and electricity can also be defined. The corresponding models compute what energy was provided to meet (or not) the associated demand at each time step, thus determining the new state of the model at the next time step. However, a complete physical description of the scene – in the form of an XML input file and a climatic data file – is needed for the simulation. The climate data includes hourly temperature, wind and irradiation values, completed with geographic coordinates and the definition of far field obstructions (which is used in a pre-process to the radiation model). The building models describe the envelope of each building (the thermal properties of each façade, the layered composition of the walls, the proportions of window and the physical properties of the glazing), as well as the infiltration rate and, when possible, the presence of occupants. This may be completed by simple models of energy systems such as solar panels, boilers and HVAC. In order to create a CitySim model, this information on each building must be encoded in the dedicated XML input file mentioned above.

METHODOLOGY

The methodology starts with the definition of a database model for the storage of the data needed and produced by CitySim, follows with the description of a Java tool developed to connect the database with CitySim and ends with a case study of 123 buildings in the Alt-Wiedikon neighbourhood in Zurich (Switzerland).

Alt-Wiedikon case study (data source)

The Alt-Wiedikon residential neighbourhood in Zurich (Switzerland) was selected as case study. In order to obtain a description of the 123 buildings in the zone of Alt-Wiedikon in a reasonable time, the following data sources were used:

- Cadastral maps, usually available in digital format, provide reliable 2D representations of buildings' footprints and were thus used as a basis to define the building entities to be modelled. The altitude and average height of each building was extracted from digital surface and terrain models (DSM and DTM).

- The buildings' register contains varying quality data about the geographical location, address, main allocation, construction date, renovation date, energy systems, etc. of buildings. In the absence of more detailed knowledge, the construction characteristics can be extrapolated from these parameters.

- A company census, containing sensitive data related to the kind, location, activity and number of employees of all firms in the area will be used in the future to estimate the number of occupants in buildings.

- A visual survey helped complete the physical model of the buildings in the area with estimates of the glazing ratio, window type and frame material of each building and allowed us to check the status and relevance for simulation of each building (demolished, garage, etc.).

It appears that sufficient data is available to create a first rough but extensive model of any urban zone in Switzerland. However, organising this data into a coherent simulation model is a highly time-consuming task if no appropriate tools are used, and research simulation tools are usually not adapted to perform this task.

Database use and data model

The use of DBMS has several advantages: 1) the disparate original source files (.shp for maps, .xls or other for text data) can be loaded as simple tables in a temporary database, 2) a dedicated data model can be designed as an intermediary data model to bridge the conceptual gap between CitySim's specific input file format and the data sources, and 3) SQL and spatial functions enable one to combine the different data sources, based on common identifiers and on spatial location, in order to retrieve the necessary data and fill-in a CitySim-dedicated database.

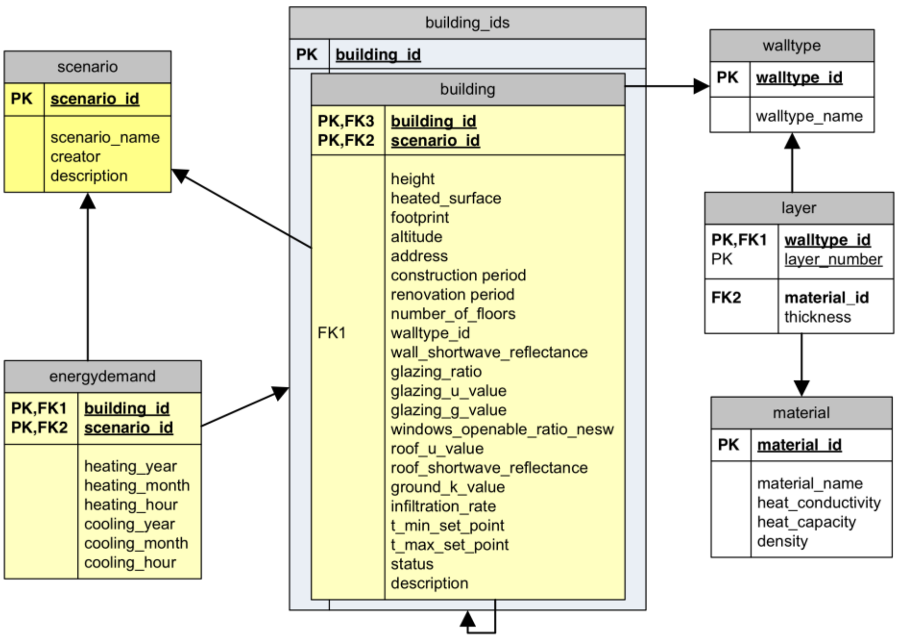

Figure 1: Schema of the data model of the CitySim database. If a building is not redefined in a scenario, its "base case" version is used. Thus the energydemand table refers to the scenario table and to the building_ids table, which contains all existing "building_id" independently of the scenario.

The data model designed for this purpose is presented in Figure 1; it is mainly composed of a central "building" table including the essential data such as the cadastre footprint of the building, the average height, the construction and renovation periods and the number of floors. The “building” table then refers to a "walltype" table and a "scenario" table. The "walltype" table lists all defined construction types, whose physical compositions are stored in the "layer" and "material" tables. The "scenario" tag defines case-study modifications of the base case (or scenario 0) model. Finally, an "energydemand" table contains the simulation results for heating and cooling demands of each building in each scenario. The energy systems are not defined within this data model, which presently focuses on energy demand.

The footprint and average height are imported from cadastre files. The buildings’ register fills in the period of construction, the treated floor area and optionally the address, the number of floors and the energy system used for heating. The wall types are chosen in a list of typical values according to the building’s construction and renovation periods. Glazing ratios, U-values and openable ratios are based on results from the visual survey. The other parameters use default values: windows g-value of 0.7, roof U-value of 0.3 W/m^2K, ground conductance of 3 W/m^2K, infiltration rate of 0.4 h^{-1}, minimum and maximum set point temperatures of 21°C and 26°C, short wave reflectance of the façades of 0.2.

Java connection tool

Once all the necessary data is gathered in the database, creating a CitySim input file for simulation and storing the results back in the database is a well-defined task that can be automated. For this purpose, a small Java program was written to access the database, retrieve the relevant data and transform it in a comprehensive CitySim model. For each building, the 2D footprint is extruded in a 2.5D model based on the altitude and average height of each building. As heat losses or gains are usually negligible between touching buildings, the shared surfaces are considered adiabatic and the corresponding façades are cut accordingly. Each building surface (wall, roof or ground) is then attributed a construction wall type or a U-value, a glazing ratio and physical properties, and a reflectance based on the attributes in the building table. Each building is also attributed with minimal and maximal set point temperatures and an infiltration rate. The model is finally written in a CitySim input XML file. The Java program then launches a simulation by calling the CitySim solver with the input file and a climatic data file produced with Meteonorm [6] and describing a typical year in Zürich. Once the simulation has ended, the result file containing heating and cooling demand for each hour of a typical year is read, prepared and inserted in the “energydemand” table of the database. Simple SQL views joining the “building” and “energydemand” tables can then be defined in the database to present a scenario’s results.

RESULTS

Our structure now enables us to quickly modify or correct our model and to simulate large urban zones in a relatively short time (the simulation takes less than twenty minutes for a hundred buildings on MacBook Pro 2.3Ghz with 4 Gb of RAM). QuantumGIS was used to access our database and produce meaningful representations of the results (figures 2 and 3).

Base case simulation

Figure 2 shows the heating and cooling demands resulting from the CitySim simulation of the neighbourhood. The total simulated heating need of the zone in the base case scenario is of 28 GWh per year, and 2 GWh for cooling. From an inspection of the database, we noted that the highest heating demand is closely related to the construction or renovation period and that the cooling demand also strongly depends on the fenestration characteristics.

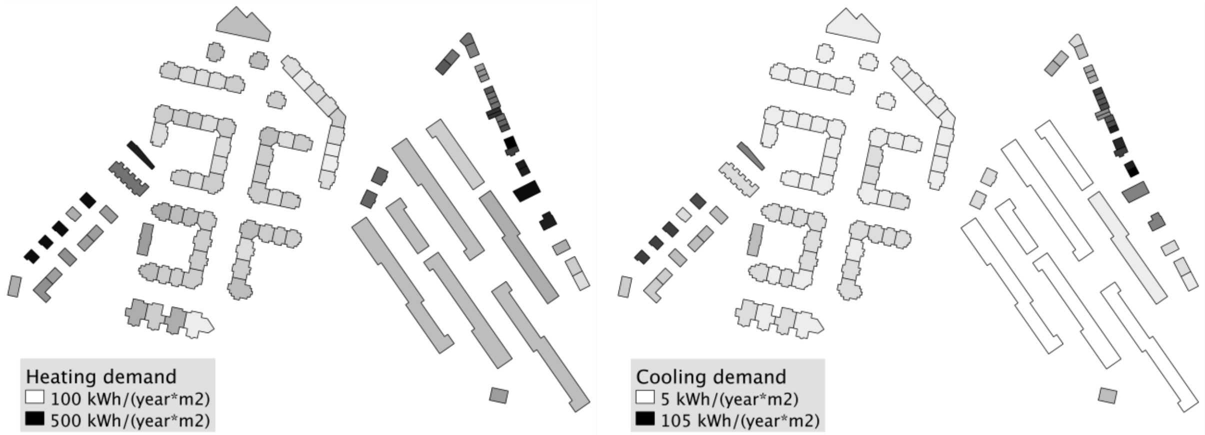

Figure 2: Simulated heating and cooling demand of the buildings in the Alt-Wiedikon neighbourhood, relative to the housing, office and commercial surfaces (continuous scale). Buildings without treated floor area are not included.

Renovation scenario

As our first simulation shows that buildings constructed before 1945 have particularly high heating and cooling needs, an interesting scenario to explore is the renovation of these buildings. The default wall type associated with these is a simple 40 cm rough-stone wall, with rendering outside and plaster inside. As old buildings' façades are often protected for aesthetic reasons, thermal insulation is usually applied inside. We therefore simulated the same zone after having added 10 cm of insulation inside the oldest (not yet renovated) buildings and obtained the results in figure 3.

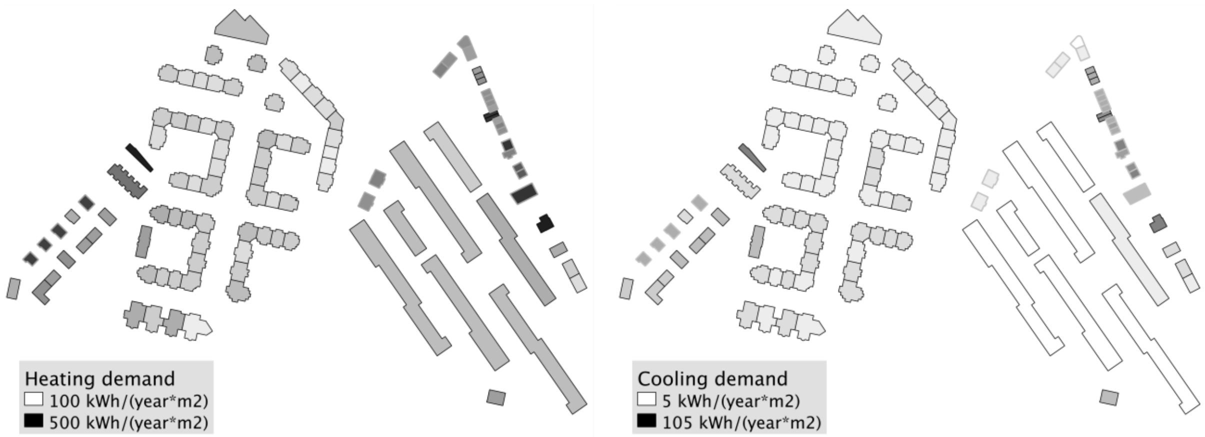

Figure 3: Simulated heating and cooling demand of the buildings for the scenario. Insulated buildings are represented with a grey border.

This scenario leads to a reduction of 19.5% of the heating demand and 50.1% of the cooling demand of the buildings concerned. However, as these represent a small fraction of the total energy need of the zone (8.2% for heating and 14.1% for cooling), the reductions of the total demand for heating and cooling in the zone are only 1.6% and 7%. The high cooling demand reduction is explained by the low glazing ratio of these old buildings and the relatively large heat flow through the opaque surfaces in the base case scenario.

CONCLUSION

The methodology described in this paper simplifies and accelerates greatly the simulation of energy demand with CitySim at a large scale – up to a few hundred buildings – by using the power of the database management system (DBMS) PostgreSQL. The simple Java tool developed to retrieve the data from the database, launch a simulation and write the results back in the database is a first step in the automation of urban energy simulation. The analysis of the results is then facilitated by PostgreSQL functionalities or by representations as maps through compatible GIS software such as QuantumGIS.

As part of a research project funded by the Swiss National Science Foundation, other typical neighbourhoods of Zürich will be simulated, as will the entire city building stock. Furthermore, the CitySim simulation of buildings' energy demand will be complemented by simulations of the city's transport energy demands using the MATSim [7] model – the means for coupling the two being the exchange of people. Energy reduction scenarios will then be studied to inform Zürich's goal of achieving a 2000W society before 2050.

The methodology developed here is also a step towards more usable simulation software to be used broadly by cities' energy services or consulting engineers. In particular, the MEU project (an acronym, in French, for Urban Energy Management [8]) intends to create a platform taking advantage of DBMS, GIS and energy simulation software capabilities to offer a complete solution for energy data management and energy scenario studies.

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IMPACT OF URBAN MORPHOLOGY ON BUILDING ENERGY NEEDS: A REVIEW ON KNOWLEDGE GAINED FROM MODELING AND MONITORING ACTIVITIES

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ABSTRACT

Urban morphology is one of the main parameters influencing directly and indirectly buildings' energy needs. Despite an increasing number of urban energy and environmental modelling tools addressing these issues, the complexity of physical relationships at this level often constrain urban energy modelers to simplify the problems by considering only parts of the phenomena, thus leading to diverging findings and recommendations related to the relevance of urban morphology.

A systematic review of published research works in the field of urban energy and environmental modelling is performed. This involves characterising the research approach, evaluating the physical effects taken into consideration in the models applied, the types of models applied, identifying whether the effect of urban morphology is isolated from other effects, whether the urban scene considered is real or theoretical and parametrised and recognising the performance indicators used for assessment. Last but not least, the type of result and the robustness of the ensuing recommendations in terms of sustainable urban design are critically evaluated according to clearly defined assessment criteria.

The main findings related to the impact of urban morphology on energy needs in the built environment are summarised and put in relation to the physical effects taken into consideration, showing that there is no common basis allowing for a generalisation of the knowledge available. Beyond an attempt to cluster the different approaches, the authors conclude that there is a clear need to further develop more comprehensive tools, but also to propose a minimal set of requirements for computational modelling activities in the urban energy field.

INTRODUCTION

Following the overall ambition to improve the quality of planning guidelines for sustainable urban development, the implications of urban morphology on the overall urban energy balance are worth being considered first. Having started from a functional description of the area of study, urban planners and designers soon translate these requirements in terms of morphological typologies included later in urban masterplans. Then, whereas other factors (e.g. share of glazing area, building performance) can still be amended in later project phases, morphological characteristics usually can not be completely redefined once the masterplans have been accepted by the responsible local authorities.

Urban morphology directly and indirectly impacts the overall urban energy balance. In the building sector, the direct impact is mainly related to radiation exchanges between building outside surfaces and their surroundings as well as heat transmission and convection losses through the building envelope, all three effects being influenced by geometrical built form properties. In the mobility sector, urban morphology influences mobility patterns mainly because of its implications on the preferred routes and transportation modes. In addition to this, a clear indirect impact is related to the dependency of building energy needs on urban climate, which again depends on urban morphology. Focusing on heat island effect in the Altanta region, the influence of urban morphology on urban climate was for instance assessed by [21]. The other effect, consisting in understanding the implications of urban climate on building energy consumption, was analysed already by [18] based on measurements performed in Athens. The demonstrated existence of both direct and indirect implications is sufficient to justify the necessity to further investigate the impact of urban morphology on the urban energy balance.

All these phenomena are increasingly being addressed by the research community, with a number of urban energy and environmental modelling tools that have recently emerged. To reduce the scope of the present study, the implications on mobility sector are not considered here. But even at the level of the built environment, the high complexity of physical relationships implies that the models developed only can handle parts of the effects, so it is clear that the related studies might lead to diverging results and interpretations. Starting from the pioneering work of Martin and March [9], this paper therefore presents the results of a review of the contributions of past studies on the impact of urban morphology on buildings' energy needs, by applying a clear set of assessment criteria. The outcome is a critical analysis of the results gained from these works and aims at paving the way for future related modelling and monitoring activities at urban scale.

METHOD

The literature review is limited to scientific publications dealing with direct and indirect implications of urban morphology on energy needs. It does not have the ambition of providing an exhaustive list of all that has been written on these topics. It refers to most cited and practically accessible articles and to contributions fulfilling a minimal set of scientific quality criteria in the eyes of the authors.

Name of criterion	Approach / value of criterion	Relevance
Scientific approach chosen	1) Computational modelling 2) Experimental procedure 3) Literature review	Whether the publication is based on theoretical and computational activities, experimental work or literature review indicates the degree of innovation of the findings presented.
Physical effects taken into consideration in the models applied (scope of physical phenomena modelled)	1) Urban climate 2) Radiation exchange between building and surroundings 3) Building energy demand calculation (for heating, cooling and lighting) based on building and urban physics	The physical effects taken into consideration indicate how far the chosen model is from reality and therefore what are the limits of applicability of ensuing recommendations.
Types of models applied	1) Meteorological model including CFD computations 2) Ray-tracing model for daylight analysis 3) Building thermal model	The types of models applied indicate how physical effects have been considered and therefore the degree of accuracy and precision of the results.
Type of urban scene considered	1) Real case study 2) Simplified geometrical form	Whether the urban scene considered is real or theoretical and parametrised indicates the degree of abstraction of the work and the scope of applicability of results. Simplified geometrical forms (archetypes) can be easily parameterised but can loose any relation to reality.
Climate zone considered	Name of location or climate zone	The specification of the climate zone considered indicates the field of applicability of results.
Urban morphology parameters	1) *individual building parameters*: wall surface area, ratio envelope area to floor area, facade convolution index, building orientation, ratio of passive to non-passive floor area 2) *parameters characterising the direct environment of a building*: obstruction angle, urban horizon angle, sky view factor, H/W ratio, surrounding building density 3) *parameters characterising a neighbourhood*: site coverage, directionality, clustering typology, directional spacing angle difference, directional space ratio	The way how urban morphology is parametrised indicates the type of urban morphology variations which are tested in the study. The parameters can be divided into 3 categories, depending on whether they describe building form only (1), the direct morphological surrounding of a given building (2) or the morphological patterns of an entire neighbourhood (3).
Main performance indicators used in performance assessment	1) *indicators of solar radiation distribution*: solar exposure, percentage of daily direct solar radiation distribution on urban surfaces (roofs, facades, ground), irradiance on facades 2) *indicators of daylight availability in internal spaces*: indicators of daylight factor, daylight autonomy, UDI (useful daylight illuminance) 3) *indicators of building energy performance*: fabric heat losses, cooling and heating energy demand, lighting electricity consumption, total energy use, change in space heating, increase in space heating, change in primary energy use	The performance indicators used show the basis on which different urban morphologies are assessed or which are the target criteria for urban morphology optimisation. The indicators can be divided into 3 categories, depending on whether they quantify the solar radiation distribution (1), the daylight availability in internal spaces (2) or the building energy performance (3).
Knowledge gained	Qualitative or quantitative description of impact of urban morphology on building energy needs	
Robustness of the ensuing recommendations	5 assessment criteria presented in Table 2	See Table 2.

Table 1: Assessment criteria used

Assessment criteria

The analysis of a high number of diverse publications (both in scope, method applied, degree of innovation, quality) is performed by applying the set of criteria presented in Table 1 and by categorising the publications (author, date, publication medium). It has been noticed that computational modelling is not the only scientific approach chosen; even when this is the case the models used do not always take into consideration all physical effects or are of different nature. Then, there are different possibilities for considering urban scenes which can be immersed in different climate zones. Last and because it might not be necessary for their works, the authors do not always isolate urban morphology parameters from other parameters. The robustness of the ensuing recommendations is assessed using the criteria reported in Table 2.

Criteria for the robustness of recommendations	Relevance
The study is performed without any initial non-verified postulate.	Taking non-verified postulates for granted is questionable in any research work.
The effects of single parameters were isolated (other parameters were normalised).	Isolating the effects of given parameters implies normalising other parameters to neutralise their influence.
Plausibility check: trends and results obtained are plausible.	Plausibility checks are necessary to be convinced of the results' validity.
A validation procedure has been applied or is under way (e.g. monitoring).	Validating the results obtained is necessary for robustness of recommendations.
The limits of applicability are clearly presented.	Presenting the limits of applicability is an indicator of awareness one's own limitations.

Table 2: Criteria used to assess the robustness of recommendations

RESULTS

30 publications written between 1972 and 2011 have been considered. This includes 5 books (some of them gathering more than one publication related to the topic of interest), 14 journal articles and 8 conference papers.

Scientific approach chosen

Given the difficulty to isolate the impact of selected morphological parameters in situ and monitor their impact on energy use in real case studies, nearly all publications assessed are based on computational modelling activities. Only few works rely on measurements performed at urban scale: mainly [18] and more recently [23] use monitored data to characterise the local urban climate ([23] uses an empirical climate prediction model based on Singapore data) in which buildings are immersed, but in both works building energy needs are practically calculated. [21] uses high resolution IR-thermography to characterise indirectly the heat island intensity, but this approach is not frequently followed. Comparing and referring to other published works is the main approach of 6 of the assessed publications, which do no rely on any new computational modelling activity.

Physical effects taken into consideration in the models applied and types of models applied

Despite the known implications of urban climate on energy needs and the available possibilities to model urban climate conditions based for instance on the work of [11], only 4 of the assessed publications consider a climate model (empirical or urban boundary-layer model) in the computations. It is clear that studies of solar radiation availability on outside building surfaces do not require an urban climate model. However, 6 publications draw conclusions on thermal building energy needs without considering or mentioning the possible implications of urban morphology on the local climate and its impact on energy needs.

The radiation models used are either based on a ray tracing or radiosity algorithm in which anisoptropic sky radiance distributions, diffuse sky occlusions and reflections from occluding surfaces may each be handled (6 publications), or relatively simplified models are used in which a limited number of these phenomena are represented.

Thermal building models, ranging from the highly simplified heat loss calculation over the building envelope used by [9] to commercial or self-developed transient building energy performance simulation tools, are applied in 14 publications. In 3 of these publications, implications on cooling energy needs are ignored. In 10 of these publications, electricity needs for artificial lighting are not considered.

Type of urban scene considered

Two approaches are used to consider urban scenes. Some authors (7 publications) use models of real urban neighbourhoods, having the major advantage to be representative of real urban design morphologies. However in these cases, there are usually limited possibilities to generalise the findings gained on the case study cities, unless there is a high number of cases characterised according to given parameters. [7]

considers 25 different urban block types in four categories: discontinuous collective housing, continuous collective housing, dense individual housing and dispersed individual housing.

Publication reference	**Urban climate model**	**Radiation model for surroundings**	**Building thermal model**	**Cooling needs calculated**	**Energy use for lighting calculated**	**Main findings: impact of urban morphology on buildings' energy needs (summary)**
[1]	TEB	Y	TRNSYS	Y	-	The effect of H/W ratio of an urban canyon is assessed and demonstrated to be not as significant as the effect of other parameters (thermal insulation, window ratio).
[4]	-	Y	-	-	-	The impact on buildings' energy needs is not assessed but it is demonstrated that solar energy available for utilisation may be increased by up to 20% if optimisation algorithms are applied on urban morphology.
[5]	-	Y (albedo)	Energy Plus	Y	Radiance and Daysim	Increasing site coverage implies higher heating and lighting needs and lower cooling needs. The results of the performed sensitivity analyses are presented graphically.
[6]	-	Radiance	-	-	-	The impact of site coverage on the solar irradiation on buildings is proven to be relatively low but the implications on energy needs are not commented. The effect of self-obstructions is proven to be relevant.
[7]	-	-	TAS	Y	-	The impact of urban morphology is not assessed because urban form parameters are not isolated from other parameters (thermal building envelope quality).
[8]	-	-	Static calculation	-	-	Theorem 1: "A simple rectangular block of given volume loses the least amount of heat if the dimension of each edge is proportional to the mean thermal transmittance value of the faces defined by the other two edges."
[9]	-	-	Static calculation	-	Y	Based on the parametric study it is proven that increasing density impacts energy use for lighting rather than heating energy use.
[12]	ENVI-MET	Y	-	-	-	The impact on buildings' energy needs is not assessed.
[14] & [15]	-	Y?	LT	-	LT	The passive to non-passive area ratio is proven to impact buildings' energy needs. A 10% difference is shown between the specific energy needs of different urban morphologies, when default values are attributed to all other variables.
[13]	-	-	-	-	From DEM	The surface to volume ratio is used as indicator of good thermal performance.
[16]	-	Y	-	-	-	The impact on buildings' energy needs is not assessed.
[17]	-	Y	SUNTOOL	Y	Y	The impact of H/W ratio on energy use for cooling, heating and lighting is calculated for different glazing ratios in a parametric study. Results are graphically presented.
[18]	Measurements	-	TRNSYS	Y	-	The impact of urban morphology is not directly assessed, but the effect of urban climate on energy consumption in buildings (heating and cooling) is quantified.
[19]	-	-	N	-	-	The impact on buildings' energy needs is not assessed.
[20]	-	-	LT (partly)	Y	LT	"Relatively high housing densities can be achieved before a negative impact on the energy demand becomes significant" (based on a limit obstruction angle of 30%).
[22]	-	Y (albedo)	Energy Plus	Y	Radiance and Daysim	Heating and cooling energy demand can be reduced by 10% to 20% by optimising urban morphology.
[23]	Empiric model	-	TAS	Y	-	In the range considered, height and density are not as relevant as green plot ratio. Cooling energy demand can be reduced in a range between 5 and 10% if green areas are addressed effectively.

Table 3: Assessment results of the publications reporting the results of computational modelling activities at neighbourhood scale

The other publications (i.e. the majority) use simplified urban morphological archetypes which can more easily be parameterised, both for performing sensitivity analyses and urban morphology optimisation, but which have the risk to lose any connection to realistic urban design proposals. Often inspired by [9], the most frequently assessed archetypes are pavilions (8), including shape variations for high-rise buildings ("I", "L", "F" and "+" shape in [6]), courtyard configurations (4), row houses and slabs (3) and urban street canyons (1). The more frequent typologies are therefore pavilions and courtyard typologies.

There is one case of real building geometry immersed in different urban contexts [23] and one case of a newly developed building form typology ("residential solar block" in [12]).

Climate zone considered

Authors have different ways to refer to climate conditions. Only few authors characterise the climate by mentioning a climate zone (locations at 48° latitude for [12], an arid climate for [13]), suggesting their results may be valid for similar latitudes in the considered zones.

Urban morphology parameters

Table 1 shows the high variety of parameters used to characterise urban morphology, illustrating the various possibilities for its parameterisation. The height to width ratio between buildings is the most frequently used parameter, followed by site coverage, plot ratio and sky view factor (and related equivalent parameters); often using ill-adapted radiation models. Few authors quantify the overall neighbourhoods' energy performance in dependency on more abstract neighbourhoods' morphological parameters.

Main performance indicators used in performance assessment

As for urban morphology parameters, Table 1 shows the high variety of performance assessment indicators used in the assessed publications, being a proof of the different authors' positions in relation to what defines an energy efficient urban morphology. The use of indicators of solar irradiation on building envelope indicates that the maximisation of solar radiation on building envelope is considered as a target function. However, even if followed in 7 of the assessed publications, this approach can only be considered as a computational exercise and can not be translated in any morphological recommendation. If thermal building energy needs are calculated by applying a thermal building model, specific energy performance ratings (specific heating energy and cooling energy needs, if applicable) or variations of these indicators are used to characterise energy performance. Indicators for electricity use for lighting are considered only in four of the assessed publications.

Knowledge gained

Generally speaking, all publications assessed confirm the impact on urban morphology on building energy needs but its intensity is rated differently, mainly depending on the physical effects taken into consideration. Few authors really conclude on percentage variations or quantify building energy performance rating in dependency of urban morphology. The last column of Table 3 is an attempt to summarise the main findings presented in the publications assessed.

Robustness of the ensuing recommendations

The robustness of the recommendations from some of the papers cited here are somewhat questionable. [12] for example proposes a "holistic approach to energy efficient building forms", without considering the seasonal differences when it comes to analysing the contribution of solar radiation and without calculating buildings' energy performance; whilst [13] uses the surface area to volume ratio as performance indicator.

The effect of urban morphology parameters is isolated in many cases, but the normalisation is rarely performed on the same way. Sometimes plot ratio and volume to facade ratio are normalised, sometimes the built volume and passive to non-passive ratio; in other works U-values as well as the share of glazing area are maintained whereas morphological parameters are varied. In 5 publications the effects of urban morphology are not isolated, which makes it impossible to deduce recommendations from this point of view.

In nearly all cases, the plausibility of trends and results obtained is commented by the authors, but only the theorems of [9] are mathematically demonstrated, mainly because they are based on very simplified problems which do not require any computational modelling to be solved. Other publications never rely on energy use monitoring to validate the findings presented, with exception of the work of [5] which mentions a satisfying comparison with energy use monitoring data from the case study.

The limits of applicability are nearly always clearly presented, with the exception of 3 cases where the recommendations provided seems to go beyond the field of application at the eyes of the authors (extrapolation is not justified).

CONCLUSIONS

The literature reviewed here seems to confirm the implications of urban morphology on energy needs. However, given that different physical effects are considered, different parameters are varied and different indicators are used for assessment, it is difficult to generalise and compare the authors' findings; there is a need for consistence regarding the phenomena examined and the manner in which the ensuing results are expressed. The next step in this work is to propose one such framework.

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EVALUATION OF WIND-DRIVEN VENTILATION IN BUILDING ENERGY SIMULATION: SENSITIVITY TO PRESSURE COEFFICIENTS

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ABSTRACT

Building Energy Simulation (BES) tools integrate wind-driven ventilation in buildings either by imposing the airflow rate in a Zone-Airflow module or by calculating it through Airflow Network (AFN) models. When the AFN models are used, pressure coefficients are crucial for obtaining accurate results. This is particularly important in case of complex geometries or buildings with large openings, when the uncertainties related with the use of simplified models are higher and can affect the results. This paper describes a preliminary study on the effects of the pressure coefficients on the BES simulations of a cross-ventilated building with large openings. The single-zone building has a high thermal mass and is subjected to wind-induced night ventilation. Simulations are performed with the Zone-Airflow module and the AFN model within the code EnergyPlus. The airflow rate imposed in the Zone-Airflow module is obtained by performing Computational Fluid Dynamics (CFD) simulations of the opened-building (i.e. the building with ventilation openings). The pressure coefficients used for the AFN simulations are obtained in five different ways: (i) the surface-averaged calculation in EnergyPlus, (ii) the Air Ventilation and Infiltration centre (AIVC) database, (iii) the Tokyo Polytechnic University (TPU) database, (iv) wind-tunnel measurements and (v) CFD simulations performed on a closed (sealed) building (i.e. the building with ventilation openings closed). Results are compared in terms of airflow rate and indoor air temperature during a Design Day characterized by a constant wind speed. Differences in airflow rates are up to the 15% among the values predicted with the AFN models and increase up to the 24% when the results of the Zone-Airflow module are compared with the ones obtained from the AFN model simulations. For the case under study, the airflow rates are very high and the indoor air temperatures are not affected by the variation of the pressure coefficients. The results indicate the importance of the pressure coefficients in predicting the airflow rates through large openings. Other ranges of airflow rates might be investigated to see the effects on the indoor air temperature for more realistic building configurations.

INTRODUCTION

Natural ventilation due to wind and buoyancy is a valuable approach to obtain comfortable and healthy indoor environments. The ventilation performance of buildings can be estimated by using simplified analytical and empirical models, measurements and computer simulations [1]. A suitable integration of ventilation models in Building Energy Simulation (BES) tools is done through Airflow Network (AFN) models, which describe a network of airflow paths from the outside and through the building zones which are driven by pressure coefficients (C_p). Pressure coefficients for the AFN models can be acquired from primary sources, i.e.

wind-tunnel measurements or Computational Fluid Dynamics (CFD) simulations on a sealed body, or from secondary sources, i.e. analytical and empirical models [2].

Simplified models can be used for simple building geometries with small openings, when the outdoor wind flow conditions can be used as boundary condition for calculating the indoor air flow (i.e. the sealed-body assumption [3]). However, large discrepancies can be obtained for more complex geometries and in case of large openings, when the sealed-body assumption is no longer valid [3; 4]. A correct estimation of C_p for these cases is therefore crucial for performing accurate building energy simulations, as well as investigating the uncertainties related with the use of different C_p sources for airflow rate calculations [5].

This paper describes a preliminary study on the effects of the C_p data sources on the airflow rate and the indoor air temperature of a cross-ventilated building. C_p extracted from primary and secondary data sources were applied to the BES simulation of a single-zone building with the openings on the opposite and adjacent walls. Wind-induced night ventilation is considered for the simulations performed with the Zone-Airflow module and the AFN model within the code EnergyPlus [6]. The airflow rates used in the Zone-Airflow module simulations are taken from the CFD simulations of the opened-building. The pressure coefficients used for the AFN model are taken from (i) the surface-averaged calculation in EnergyPlus [7], (ii) the Air Ventilation and Infiltration centre (AIVC) database [8], (iii) the Tokyo Polytechnic University (TPU) database [9], (iv) wind-tunnel measurements [10] and (v) Computational Fluid Dynamics (CFD) simulations performed on a closed-building [11].

BUILDING CONFIGURATION

A single-zone building (Fig. 1) was defined in order to reproduce, at full-scale, the geometry of the reduced-scale model tested in the wind tunnel [10; 12]. The full-scale dimensions are 20 x 20 x 16 m³. Two openings are placed in the centre of the opposite (Case A) and adjacent (Case B) walls at the height of 6.2 m. The openings, sized 9.6 x 3.6 m², provide a wall porosity of the 10% [12] and can be characterised by a discharge coefficient of 0.61 [10].

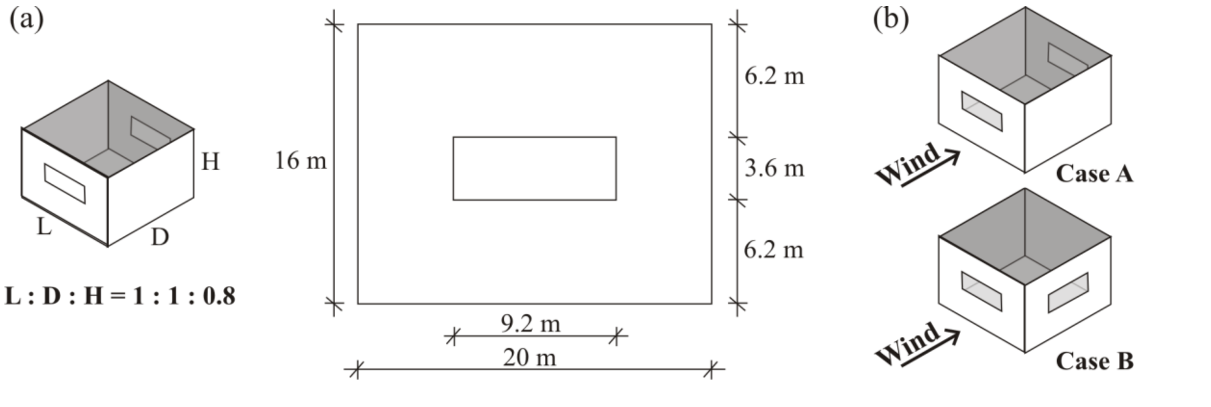


Figure 1: Geometry of the building configurations under study and view of windward facade with opening (a) and opening configurations for Case A and B (b).

The thermal transmittance of the building walls (U-value) is equal to 0.512 W/m²K for the external walls, 0.039 W/m²K for the floor and 0.318 W/m²K for the roof [13]. The internal loads were considered as a constant value of 10 W/m². Wind-induced night ventilation was imposed from 22:00 to 7:00. The heating system is considered always off, The cooling system is working from 7:00 to 22:00 with a set point temperature of 27°C. Based on the climate conditions of Denver (USA), a design day was defined for the analyses by considering the temperature conditions of the maximum dry bulb temperature day of the year (26 July) and imposing a constant reference wind velocity of 3.24 m/s at 10 m height.

INPUT DATA FOR THE AIRFLOW CALCULATION

Zone-Airflow module

Reduced-scale models (scaled 1:200) of the opened-buildings in Case A and B were simulated with the software Fluent [14]. The computational domain and grid were created with the code Gambit 2.4.6 using the surface-grid extrusion technique [15] and in accordance with the existing guidelines [16, 17]. An approaching-flow wind velocity profile was described by a power-law with an exponent of 0.12 and a reference velocity of 6.97 m/s at the building height (0.08 m – 16 m full scale); the turbulence intensity at the same height was 10% and 17% near ground level (0.01m). The building is placed in open terrain. The 3D steady Reynolds-averaged Navier-Stokes equations were solved with the RNG k-ε turbulence model and successfully validated with the wind-tunnel measurements by Karava [10] and Karava et al. [12]. Further details on the simulations can be found in [11]. The calculated airflow rate through the inflow opening was used for the Zone-Airflow module simulations.

Airflow Network (AFN) model

C_p coefficients used in the AFN model are extracted from the sources described below. Note that due to the geometric ratio between the dimensions of the building (Length:Width:Height = 1.0:1.0:0.8), low-rise building methods were used for the analyses when required.

(i) Surface-averaged calculation in EnergyPlus ($C_{p,AVE}$)

The automatic surface-averaged C_p calculation for low-rise building in EnergyPlus is based on the formula by Swami and Chandra [7] for rectangular buildings. The formula allows the estimation of a surface-averaged C_p coefficient in each wall considering the building geometry (ratio between adjacent walls) and the wind direction.

(ii) AIVC database ($C_{p,AIVC}$)

In the AIVC database, C_p values for low-rise buildings are collected from different data sources [8] and presented in tables. The C_p values are surface-averaged and the building geometry (L/W ratio), the sheltering conditions and the wind direction are considered. For the present study, an exposed building with L/W=1 is considered.

(iii) TPU wind pressure database ($C_{p,TPU}$)

The TPU web aerodynamic database is based on extensive wind-tunnel measurements [9]. The database for the low-rise buildings provides surface-averaged wind pressure coefficients and C_p distributions on the building walls and considers different roof shapes, sheltering conditions and wind directions. The C_p used for the analyses are extracted from the isolated low-rise building database, considering a flat roof and a geometric ratio of L:W:H=4:4:3.

(iv) Wind-tunnel measurements ($C_{p,WT}$)

C_p values were extracted from wind-tunnel measurements conducted by Karava [10]. The geometry of the scaled model, the approaching wind profile and the ground conditions are as described above. Pressure measurements were conducted for a closed-building and are described in detail in Karava [10]. Pressure coefficients were derived by the mean pressure measured in the centre point of each wall.

(v) CFD simulations of a closed-building ($C_{p,CFD}$)

CFD simulations on a closed-building were performed to extract the pressure coefficients on the openings' area, The same settings described above for the opened-building were used in this case although steady RANS equations have some deficiencies in modelling the surface pressures downstream the windward facade [18]. Pressure coefficients were derived from the static pressure by extracting the averaged C_p values on the openings areas.

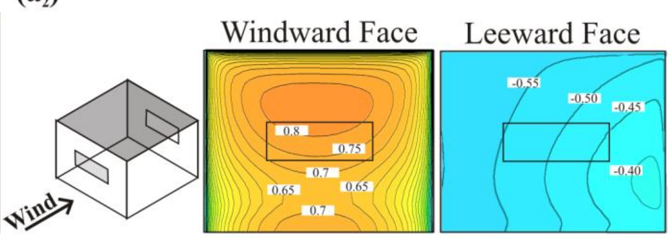
RESULTS AND DISCUSSION

Figures 2 summarises the C_p and ΔC_p values obtained for Case A and B from the primary and the secondary sources analysed. It can be noticed, that ΔC_p from the surface-averaged calculation ($\Delta C_{p,AVE}$) differs from the value obtained with wind tunnel measurements ($\Delta C_{p,WT}$) up to 10% in Case A and up to 15% in Case B.

(a$_1$)

Case A	$C_{p,\ windward}$	$C_{p,\ leeward}$	$\Delta C_{p,}$
$C_{p,AVE}$	0.6	-0.36	-0.96
$C_{p,AIVC}$	0.7	-0.2	-0.9
$C_{p,TPU}$	0.65	-0.25	-0.9
$C_{p,WT}$	0.72	-0.15	-0.87
$C_{p,CFD}$	0.76	-0.49	-1.25

(a$_2$)



(b$_1$)

Case B	$C_{p,\ windward}$	$C_{p,\ leeward}$	$\Delta C_{p,}$
$C_{p,AVE}$	0.6	-0.44	-1.04
$C_{p,AIVC}$	0.7	-0.5	-1.20
$C_{p,TPU}$	0.65	-0.54	-1.19
$C_{p,WT}$	0.72	-0.51	-1.23
$C_{p,CFD}$	0.76	-0.62	-1.38

(b$_2$)

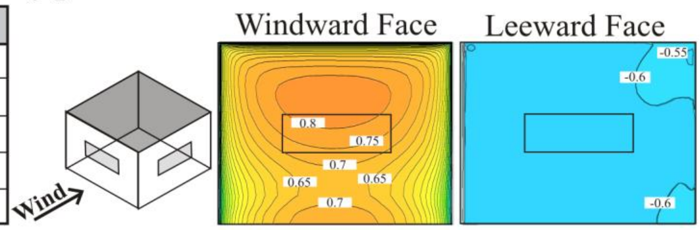


Figure 2: (a$_1$, b$_1$) C_p values for Case A and B using the surface-averaged calculation ($C_{p,AVE}$), AIVC database ($C_{p,AIVC}$), TPU database ($C_{p,TPU}$), wind-tunnel measurements ($C_{p,WT}$) and CFD simulations ($C_{p,CFD}$). (a$_2$, b$_2$) Distribution of $C_{p,CFD}$ on the windward and the leeward faces.

Results of the BES simulations by using the AFN model with different C_p and the Zone-Airflow model are compared in terms of airflow rate (Fig. 3) and indoor air temperature (Fig. 4). Differences in the airflow rates (Fig. 4) reproduce the trend shown by the ΔC_p values. Among the airflow rates calculated with the AFN model in EnergyPlus, results vary up to 15% for Case A and to 13% for Case B. Higher discrepancies (up to 24%) are noticed when the results from the AFN model are compared with the airflow rates extracted from CFD and imposed to the Zone-Airflow model. Further efforts are necessary to understand these outcomes, focusing on the possible role of the integration between the airflow and the thermal networks in EnergyPlus and on the influence of the C_p distribution on the facades.

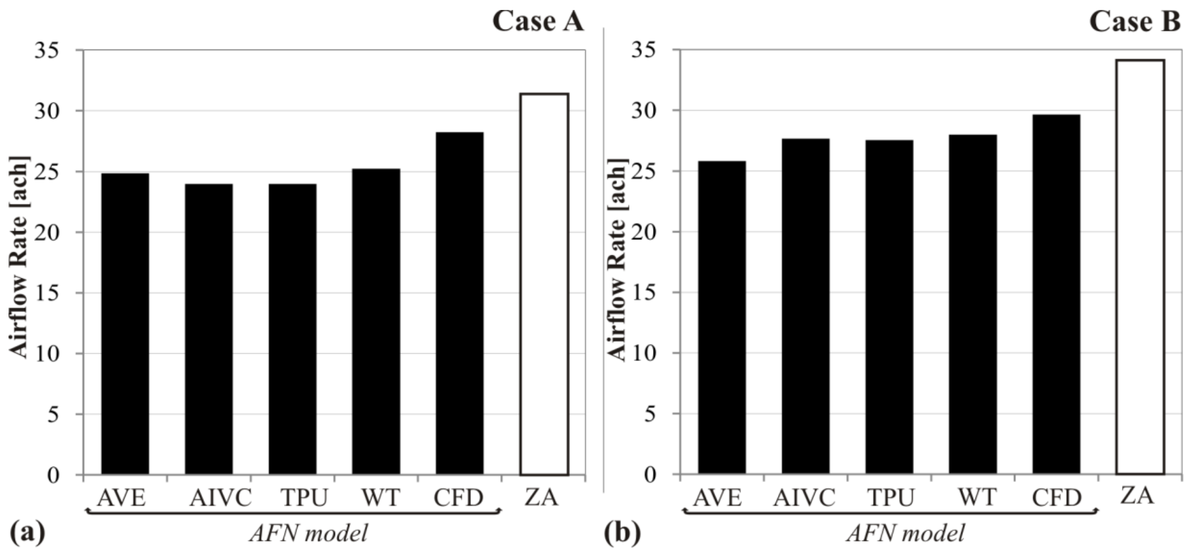


Figure 4: Airflow rates predicted by using the Zone-Airflow model (ZA) and the AFN model with the C_p extracted from different data sources for Case A (a) and B (b).

The differences shown in the airflow rate do not influence significantly the indoor air temperature profile during the night, which almost overlaps the outdoor air profile (Fig. 5). Among the results of the AFN model simulations, only the predicted indoor air temperature using $C_{p,WT}$ and $C_{p,AVE}$ are shown in Figure 5, because of the negligible differences among the results. A small variation is noticed with the Zone-Airflow model is applied to Case B. These small differences might be due to the fact that in the chosen case study the airflow rate is steadily high. Other range of airflow rate values should be investigated.

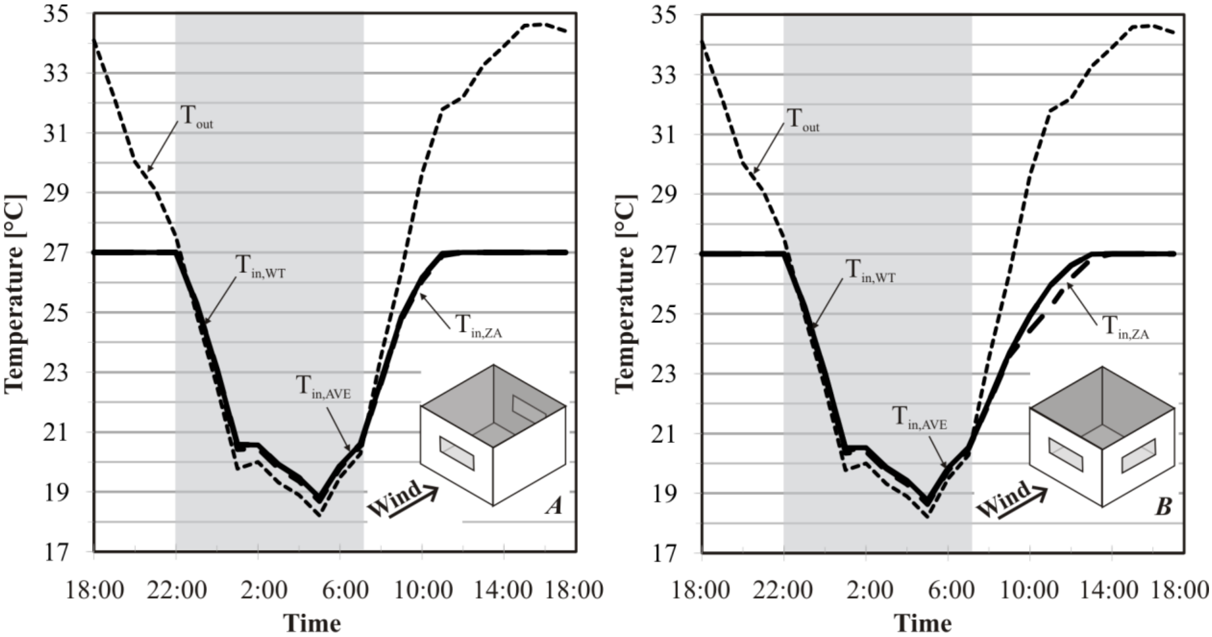


Figure 5: Outdoor (T_{out}) temperature in the Design Day and indoor temperature for Case A and B obtained with the Zone-Airflow module ($T_{in,ZA}$) and the AFN model with C_p values from wind tunnel measurements ($T_{in,WT}$) and surface-averaged calculation ($T_{in,AVE}$)

CONCLUSIONS

Based on the results presented in this paper it can be noticed that the values of C_p are strongly influenced by the data source and the estimated ΔC_p from the CFD simulations are up to the 30% higher than the others. These differences affect the predicted airflow rates with the AFN model up to 15%. It is observed that the airflow rate extracted from the CFD simulations tends to be higher than the airflow rate predicted by using the $C_{P,CFD}$ in the AFN model (up to the 24%). The indoor air temperature is not influenced by the variation in the airflow rates, which are very high in every case tested. Further studies may focus on a more realistic building configuration.

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CO-SIMULATION FOR BUILDING CONTROLLER DEVELOPMENT: THE CASE STUDY OF A MODERN OFFICE BUILDING

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ABSTRACT

We report our experience from using co-simulation in the context of a demanding building control study. The object under investigation was a 20'000 m^2 newly-built office building in Munich. Considered was the control of radiant ceilings, heating convectors, mechanical ventilation, blinds and lighting for one floor that was subdivided in 28 building zones. We employed the Building Controls Virtual Test Bed (BCVTB) middleware to couple the EnergyPlus building energy performance simulation software with the MATLAB numerical computing environment. We found that this set-up enables a structured and flexible approach to controller development and building simulation, even for sophisticated control problems. On the downside, debugging of the simulations became more difficult and simulation times were found to increase by a factor 2 to 10. Considerable know-how and effort are currently necessary to set up and operate the co-simulations. A newly developed software layer that helps minimizing this effort is presented.

CONTROL IN BUILDING ENERGY PERFORMANCE SIMULATION TOOLS

Improved building control is gaining increasing attention as a means to improve energy efficiency and comfort of buildings, to handle the complexity of modern building systems, and to make optimal use of modern information and communication technology. The development and testing of novel control technologies can only be accomplished efficiently with the aid of computer simulations. Moreover, dynamic simulations are the only way to study the role of control already in a building's planning phase. It is in this context that co-simulation provides an attractive option to combine existing building simulation software's sophisticated capabilities with the extensive expertise and software tools available from the field of control engineering.

However, modern building energy performance tools were developed and optimized for building energy performance simulation in the first place. Although they can be customized in many ways their flexibility in terms of control is very limited. I.e. they often support building control only in a very rudimentary manner, e.g. by allowing for simple manipulation of set-points or the setting of component availability. Crawley et al. (2005) provide a summary of simulation tool capabilities. Advanced control requires programming features not available in most traditional building simulation tools. Amongst others, this includes the needs for flexible I/O and manipulation of control parameters, matrix algebra, and calling of external optimization routines. One line of current research consists in developing a new generation of building simulation tools that overcomes these problems (Wetter, 2009). In this paper we consider as an alternative the combination of traditional tools by means of so-called co-simulation.

COUPLING CONTROL AND BUILDING SIMULATION

Co-simulation consists in the integration of different software components by run-time coupling. Fundamentals for building simulation such as coupling strategies and data transfer are described in Trčka et al. (2009).

Several energy performance simulation tools already feature interfaces to other software, e.g. the well-known TRNSYS software offers an interface via the so-called Trnsys Type 155 for coupling to the MATLAB numerical computing environment and fourth-generation programming language (MATLAB, 2011). However, the value of such solutions is often limited by the fact that the building simulators will typically maintain full run-time control over the course of a simulation. Efficient controller development requires a different, much more flexible approach that supports structured and hierarchical coupling of subsystems into overall systems. Precisely this functionality is provided by the Building Controls Virtual Testbed (BCVTB) software developed by the Lawrence Berkeley National Laboratory (Wetter and Haves, 2008).

BCVTB is a middleware that allows coupling of various software codes for distributed simulation. Currently, programs to be linked via the BCVTB are EnergyPlus, MATLAB, Modelica and Radiance. Data exchange with BACnet building automation systems is also possible. Here we report our experiences from using BCVTB to couple the EnergyPlus building energy performance simulation software (EnergyPlus, 2011) with the MATLAB environment in the context of a demanding case study.

CASE STUDY

The object under investigation was a 20’000 m^2 newly-built office building in Munich (Figure 1). Our goals were (i) to assess the performance of present-day rule-based control (RBC) in terms of energy usage, thermal and light comfort, peak electric power demand and (ii) to investigate possible advanced control approaches including Model Predictive Control (MPC; e.g., Maciejowski, 2001) with the aid of simulations.

In a first step we developed an EnergyPlus model comprising 28 coupled zones that covered an entire floor of the office building. 24 zones were controlled from within MATLAB, 4 auxiliary zones were controlled from within EnergyPlus using a simple two-point controller. The RBC strategies for plant equipment plus radiant ceilings, heating convectors, mechanical ventilation, blinds and lighting as specified by the building planners were analyzed and translated into MATLAB codes such that they could be simulated outside of EnergyPlus. BCVTB was used to close the control loop between the MATLAB controller and the EnergyPlus model by exchange of input and output signals at each simulation time step (Figure 2).

In the case study it was decided to only have high-level control decisions outside of EnergyPlus. Low-level control of zone equipment (such as massflow rates) remained in the EnergyPlus controller domain. Temperature setpoints as well as plant and zone equipment availability signals were determined from within MATLAB. By means of BCVTB, corresponding schedules related to equipment operation and internal gains, as well and actuator manipulations were passed to EnergyPlus. Table 1 gives an overview of the signals involved in the RBC of the office floor.

	MATLAB to EnergyPlus	EnergyPlus to MATLAB
Controller Outputs: Temperature setpoints	101	–
Controller Outputs: Plant and equipment availability	45	–
Controller Outputs: Blinds positions and slat angles	62	–
Internal Gains Status: Occupancy, equipment fraction	48	–
Controller Inputs: Zone temperatures, return temperatures	–	53

Table 1: Overview of information flows managed by BCVTB for the rule-based control of 24 building zones.

IMPLEMENTATION

Implementation of the co-simulations required correct handling of a large number of software objects related to the exchanged signals (Table 1) plus the global simulation parameters (simulation begin and end time, time step etc.) in all three involved software components:

BCVTB requires the specification of the global simulation parameters, the co-simulation actors, their respective in- and outputs, and their coupling. All this data had to be provided in an Extensible Markup Language (XML) coded text file.

EnergyPlus requires that the simulated building's geometry and construction details, the zone and plant equipment, the plant's water and air loops, the internal gain schedules, the control, and the definition of the requested outputs are specified in a so-called input data file (IDF). IDFs contain records defining various types of objects plus optional, non-standard control functions that are written in the EnergyPlus Runtime Language (Erl). IDFs are human readable text files, but they can become very large – in our case the IDF without high-level controls had 28'000 lines of code. Including the high-level RBC controller would have added another ca. 3'000 lines of code.

MATLAB offers a powerful programming language that supports among other things elementary typed variables, vectors and matrices, structured variables (consisting of elementary plus structured variables) and functions. In our case, all inputs to the MATLAB controller were provided by BCVTB at runtime in a real valued vector. Its elements had to be mapped to corresponding MATLAB data structures for processing by the control algorithms that in turn returned a real valued vector to be provided by BCVTB as an input to EnergyPlus.

Figure 3 shows the architecture of a general software that was developed for the support of the co-simulations. It consisted of three main elements:

(i) Preparation of EnergyPlus IDFs ("PrepEPIDF"). This program takes EnergyPlus objects from a model objects database as an input. The objects are defined in Excel files with predefined structures. The program produces the EnergyPlus simulation's IDF as an output.

(ii) Preparation of BCVTB and controller files ("PrepBCVTB"). This program retrieves the specifications of all EnergyPlus control inputs and of all EnergyPlus outputs required by the external controller from the above-mentioned Excel database. It produces two kinds of outputs: the XML file required by BCVTB, and MATLAB codes that define all objects needed for the interaction of MATLAB with BCVTB.

(iii) Running of the co-simulation and automated post-processing of its results ("RunBCVTB").

All above programs were implemented as Unix/Linux shell scripts. They were based on standard Unix/Linux tools plus some auxiliary scripts involving programs that were written in the Python and Pearl programming languages.

In order to assess the performance of the co-simulations we considered annual simulation runs with two different building models. Each model was first run stand-alone to obtain a benchmark, and then it was run using BCVTB. All simulation experiments were done with EnergyPlus 6.0.0 and BCVTB 1.0.0 under the Debian Linux 5.0 operating system on a computer with 8 Intel Xeon processors at 2.53GHz. From Table 2 can be seen that for the 28 zone model the co-simulation was ca. 2.5 times slower than the stand-alone simulation, whereas for the smaller 9-Zone model the co-simulation was slower by a factor of 10.

	28-Zone Model	**9-Zone Model**
Number of exchanged inputs	315	76
Number of exchanged outputs	261	83
Computation time stand-alone simulation	71 min	7 min
Computation time co-simulation	181 min	71 min

Table 2: Comparison of BCVTB performance for annual runs of different sized EnergyPlus models (simulation time step 10 minutes)

DISCUSSION

The proposed co-simulation approach was found to have several advantages as compared to stand-alone simulations with EnergyPlus:

Firstly, it allows the controllers to be coded in a highly structured and modular way. This dramatically enhances code reusability and maintainability. For instance, we used for each given RBC rule (e.g. for heating availability or for blind positioning) a separate function that can be easily replaced without interfering with the rest of the controller.

Secondly, it allows all code related to control to be pulled together such that it is much easier and safer to modify. Moreover, controller parameters can be conveniently summarized in Excel spreadsheets and can be dynamically adjusted at run-time. Quite differently, IDFs support only static control specifications, and these are typically spread out over several hundred lines of code and multiple instances of EnergyPlus objects.

Thirdly, the proposed solution makes it possible to flexibly drive the building model with arbitrary signals in order to study the system's dynamics, or to identify simplified models for MPC. These possibilities are far beyond the support currently provided by EnergyPlus for parametric simulation runs.

Finally, we note that the rich programming capabilities provided by MATLAB are not limited to control purposes. Integration of MATLAB also enabled efficient post-processing of EnergyPlus output files.

On the downside, the proposed co-simulation approach requires additional effort to define and implement interfaces for data exchange. However, the general software developed (Figure 3) was found to drastically reduce the probability of errors and to shorten development cycles.

A further disadvantage is the found increase in simulation time. This was partially due to communication overhead. However, our results (Table 2) suggest that the number of exchanged variables could be of secondary importance. We suspect that the found increase in simulation time relates to the discontinuity introduced by the breaking up of control into external high-level control and EnergyPlus internal low-level control. This could cause an increase in the average number of iterations EnergyPlus has to perform internally within each simulation time step in order for its simulation results to converge.

Finally, debugging of the co-simulations proved not very easy, since BCVTB in its default configuration can only listen to ports i.e. transmitted values. Adding of breakpoints into the MATLAB code is not possible since it terminates the entire simulation run. Advanced features are available only after recompilation of a given BCVTB actor, which is however only possible for open source software. Therefore the MATLAB debugger cannot be used during co-simulation. This problem can at present only be alleviated by writing of extensive output files.

Concluding Remarks

The application of advanced control approaches to the built environment makes it necessary that highly sophisticated building and plant models such as EnergyPlus can be integrated in controller development. This can be well achieved by the proposed tools suite, when enhanced by an additional software layer to support the co-simulations.

This case study presented a joint effort of building and control engineers. From an organizational point of view we can conclude that co-simulation can much facilitate multi-disciplinary collaboration and presents a powerful tool to efficiently integrate dispersed knowledge and expertise.

Acknowledgements

The support of this research by ICADE REIM Deutschland GmbH is greatfully acknowledged.

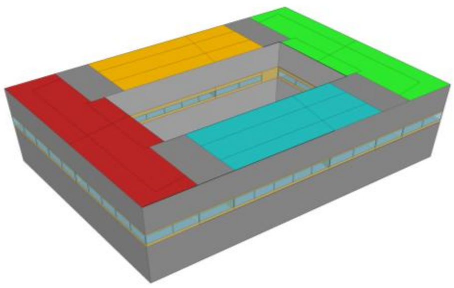

Figure 1: The building investigated and its 3D representation for the simulation of the third floor (other floors are used for shading purposes only). For Illustration the zone layout is shown on top. Colored zones were controlled via BCVTB.

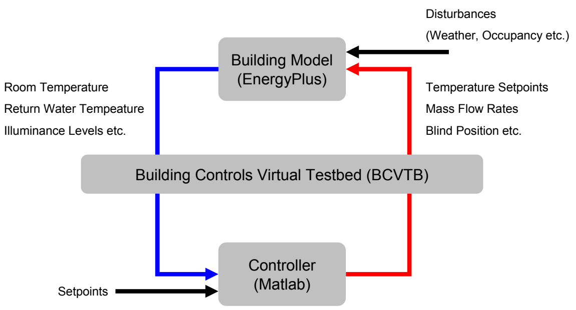

Figure 2: Schematic of the implemented control loop.

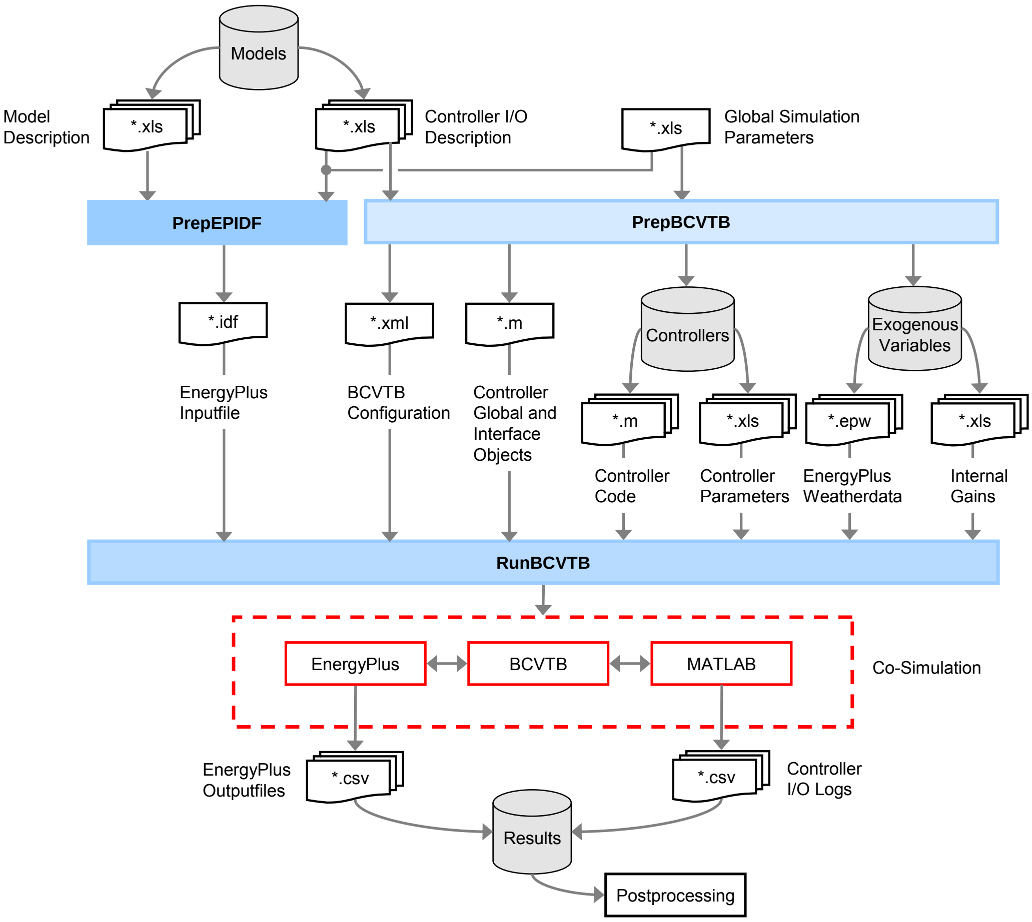

Figure 3: Data flow in the proposed software solution for co-simulation support

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EXTERNAL AND INTERNAL SOLAR-CLIMATIC PERFORMANCE ANALYSIS OF BUILDING GEOMETRIES USING SOLARCHVISION

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ABSTRACT

Since no architecture could stand without a proper structure, the life of no architecture could be considered without the essential effects of the sun. In our country, Iran, the sun had an extraordinary role in Persian life, culture and architecture; worshiped as MITHR goddess, acted as the foremost environmental factor in forming Persian traditional architecture amongst other important aspects. Consequently the word *MEHRAZ* which means architect in Persian language is based on two words of "MEHR (the sun)" and "RAZ (the mystery)". Thus, "*ancient Persian architects were regarded as the ones who knew the mystery of the sun.*" [1]

Today, while new technologies bring in a variety of modern products to benefit from the pure and unlimited energy of the sun for people all over the world; unfortunately, within most developing countries not enough attention is being paid to the proper use and vast benefits of renewable energies. Taking the example of Iran, where an abundance of solar radiation is available in the shadow of its considerable yet finite resources of oil and gas, it ironically seems that "*the richer we are in resources, the poorer we act*" [2]. Moreover, every year many new architectural projects are starting over within the Middle East with no proper concern given in time or expenditure to their proper design. As a result, we see an ever increasing pollution from nano to urban scale! In this unhealthy context, discussions concerning most efficient building orientations, sound proportions of building masses and the suitable clothing for each building facade in different climates are missing between most architects and urban designers in Iran; but this is exactly our mission here.

Beside the contextual problems mentioned, the complexity and variety of climates are major problems of architectural and urban design. Considering buildings as standing objects, the urban design should be so intelligent to provide comfort both inside and outside through the whole cycle of the year; discovering this intelligence could be done through SOLARCHVISION [3]. The significance and complexity of optimizing the orientation and proportion of building masses at the scale of neighbourhood and city greatly increases when we take into consideration the comfort factor outdoors beside indoors. The comfort and discomfort inside a building have a direct effect on the building energy consumption and the energy costs paid by the occupants, while in outdoor spaces the problem is more related to the health and safety rather than energy and money. Thus, even though orientating long rows of building masses toward the South direction is a common idea to achieve maximum solar radiation in winters and to minimize summer gains, in most cases it results in developing uncomfortable areas between building blocks (i.e. paths and yards) where these parts will be in long-time shade in winters as well as long-time radiation in summers. Although these negative effects could be corrected by proper shades, reflectors, planting, etc., different and more enhanced optimizations would be gained from sound integration and distribution of indoor and outdoor spaces within the design as "*the state of art in architecture is to adjust both internal and external living spaces together and beside each other*." [4]

PROBLEM DEFINITION

"In regard to the sun and climate, what are the optimum orientation and form of buildings?" is one frequently asked question in the very first steps of architectural and urban design. However there are several answers to this question available right now; the main idea has not changed much from what Socrates told: "*Now in houses with a South aspect, the sun's rays penetrate into the porticos in winter, but in the summer the path of the sun is right over our heads and above the roof, so that there is shade. If, then, this is the best arrangement, we should build the South side loftier to get the winter sun and the North side lower to keep out the winter winds.*" [5]

But here we want to point toward the complexity of this problem from an integrated design approach as well as the urban point of view. First and most importantly the proper answering of such questions needs to consider the general passive or active strategy that an architect seeks. In an active strategy, form and orientation are designed so that the building facades receive more energy from the sun; while this energy is useful directly in cold times, also it can be used in cooling systems in hot times.

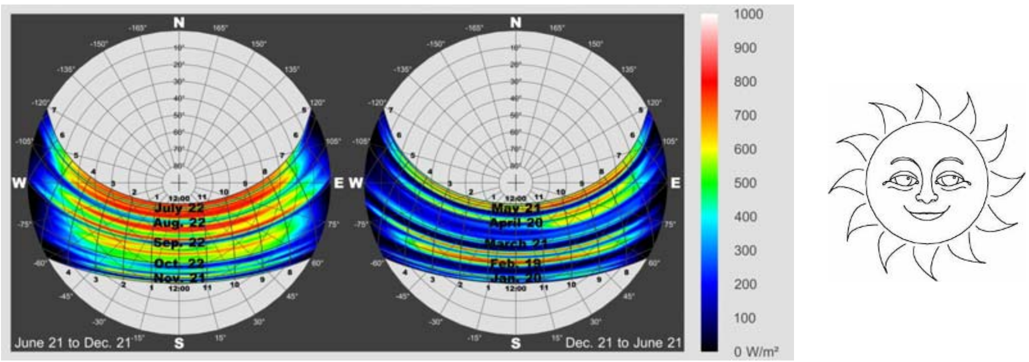


Fig. 1. Direct Radiation of Hashtgerd (5-day Normalization) - Data Source: [6]

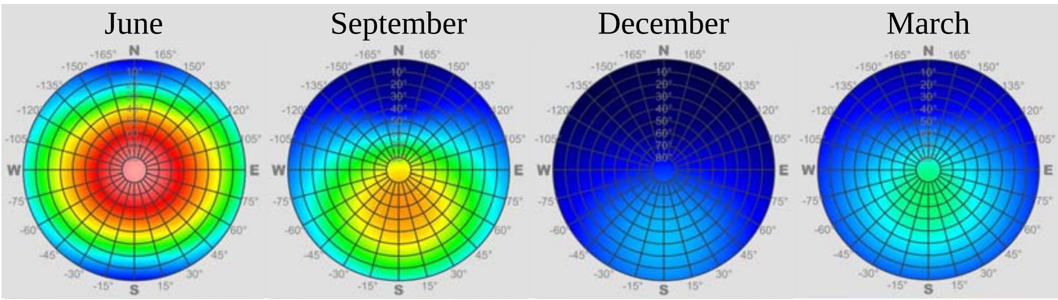


Fig. 2. Hashtgerd Monthly Global Solar Radiation on Different Directions and Solpes

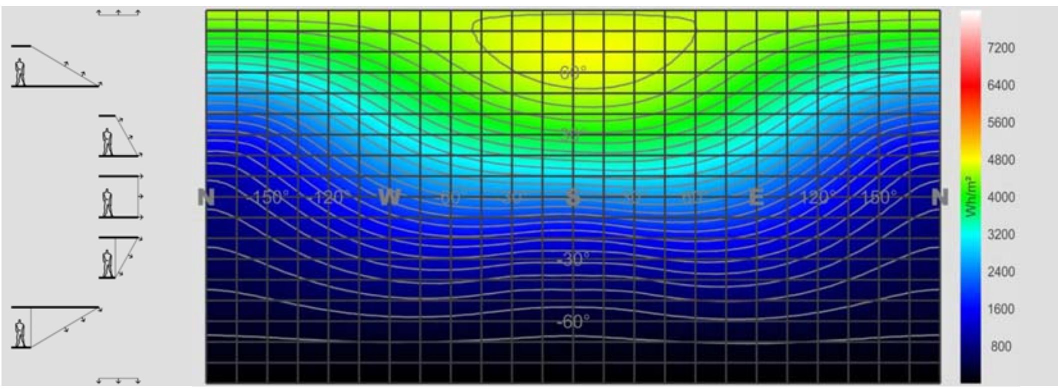


Fig. 3. Hashtgerd Year Cycle Global Solar Radiation of Different Directions and Slopes

Therefore, in an active strategy the sun would better be considered as a friend; and the best active orientation is the orientation which receives maximum total solar radiation. Taking the example of Hashtgerd (36 N, 50:40 E), a new town near Tehran, although the South direction is publicly considered as the direction which receives maximum solar radiation between different vertical surfaces, in optimizing a cubic building much more solar radiation could be gained by S.E., S.W., N.W. & N.E. directions instead of S., W., N. & E. directions. This is why the amount of solar radiation on the South facade is too low in summer (see diagram of June in Fig. 2).

On the other side in the passive strategy the situation is much more complex while relating to the low and high temperatures during the year "*the sun has two different faces.*" [7]

{Note: Colour representations of the images below can be found in the CD edition of the CISBAT 2011 Proceedings.}

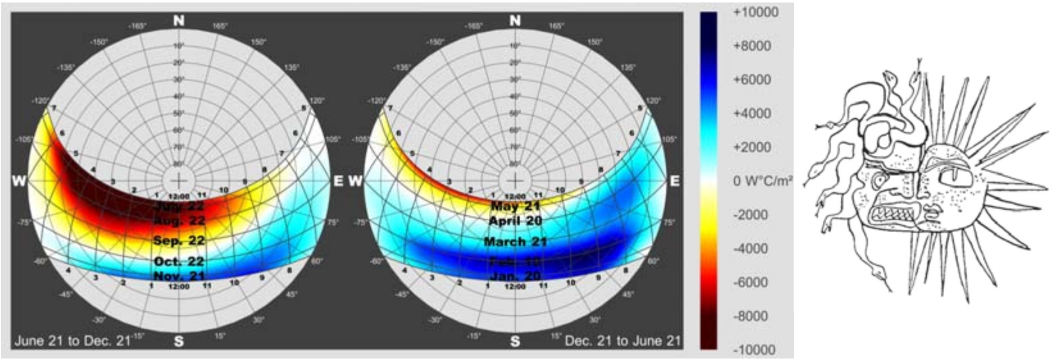


Fig. 4. Solar +/- Effects in Hashtgerd Calculated by SOLARCHVISION (30-day Normalization)

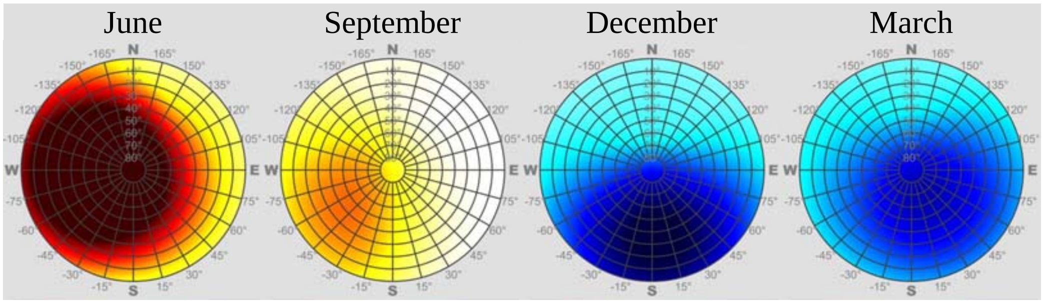


Fig. 5. Hashtgerd Monthly Global Solar +/- Effects on Different Directions and Solpes

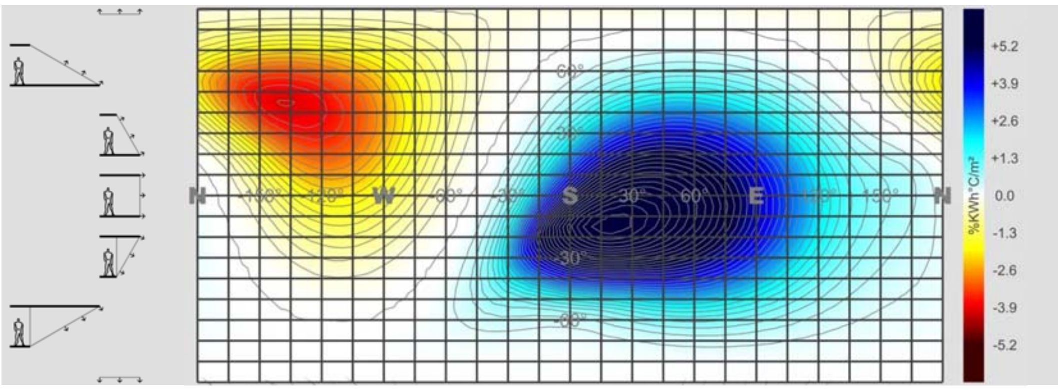


Fig. 6. Hashtgerd Year Cycle SOLARCHVISION Scores of Different Directions and Slopes

The figures above present monthly solar positive and negative effects on different directions and slopes in Hashtgerd using 20°C as the base comfort temperature. In 7 months of the year the positive effect of the sun has a remarkabe intensity maximized on tilted surfaces oriented between S.E. and S.W.; while in 5 other months of the year the negative effect of the sun is maximized between the horizontal plane (roof) and the Western direction. In these warm months the Eastern direction receives much lower negative solar effect in comparison with Western direction, however the amount of global solar radiation received by the Eastern side is equal to that of the Western side. The year cycle analysis in Fig. 6 illustrates most positive orientations of building facades between South and East inside ±30° slopes as the dark blue area. This table also shows the most negative orientations in Hashtgerd in a passive strategy about N.W. between slopes of 0° and +70°. These orientations receive considerable negative solar effects in summer, however in winter they receive almost no positive solar effect. So the red, orange and yellow negative areas contain the worst building facades which would better not be opened. On the other side, a proper decision must be taken for facades located in the middle areas as plotted in white colour, in regard to their different monthly and hourly situations, such as using static or interactive shading devices.

Two remarkable questions here are what will happen to the building envelope and what will happen to the urban fabric when building masses are oriented to these optimized orientations?

NEW GENERATION OFFICE BUILDING CASE STUDY

A new generation office building is planned within the German-Iranian Research Project "Young Cities - Developing Urban Energy Efficiency in Hashtgerd New Tow". Considering the main aims of this pilot project which are the reduction of energy consumption in comparison to existing office buildings in Iran and the improvement of internal thermal comfort predominantly by means of architectural design as the main source of saving energy, different simulations are used for studying the thermal behaviour of this office building. Besides regarding the importance of effects of the sun both indoor and outdoor spaces were studied and evaluated by SOLARCHVISION. [8]

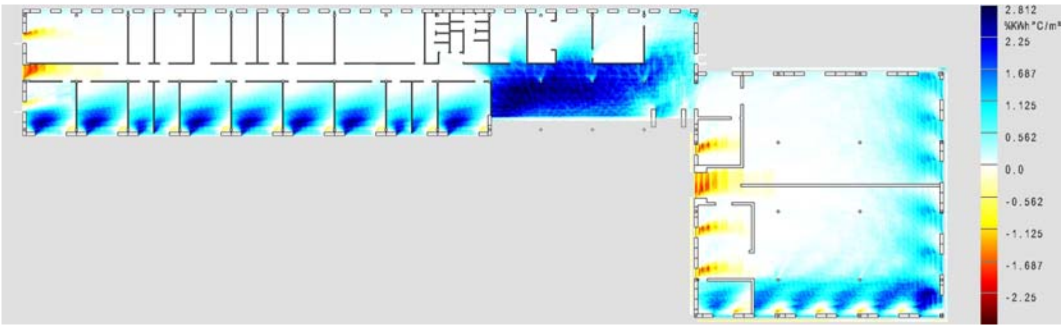


Fig. 7. Year Cycle SOLARCHVISION Analysis of Office Building Ground Floor Plan

The above diagram shows the year cycle SOLARCHVISION analysis of the 3D-model of this building in a case where all radiation is transmitted through windows and is blocked by walls. This model discovers the general capacity of different spaces of the building in receiving positive and negative solar effects. Using this data can help the architects to create better interior spaces or change the design of the building skin where required. This information also can help in design of the mechanical system of buildings.

A year cycle building skin study (Fig. 8 left) shows the positive performance of the building model which resulted from being sun exposed in the heating period and shaded in the cooling period. The positive performance of the designed South facade of the office building, which is almost in dark blue, i.e. with an optimised climate, can be compared with the light blue situation of simple South facades of the neighbourhood, who perform less well. On the other side, a study of the heating period (Fig. 8 middle) shows an undesirable performance of the pedestrain path on the North side of the building. Although these negative areas which are painted in red could be slightly corrected by use of two reflectors which were designed on the roof and the upper part of North facade of this building, major parts of this area will not be in a desirable situation during cooling period too (Fig. 8 right).

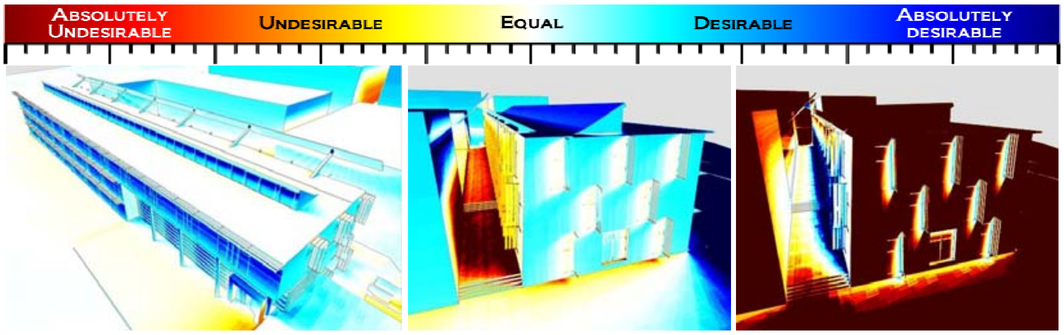


Fig. 8. Year Cycle Analysis of South side (Left), Heating Period (Middle) and Cooling Period (Right) Analysis of West side and North path

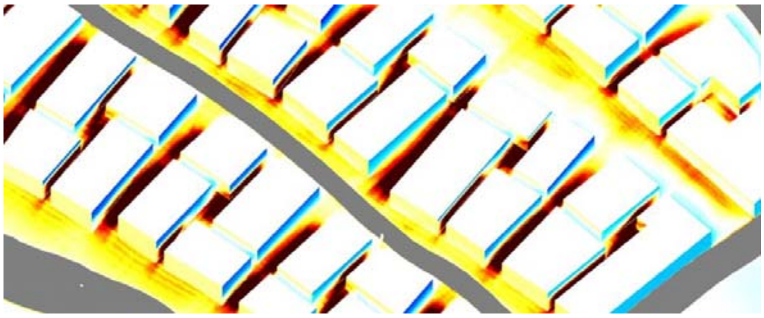


Fig. 9. Year Cycle Analysis of Proposed Urban Fabric of Hashtgerd New Town (S.W. View)

For the whole fabric (Fig. 9), however the comfort level at the undesirable points could be improved using trees and secondary structures, the proper orientation and form of the site should be considered as the main objective of solar-climatic design of such new urban fabrics, while several practical possibilities are available to improve the performance of each facade. The diagrams below of solar-climatic performances of different alternatives in Hashtgerd illustrate that by shaping building masses toward optimized orientation resulted from energy efficient point of view (which is almost between South and East), the comfort level of urban spaces between blocks decreases significantly.

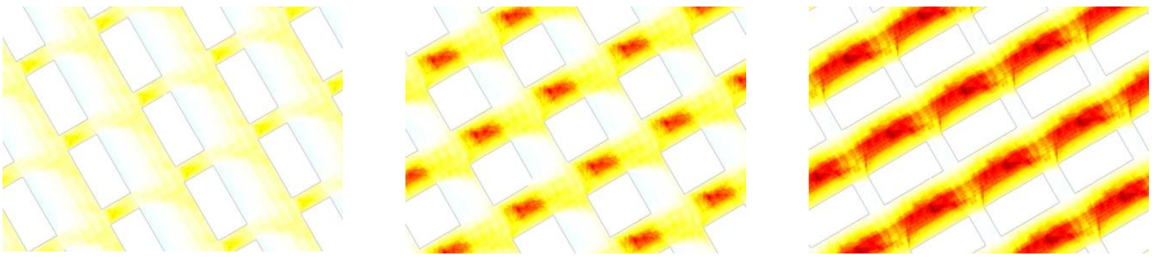


Fig 10. Year Cycle Outdoor Analysis of Different Alternatives of Urban Fabric in Hashtgerd

The next table also shows how the changes in proportion and direction of a cubic building can affect comfort conditions of the space around the building volume. In general, selecting the most proper alternative needs overlaying several layers (e.g. architectural, structural, construction, day lighting, etc.); but always some alternatives exist that create both internal and external proper conditions from the solar-climatic point of view. Taking the example of Hashtgerd, Proportion #2 with Orientation #2 can be suggested which has low negative effect on outdoor spaces and also creates three almost positive facades toward directions -15°, +75° and +165°. (see “Hashtgerd Year Cycle SOLARCHVISION Scores of Different Directions”)

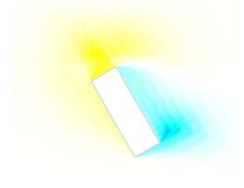
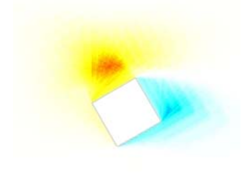
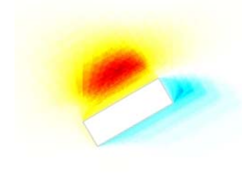
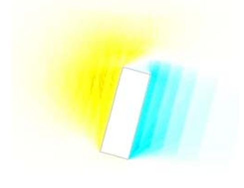
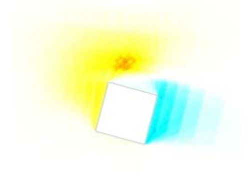
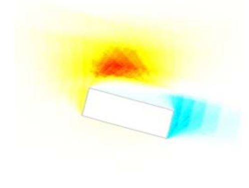
	Proportion #1 (½, 2, 1)	Proportion #2 (1, 1, 1)	Proportion #3 (2, ½, 1)
Orientation #1 (+30° or -60°)			
Orientation #2 (-15° or +75°)			

Fig. 11. Outdoor Analysis of Different Proportion and Orientation of a Cubic Building

CONCLUSION

To build more comfortable, safe and healthy living spaces of tomorrow, which should certainly also be energy saving, an integrated optimization is needed through the design process to improve the quality of indoor and outdoor areas together. As the optimization of a problem in limited dimensions may result in improper function of the other dimensions, a result of limited optimizations should not be generalized in several cases. Consequently, the key to solar-climatic optimizations in architecture and urban planning would result from analyzing all the considerable alternatives. From this point of view the most appropriate alternative is one which responds in an optimum way to all requirements by use of "less" (e.g. less cost, less weight, less material, less energy, etc.). This is why the main goals of SOLARCHVISION studies are: 1st, Producing basic design guidelines using the available data of different climates; 2nd, Evaluation of alternatives for urban fabric, building skin and interior spaces through design process from point of view of the sun and climate.

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TOWARDS ASSESSING THE ROBUSTNESS OF BUILDING SYSTEMS WITH POSITIVE ENERGY BALANCE – A CASE STUDY

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ABSTRACT

The paradigms in building design change. In the 90ies the focus was on minimising the consumption of fossil fuel. Nowadays the focus is on generating energy locally and using the smart grid for intelligent distribution.

The approaches have in common that they first aim at minimising the energy demand and using renewable energy sources. The energy demand is minimised by using passive design and efficient building services. Experience with low-energy housing shows that the more the impact of use pattern and external climate on the energy demand increases, the more efficient the services become.

To achieve a net-zero or positive annual energy balance, optimisation of the building services is needed. As the efficiency of the system under design conditions increases, it is expected that its flexibility to perform well under deviating conditions is reduced. The risk exists that although the building services work in a highly efficient way and the integrated performance was subject to design optimisation, a positive energy balance cannot be achieved.

In the presented paper the authors investigate the robustness of the final electric energy balance for a typical Swiss residential building. The robustness of the energy balance to use pattern and climate variation, namely the availability of solar irradiation, is quantified.

The starting point for the investigation is a refurbish code compliant building. The energy generation components are optimised to maximise their performance. After reviewing three optimisation tools GenOpt was used for the optimisation.

It was found that for the specific existing Swiss residential building the use of PV-panels alone does not enable offsetting the user induced demand for electric energy. The annual electric demand coverage varies between 48 and 88% due to use pattern and climate.

INTRODUCTION

Paradigm shift in building design and definition of plus-energy buildings.

The paradigms in building design change. Whereas the focus of the Trias Energetica [1] was on minimising the consumption of fossil fuel, the focus nowadays is on generating energy locally and using a smart grid for intelligent distribution [2].

There exist a great number of definitions for zero and definition plus energy houses [3, 4]. The authors make use of the definitions of the energie-cluster.ch [5]. The definition differentiates three types of system boundaries:

Type 1: Annual property-specific generated energy equals or exceeds its demand. The demand is defined as energy used for providing domestic hot water, space heating, ventilation as well as small power and electrical equipment.

Type 2: As type 1 but the demand additionally includes the embodied energy for the building over its life cycle.

Type 3: As type 2 but the demand also includes the energy required for user induced mobility.

The considerations of the paper do not go beyond the type 1 boundary. The presented work focuses on modelling and optimising supply profiles for residential buildings. The energy generation system is represented by high efficiency photovoltaic panels.

Robustness of integrated building systems (IBS)

Integrated building systems are exposed to a great variety of climate conditions and operational scenarios over their life time. Those conditions and scenarios are likely to deviate from the design conditions. The risk exists that although the building technology works in a highly efficient way, due to applied optimisation under design conditions, a positive energy balance cannot be achieved in building operation. In this context the robustness of an IBS is: "The ability to maintain defined performance requirements, even being exposed to conditions deviating from design conditions" [6]. The robustness of integrated building systems is of particular concern once the building concept was subjected to a performance optimisation process during design.

METHODS

For the purpose of estimating the impact of use pattern on the energy balance of IBS's a number of research methods were employed such as a literature and software review, prototyping, dynamic thermal system simulation and numeric optimisation.

Firstly, a *literature and software review* was carried out. The aim was to first identify the state-of-the-art in optimising IBS's to achieve a positive energy balance. The literature study focused on review articles targeting tools for the generic optimisation of virtual building models based on predefined cost functions.

Secondly the most suitable tool was selected and *prototypically* coupled to IDA ICE. For a representative Swiss residential building size, angle and orientation for a PV-Panel installation was optimized by parametric simulations.

Finally the robustness of the optimised panel installation was established and compared to realistically distributed electricity demands.

Literature and software review

The literature and software review was conducted for three tools GenOpt [7]. BEopt [8] and TopLight [9]. Nine criteria highlighting the three aspects (1) functionality, (2) application and (3) practice were used for the tool assessment, see Table 1.

BEopt is an optimisation tool which uses an automated sequential search technique to identify the building design option that best leads the path towards a zero net energy design. It accounts for costs as well as energy demand and is therefore particularly interesting to home owners.

GenOpt is a generic optimization program for minimising cost-functions, such as the energy demand of buildings, that specifically addressing the functionality of building performance simulation tools. It works platform independent and allows easy coupling via text files. The user can choose between different optimisation algorithms.

TopLight is a toolbox for parameter optimization. It was developed to implement, test and apply state of the art optimisation algorithms. The great variety of optimization algorithms can either be executed by batch commands or using a platform independent user interface.

Based on the review GenOpt was chosen for a case study application. GenOpt when compared to TopLight and BEopt provides a limited user interface and guidance for the coupling procedure. The advantage over BEopt is that the user can individually define the cost-function. However, it is less time consuming to run a quick optimisation calculation due to the user friendly modelling process in BEopt.

Pos.		**GenOpt**	**BEopt**	**TopLight**
	Application			
1	User interface	+	+++	+
2	Cost-function and parameter flexibility	+++	+ (Costs & energy)	+++
3	Target group	Simulation experts (Global)	Designer (North-America)	Software developer (Global)
	Functionality			
4	One or multiple objective optimisation	Single + Multi	Single + Multi	Single + Multi
5	Parametric simulation	++	+++	+
6	Algorithmic extendibility	++	+	+++
7	Potential for coupling with sim-tools	All with txt in- and output	eQuest, Trnsys, DOE2	All with txt in- and output
	Practice			
8	Open source	yes	yes	yes
9	Operating system	Java	Windows	Unix & Windows (Windows version is not maintained)

Table 1: GenOpt, BEopt & TopLight - Tool assessment.

The use of TopLight for the optimisation study would have been possible. The characters of GenOpt and TopLight are similar, still GenOpt is more attractive to use as it specifically addresses simulation experts and is easy to install and operate.

The coupling procedure requires the definition of the cost function – maximisation of the harvest from the PV panels, the definition of the parameters to optimise – length and width of PV panel area, panel inclination and orientation. The coupling of the two tools IDA ICE v4.0 and GenOpt works via four files the initialization.ini, command.txt, configuration.cfg and template.ida.

Robustness study

To address the impact of use pattern the final electrical energy demand was investigated. To assess the robustness of the system's energy balance it was necessary to firstly identify the electrical energy demand of the building system. Secondly the portion of the electrical energy demand, which directly results from user actions, was varied within realistic boundaries. In a third step the generated energy profile was compared to the demand profile.

The case study is based on a Swiss residential building built in 1980 and located in Zürich. The building is occupied by four people. It is equipped with a heat pump and under floor heating.

The use profiles for heating, domestic hot water and electricity correspond to the Swiss average, see [10, 11]. The resulting thermal and electrical demand distribution is indicated in Figure 1. The largest portion of the net-energy demand originates from the generation of the domestic hot water. As the net-energy demand for domestic hot water demand governs the energy balance it was used as variable representing the occupancy behaviour.

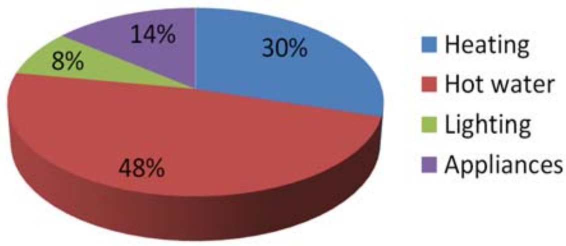

Figure 1: Distribution of residential net-energy demand.

	Optimal parameter settings
Area (m^2)	24
Orientation (deg.)	170
Inclination (deg.)	31

Table 2: Optimal parameter settings for PV-panel installation.

The locally generated energy originates from high performance photovoltaic panels, see Appendix 1. The panels are installed on one side of the double pitched roof. To ensure the highest possible harvest the design parameters for the panel installation were optimised. The parameters considered were area (length and width), orientation and panel inclination. Table 2 shows the optimal parameter settings for the PV-panels. To establish the demand coverage of the electrical energy demand by PV-panels the net-electric energy use was converted into final energy demand by taking into account a COP of 3.5 for the heat pump. First the representative daily profiles for September 22nd were compared.

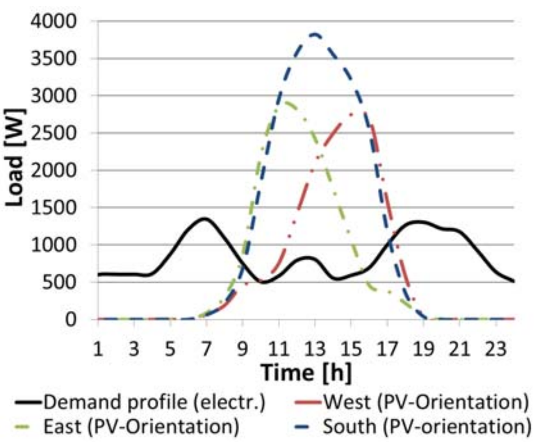

Figure 2: Final electrical demand and generation profiles for September 22nd.

	Electrical energy [kWh]		
Orient.	Generation	Demand	Coverage
East	16	21	76%
South	24	21	114%
West	16	21	76%

Table 3: Final electrical demand and generation for September 22nd.

As expected the final electrical energy profiles for generation and demand peak at different times of the day. For PV-panels orientated south, the generated energy peaks at a time where the demand is the lowest. It can be noticed that the time of the peak generation can be shifted two hours fore-or backwards if the PV-panels are orientated East or West, respectively.

However, the solar irradiance is not constant of the year. It varies with season, cloud cover and location. To assess the sensitivity of the generated electrical energy the PV-system performance was simulated for the Swiss locations Samedan and Buchs-Aarau. For assessing the sensitivity of the demand profile the domestic hot water use was varied from the base value 100l/p/d to 70l/p/d and 120l/p/d. The corresponding annual results are presented in Figure 3.

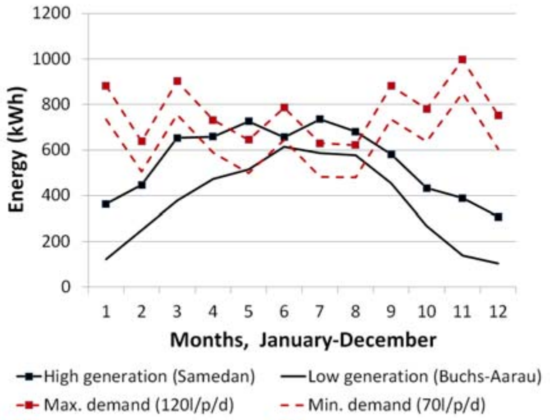

Figure 3: Annual electricity demand (70& 120l/p/d) and generation profiles (Samedan & Buchs-Aarau) as sensitivity indicators for the annual electric energy balance.

	Electrical energy [kWh]		
Scenario	Generation	Demand	Coverage
High gen./ low dem.	6630	7510	88%
Low gen./ High dem.	4480	9250	48%

Table 4: Final annual electrical demand generation & demand coverage.

Table 4 gives the annual demand coverage for two scenarios (1) high generation/ low demand and (2) low annual generation/ high demand. The demand coverage varies widely. The demand coverage for scenario 1 is 88% and for scenario 2 48%.

DISCUSSION

As expected, the simulations for a representative Swiss residential building confirmed, that the installation of roof mounted PV-panels alone does not result in a positive annual energy balance.

Considering the harvest for September 22nd it was found that the demand curve does not resemble the generation curve. However, the peak can be shifted approx. 2 hours fore- and backwards rotating the panels east or west, respectively. Still, rotation results in a reduction of the generated energy.

The annual simulations indicated that the demand for final electrical energy is highly sensitive to user behaviour and availability of solar irradiance. Two scenarios were considered, a best and worst case scenario. From the scenarios, it can be concluded that the demand coverage can vary widely. Whilst the best case scenario resulted in a demand coverage of 88% the worst case scenario only provides 48%.

CONCLUSION

There are a number of tools available for supporting designers optimising building and system concepts during design. From the three tools reviewed the authors conclude that GenOpt is best suited as it allows a great degree of freedom for defining cost-functions and building and system concepts. At the same time GenOpt provides an interface that eases the coupling with the tool for building performance simulation.

The daily demand and energy generation profiles indicate that the orientation of PV-panels could be a useful parameter, when targeting better matching demand and generation.

The study indicates clearly that building use pattern and availability of solar irradiance have a significant impact on achieving a net-zero or positive annual energy balance.

The optimisation study confirmed that achieving a positive energy balance requires reducing the demand. This can be achieved by the use of more efficient technical equipment, reduced energy losses through infiltration, ventilation and the building fabric.

The authors propose plus-energy renovations of the existing building stock being based on a minimum energetic standard for the building fabric. The amount of energy to be generated locally should be maximised using numeric system optimisation. The potential gap between demand and generation is to be closed by further reducing and steering the demand through smart appliances.

The authors suggest the robustness assessment to become an integral part of the planning process, to be able to quantify the risk of not being able to provide the required positive-energy balance.

ACKNOWLEDGEMENTS

The authors acknowledge the support by Craig Christensen and Michael Emmerich.

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APPENDIX 1 – PV PANEL PRODUCT INFORMATION

	Specification
Description	SunPower (R) 315
Conversion efficiency	19.3%
Watt/ module	96 cells/315W

Table 5: Sunpower product information [12]

TOWARDS MORE EFFECTIVE COMMUNICATION OF INTEGRATED SYSTEM PERFORMANCE DATA

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ABSTRACT

Enhancing well-being and productivity in buildings and reducing the energy demand are conflicting targets in building design. To find suitable design solutions, it is necessary to evaluate and communicate the impact of building system parameters on specific performance indicators.

The impact of integrated system parameters on performance indicators is complex and rarely linear. The question is: "Which parameter combination successfully maintains the user requirements now and under future conditions?". To address the question it is required to analyse time series data for system parameters, to recognise performance pattern and to diagnose potential performance failures. Performance data can either be obtained by dynamic thermal building simulation during design or by taking measurements during building operation.

The authors argue that traditional display formats such as tables and graphics are insufficient to communicate dynamic performance data as they are not adaptable to the user demands and do not allow analysing the interactive influence of the system parameters on the performance indicator.

As a first step towards more efficient communication of integrated building and system performance data three questions are addressed in this paper: (1) "Where are our capacity limits towards converting data to meaningful information as basis for decisions steering our interaction with the indoor environment?"; (2) "What innovative means of communicating performance data exist that can be adapted and expanded for the use in building design and operation?"; (3) "How to assess the potential of innovative data representations to support decision making?".

Based on a review of data representations it was concluded that the current form of the integrated performance view (IPV) provides a data density that is difficult to comprehend. The dynamics are only limited accounted for and the parameter impact cannot be assessed.

The review resulted in the identification of six aspects for assessing data representations: impression, understandibility, data conversion, visual language, interactivity and display conventions. The application of the aspects to carpet plots indicated a great potential communicating building and system performance data to both specialists and non-specialists. Still the representation needs to be extended to be able to allow an multi-parameter impact assessment.

INTRODUCTION

Different studies indicate a significant energy saving potential for buildings in operation [1-4]. The authors argue that by better energy management and building automation the saving potential can easily exceed 20% (see Table 1).

Source	Parameters	Range
Experts [4]	Final energy, building	20-40%
Building management [2]	Final energy, building (643)	13-60%
Statistical analysis [1,3]	Final energy, electricity CH	20%

Table 1: Energy saving potential for integrated building systems

To exploit the saving potential the performance of integrated building systems needs to be quantified. That can be achieved by either building performance simulation or by conducting measurements during system operation. In the due-course of the work the authors focus on results from building simulation tools. The resulting time series data sets are very complex and different in character. The data in its final form, needs post-processing for the: (1) recognition of performance pattern, (2) identification of performance faults, and (3) quantification of parameter impact on selected performance indicators.

For the data to provide meaning to the specific stakeholder it needs to be converted to information and subsequently to knowledge. The conversion process from data to information contains phases as (1) data collection, (2) analysis, (3) organisation and (4) representation. For the information to become knowledge the information needs to be contextualized before it can be applied [5].

METHOD

However, performance data from integrated building systems become very complex due to their dynamic character. The data analysis and organization is therefore a non-trivial task.

The work presented results from an incremental research approach. In a first step the human data processing capacity for decision making was reviewed. Secondly, shortcomings in data presentation originating from performance simulation are identified. Thirdly, assessment aspects for dynamic data representations are derived, accounting for the human processing capacity. Finally the assessment aspects are tested on an innovative data representation technique.

Human data processing capacity

To efficiently communicate performance data to stakeholders of integrated building systems it is necessary to be aware of their capacity to process information. The processing capacity depends on a number of variables such as profession, gender, age etc. However, the current work does not differentiate between the processing capacities relative to the stated variables.

Information theory makes use of the “bit” as unit of measurement. The bit expresses thereby the ability to distinguish differences. Information is defined as the logarithm of the number of microstates. Information processing can be simplified described using the model analogy input-model-output, whereby the input is governed by our sensory system consisting of eyes, ears, skin, taste and smell. The model, our brain, processes the data either consciously or unconsciously. The model output are thoughts eventually leading to actions.

The data input is extensive and can easily sum up to beyond 11mio bits/s, see Table 2. However the capacity to take in data consciously is much lower [6].

Sensory system	Total bandwith (Bits/s)	Conscious bandwith (Bits/s)
Eyes	10.000.000	40
Ears	100.000	30
Skin	1.000.000	5
Taste	1.000	1
Smell	100.000	1

Table 2: Information in-flow to sensory systems

The fact that humans' conscious data processing capacity is limited has a noticeable impact on how we take decisions. Dijksterhuis et. al. [7] identifies two reasons, why conscious thought might lead to poor judgement: (1) consciousness has a low capacity only taking into account a subset of relevant information and (2) suboptimal weighting of the attributes importance.

Dijksterhuis demonstrates the relationship of post-choice satisfaction to mode of thought and the number of aspects to be evaluated. The mode of thought thereby relates to conscious or unconscious thinking. His work concludes, that the post-choice satisfaction increases when unconsciously evaluating (deliberating without attention) products with increasing complexity see Figure 1.

Another source for results of psychophysical measurement is the work by Norretranders [6]. He reviews seven studies dated 1951-1955 aiming at quantifying the ability to distinguish for three sensory systems: eyes, ears and taste. The numbers lie between 2.1 and 7.0 Bits/Distinction (Bits/D), whereby an orchestra leader scored the highest distinguishing the musical pitch and dynamics with 5.5 and 7 Bits/D, respectively. Norretranders argues, “…the difficulty increases the more dimensions there are that describe states one has to distinguish between”.

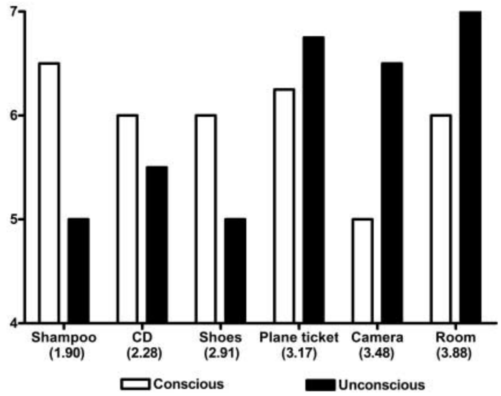

Figure 1: The relation between mode of thought and post-choice satisfaction (on a scale of 1 to 7) for six products most frequently. The more complex the product (on a scale of 1 to 5), the further to the right it is shown. The complexity score is given in parentheses [7].

There are few publications providing guidance for choosing the appropriate complexity of data representation. Although Dijksterhuis makes no explicit statements about how many product aspects define a high-complexity product, he differentiates in an example - choosing a desirable car - between low-complexity, 4 aspects, and higher-complexity, 12 aspects. Miller [8] argues from observations that we are capable of dealing with plus or minus seven stimuli for absolute judgement and span of immediate memory.

Reading data representations

To reduce the information we are exposed to, to an amount we can process, we apply precognitive visual triage. Precognitive visual triage is the reduction of the available visual information to portions the brain is able to process. It works without conscious mental effort and is an intuitive reaction to sensory stimuli or precognitive attributes. Common precognitive visual attributes are proximity, colour, size, orientation, direction, shape and shading [9]. Roam differentiates and evaluates eight visual attributes, see Table 3.

Pos.	Visual attributes	Description	Qualification
1	Proximity	Objects closer to each other are assumed to be related.	Good.
2	Colour	Differences are immediately noticed, groupings are assumed based on like-colouring	Good.
3	Size	Perception of differences assuming the outstanding is worth noticing.	Good.
4	Orientation	Distinction between horizontal and vertical.	Good.
5	Direction	Perceived movement can be picked up without conscious thought.	Good.
6	Shape	Differentiation between shapes.	Less good.
7	Shading	Detection of differences in shade as indication for up/ down or in/out.	Good.
8	Angles	Distinction between angled objects.	Less good.

Table 3: Visual attribute (adapted from [9])

Building performance data characteristics

Time series data as a result from building performance simulation can be very different in character. The data can be (1) continuous or discrete, (2) dependent or independent as well as (3) qualitative or quantitative. Prazeres [10] also differentiates between formats and attributes. The formats correspond to our perception and are related to our senses. Attributes refer to how the data is communicated. The named attributes are dynamicity, colour, type and interactivity.

With the purpose to better communicate the performance of integrated building systems the integrated performance view (IPV) was defined [11]. It extends the representation of individual building performance indicators to one screen, displaying a great number of performance indicators, see Appendix 1. The example for the IPV shows more than 10 performance indicators with different characters. The high density data display is complex and difficult to read, even for a performance specialist. However, the innovation of the IPV was not the communication of the performance data to the stakeholders, but to provide an instantaneous snap-shot of the integrated building and system performance. The example makes clear, that although the quality of a data representation is crucial for communication of its content, there is little knowledge available about how to evaluate innovative data representation formats.

Aspects for the assessment of state of the data representations

Aiming at the definition of assessment criteria for innovative data representation formats a review of data representations was undertaken. First, non-domain specific data representations and, second specific representation for communicating building performance data were reviewed. It was found that the domain specific representations merely use visual data displays.

From the review six aspects were identified, which contribute to defining the success of communicating the data to the recipient. The aspects are impression, understandability, conversion, visual language, interactivity and display conventions.

(1) Impression: Ability of the representation to catch the attention of the recipient. That includes compliance with domain specific conventions and standard.

(2) Understandability: Ability of the representation to communicate the data to the targeted stakeholder. Understandability strongly focuses on the anticipated function of the representation representative Graphic or decision aid. It also accounts for the degree of the self-explanation of the representation.

(3) Data conversion: Criteria for assessing the successful translation of the data to information and knowledge. That includes a thorough data analysis as well as placing the results into a context the recipient can relate too.

(4) Visual language: Relates to the intuitiveness of the representation to the user group and is differentiated into typography, graphical elements and colour use.

Typography: Relates to the use of typography to support communicating the inherent message. Does the use of typographic characters enhance or reduce the understandability. Typography is commonly used as text in legends.

Graphical elements: It ensures that the use of graphical elements (construction lines, arrows, etc.) is specific to the expectations of the target group.

Colour use: Colour is to be used specific for the subject, target group. Its use can be limited by the technical possibilities. Different target groups associate differently to colour. Colour can also be used as code for data representation, e.g. in legends.

(5) Interactivity: Relates to the possibility of the target user to manipulate the data representation to obtain feedback on different resolution levels, e.g. number of variables or temporal resolution)

(6) Display convention: Refers to consistency; e.g. use of the same standard for more representations; information density and necessary complexity relative to target group.

The aspects are exemplarily used for the assessment of the data representation technique, the carpet plot see Figure 1. For the data representation the perspectives of the design engineer (specialist) and non-specialist are considered.

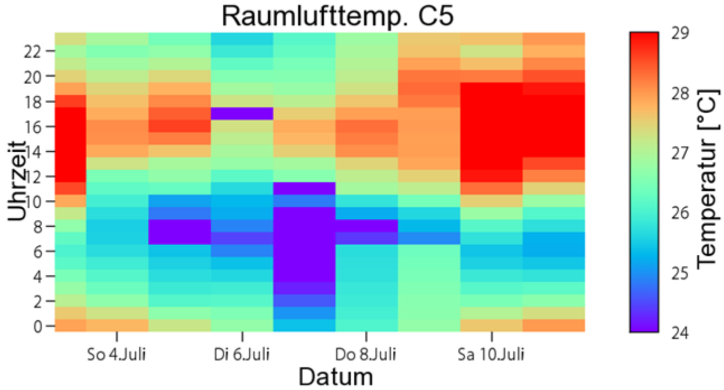

Figure 1: Carpet plot - The example shows the air temperatures for each hour of an eight-day period.

(1) Impression: The carpet plot is due to the extensive use of colour highly eye-catching. The arrangement, a two-axis coordinate system, corresponds to the format of frequently use two-dimensional line graphs. The carpet plot is limited to representing one variable.

(2) Understandability: The plotted variable "air temperature" is comprehendible for experts and non-experts. The chosen scale allows easy communication of the temperature range and extremes of hot and cool periods within the considered office space. Relationships between variables cannot be represented.

(3) Data conversion: The conversion from data to information works, due to the use of an intuitive colour scale: blue-cold, red-hot. The contextualization of the information is not supported as no reference is made to layout and use pattern of the office space.

(4) Visual language: The typography provides the only contextual reference. The readability is hindered due to the narrow placement of the axis-annotations and their different alignment. There are no further graphical elements apart from the colour code. Without colour code the representation is not readable. The colour code is defined based on commonly used association. Three base-colours are used red, green and blue. The colour specific spectrum is extensive. The information is qualitative. It is not possible to extract temperature values for one hour.

(5) Interactivity: The representation is not interactive. Interaction appears possible by layering representations for additional variables as CO_2 concentration and relative humidity.

(6) Display conventions: Consistency is provided; information density is high but comprehendible. The degree of abstraction can be reduced by contextualising the content specific for the target group by using images of, e.g., buildings, trees or people.

The exemplary application of the assessment aspects to the discussion of the carpet plot indicates that they have good potential to be used for the assessment of innovative data representations.

For the assessed carpet plot the following strength can be identified: (1) Intuitive - The carpet plots supports visual triage due to extensive use of colour and shading. It uses the association that red is hot and blue is cool. (2) It appears understandable to many stakeholder. Only one variable is plotted.

The following weaknesses were identified: (1) The interaction between variables cannot be represented in the carpet plots current form. (2) The information provided is qualitative. (3) Additional data is necessary to put the information into context.

CONCLUSION

The paper is based on the hypothesis that better performing buildings can be arrived at, if the industry succeeds in better communicating the dynamic performance of integrated building systems.

State of the art data representation techniques, such as the integrated performance view, are complex and create the risk to exceed our data processing capacity. That is why innovative data representation techniques need to match the capacity limits.

To evaluate innovative data representation techniques assessment aspects are needed specific for the targeted user groups. In the presented paper the authors propose six assessment aspects such as impression, understandibility, data conversion, visual language interactivity and display conventions. The application of the assessment aspects for testing carpet plots was demonstrated. It was possible to identify the strength such as: intuitive to read and good understandibility for different stakeholders. The following weaknesses were identified: variable interaction cannot be represented, qualitative information representation and need for additional data for contextualisation.

FUTURE WORK

It is expected that the assessment aspects are not equally important for assessing innovative data representations. Therefore, it is anticipated that the weight will vary according to the selected target group: non-specialist and specialist. That means the applicability of the aspects has to be tested on more data representation formats and user groups.

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Appendix 1

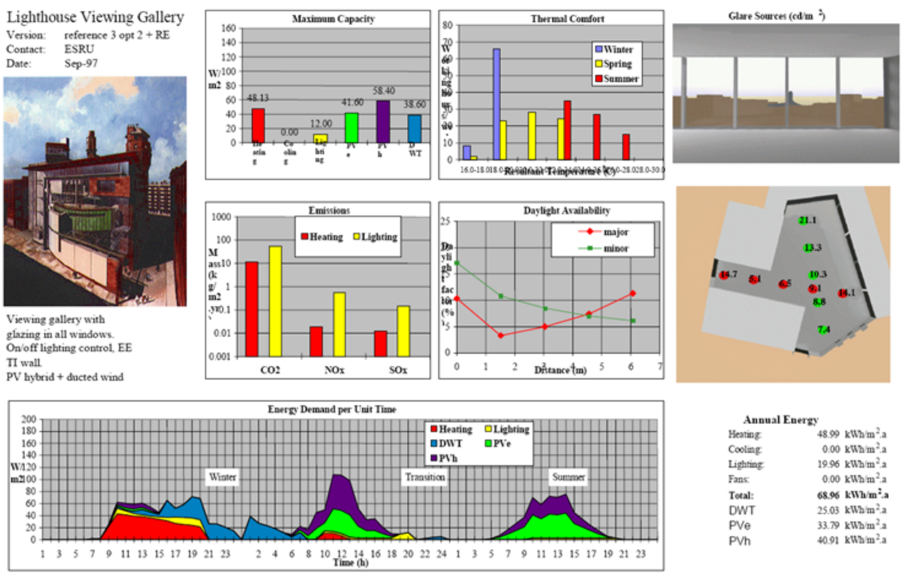

Figure 2: Integrated performance view – Example for the Lighthouse Viewing Gallery [11].

Information Technologies and Software

TOOLS AND METHODS USED BY ARCHITECTS FOR SOLAR DESIGN: RESULTS OF AN INTERNATIONAL SURVEY IN 14 COUNTRIES

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ABSTRACT

An international web-based survey was carried out as part of IEA-SHC Task 41 – Solar Energy and Architecture. This paper presents the results of the survey for Subtask B, which focused on tools and methods used by architects for solar design. A total of 627 responses from 14 countries were received, but only 350 were fully analyzed in detail. Building professionals were contacted by email and asked to fill out a web-based questionnaire about their use of methods and tools for solar design and related themes, such as barriers for the use of tools or their design process. In addition, general data concerning the architectural firm (size, type of buildings) and personal facts (age, experience and profession) were collected. The response rate was lower than expected; nevertheless, the results point out that there is a high awareness of the importance of solar energy use in buildings, but that a number of barriers still exist regarding the widespread application of digital tools during the design process. The survey confirms results of former investigations by other researchers presented in a literature review in the second official report of Subtask B, which shows that architects are lacking digital tools for solar design specifically adequate for the early design phase (EDP). The identification of opportunities and obstacles, and requirements expressed by professionals and suggestions for improvements will help formulate the next step of the Subtask B work plan, which will consist in the development of guidelines for both professionals and software tool developers in order to encourage and accelerate the development of solar energy in building projects.

INTRODUCTION

In the context of Subtasks A and B of IEA-SHC Task 41 – Solar Energy and Architecture, an international survey was carried out which was separated in two parts. The Subtask-A survey concerned the integration of solar energy systems in architecture, while the Subtask-B survey was about the adequacy of existing tools and methods for solar design, with emphasis on the early design phase (EDP). This article presents only the results of the Subtask-B survey, which are discussed in detail in the final IEA report [1].

The objectives of the Subtask-B survey were:

1. To identify barriers of existing digital tools and design methods for solar design;
2. To identify the needs of architects for better or improved tools and methods.

The results of the survey will be used to develop guidelines for software developers and architects, which will be completed during the last year (2011-2012) of the Subtask B work plan.

METHOD

The survey was designed by the international expert team involved in Task 41 and then programmed into Questionform, an online survey creator developed by Forweb software (Portugal). Then, in each participating country, one national coordinator involved in Task 41 was appointed for distributing the survey. The coordinators used a variety of methods to reach practitioners: by publishing links for surveys through national associations of architects, through professional newsletters and magazines, through custom mailing lists developed from yellow pages or the like. This variety of survey distribution methods made it difficult to know the response rate precisely. A total of 627 responses were received from 14 countries (Australia, Austria, Belgium, Canada, Denmark, France, Germany, Italy, Korea, Norway, Portugal, Spain, Sweden, and Switzerland). Of these 627 surveys, 350 were considered in the analysis. Many surveys were not analysed because they contained only one or two completed answers, since many respondents abandoned the survey very rapidly. Although the precise response rate was difficult to calculate due to differing distribution methods in every country, a rate of 6% was roughly estimated. This is a rather low response rate, which may reflect the limitations of distributing the survey, lack of time for answering or a general low interest for solar design issues in some countries.

RESULTS

1. Respondents' profile

The majority of respondents worked for small or medium sized firms (1-10 employees) mostly active nationally. The respondents' work encompassed a wide variety of projects and building types, with residential buildings being the most common type. Sixty-seven percent (67%) of respondents indicated that they used a 'Conventional project delivery method', with 'Design-Build contracts' and 'Construction Management' being the second most common methods used. The majority of respondents were born between 1960 and 1979. Sixty-six percent (66%) of the respondents were males, and most of the respondents were architects or designers, with a few engineers and other professions also represented. The majority (74%) of respondents had more than 10 years of experience.

2. Interest for solar energy

Eighty-two percent (82%) of the respondents answered that solar energy aspects were important in their current architectural practice (Fig. 1).

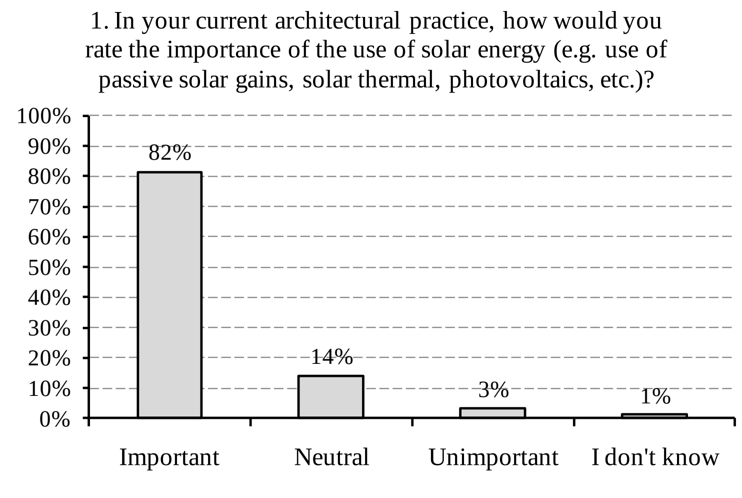

Figure 1: Distribution of answers for question 1 about importance of solar aspects in current architectural practice, for all countries (n=346, four respondents did not answer this question).

The most common solar design strategy used was 'Daylight utilization', with 74% answering that this was always or often included in their projects. 'Passive solar for heating' was the second most common strategy, with 57% of respondents always or often including this solar design strategy in their projects. Forty-seven percent (47%) always or often included 'Solar thermal for hot water use', while 'Photovoltaics' and 'Solar thermal for heating' were less common (see Fig. 2). The least common solar strategy was 'Solar thermal for cooling', which was used always or often by only 7% of respondents, see Fig. 2.

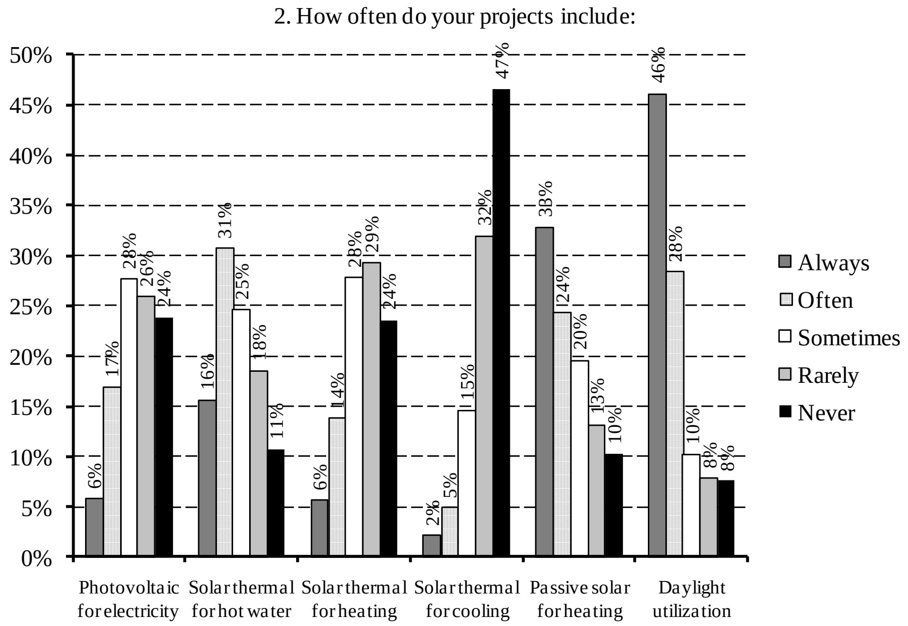

Figure 2: Distribution of answers for question 2 about the use of solar energy systems, for all countries (n=325 to 342).

3. Methods for solar design

The survey questions on methods focused on the design process as well as the decision making process. The results indicated that respondents used a variety of design processes: 33% answered that the 'Integrated design process (IDP)' corresponded best to their own practice, with the remainder split between 'Intuitive design process' (25%), 'Participatory design' (21%) and 'Energy-oriented design' (18%). Sixty-nine percent (69%) of the respondents stated that solar energy technologies were first considered in the conceptual phase, underlining the need for well-developed conceptual design tools. Most respondents said they base their design processes upon experiences, interaction with the project owner and by collaboration with others.

Responses concerning decision making in small projects indicated that the conceptual phase was largely handled by the architect alone (53%). Specialists were more likely to be involved in later design phases, and multidisciplinary workshops played a fairly small role with a 6-10% response rate depending on design phase. On the other hand, concerning decision making in large projects, 32% of respondents stated that this phase was handled solely by the architect. External solar energy consultants and building science specialists were relatively common in the later phases of large projects. Multidisciplinary workshops also played a more important role than in smaller projects (10-12% depending on project phase).

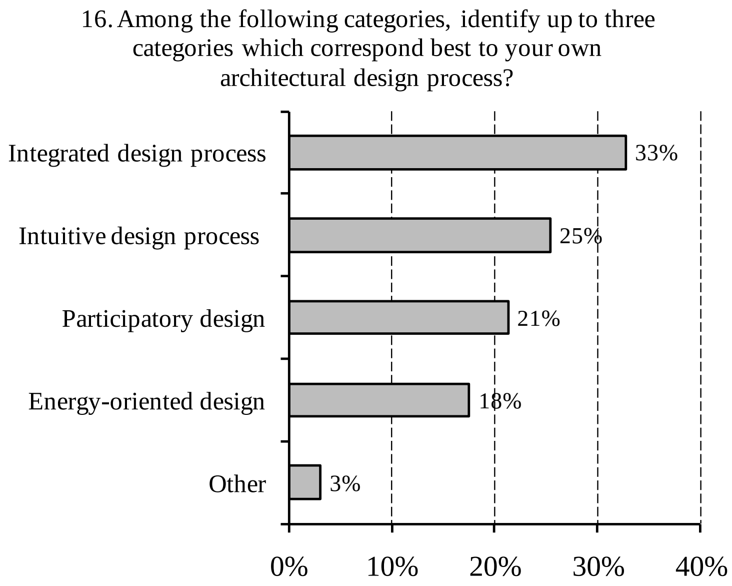

Figure 3: Distribution of answers for multiple-choice question 16 about the architectural design process (n=587, some respondents selected more than one design process).

4. Tools for solar design

The majority of respondents described their skills with graphical solar design methods as fair (37%) or poor (20%). With regards to solar design tools in CAAD and advanced simulation tools, the majority answered that they considered their skills to be poor (30% and 27% respectively) or very poor (31% and 41% respectively). However, most respondents described their skills with CAAD software -an integral part of architects' practice- as advanced (28%) or fair (27%).

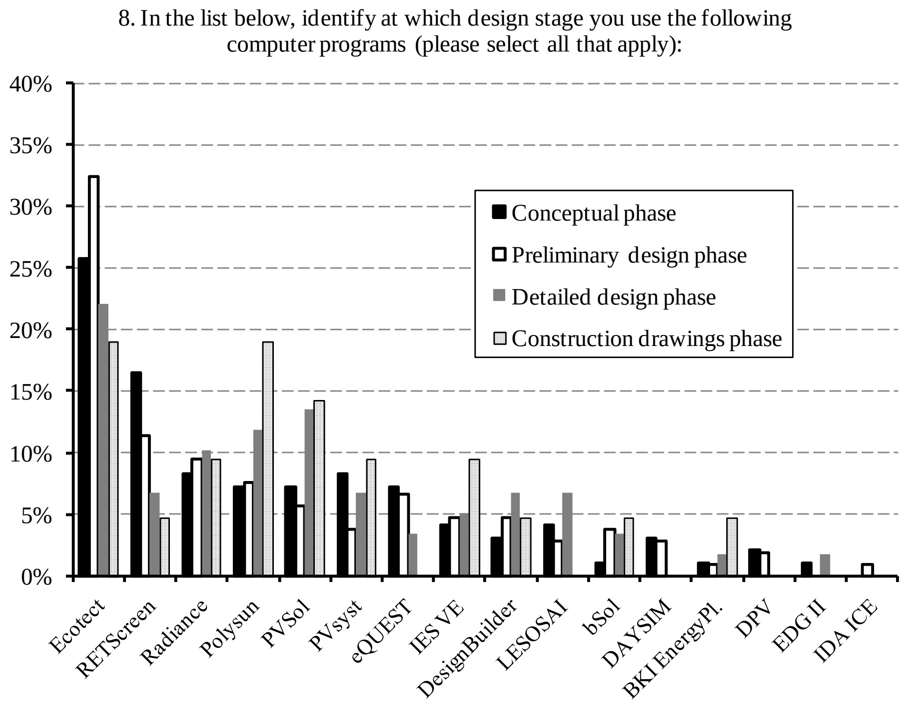

Figure 4: Distribution of answers for question 8 about simulation software used per design phase, for all countries (n=282).

A question about the design stage where various software tools were used returned a number of results. The most commonly used CAAD tools were AutoCAD, Google SketchUp, Revit Architecture, ArchiCAD, Vectorworks and 3dsMax. The most common visualization tools were Artlantis, V-Ray, RenderWorks and Maxwell Render, while Ecotect, RETScreen, Radiance, Polysun, PVSol, PVsyst were the most common tools for simulation (Fig. 4).

The most common CAAD, visualization and simulation tools were all used in all project phases, but the relevance of different tools for different phases is well reflected in the responses. CAAD tools prioritising a simple user interface and rapid modelling (e.g. Google SketchUp) were used extensively in the EDP, while more complex tools (e.g. Revit Architecture, AutoCAD) were more common in the later project phases.

A similar trend is visible concerning simulation software, with some products being preferred in the EDP (e.g. Ecotect, RETScreen) and others used more heavily in later stages (e.g. Polysun, PVSol). The most common visualization software programs were used fairly evenly across the design phases. The factor that most influenced the respondents’ choice of software was a user-friendly interface (27%). The next most common factors were costs (20%), interoperability with other software (18%) and simulation capacity (13%). Quality of output (images), 3d interfaces, availability of plug-ins and availability of scripting features were considered to be less important.

5. Satisfaction and barriers with tools

Respondents reported varying degrees of satisfaction with their chosen software programs (CAAD, visualization and simulation tools) in terms of support for solar building design. For many programs, the response rate was so low that it was not possible to formulate meaningful conclusions.

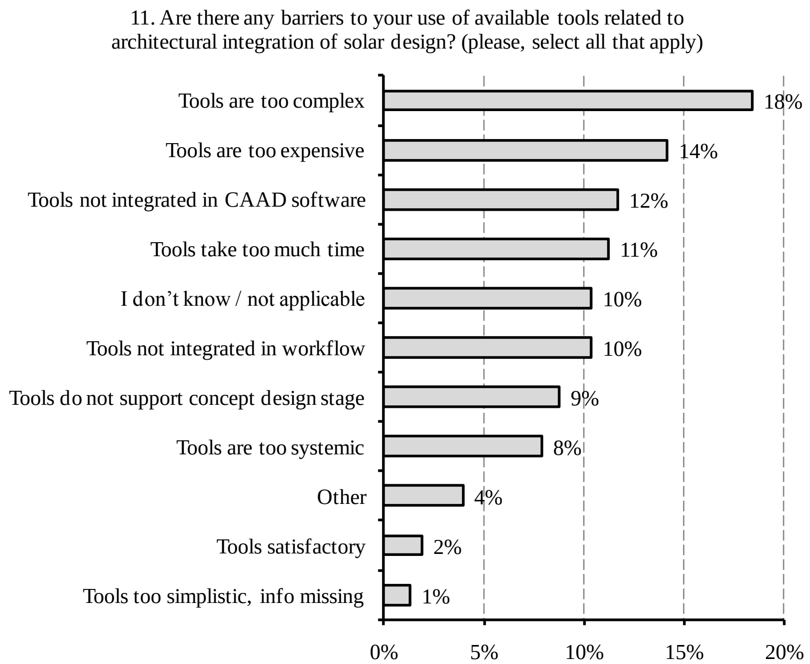

Figure 5: Distribution of answers for question 11 about barriers related to the use of tools for the architectural integration of solar design (n=685).

The most common barriers reported by respondents were ‘Tools are too complex’ (18%, see Fig. 5). Other common barriers were ‘Tools are too expensive’ (14%), ‘Tools are not integrated in CAAD software' (12%) and 'Tools take too much time' (11%). Respondents also stated that the tools do not adequately support conceptual design (9%), that they are too systemic (8%) and that they are not integrated in normal workflow (10%). Only 2% reported to be satisfied with the existing tools.

6. Improvements needed

Respondents were then asked about the need for improved tools in each design phase. In the conceptual phase, 28% answered they would like to have improved tools for visualization, followed by preliminary sizing (20%) and tools that provide explicit feedback (18%). In the preliminary design phase, the most common request was improved tools for preliminary sizing (26%), followed by tools for key data and explicit feedback (22% and 20% respectively). For the detailed design phase, most respondents requested improved tools for key data (28%), followed by preliminary sizing (18%), explicit feedback and visualization (both 16%). The most common response for the construction drawings phase was 'I don't know/ not applicable' (29%). However, 21% also wished improved tools for key data, 16% for preliminary sizing, and 10% for tools that provide explicit feedback.

CONCLUSION

The literature review and survey results both strongly indicate the need for further development of software tools for solar architecture, focusing on a user-friendly, visual tool that is easily interoperable between different modelling software packages, and which generates clear and meaningful results. There is a need for tools to be easily compatible with the existing work flow of the architect. Also, since each design phase has its own requirements and specifications, software tools should be able to adapt to specific design phases.

The survey also indicated a strong awareness about solar aspects among respondents. However, this was combined with a limited use of solar energy technologies, suggesting the need for further skill development and tools to support the development and use of these technologies in buildings. The survey has resulted in a number of concrete suggestions about the needs of practitioners.

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VOLUMETRIC INSOLATION ANALYSIS

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ABSTRACT

Due to the growing world population and the global urbanisation phenomenon, the creation of sustainable living and working spaces in cities is one of the main challenges for architects and urban planners. Insolation is one of the most important climate variables for human comfort and for the employment of emission-free, energy-efficient technologies in buildings. A better understanding of insolation and its heterogeneous distribution in the urban space would help to identify the site-specific solar potentials. Once identified, such potentials could be included in the design process supporting architectural and urban concepts that consider insolation as a site-specific, local resource. This research work introduces a new analytic method for the quantification and representation of direct insolation which we call *Volumetric Insolation Analysis* (VIA). Insolation is traditionally computed for surfaces. VIA expands this concept into the volume, in our case the unoccupied volume of a selected building site in an urban context. The principle of VIA consists in discretizing the volume of a site into a grid of points, tracing for each of these points a set of sunrays, and verifying if the sunrays reach the points or are obstructed by an obstacle. This paper presents the methodological steps of the technique followed by a 3D and a 4D example of VIA. The proposed methodology introduces novelties by combining the following aspects:

- analysis of direct insolation of a volume
- representation of directional results through 3D and 4D vector-fields
- accurate consideration of the influence of topography, vegetation and built environment

Through VIA it is possible to describe the non-homogeneous distribution of direct insolation in the unoccupied space of a building site. The aim is to allow the identification of specific locations, orientations and tilts that allow an optimal exploitation of the local solar potentials. The ability to represent this kind of data volumetrically allows an in-depth understanding of insolation as a spatial phenomenon. Through this new awareness, the spatial qualities of the site can be transferred into architectural solutions for an optimal position, orientation and shape of a building and building elements such as openings. In addition, this information can be used to layout and integrate means of active and passive solar energy uses, for example for daylighting, passive solar gains and building technologies such as photovoltaic cells or thermal collectors.

INTRODUCTION

The common approach in using solar energy for active and passive purposes is to maximize the incident solar radiation on a given surface. The global radiation is composed of the direct, diffuse and reflected components. The direct component, arriving directly from the sun, often represents the major part of the global radiation, and is the only one with a clearly definable direction. For simple applications the position, orientation and tilt of a collecting surface are therefore often optimised towards the direct component of solar radiation. The maximal irradiation is obtained when the surface is normal to the incident sunrays, so that the direct radiation component and the circumsolar-diffuse component are best exploited. Collecting surfaces are therefore usually positioned in non-shaded locations at a mean orientation and tilt, possibly including angular shifts due for example to higher heat demands in winter or to higher electricity demands during certain hours of the day. This work aims to expand the understanding of insolation into a volume by examining the direct component of solar radiation and its non-homogeneous distribution in the unoccupied space of urban building sites as partially experimented by Marsh [1]. The objective is to allow the identification of ideal positions and directions that allow an optimal exploitation of the local solar potentials considering the site-specific context of topography, vegetation and buildings.

This approach proposes a radical shift compared to other research work in the field. Instead of evaluating the performance of a proposed architectural design and improving it through iterative processes [2, 3], attempting to identify optimal architectural and urban forms trough analytic and comparative studies [4, 5, 6], or developing rules that try, often in controversial manners, to ensure solar access to every plot [7]; we

propose to first start by evaluating the solar potentials of the unoccupied volume of a site. Once identified, these potentials can be used to derive suggestions for an architectural or urban design concept that encloses the local solar specificities.
The steps of the proposed methodology (Figure 1) include the modelling of the site and its proximity, the generation of a set of sunrays, and the calculation of their irradiance values. Successively, an intersection test verifies if the rays are reaching the site and, for positive cases, adds their values to the insolation values of the point. These values are then exported and evaluated in a custom visualisation framework.

```
Import site parameters
Import obstacles and transform them into a mesh of triangles
Create points subdividing the site volume with chosen space step
Create rays over the chosen time period with the chosen time step
For each point
   For each ray
      For each triangle
         Test ray-triangle intersection
         If the ray is reaching the point add ray values to point
Save and Visualize results
```

Figure 1: pseudo-code for the methodology

METHODOLOGY

Modeling of site and proximity

Several parameters have to be taken in consideration in order to perform the analysis: the Sun path at the site (influenced by location, day of the year, and time of the day), the geographical situation (local altitude and climate type), the surrounding environment (topography, buildings and vegetation), and the volume of the site itself. In a first step, a three-dimensional model of the site topography and the volumes of the built environment is established by importing measured terrain elevation points and building geometries. The topography and the buildings are then subdivided into a series of triangles to allow a faster treatment during the analysis process. In a second step, the empty volume of the site itself is discretized into an orthogonal three-dimensional grid of points at each of which the total amount of insolation will be computed. In order to calculate the insolation, a set of sunrays according to the Sun path has to be generated.

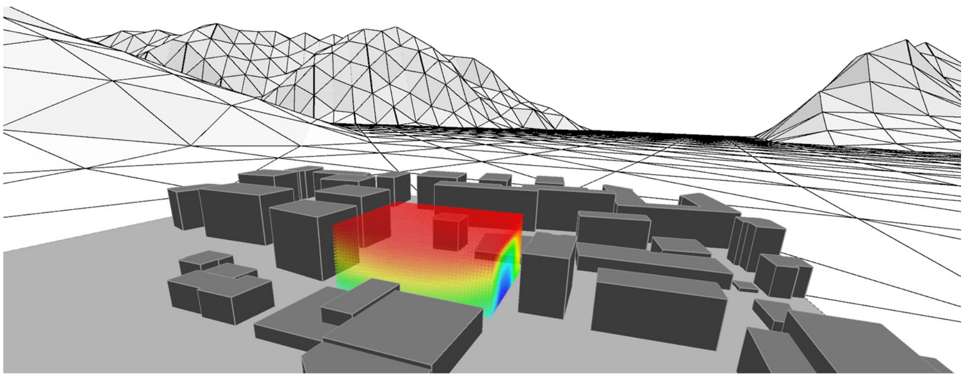


Figure 2: volume points, buildings and mountains

Generation of rays

The direction of the Sun can be calculated according to the zenith angle θ_z, the angle between the vertical and the line to the Sun, and the azimuth angle γ_s, the horizontal angle between the South and the vertical projection of the Sun. These two angles are defined by the latitude of the site φ, the declination angle δ, and the hour angle ω. The declination, the angle between the plane of the equator and the line Earth-Sun, is derived from the day of year n. The hour angle, the angle through which the Earth would turn to bring the meridian of the observer directly under the Sun, is derived from the solar time. The solar time, the time based on the rotation of the Earth with respect to the Sun, is calculated by applying two corrections to the local time of the site. The first is a constant correction related to the local time zone and local longitude, the second is a correction related to the obliquity of the ecliptic and to the elliptical orbit of the Earth. More details on these calculations are described by Duffie and Beckman [8].

$$\theta_z = \cos^{-1}(\cos\varphi\cos\delta\cos\omega + \sin\varphi\sin\delta) \tag{1}$$

$$\gamma_s = sign(\omega)\left|\cos^{-1}\left(\frac{\cos\theta_z\sin\varphi - \sin\delta}{\sin\theta_z\cos\varphi}\right)\right| \tag{2}$$

A first verification discards the rays obstructed by the Earth by checking if the hour angle is in-between the sunrise and sunset angles. The zenith and azimuth angles are used to generate a normalized directional vector ($\overrightarrow{dir}$) that points in the direction of the Sun. Finally a set of rays are generated and stored for a time period and a time step defined by the user (e.g. over an entire day a ray will be generated each 5 minutes).

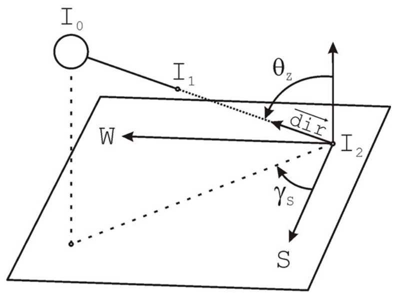


Figure 3: rays direction and irradiances

Calculation of direct irradiance

Each of the generated rays will have a different irradiance (power incident on a surface) firstly, due to the current Sun-Earth distance at the specific moment and secondly, because of the different mass of air to be crossed in the atmosphere inducing more or less losses. The solar constant ($I_0 = 1367\ W/m^2$) is the irradiance received outside of the atmosphere at the mean Earth-Sun distance. To estimate the current extra-terrestrial irradiance (I_1) the variable Earth-Sun distance according to the elliptic orbit of the Earth has to be taken in consideration [8].

$$I_1 = I_0 \left(1 + 0.033 \cos \frac{360\, n}{365}\right) \tag{3}$$

The direct irradiance at the Earth surface can be calculated by applying a transmittance reduction factor (τ) to the extra-terrestrial radiation taking into account the atmospheric losses. The reduction of solar radiation by the atmosphere is influenced by different meteorological effects such as scattering and absorption. The intensity of these effects depend on the air mass the ray has to cross and on the geographical location of the site. The air mass is the ratio of the mass of the atmosphere through which the radiation passes to the mass it would pass through if the Sun would be at the zenith. It can be calculated using the zenith angle ($am = 1/\cos\theta_z$). The resulting clear-sky direct normal irradiance (I_2) can be estimated through the method introduced by Hottel [9] that allows the calculation of the atmospheric transmittance through clear atmospheres. The transmittance equation factors (a_0, a_1, k) depend on the altitude of the site and on the local climate type. It should be noted that cloudiness is not considered and that the variation of the solar constant due to the solar cycles is neglected.

$$I_2 = \tau\, I_1 \tag{4}$$

$$\tau = a_0 + a_1\, e^{(-k/\cos\theta_z)} \tag{5}$$

These calculations allow to dispose of a set of rays, knowing their direction ($\overrightarrow{dir}$) and irradiance (I_2).

Intersection test

The core principle of the analysis consists of verifying for each point of the grid whether the sunrays are reaching the point or are blocked by an obstacle. The number of intersection tests to be performed, resulting from the multiplication of the number of points, rays and triangles, can be considerably large. In terms of computational cost, this intersection test is the most demanding step of the simulation. Therefore a fast minimum-storage ray-triangle intersection algorithm is used [10]. If it is verified that the current ray meets the current point of the volume without being obstructed, the following pre-computed values are retrieved for each ray:

- its direct insolation time (T) in seconds (the time step at which the ray has been generated)
- its direct insolation energy in J/m^2 (given by its irradiance I_2 multiplied by the time step)
- its direction as a normalized 3D vector ($\overrightarrow{dir}$)

The total insolation time and insolation energy can be computed for each point of the grid by adding up the values of the related rays. The total values are computed and stored by both scalar (eq. 6-7) and vectorial (eq. 8-9) addition.

$$T_s = \textstyle\sum_i\ T_i \qquad\qquad I_s = \sum_i\ T_i I_{2i} \tag{6-7}$$

$$\overrightarrow{T_v} = \textstyle\sum_i\ T_i\, \overrightarrow{dir_i} \qquad\qquad \overrightarrow{I_v} = \sum_i\ (T_i I_{2i})\, \overrightarrow{dir_i} \tag{8-9}$$

In this set of results the scalar values (T_s and I_s) represent the total amount of insolation arriving at that point independently from the directions of the radiations and the vectorial values ($\vec{T_v}$ and $\vec{I_v}$) represent the mean direction of insolation at the specific point obtained through weighted vectorial addition. The value $|\vec{I_v}|$ of a point corresponds to the insolation energy of a surface at the conditions that the surface is perpendicular to $\vec{I_v}$ and that all the rays are reaching the surface on its front face. It is important to remark that using the direction of $\vec{I_v}$ to optimally orient collecting surfaces is a simplification that is not appropriate for every site and for every need. To accurately identify the optimal direction more detailed techniques have to be used. The calculated insolation values of each ray should be memorized to analyse insolation as function of the two angles θ_z and γ_s. In a situation without obstructions this insolation function will present a centred maximum around the direction given by an γ_s equal to 0° (180° in the southern hemisphere) and a θ_z equal to the local latitude, this maximum will correspond to the mean direction calculated by the weighted vectorial addition. In urban contexts, and especially in high-rise areas, the situation is different. Due to the discontinuity of the obstacles around the site the insolation function could present several local maxima and minima, and, depending on the goals, the use of the resulting mean direction could be inappropriate. In these cases the optimal direction could be identified through computational optimisation techniques considering possibly also time- and season-related constraints of the goals.

Visualization of results

Performing these calculations for each point of the grid and mapping the sets of results to the volume of the building site will generate a multidimensional multivariate (mdmv) scalar/vectorial dataset. This 3d4v dataset represents the insolation within a volume in terms of both time and energy values and their mean directions over the considered period of time. Alternatively, the calculation, the addition and the storage of the values can also be done independently for a set of time frames (e.g. every hour of a day). The generated results will consequently result in a 4d4v dataset representing the evolution of insolation over the overall time period. The results can be exported and visualized by importing them into a custom visualisation framework in which the data can be evaluated. The framework allows the display of the heterogeneity of these usually invisible spatial properties through different visualization elements such as point clouds, voxel grids or vector fields. A graphical user interface allows the user to interact with the data through different operations such as color gradients, slicing, thresholding and others. In addition, for 4D datasets, the evolution of the values can be visualized over the chosen time period.

EXAMPLES OF SIMULATION

In this section we present two different VIA examples. Both examples are based on the same plot in the city of Lugano, Switzerland (latitude 46°00'33.95"N, longitude 8°57'42.28"E, altitude 280masl). The volume of the plot (49x40x23m) is subdivided with a step of 1m into an orthogonal grid of 45’080 points. The following results have been generated by applying 3D and 4D VIA.

3D yearly VIA

A 3D VIA is performed for a period of one year. The rays are generated every five days of the year and every five minutes of each day. The resulting minimal and maximal insolation values of the points are:

T_s : 1’788 – 3’713 h/y $\qquad$ I_s : 4’576 – 8’628 MJ/m²/y

$|\vec{T_v}|$: 1’505 – 2’442 h/y $\qquad$ $|\vec{I_v}|$: 3’922 – 6’103 MJ/m²/y

The order of magnitude of insolation values obtained with these calculations corresponds to the value of the unobstructed yearly clear-sky direct normal radiation of 10’789 MJ/m²/y given for Lugano by *Meteonorm* [11]. Observing the values ranges, for example of T_s, it is interesting to remark how at certain points of the volume the sun shines less than 50% of the time than at others.

4D daily VIA

A 4D VIA is performed for an overall period of 1 day (the 20th of March). The data is computed, stored and visualized independently for sub-periods of one hour. The rays are generated every minute of each hour. The resulting minimal and maximal insolation values of the points are:

T_s : 0 – 60 min/h $\qquad$ I_s : 0 – 2.91 MJ/m²/h

$|\vec{T_v}|$: 0 – 59.7 min/h $\qquad$ $|\vec{I_v}|$: 0 – 2.84 MJ/m²/h

3D VIA - visualization of the yearly I_v

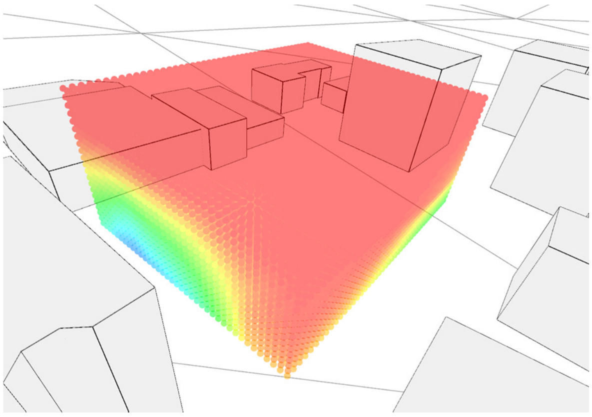


Figure 4: volumetric scalar field as point cloud

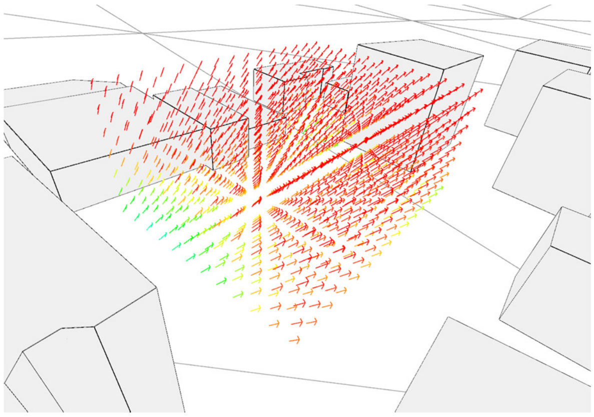


Figure 5: volumetric vector field

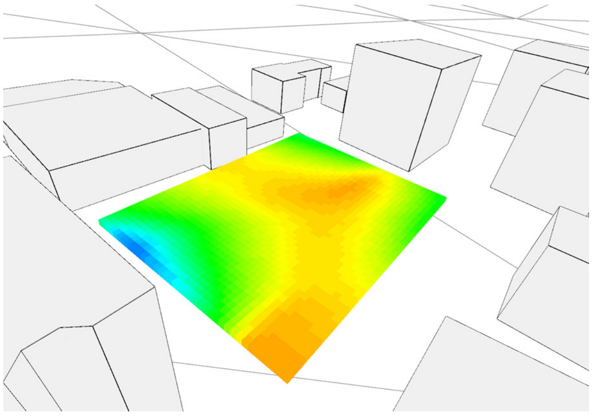


Figure 6: horizontal slice of a voxel grid

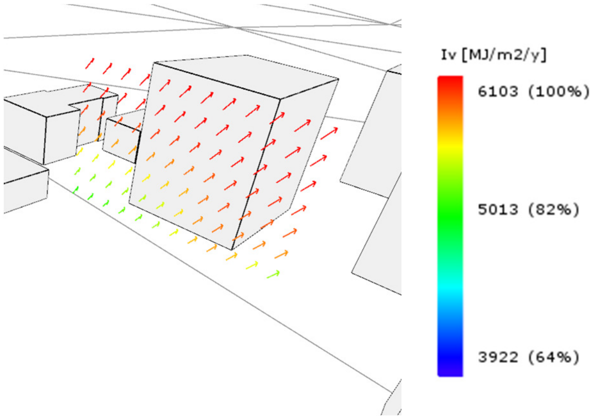


Figure 7: vertical slice of a vector field and legend

4D VIA - visualization of the hourly I_v at three different times of a day

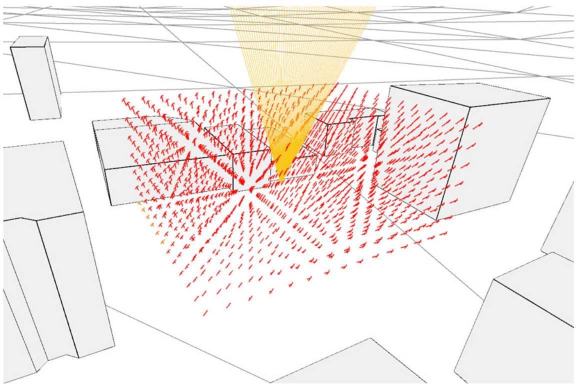


Figure 8: insolation from 12:00 to 13:00

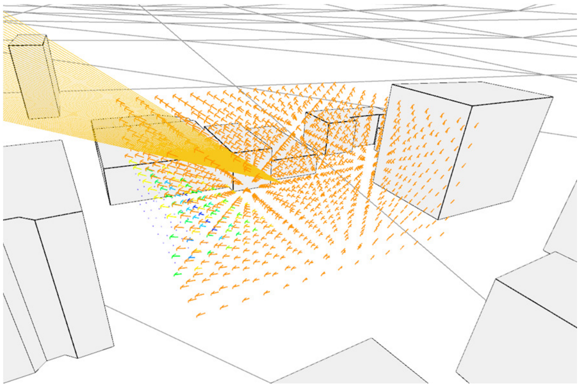


Figure 9: insolation from 14:00 to 15:00

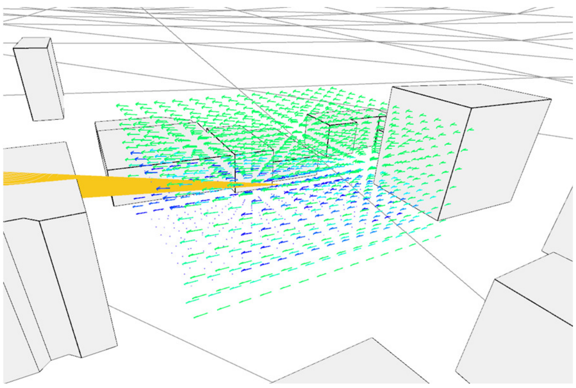
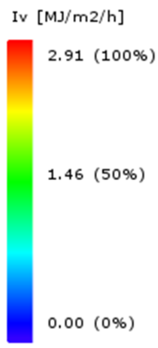


Figure 10: insolation from 16:00 to 17:00

In the 4D visualisation mode it is possible to scroll through the different time frames of the simulation. To facilitate the interpretation of the VIA results, the set of sunrays that have been used to generate the currently visible frame can be visualized together with the insolation values.

For colour representation please see CD-ROM version of CISBAT 2011 Proceedings



CONCLUSION

This paper introduces the concept for a new solar analysis technique we call *Volumetric Insolation Analysis* (VIA). At the current stage of development this technique allows to estimate the total values of direct insolation time and energy and their mean directions in the volume of the site. VIA allows the analysis of direct insolation considering the influence of topography, vegetation and surrounding buildings. One of the features of this concept is the ability to represent the solar radiation information in the same dimensions and modelling environments that architects are used to work with. The resulting values can be represented through 3D and 4D scalar and vector fields and evaluated in an interactive visualisation framework. These results describe the non-homogeneous distribution of direct insolation in a site allowing an intuitive understanding of the site-specific solar potentials. The focus of the current development of VIA is to analyse the direct component of insolation and its relative distribution in the space-time of the site in order to derive how the solar resource could be optimally exploited. This technique will have to be further developed and applied in case-studies. For this first experiment a streamlined approach has been used for the estimation of insolation. This methodology cold be optimized implementing existing and more accurate solar radiation models that include the diffuse and reflected components possibly using a lighting simulation engine such as *Radiance* [12]. The potentials of the presented method have only been briefly explored but the preliminary results are promising. The ability to compute, map and visualize direct insolation of a building site volume offers a better understanding of the local solar potentials. Additional synthesis methodologies for the transfer of the simulation results into site-specific architectural and urban solution concepts have to be developed. These include for example the position, orientation and shape of the building and its components, and the distribution of its spatial programme. VIA allows also to evaluate the use of solar energy through active or passive means. Examples are the use of passive solar radiation gains, an enhanced use of daylighting, and the optimal positioning of photovoltaic panels and thermal collectors. Beside a potential reduction of the energy use and the generation of energy by using a renewable emission-free energy source, the improved access to natural lighting would also have positive effects on the comfort of the occupants.

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A PROCEDURAL MODELING APPROACH FOR AUTOMATIC GENERATION OF LOD BUILDING MODELS

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ABSTRACT

In this paper we propose a procedural-based modeling system for building generation that can be automatically structured into different levels of detail (LoD). Starting from a ruleset-based model, the user can decide the level of specification to represent the model. This specification is described through a semantic combination using tags associated with the rules. As a result, we can obtain multiple representations of the same building model, each one having the appropriate accuracy for the required analysis task, in a flexible and automatic way. By giving meaning to the architectural element structures we allow the possibility to export the model to a standard format, as for example City Geography Markup Language (CityGML), appropriately designed to unify urban models at different levels of detail.

INTRODUCTION

Virtual 3D city models are currently used for sophisticated analysis tasks in different application domains like simulations, visualization, urban data mining and thematic inquiries. Targeted applications include a wide range of areas including urban and landscape planning, architectural design, tourist and leisure activities, 3D cadasters, environmental simulations, mobile telecommunications, disaster management, and vehicle and pedestrian navigation. In many of these areas robust 3D urban model representations are a big challenge since various levels of detail and different abstractions are required for each particular application. Another difficulty is the amount of geometry data to deal with; city models are huge (of the order of billions of polygons) and manually modeling them is a tedious and complicated task.

One promising approach for the efficient low-cost creation of detailed building models is procedural modeling, where rules and parameters are used to generate new content algorithmically [1]. In this approach, large-scale city models as well as very detailed building models can be quickly created using procedural techniques, and time-consuming modeling task are avoided. However, for simulation processing tasks, where only a simplification of the urban model may be enough, the amount of geometry generated could be excessive. The automatic control of model complexity and simplification to improve procedural tools is a current research topic [2].

In this paper a new system tool to generate buildings that can automatically obtain different levels of detail is proposed based on a procedural modeling approach. From a ruleset-based generated model, the user can decide different levels of specification to represent the model. This specification is described through a semantic combination using tags associated with the rules. In this way, multiple representations of the same building can be generated, each one having the appropriate accuracy for a given analysis task, in a flexible and automatic way.

RELATED WORK

Specific works on level of detail for building models can be found in different contexts. For cartographic generalization, Anders [3] proposed an approach for the aggregation of linearly arranged building groups. Other works focus on the building model simplification by collapsing faces from known constructive structures as walls and roofs, like Rau et al. [4] did. Another kind of LoD proposals comes from the use of a semantically well-defined dataset structure, as for example the CityGML schema [5]. CityGML differentiates between five consecutive LoD-levels, where objects become more detailed with increasing LoD regarding both geometry and thematic functionality differentiation. They range from a coarsest level in LOD0, which is essentially a 2½ dimensional digital terrain, to full interior structures like rooms, stairs, and furniture at the top level LOD5. These different LoDs often result from independent data collection, processes, and allow efficient visualization and data analysis. Frequently these models come from GIS database or they are converted from BIM models. Generating such kind of models from a single 3D model is in general a complex task [6]. The model must be obtained with consistency between the different levels of detail where geometric elements are shared, that is, a geometric element of one level must become a part of the geometry in the adjacent level. We propose a new approach for generating level of detail models where using semantic labels to specify structures, in a way such that all levels could be obtained in a single process.

Parish and Müller [7] presented an initial proposal intended for city generation using procedural modeling based on the L-system recursive nature. Automatic LoD-generation is obtained by starting from the building envelope as axiom, and the output of each rule iteration represents a refining step in the building generation. Although it is simple and automatic, this approach does not provide control on geometric building details. Our method is based on grammar procedural modeling for building generation, introduced in the seminal work of Müller et al [1]. A very well known engine that works on this paradigm is the CityEngine system [8]. Using such tool, LoD can be added manually in the grammar-rules by using a switch-case scheme for controlling the insertion of geometry. In this case, defined attributes are associated with different geometry resolution levels, and used to specify whether an asset must be inserted at full geometry, with a reduced version or as a texture. But this representation is hard-coded for the whole building model; that is, the simplified geometry is set manually in the ruleset specification. We propose an automatic system that produces level of detail representations automatically from semantic criteria

PROCEDURAL MODELLING OF BUILDINGS

Müller et al. [1] introduced Grammar-based procedural modeling for building. The main concept of a shape grammar is based on a rulebase: starting from an initial axiom shape (e.g. a building outline), rules are iteratively applied, replacing shapes with other shapes. A rule has a labeled shape on the left hand side, called predecessor, and one or multiple shapes and commands on the right hand side, called successor:

PredecessorShape → Successor

The main commands, the macros that create new shapes in the classic approach [1] are: *Subdivision* (*Subdiv*) that performs a subdivision of the current shape into multiple shapes, *Repeat* that performs a repeated subdivision of one shape multiple times, *Component split* (*Comp*) that creates new components shapes (faces or edges) from initial volumes, and the *Insert* command that replaces a pre-made asset on a current predecessor. The whole production process can be seen as a graph where each node represents an operation applied to its incoming geometry stream and the leaf nodes are the geometry assets. This representation results in a Directed Acyclic Graph (DAG), where nodes represent rules and links the stream of geometry [9, 10].

Figure 1 shows a procedural building model designed using a visual graph-based rule system. By describing a building structure through a ruleset we can obtain a compact representation with geometric details in a simple modeling task process. The main potential of shape grammars lies in the variations they can produce, as each created instance of a building could look different by changing parameters of the rules.

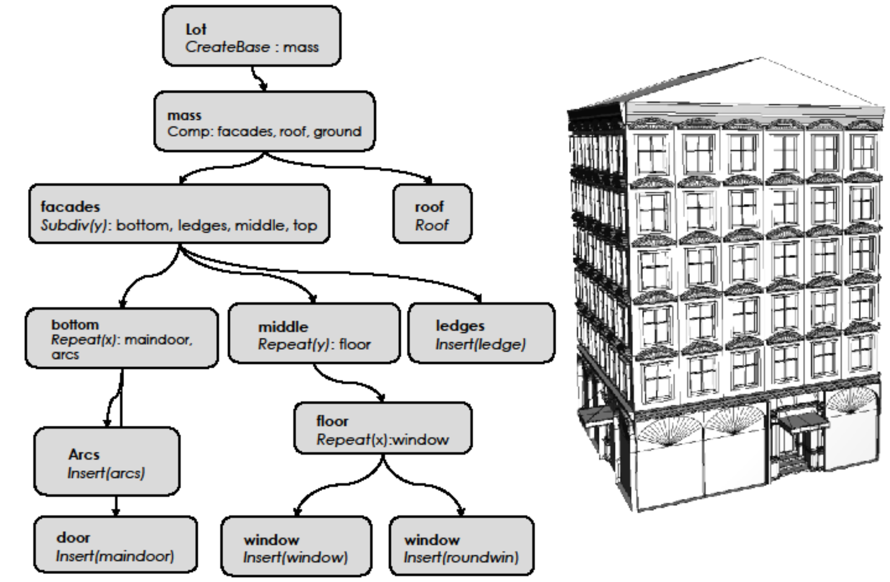

Figure 1: An example of a procedural model of a building. From the envelope mass of the building, facades are selected and described with rules according to the common window and door patterns. Subdivision and Repeat command are used to describe these patterns, and assets geometry are finally inserted to complete the model.

In order to obtain specific levels of detail for the generated model, where constructive elements are already defined in each level, we need a flexible way to instantiate all generated products of the model. We based our system on a graph-based approach including semantics of all generated products as in [10]. A similar approach is proposed in [11] for their semantic instance locator. Using such an approach, semantic tags are attached to all product results of each rule. For the example used in Figure 1, a *facade* semantic tag will be produced from the component split, and semantic tags *bottom, middle, ledge* and *top* will be produced from the *Subdiv* command. We keep track of all tag labels used in any derived geometry. Therefore, the products produced by the *Repeat* rule with *middle* predecessor in Figure 1 will also have its own tag and will maintain both the *facade* and *middle* tags of the predecessors. See Figure 2. As a consequence, it is possible to identify the presence of a specific product at any level in the hierarchy. We apply this feature in our system to identify building structures that accomplish a required tag combination.

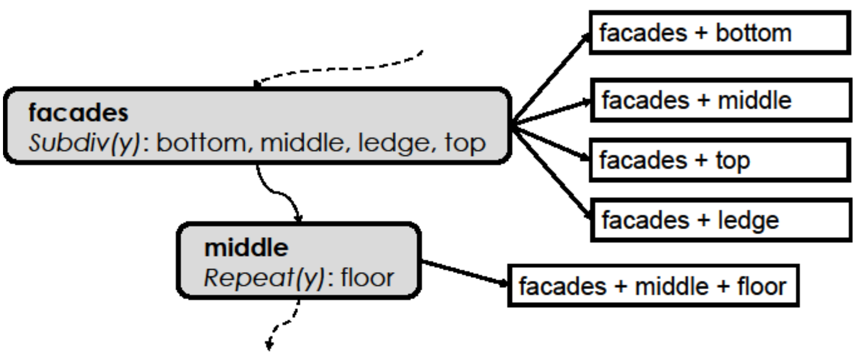

Figure 2: Tag labels for the building model of the example of Figure 1. In this example, the rule Subdiv generates four products and a set of label combinations is generated with the predecessor labels. In this way, all derived products of a rule are present in the hierarchy.

OVERVIEW OF THE LOD SYSTEM

The main goal of our system is to provide model designers with a flexible procedural generation method that allows the use of level of detail to adequate the model to the required analysis needs. Given a set of specific interesting shapes, we base our approach on a graph transformation process of the original representation. Our system workflow is described in the Figure 3. First, a procedural building model is generated using semantically enriched rules as in Figure 1. Semantic tags represent the architectural structure meaning of the model parts. In the following step, levels of detail are described through semantic combinations that are specified using a user-selection interface. The user can build any valid combination, as well as use previously stored combinations. Then, the system automatically processes the model for the specification, transforming the graph and generating the geometric representations. The final model can be exported separately in a 3D geometric format (OBJ or DXF) or in a multilevel format as CityGML, as shown in Figure 4 (Top)

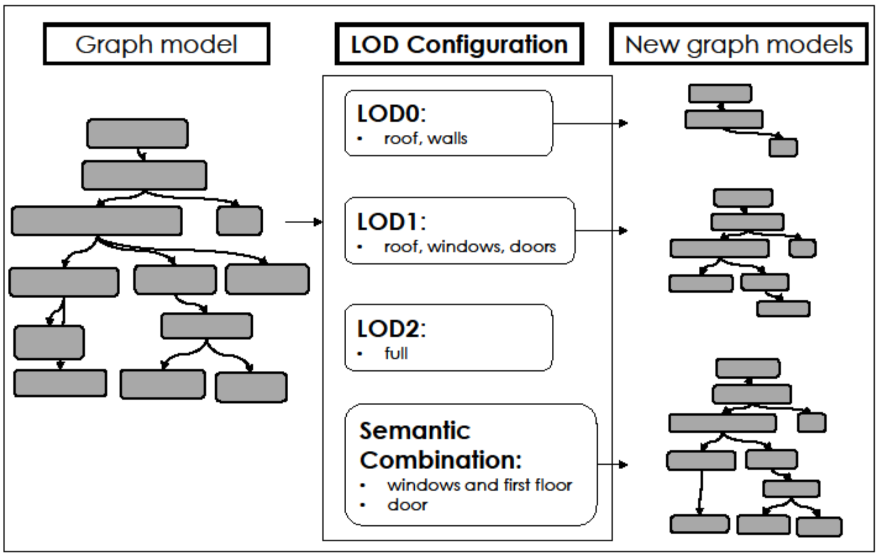

Figure 3: Workflow system. From a semantic ruleset model the user configures LoD descriptions using tag labels. An automatic process generates the new graph models representations.

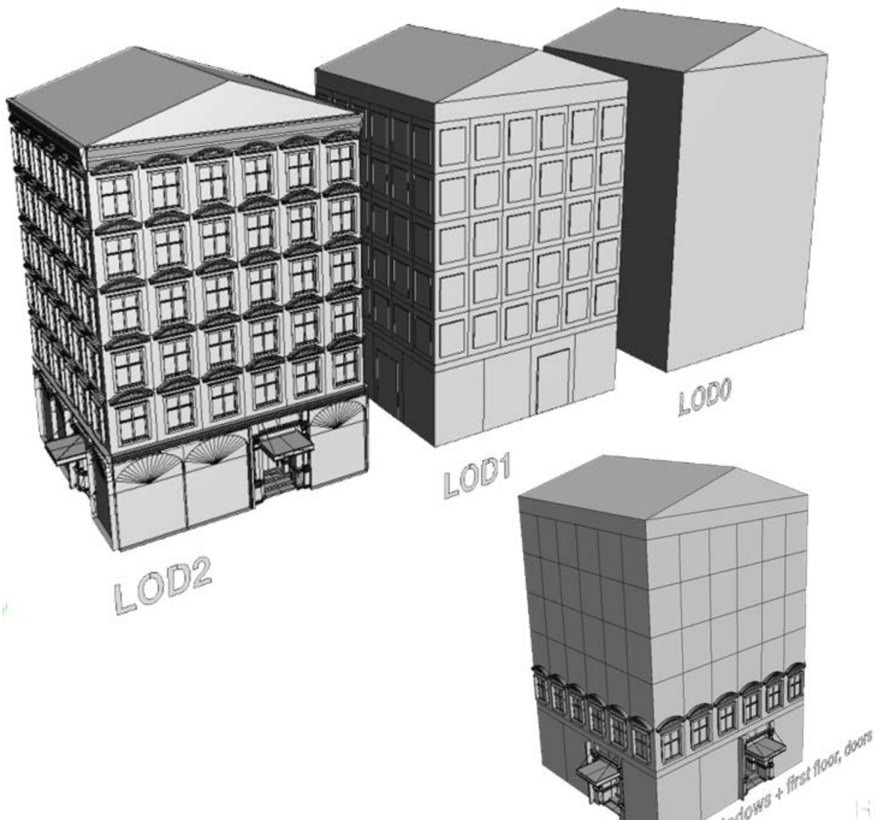

Figure 4: Top: Geometric model output generated from the settings of

Figure 3. Bottom: a model with both simplified geometry and full geometry for user-selected assets (e.g. “windows + first floor”, or “doors”)

AUTOMATIC PROCEDURAL LOD

The base of our system essentially is an automatic transformation of the initial building represented by a semantically enriched graph-based interpretation of the original ruleset. Its main advantage is that it allows finding a specific product in the derived geometry, given that all tags produced by any rule can be recovered at any level in the hierarchy, see below. Going forward with this idea, we can build semantic rules relating product names. Within our approach, this is performed by selecting the semantic criteria to apply, called a semantic combination. We create a new command, called *Filter*, which automatically selects all products in the graph that accomplish a given semantic combination. A valid combination can be described using any expression associating tag labels through boolean operations. For instance, locate "*first floor and window*" in the building means identifying all windows of the first floor. We let the system find where these criteria are met. Once found, the *Filter* command is instantiated with the required products.

In order to locate the semantic label combination, we design an algorithm that traverses the graph processing all required labels and returns the first rule that satisfies the requirements, if any. Firstly, we perform a topological sorting algorithm in order to obtain a sorted list of all rules. A topological sort on a DAG is a linear ordering of its nodes, which guarantees that each node comes before all nodes to which it has outbound edges. Then, we operate on each rule of the list analyzing all labels in order to find the desired combination. The procedure returns the first rule where all required labels are obtained. Finally, we combine them using a *Filter* operator as described above.

RESULTS AND DISCUSSION

We implement our system on top of the SideFX's Houdini using Houdini own nodes [12] embedded Python scripts and external Python methods. Figure 4 show resulting models generated with our system for the specified LoD configuration of *Figure 3.* The full model (LOD2) is composed of 28781 polygons, the LOD1 by 921 polygons whereas at LOD0 has only 11 polygons. Output models can be obtained in a geometric format independently or in a multilevel format as CityGML.

Using a semantic combination to represent level of details give also flexibility to obtain arbitrary model compositions according to the application requires. For instance, the user may be interested only on the first floor and the entrance doors of all the buildings in a given street, as shown in Figure 4. This may be possible to obtain with CAD systems that model and store with BIM representation, but it is a difficult task for current 3D models.

With our approach we can guarantee the different level of details obtained are consistent, meaning that a geometric element of one level becomes part of the geometry in the adjacent level. Obtaining such kind of models may be a complex task for current unstructured 3D models. We solve this issue by generating the model from a graph ruleset that builds the model in procedural steps, where the children products of a rule are contained in the generator.

The main difference between of our technique and the one provided by CityEngine [8] is that in their system LoD have to be set manually for each desired rule whereas in our is obtained automatically from a semantic combination of tags.

Although the LoD generation process is automatic, the setting have to be done manually, the designer has a visual interface where the semantic tags can be displayed and selected. A deficient tag naming selection may difficult the system's correct usage. While initial tags naming is always responsibility of the model designer, the use of a standard library of tag names may help our LoD system usage.

Our system it is based on procedural modeling of buildings, that has the advantage that can create in fast and flexible way architectural contents for city modeling. Hence, we believe that our LoD approach could be applied to prototype urban simulation, where different levels of details of the same city are required for different analysis processes (acoustics, solar impact, visibility, etc).

ACKNOWLEDGEMENTS

The authors would like to thank Narcís Ventura for his initial implementation of the semantic criterion. This work was partially funded with grant TIN2010-20590-C02-02 from Ministerio de Educación y Ciencia, Spain.

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WEB BASED BUILDING MODELLING AND SIMULATION

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ABSTRACT

The use of web based building simulation enables students to comprehend interrelations between energy and building physics on one hand, and architectural features (design and construction) on different scales (building, room, building element) on the other hand.

There are specific simulation applications for diverse aspects like thermal comfort, heat load, energy consumption, visual comfort, daylighting or ventilation. For e-learning and especially for comprehending interrelations between topics the diversity of simulation applications is troublesome. Switching between applications to simulate several topics usually implies detail or building modelling for every application from scratch. Learning by building variants and experiencing the consequences of diverse topics is very exhausting by switching the applications. For understanding the partially complex interrelations between several topics it is important to offer tools to show diverse main indicators at a glance.

The web platform EnOB:Lernnetz enables students to acquire self-organized fundamental knowledge about energy-optimised design and building physics. Students can acquire knowledge by content and experimental research (simulation).

To support self-organized learning it is important to reduce any hurdles by supporting intuitive handling and easy access. A good user experience is aspired. Uniform component behaviour for diverse applications is therefore indispensable. To achieve this the EnOB:Lernnetz is completely web based and consists of reusable modules and components. Modules are small application units, which can be dynamically embedded in the e-learning platform. Graphical components are standalone elements for display and user interaction. Special components allow editing and visualization of complex building elements or physical information. The use of the same components for several applications reduces module creation time and improves intuitive handling.

The modular concept allows the integration of basic visualization modules up to complex simulation modules within a uniform platform and within semantic contexts. Modules are operating system independent. These aspects and diverse integrated help components help to reduce comprehension problems and technical hurdles for users.

A platform integrated basic CAAD module allows modelling of free-formed buildings, rooms and elements within the web browser to use for complex simulations. The modelled data is stored on the server and can be shared with other users for teamwork. The project data is transferred and stored in a compact, XML-based format, especially designed for the use in web contexts in combination with web services for building physics applications.

Sharing the same data for multiple applications enables the comparison of variants and the understanding of interrelations between topics. The integration of simulations within the modelling process allows value assessment during design time.

For authors of simulation modules the EnOB:Lernnetz offers techniques to reduce work on modelling and visualization. Authors can concentrate on module specific demands and profit from the web based simulation framework.

THE LEARNING PLATFORM

The EnOB:Lernnetz is an e-learning platform designed for educational purposes. It is based on the open source e-learning platform ILIAS [1]. The user and respectively the course and role management is used to control the resources students have access to. The content related part of the platform is built by ILIAS learning modules, glossaries and tests for self-assessment.

The experimental part of the platform using building simulations for empiric studies is an extension to ILIAS. The content related and the experimental parts are strongly interwoven. Users may look up terms and topics within simulation modules and easily switch to further explanations.

The project EnOB:Lernnetz is funded by the German Federal Ministry of Economics and Technology [2].

LEARNING BY DOING

The experimental area provides building simulation modules for students to play with. Learning by doing offers students the possibility to choose an individual learning speed and intensity. As already mentioned the intuitive handling is a very important aspect for self organized learning. For this reason any simulation modules should support techniques for intuitive user interaction. The EnOB:Lernnetz provides several techniques to improve intuitive handling for the user.

For building physics applications there are specific components like dialogs for wall or window editing. Because of the complexity of input requirements and the aim of quick and easy editing these components may have a special behaviour not covered by the users experience. Using these components with the same behaviour multiple and integrating help on component behaviour can improve intuitive handling for users.

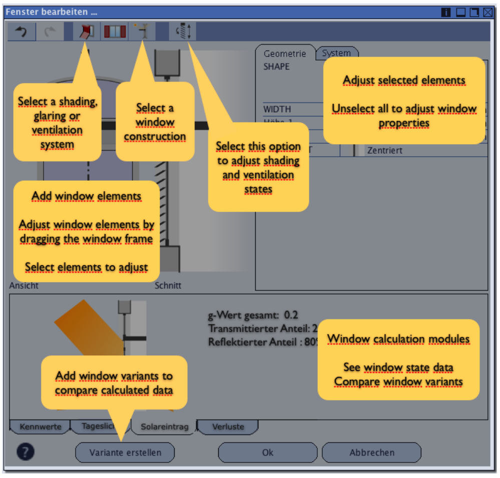

Figure 1: Supporting intuitive user handling by integrating help on special component behaviour

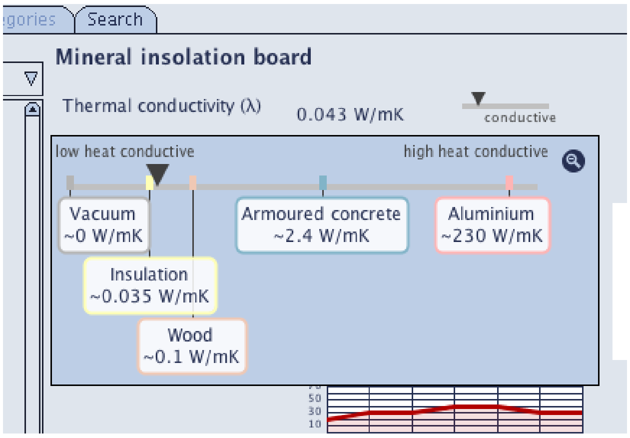

Figure 2: Integrated help for value assessment

In addition to an intuitive platform handling the understanding of terms, values and topics is important for self-organized learning. Diverse help components are integrated for term and topic lookup and for value assessment.

To reduce technical hurdles and improve the user experience graphical modules must be realized by using JAVA[3].

MODELLING BUILDINGS

For the use by any simulation module building elements, rooms or buildings can be modelled and quickly modified within the web platform. Modules for visualization or basic calculation can be integrated in the modelling components to show important data during design time.

The basic CAAD module is designed for building modelling. Freely shapeable buildings, rooms and zones can be created by drawing wall elements and edges. Further definitions on elements like surface or material can be done by using properties and by object insertions. Complex elements like walls or windows with shading, glare protection or ventilation systems can be integrated using special editors. These editors are designed to allow quick visual changes and module integration.

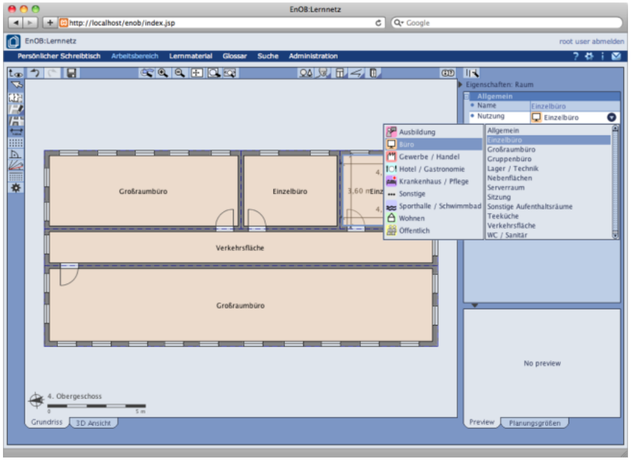

Figure 3: Platform integrated CAAD module

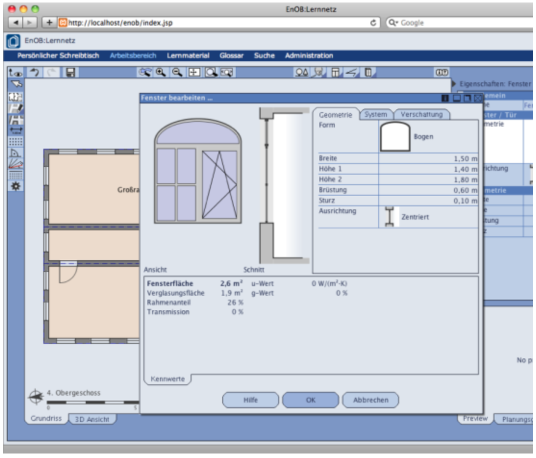

Figure 4: Editing-dialog for windows

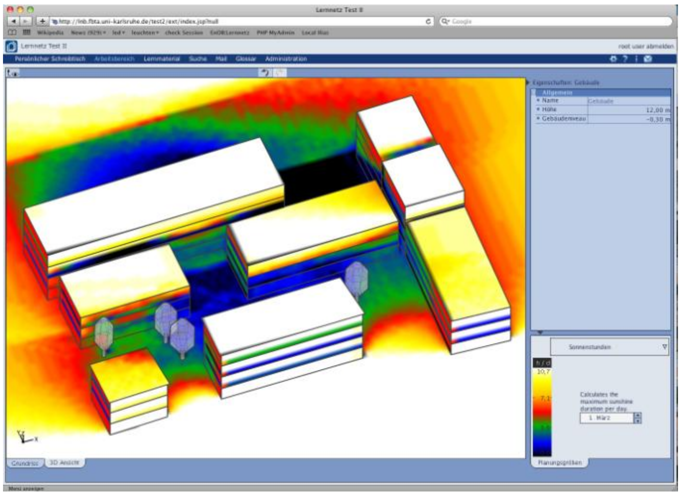

Figure 5: Editor integrated module for solar studies during design time

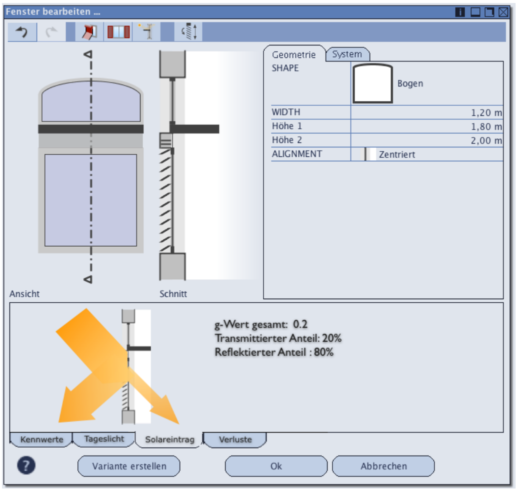

Figure 6: Window dialog with module integration for design time studies

The platform integrated tools allow the modelling of multiple buildings with highly detailed elements like walls, windows and sources for sound, light, heat, humidity and ventilation.

Detailed element, building and project definitions can be derived from central libraries. These libraries can contain detailed product data with descriptions and images. Libraries are used for example for weather data, materials, glazings, shading systems and emitting objects like luminaires.

PROJECT DATA MODEL

All data for buildings, projects and libraries is stored by using a custom project data format. The XML-based [4] format is designed for web use distinguishing between required data and generic data. Generic data can be left off for data transfer and storage. Library data can be linked within the XML-document.

The XML-based document format is structured hierarchical and relational. This means, that within a building all subcomponents are stored with their related main component (e.g. walls of one room together with the room, rooms of one floor together with the whole floor). This hierarchical structure starts on site level with multiple buildings and surrounding parameters and reaches down to element level like windows or luminaires. Besides the hierarchical structure relations between elements are described. This enables for example to find out which elements are associated with each other or which rooms are next to the elements. This is the precondition to deliver different simulation modules like acoustic modules or thermal modules with the same project data. The hierarchical and relational data structure simplifies optimization to reduce simulation times.

The generic data sections contain element based 3D data and calculated data like areas, volumes or resulting U-values for elements and windows.

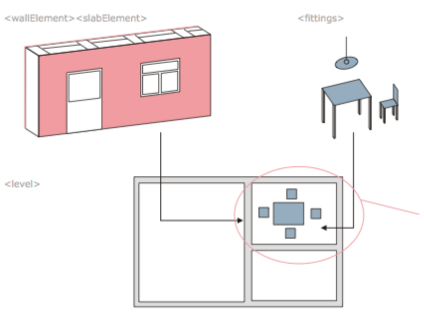

Figure 7: Hierarchical structure of the building data model: walls and rooms of one floor, objects within a room and windows within walls

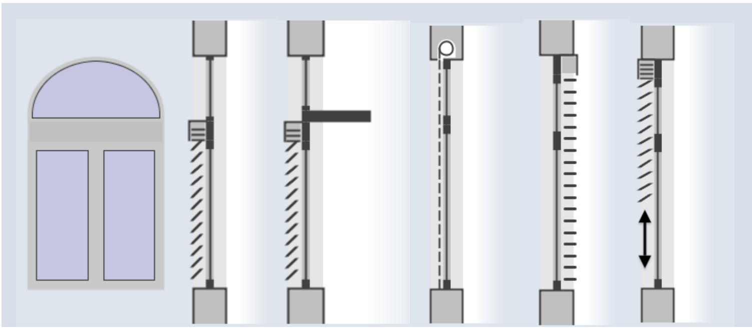

Figure 8: The window definition allows multiple and dynamic systems for shading, daylighting, glare protection and ventilation

Picking out the window with shading and ventilation will illustrate the demands of advanced building models. The state of a shading system has influence on daylighting, thermal loads and ventilation. Calculating with different states or systems for different topics will lead to results which are not comparable.

The project data format therefore uses controlable 3d elements for shading, glare protection and ventilation systems. This allows custom system states for calculations and control strategies.

For furniture, luminaires or heating devices the project data model uses a common object description. Any object may have multiple receiving and emitting surfaces. Objects can be used as sources for heat, ventilation, light, humidity and sound. Objects like luminaires with integrated ventilation or cooling units can be defined within the project data model. The capabilities of sources can be described precisely. This offers detailed information for simulation modules. For control strategies for example a module can use the light source capability to determine if a luminaire is dimmable or not.

For research aspects the project data model allows the integration of custom definitions attached to any element on any document level.

STATE AND PERSPECTIVE

The e-learning platform is available currently in beta state. Students can work on the platform using basic modules for the topics light, heat, humidity and energy. A guest account is offered on request and allows to get an impression of the future opportunities of the platform.

Complex simulation modules for light, heat and energy will be implemented as modules by using RADIANCE [5] and EnergyPlus[6] until 2012.

The long term management of the platform and the coordination of further development will organized by the non-profit association “Lernnetz-Bauphysik” [7].

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SOFTWARE

EnOB :Lernnetz		***Available languages*** ☐ **Français** ☒ **English** ☒ **Deutsch** ☐ **……….** ☐ **Italiano** ☐ **……….**
Editor **Arne Abromeit**	***Distributor:*** **www.lernnetz-bauphysik.de**	***Price:*** **free**

Description

The EnOB:Lernnetz is an e-learning web-platform using building simulations. Diverse building simulation modules are included for the topics building physics and energy-optimised design. Custom modules can be added. A basic CAAD module is included for building modelling within the web platform.
The client-server architecture of the EnOB:Lernnetz allows the usage by any browser on desktop or mobile devices. For full functionality a web browser and JAVA-VM must be installed on the client. For devices without JAVA-VM simulation modules are not available but simulated data can be accessed.
There are no special requirements on memory or disk space.

Technical Data

Operating System		***Processor*** **-**
☒ **Windows 2000/XP**	☒ **Mac OS/X**	***Required memory*** **-**
☒ **Windows Vista**	☒ **Mac + SoftWindows**	
☒ **Windows 7** 32bit		***Required disk space*** **-**
☒ **Windows 7** 64bit	☒ **LINUX**	
☒ **Others (reduced functionality on mobile device OSes i.e. iPhone/iOS or Android)**		

A NEW RENEWABLE ENERGY PLATFORM

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ABSTRACT

In this paper, we present a new renewable energy platform named MUSE (Modelisation of Urban Shape and Energy) based on a geographic information system (GIS). The innovation of MUSE lies in the development of a Decision Support System (DSS) integrating the morphology of cities with energetic issues: It allows the intersection of geometrical, topological, energetic and demographical data. For instance, this software allows the user to easily set up a system to monitor several energy related variables: Floor Area Ratio (FAR), building height, length of streets, adjacency of buildings, facades, street-distance to bus stop and other demographic parameters. The importance of this platform comes from the fact that it allows users to evaluate energy consumption and renewable energy potential across one or more urban blocks.

INTRODUCTION

The control and understanding of the climatic change has been a subject of researches in the last few years. Indeed, several models have been proposed and constitute the base of many decision support systems (DSS). In this sense, Adolphe et al, has developed the Geographic Information Systems (GIS) platform named Morphologic at LRA-GRECAU in 2002 see(Support System for Management of Urban Atmospheres, Adolphe et al, 2002b) [7]. The Morphologic software can be used to compute the energy consumption and production integrated energy across one or more blocks. This simulated consumption and production energy is evaluated by taking into account both buildings, public spaces including streets and vegetation. The importance of this platform comes from the fact that it allows the intersection of geometric, topological, energetic and demographical data. For instance, this software is designed to allow the user to easily set up a system to monitor several variables: Floor Area Ratio (FAR), building height, length of the street, adjacency of buildings, facades, street-distance to bus stop, chosen technologies for heating and other demographic parameters. However, the actual version of Morphologic software is not open-source and it was developed by using the non-oriented object programming language MapBasic under the platform MapInfo [5].

In this context, our main objective is to develop a new platform called MUSE (Modellisation of Urban Shape and Energy) based on the most useful features and capabilities of the existing Morphologic. A major goal we set for developing MUSE as open-source software is to create a well-organized, modular structure to facilitate the addition features and links to other programs. Because of the advantages of the structure and object-orientation of Java, we decided to use this language as the programming language for MUSE. Thus, MUSE comprises completely new, modular, structured code written in Java and using the existing Java libraries. The graphic rendering is possible with standard Java classes (java.awt.Graphics) and the interface with Swing components.

The new platform will integrated new models, for instance, solar energy able to simulate the part of solar energy irradiance received by surface obscured by other constructions. Some other new features already under development such as wind power, biomass energy, or geothermal heat.

DEVELOPMENT ENVIRONMENTS

For purposes related to the development of software MUSE, two solutions are retained: first Java, which has the support of a large community of developers and for which many open source libraries exist, and secondly SVG, a standard format in which the tools of creation are those in which XML and plug-ins for reading are free. We choose to compute MUSE with Java [2].

The Graphical User Interface (GUI) of MUSE, shown in Figure 1, is composed of modules serving different needs and the GIS module is used to integrate most needed datasets, analyze the various spatial entities, prepare the input for models and the decision making models, store and visualize the results.

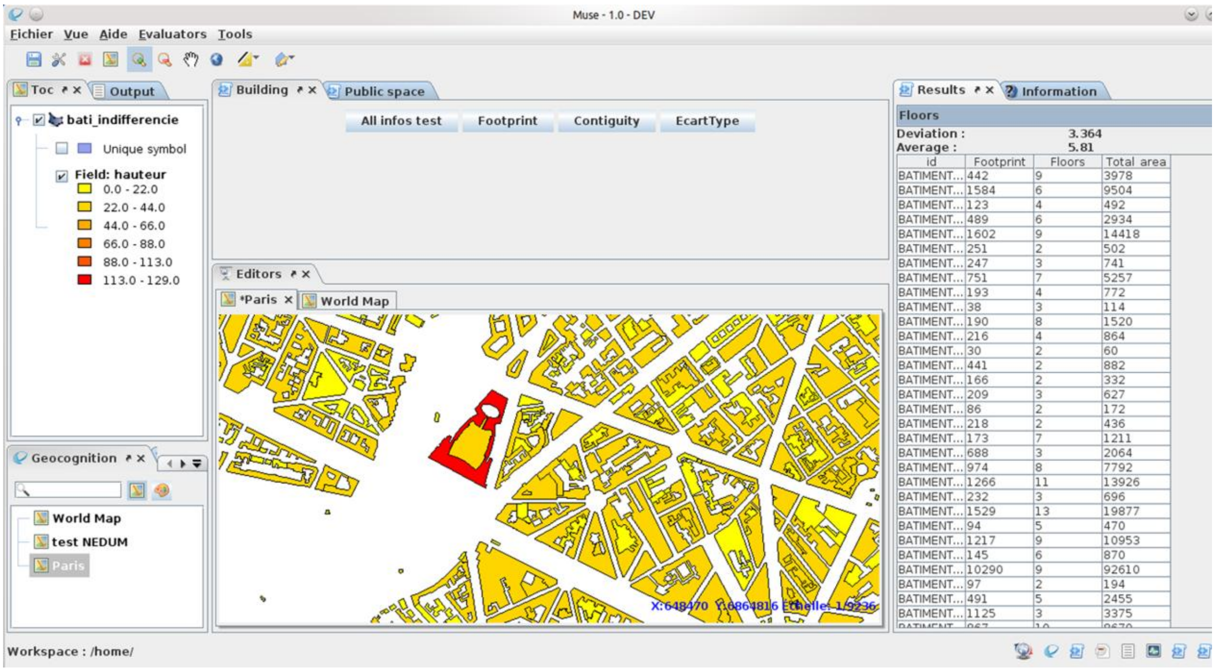

Figure 1: MUSE Graphical User Interface.

First, we present some existing integrated development tools to process the data mapping, namely MapServer [4] and JUMP [3]. These tools allow saving time of development by delivering a variety of tools and reusable functionality.

MapServer is an Open Source platform for publishing to the web spatial data and interactive mapping applications. It is based on the geo-references data and runs on all major platforms.

The Unified Mapping Platform (JUMP) is a GUI-based [1, 6] application for viewing and processing spatial data and it is open-source written in pure JavaTM. It includes many common spatial and GIS functions. It is also designed to be a highly extensible framework for developing and running custom spatial data processing applications.

MUSE DATABASE

A database and a Human-Computer-Interaction (HCI) which allows running SQL queries from connections created via a user form are developed. The knowledge structure used in MUSE is based on a system of environmental indicators, as well as a multi-criteria analysis, the weighted average. The indicators are grouped into three areas: building, transportation, vegetation. Based on environmental data and knowledge needed to describe urban projects, the attribute of the database selected for the new version of MUSE are:

1) Blocks, Parcel, External space,

2) Building, Road, Public Lighting Network, Public transport,

3) Vegetation, Hydrology, Environmental Indicators.

NEW FUNCTIONALITIES

Several other modules have been engineered for inclusion in MUSE: Solar wind power, biomass and geothermal potentials. The first model deals with the solar energy potential and takes into account the following parameters:

- Position of the sun hour per hour depending on the location of the project,

- Meteorological data related to the sun irradiance over one year (Météofrance),

- Urban geometry.

It then uses a simplified model of shadow masks and sun irradiance as presented by Robinson [5]: the geometry is considered as urban street Canyon equivalent and associated with the model of Perez anisotropic sky [10]. From this model we deduce the solar masks and shadows of urban geometry.

We deduce the irradiance [kWh/m²] for each the facades, roofs and other panels. We then calculate, using a state of the art of existing and projected technologies, the potential energy used by thermal or solar panels.

Another important model added to MUSE allows the users to evaluate the wind power potential. The parameters considered here which constitute the input data for the model, are:

- Meteorological data related to wind speeds and directions (data given by Météofrance)

- Urban geometry.

Series of parametric aerodynamic modelling on five case studies will give us a simplified model to calculate wind potential in an urban scene. MUSE deduced influent indicators that will be the entries of the model. We then determine a new wind profile above the urban canopy. We finally, calculate, using a state of the existing art and projected of technologies the potential of usable energy from wind turbines.

These physical models are then integrated into the platform MUSE to obtain a functional tool. The robustness of the models will be validated by comparison with results obtained from simulations performed using a battery of existing tools (ENERGY PLUS SOLENE, SUNTOOL ...), both in terms of energy consumption and renewable energy[8,9]. This will be done on several contrasted case studies. They will be ideal blocks corresponding to references in terms of urban planning (pavilions, small and large collective building, medieval blocks, Hausmanian blocks) For each of these blocks will be varied the following parameters: density, height, proportion of buildings, street width, depth of the frame and compactness.

The MUSE platform will allow developers to target urban areas that are not energy efficient and to evaluate the best solutions: thermal renovation or installation of renewable energy systems. MUSE will also help designers in their search for an optimal density for the planning of new or rehabilitated districts.

In the longer term, the goal is to integrate the platform into other models of renewable energy: geothermal, district heating, biomass...

CONCLUSION

The platform MUSE is a new building energy simulation program and it is an open source platform developed in order to make it easy for developers to add new features and modules. MUSE do not only reproduce basic GIS features but also constitute a first platform able to simulate the green energy and it constitute a real tool for decision support system (DSS) for urbanism and represents a significant step forward in terms of computational techniques and program structures.

ACKNOWLEDGEMENTS

The authors gratefully thank the ACCLIMA-MUSCADE project for supporting this work.

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SOFTWARE

MUSE **Modelisation of Urban Shape and Energy**		***Available languages*** ☒ **Français** ☐ **English** ☐ **Deutsch** ☒ **……….** ☐ **Italiano** ☒ **……….**
Editor **Laboratoire de Recherche en Architecture (LRA) ENSA Toulouse**	***Distributor*** **LRA**	***Price*** **Open-source**

Description

MUSE (for Modelisation of Urban Shape and Energy) is a new renewable energy platform based on a Geographic Information System (GIS) developed by the Architectural Research Laboratory (Toulouse) and financed by the National Research Agency (ANR) as part of the programme MUSCADE: Urban Modeling and Adaptation Strategies for Climate Change anticipate demand and energy production.
The platform MUSE is a real Decision Support System (DSS) tool that integrating the morphology of cities with energetic issues: It allows the intersection of geometrical, topological, energetic and demographical data. For instance, this software allows the user to easily set up a system to monitor several energy related variables: Floor Area Ratio (FAR), building height, length of streets, adjacency of buildings, facades, street-distance to bus stop and other demographic parameters. The importance of this platform comes from the fact that it allows users to evaluate energy consumption and renewable energy potential across one or more urban blocks.

Technical Data

Operating System ☒ **Windows 2000/XP** ☐ **Mac OS/X** ☐ **Windows Vista** ☒ **Mac + SoftWindows** ☒ **Windows 7** 32bit ☒ **Windows 7** 64bit ☒ **LINUX** ☒ **Others Licence GPL V3** **…………………………………………………**	***Processor*** **500MHz** ***Required memory*** **256 MB RAM** ***Required disk space*** ***Depend on the expected data volume***

INFORMATION TECHNOLOGY MEETS SCIENTIFIC RESEARCH ON THE WEB. DOCET^{PRO}2010 AND XCLIMAEUROPE: THE ITALIAN EXPERIENCE ON DIAGNOSIS AND ENERGY CERTIFICATION

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ABSTRACT

Buildings account for a large share of final energy consumption. To meet the requirements of the European Directives, computational tools and methodologies for the assessment of the energy performance of buildings have been developed over the years by ITC-CNR, Construction Technologies Institute of the National Research Council of Italy.

The meeting of sophisticated scientific knowledge with technological know-how has led to the realization of the project XClimaEurope.

XClimaEurope, as a web-based multi-language platform, is a meeting place for the exchange of knowledge and experience in relation to energy saving and renewable energy. The latest results of research are made available in the form of analytical and computational tools for energy consumption in buildings, renewable energy sources and in general for environmental protection.

The first product of the new platform is DOCET^{pro}2010, a diagnosis and energy certification tool, open to all stakeholders in the sector: from energy certifiers to architects, from research to industry, from public institutions to end users. The tool is focused on trying to identify methodological approaches to facilitate data entry via an online interface, making it more flexible and intuitive at the same time to allow energy certification to become a positive process of cultural identity.

Customers can define the building model, creating several surfaces with different physical and construction characteristics, the heating system, with one or more traditional and non-traditional heating and domestic hot water plants. It is also possible to specify the thermal solar systems and the photovoltaic systems. The last part of the software consists of the cost/benefit analysis that allows the economic evaluation of several energy refurbishments.

XClimaEurope operates independently from any operating system, location (office, building yard, home) and device (computer, laptop, iPhone, iPad). It only needs an Internet connection and a free standard-browser. Each update is provided automatically and requires no additional intervention or action. The platform is permanently evolving through the continuous integration of different tools and offers the possibility of widely disseminating of the concepts of sustainable living.

CONTEXT

In 2007 ITC-CNR, the Construction Technologies Institute of the National Research Council of Italy and ENEA developed a software at Italian level, called DOCET; the idea behind the software was to create a calculation tool with a simplified interface for the energy certification of existing residential buildings.

Since mid-2008 UNI TS 11300 part 1 and 2 were issued in accordance with standards developed by CEN under mandate M/343 in support of Directive 2002/91/EC on the energy performance of buildings; the need to define a single national calculation tool was born out of this context. The goal was to create an Italian Web portal, called XClimaEurope, to support the calculation engine DOCET^{pro}2010 updated to UNI TS 11300 for the energy certification of buildings.

UNI TS 11300 defines three different types of energy assessment:

- Design assessment: the calculation is made on the basis of design data; a continuous operating system is assumed for the conditions of *occupancy and* use of the building and the system;
- Standard assessment: the calculation is made on the basis of the data concerning both the building and the real system, as built; a continuous operating system is assumed for the conditions of occupancy and use of the building and the system;
- Assessment under actual use conditions: the calculation is made on the basis of the data concerning both the building and the real plant, as built; actual operating values are assumed for the conditions of occupancy and use of the building and the system.

As an energy certification software, DOCET^{pro}2010 is consistent with the design and standard assessment.

ACTIVE PROJECTS

Two projects developed by ITC-CNR and KlimaHouse agency are currently underway. The former, called DOCET*lab*, is a "virtual" laboratory where experts and research institutions can meet serving the common purpose of developing solutions, guidelines and methods in order to reduce the amount of energy consumed in buildings.

The results gained are published gradually in the form of calculation tools, simulation tools and analysis tools in XClimaEurope. Further studies and analysis of current and interesting topics are carried out, in order to develop tools and make them always available online.

The KlimaHouse project aims to provide an energy certification tool designed to perform tests on each project, a control audit during the construction phase and to realize the high-quality of buildings.

APPLICATIONS AVAILABLE

Basic Applications and Services

The main applications are the following:

- File manager;
- X-Trainer;
- Archive Construction Materials.

The File Manager is a centralized application that allows to create, manage and organize all documents and folders created in XClimaEurope. The File Manager also allows to share documents with other users (file sharing), view public publications and consult materials archives. With the introduction of the file concept, it is also possible to start multiple sessions for different applications.

A highly efficient application allowing to keep all the training events under control. The application is divided into online Training and on-site Training. Online trainings are organized by date and topic while on-site trainings are arranged by date and region.

Archive Construction Materials is an application that allows to create customized materials archives.

For each material it is possible to define relevant physical values such as material thickness, thermal transfer resistance, density, specific heat capacity, surface mass, water vapour diffusion resistance and limited amount of condensation admissible. Once created, the materials can be assigned directly to a single wall layer in StratiX tool.

Calculation Tools

The main software available are:

- DOCET^{pro}2010;
- StratiX;
- ProCasaClima2009.

DOCET^{pro}2010 is a simulation tool used to create the energy certification for buildings in accordance with Italian Decrees 192/05 and 311/06, according to the calculation method as provided for by Italian standards UNI TS 11300 1 and 2 and the guidelines for energy certification, Ministerial Decree 26/06/2009.

StratiX allows to create customized "wall libraries". The material for a single wall layer can be assigned directly from customized or extensive materials archives, available in XClimaEurope. Based on the inputs, it can calculate different values such as the internal and external heat capacity and the heat transfer coefficients according to EN 13786 and EN ISO 6946 for the entire wall structure.

ProCasaClima 2009 is an application, developed by KlimaHouse agency, used to calculate the energy performance of buildings (primary energy), considering the energy requirements to produce hot water according to the standards of the Province of Bolzano.

Manufacturers Catalogues and Archives

They include some manufacturers archives and catalogues of Weather Data of Italy, the Material Archive UNI 10355 – 10351 and catalogues of RÖFIX.

The weather data archive of the provinces of Italy is available. With this archive, considering the sea level and the latitude, it is possible to determine the temperature and radiation of each municipality according to UNI 10349 and UNI TR 11328.

Customers can also use materials database, called MatiX, developed in accordance with UNI 10355 - Walls and Ceilings (Thermal resistance values and calculation methods) and UNI 10351 - Building Materials (Thermal conductivity and water vapour permeability). The materials can be assigned to single wall layers in StratiX to create *customized* wall libraries.

Finally, the company RÖFIX AG has been working for over a hundred years to develop high quality building technologies. Today, RÖFIX offers innovative system products, that meet technical, environmental and economic demands.

DOCET^{PRO}2010

DOCET^{pro}2010 can be used for new and existing buildings according to the Decree of the President of the Italian Republic of 26th August 1993, number 412 and for any type of intended use.

The software is based on the monthly balance method, aimed at the energy certification of buildings, according to different uses.

The calculation of net energy for heating is carried out according to UNI TS 11300 part 1, which defines the net energy as the balance of heat losses and heat gains.

The primary energy for heating is calculated according to the methodology laid down in UNI TS 11300 part 2, which defines the primary energy as the balance of heat loss and heat and electrical recovery for every subsystem of the heating and domestic hot water system.

The model building is user-defined as a single thermal zone, thus creating different opaque and transparent, horizontal and vertical scattering surfaces, as deemed appropriate by setting a minimum number of areas according to the differences between building, physical and exposure characteristics of the individual elements.

For existing buildings, where information retrieval is often an issue, the software gives tips based on the input data and qualitative input entered by the user and according to the abacus contained in the regulations.

The software also includes a cost-benefit analysis, called CBA, for specific types of energy retrofits; starting from a given fuel price and a cost manually entered, the certifier can get some economic parameters to determine the specific financial indicators (e.g., payback time, NPV, etc.).

The cost-benefit analysis is therefore an objective tool that can evaluate, compare and optimize the economic feasibility of possible energy-efficiency refurbishment works identified by the energy diagnosis and fits in the evaluation approach of a building as follows:

- specific energy diagnosis made by the certifier;
- identification of performance deficiencies of the building;
- definition of energy refurbishment targets;
- study of possible alternative technological actions, on equal performances, to achieve the set targets;
- assessment of the viability of alternative technologies through the CBA identified and definition of the solution allowing the aspects of performance to match at best the economic efficiency.

Energy indicators

The methods developed within CEN define three steps of calculation with related performance indicators:

- net energy;
- delivered energy;
- primary energy.

Net energy requirement is the amount of energy needed to meet the comfort criteria, taking into account the thermal losses and gains; this parameter varies depending on the thermal transmittance, orientation, shape factor, profiles of use, etc., and basically indicates that the architectural and construction solutions are fit for the building envelope. The net energy requirement depends on the characteristics of the building envelope, such as: geographical location (province, municipality, degrees/day, latitude, altitude, etc.); intended uses of the building; geometry of the building; thermo-physical features of opaque and transparent technical elements (thermal transmittance, surface colouring, solar factor, etc.).

Delivered energy is the amount of energy actually measurable at the "power meter"; the calculation depends on the type of technological systems installed, their efficiency and the performance factor, and gives comprehensive information on the efficiency of the “building-plant system”.

The energy delivered for heating purposes and/or for the production of hot water for domestic use depends on the technological systems installed. The heat producing systems can be divided into the following subsystems:

- heating: emission, regulation, distribution, stoke, generation;
- DHW production: emission; distribution; stoke; generation.

For each subsystem the following shall be determined:

- total amount of energy entering the subsystem;
- total auxiliary energy of the subsystem;
- recovered losses;
- losses.

The third indicator is the primary non-renewable energy, which indicates the actual consumption of non-renewable resources, depending on the fuel used and the actual use of renewable energy sources.

Primary energy is defined as the energy potential presented by energy carriers and energy sources in their natural form, i.e. energy that is not subject to any conversion or transformation process; the tool adds different forms of energy such as fuel (natural gas, oil, biomass, etc.), self-produced or purchased electric energy, derived from renewable sources (geothermal, hydroelectric, wind, etc.) or fossils.

Only the evaluation of all performance indicators described provides comprehensive information on the strategies and the choices made to serve the purpose of increasing the energy efficiency of a building.

Economic and energy diagnosis indicators

According to the European EPBD (Energy Performance of Buildings Directive) normative framework the energy certificate must be accompanied with recommendations for the improvement of the energy efficiency of the building.

DOCET^{pro}2010 contains a section devoted to the cost-benefit analysis, in which possible energy-efficiency refurbishment actions are evaluated from the point of view of improving performance and taking into account their economic and financial impact; to this end, the simple payback time of investment is calculated.

The simple payback time is defined as the number of years necessary so that the cash flows (excluding debt payments) equal the total investment, according to the formula:

$$SP = \frac{\text{Initial investment}}{\text{Annual saving}}$$

The simple payback time is one of the most important financial indicators because it determines the time needed to recover the capital invested through the analysis of annual flows of each specific operation.

Since this method does not evaluate the cash flow after capital recovery time and does not take into account the possible currency floating over the time, the SP value calculated by years needs to be compared with the expected useful life of the refurbishment; in order for the solution to be economically feasible, the SP must be less than the useful life of the refurbishment.

CONCLUSIONS

According to promotion activities and awareness of users of the European Union about the energy performance and certification of buildings, the Italian regulatory framework (D.Lgs 192/2005, D.Lgs 115/2008, DM 59/2009 and National Guidelines for energy certification) is intended to contain costs for end users, to have simplified calculation methods and to standardize procedures.

The goal is the realization of a web platform where DOCET^{pro}2010 can be used as a calculation engine at national level to carry out energy certification on buildings updated to UNI TS 11300.

Certifiers can therefore rely on a single platform for the implementation of energy performance certificates for different regional contexts.

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COMPUTER-BASED TOOL « PETRA » FOR DECISION-MAKING IN NETWORKS ABOUT THE MAINTENANCE AND RENOVATION OF A MIXED BUILDING ESTATE.

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ABSTRACT

The PETRA project aims at developing an computer-based tool for decisions-making in networks for building estate management that encompasses both a rapid assessment and the planning of renovations according to different indicators.

It is addressed to all people or institutions managing a mixed building estate and particularly, to technical services for project management, architects and engineers, owner's associations and expert offices. In order to establish a correct maintenance management programme, these « clients » are in need of a method for analyzing buildings that allows to rapidly and simply «scan » the building estate and estimate the typology and the investment costs of rehabilitation interventions.

The aim of the project is to bring innovation by offering extra speed and universality for better answering the real estate market's new requirements in the area of maintenance and renovation. Indeed, the market needs fast and precise methods that help the expert to reconcile the needs of heritage protection and new energy requirements. Within the next 10 to 30 years, the biggest building estate conversion ever will take place in Switzerland. This implies the refurbishment of buildings from the years 1950-1970 that are now at the end of their lifetime and that have a 2-3 energy consumption reduction factor. Given this reality, an owner cannot only trust the manager's intuition ; this intuition must be reinforced by appropriate analytical tools such as the new method that will be developed with this project. PETRA develops a new evaluation methodology that allows to analyze the buildings' conservation state and to calculate the renovation costs of each building in a simple and quick way. In order to carry this out, a process of data aggregation and element grouping, based on existing methods previously developed by the work group (EPIQR+[1], INVESTIMMO[2]), will be set up.

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[1] [2] EPIQR+, INVESTIMMO : méthodes d'aide à la décision pour la maintenance et la rénovation des bâtiments et parcs immobiliers développé dans des projets internationales précédent par le groupe de travail du projet PETRA

INTRODUCTION

From the analysis of different building estates, it was possible to observe that the average maintenance, renovation and management costs, calculated on the lifetime of a building, are 2 to 3 times higher than the object's initial building costs. In the past, these costs have often been neglected because the focus was on new buildings. This lack of appropriate maintenance programmes has resulted in a gradual degradation of buildings. Today, we have building estates that requires urgent and significant maintenance and renovation interventions on essential elements of the construction. These interventions constitute today an increasing part in the building market. In Europe, building renovation represents approximately 40% of the civil engineering works related to buildings. In Switzerland, at least half of the investments in construction are dedicated to renovations. To insure that these interventions be effective and sustainable over time, it is indispensible that all actors involved operate according to a systematic intervention agenda, based on predictive property management that considers a series of criteria linked to sustainable development.

The PETRA project, is the answer to the lack of rapid assessment online decision making support tools for analyzing a complete building renovation. The tool is accessible through an online platform which also provides users with information such as documents and data on building maintenance and renovation. This platform is the interface of the new competence centre ("Centro di competenza sul risanamento e la manutenzione degli edifici") based on the partnership between the Institute for Applied Sustainability to the Built Environment (ISAAC) in Ticino and the Laboratory for Construction and conservation (LCC) at the EPFL in Lausanne.

Figure. 1: Degraded building envelope elements

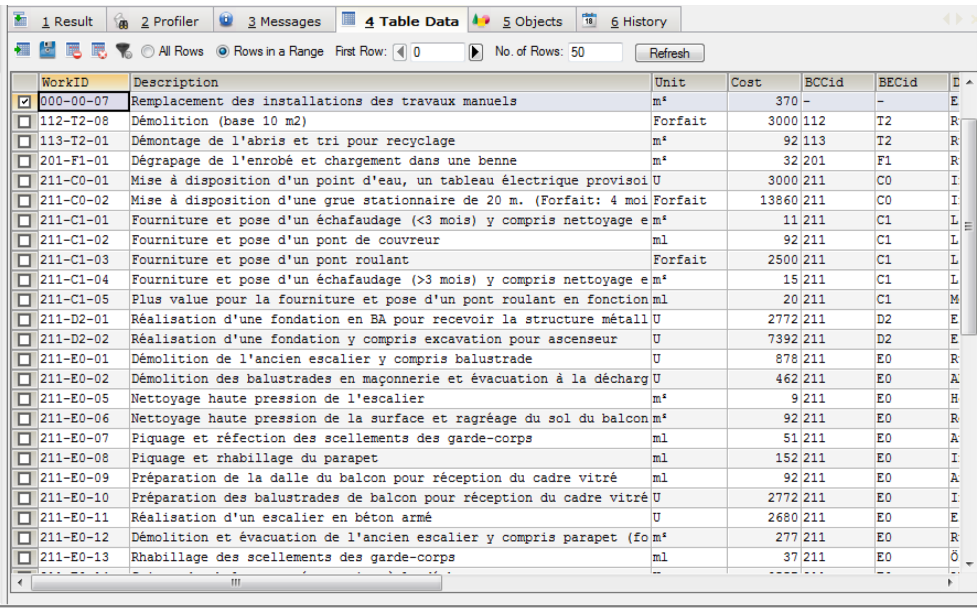
METHOD

Currently, in the area of building renovation, a comprehensive database containing all the essential information concerning the key dimensional coefficients compared to the intervention costs for all building types does not exists. The other computerized methods currently on the national and international market do not rely on such a database and particularly do not have an inductive approach that allows the analysis of a building estate starting from the analysis of each building. The PETRA project is based on the previously developed inductive analysis methods, namely EPIQR+ and INVESTIMMO. The new methodology is principally based on the following aspects :

- Modelling of all building categories
- Conceptual study of the new method based on data aggregation

The new database exploits both information already present for certain building categories and data for new categories that will be progressively implemented as the project and the utilization of the new method progress. The aggregation of new data from the existing database is a key step for allowing a quick and reliable building assessment.

The existing Access format database of the tool has been transferred to a MySQL format. This allows a web compatibility and increased flexibility. At the same time, a new data structure has been created for simplifying the analysis. Also, the present structure allows to add new data about building categories that are not yet analyzed and to refer to a lower amount of data input compared to EPIQR+ e INVESTIMMO.



WorkID	Description	Unit	Cost	BCCid	BECid	D
000-00-07	Remplacement des installations des travaux manuels	m²	370	-	-	E
112-T2-08	Démolition (base 10 m2)	Forfait	3000	112	T2	R
113-T2-01	Démontage de l'abris et tri pour recyclage	m²	92	113	T2	R
201-F1-01	Dégrapage de l'enrobé et chargement dans une benne	m²	32	201	F1	R
211-C0-01	Mise à disposition d'un point d'eau, un tableau électrique provisoi	U	3000	211	C0	I
211-C0-02	Mise à disposition d'une grue stationnaire de 20 m. (Forfait: 4 moi	Forfait	13860	211	C0	I
211-C1-01	Fourniture et pose d'un échafaudage (<3 mois) y compris nettoyage e	m²	11	211	C1	L
211-C1-02	Fourniture et pose d'un pont de couvreur	ml	92	211	C1	L
211-C1-03	Fourniture et pose d'un pont roulant	Forfait	2500	211	C1	L
211-C1-04	Fourniture et pose d'un échafaudage (>3 mois) y compris nettoyage e	m²	15	211	C1	L
211-C1-05	Plus value pour la fourniture et pose d'un pont roulant en fonction	ml	20	211	C1	M
211-D2-01	Réalisation d'une fondation en BA pour recevoir la structure métall	U	2772	211	D2	E
211-D2-02	Réalisation d'une fondation y compris excavation pour ascenseur	U	7392	211	D2	E
211-E0-01	Démolition de l'ancien escalier y compris balustrade	U	878	211	E0	R
211-E0-02	Démolition des balustrades en maçonnerie et évacuation à la décharg	U	462	211	E0	A
211-E0-05	Nettoyage haute pression de l'escalier	m²	9	211	E0	H
211-E0-06	Nettoyage haute pression de la surface et ragréage du sol du balcon	m²	92	211	E0	R
211-E0-07	Piquage et réfection des scellements des garde-corps	ml	51	211	E0	A
211-E0-08	Piquage et rhabillage du parapet	ml	152	211	E0	I
211-E0-09	Préparation de la dalle du balcon pour réception du cadre vitré	ml	92	211	E0	A
211-E0-10	Préparation des balustrades de balcon pour réception du cadre vitré	U	2772	211	E0	I
211-E0-11	Réalisation d'un escalier en béton armé	U	2680	211	E0	E
211-E0-12	Démolition et évacuation de l'ancien escalier y compris parapet (fo	m²	277	211	E0	R
211-E0-13	Rhabillage des scellements des garde-corps	ml	37	211	E0	Ö

Figure. 2: Reorganized MySQL format database extract

RESULTS

One of the main results of the PETRA project will be the development of an network platform from which all users, through special access, will have the possibility of working on their projects using the fast assessment method established through the new database. Meanwhile, we will be able to improve the database's accuracy and reliability and to assure a systematic updating by using the information related to the users' own renovation projects.

The systematic diagnosis has been reinforced and the database extended by the online operating possibility. The frequent users that this attracts and the controlled access management, help increase its representativeness of all building types. Furthermore, by drawing on user feedback information, the database is systematically and continually supplied, controlled and updated. For the new tool to be standardized, the data goes through a reliability control.

Also, interested users can find information, documents and data on building maintenance and renovation on the platform that is also directly linked to organizations/institutions, such as the Swiss association for facility management and maintenance (www.fmpro-swiss.ch), that handle related subjects. Thus, the platform has the role of service provider and competence centre for the field.

The tool and platform will change the way actors in building management and renovation planning work and will become a benchmark for the encouragement and the carrying out of works that lessen energy consumption of buildings.

Figure. 3: Platform design

Another main result of this research project is the Renovation and issues linked to architectural conservation. The development of an extensive and meaningful database will especially apply to buildings with particular elements but not to the extent of being classified or protected. This building typology represents an important percentage of all buildings of our cities and has an enormous energetic improvement potential. Often however, it is difficult to effectively intervene because of their characteristics and particularities.

Since it is essential to know and represent the buildings characteristics in order to diagnose them in all their elements and define the intervention scenarios for their maintenance or renovation, with the PETRA approach, it is possible, even at the early project phase, to consider all aspects and restrictions that the specific building category entails.

With raw material price raise and the increased requirements of energy consumption related new legislations, energy waste reduction has become one of the key drivers of renovation. Most of the existing methods allow renovation impact assessment on energy consumption and investment costs, but this is not a satisfactory enough incentive. Indeed, a multitude of scenarios can occur while not knowing the level of regulation to achieve and what the operating cost reductions are.

PETRA on the other hand, aligns renovation scenarios not only with investment costs, but also with operating expense reductions, with references to various energy standards (ex. MINERGIE, energy labels) and legislations.

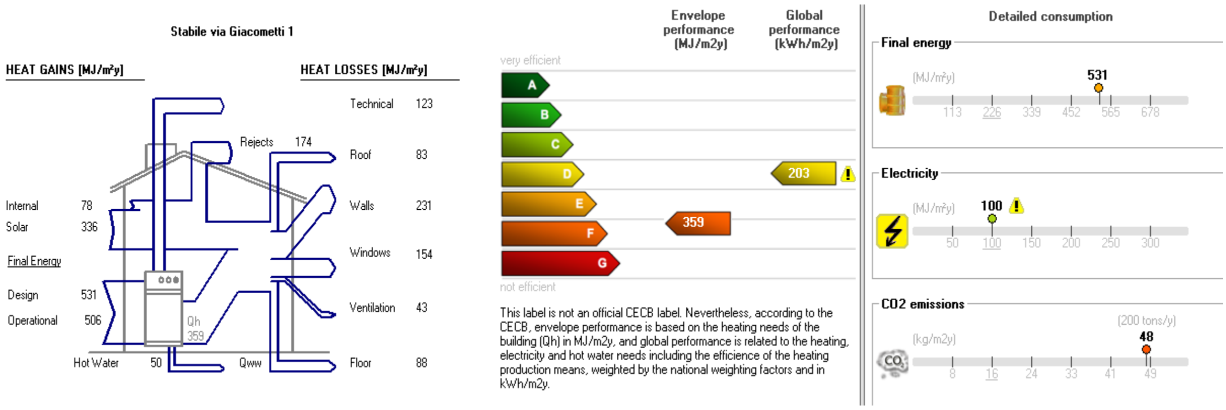


Figure. 4 : Energy balance (SIA 380/1 norm) aligned with the cantonal energy building certification by the new online tool PETRA

DISCUSSION

The major challenge of the project was to develop a new decision making online support tool with unique features. Indeed, the existing methods in this area are on the one hand very precise (capitolati d'architetto) but long to set up; on the other, there are tools that analyze the building fairly quickly, but they are not destined to professionals but rather to the wider public with results that are not linked to norms nor to a reliable database. Therefore, the new tool had to be able to give quick (two or three days per simple building) results on building conservation state and renovation scenario costs with a reasonable accuracy (+/- 15%).

The uniqueness of the new tool is also based on it's simple access and the database's update. The tool has a universal development potential by the access via all online computers. This also facilitates the updating of the tool that can integrate the user's data via a control system that structurally "feeds" the new database.

Here, the diagnostic work on building conservation state and renovation scenarios has a holistic vision of the issue. Renovation costs are linked to specific features of the analyzed building and to normative contexts concerning energy consumption, security, accessibility and heritage (cantonal regulations and energy standards). All these aspects are reported and taken into account in an investment financial analysis. Once the data insertion is complete, the user obtains an instant report and has therefore access to a complete and quantified vision of the renovation of his building or building estate.

Finally, users are able to work online benefiting from the expert knowledge of other professionals who are connected by the new competence centre through the online platform.

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A METHOD TO COMPARE COMPUTATIONAL FLUID DYNAMICS AND MULTIZONAL DYNAMICS SIMULATIONS IN BUILDINGS PHYSICS

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ABSTRACT

This paper focuses on the development of a new evaluation method that combines data obtained by two different approaches: "multizonal dynamics" and "computational fluid dynamics (CFD)".

This research is a part of a project whose the main objective is to define guidelines for architects and buildings engineers. This guidelines aims at determining the adequate approach needed to evaluate the occupant thermal comfort and the building energy consumption for cooling and heating.

In this context, the first step of our research consisted in comparing results obtained with measurements, with a CFD approach (through FLUENT simulations) and with a multizonal approach (through TRNSYS simulations). At this aim, the study selected published reference cases in order to encounter:

- heterogeneity of physics phenomena involved in building physics: free-float, mechanical ventilation, natural ventilation, radiating walls.
- diversity of scales: a single room, partitioned building, unpartitioned building, sunny atrium.

These cases were evaluated by both types of simulations, CFD and multizonal. Comparing the results of simulations with experimental data published in these reference cases, CFD simulations appear to give really accurate results but it is not the case for all multizonal analysis. However CFD needs more runtime than multizonal approach and needs more technical knowledge to implement simulations. Indeed, multizonal approaches are often more user-friendly and intuitive for architects than CFD.

The second phase of this research consisted in bringing out the complementarities of both simulations methods. In order to achieve this goal, a method to evaluate the matching between CFD and multizonal results is suggested in this paper.

Specifically, the usual confrontation of absolute differences and relative errors was completed with a superposition of the spatial representation of temperature for a building section, resulting from each method (CFD and multizonal). The discussion argues the spatial match between FLUENT and TRNSYS results, for the total thermal zone and for the occupied zone only. Highest precision is achieved, in the occupied zone, where it has a real impact on people comfort. This combined representation of results improves the appreciation of the multizonal evaluation of the mean ambient temperature.

INTRODUCTION

Due to growing interests in environmental performance of buildings, building physics simulations are more and more used and need to be more accurate. Basically, there are two kinds of mathematical approaches: “multizonal dynamics” and “computational fluid dynamics (CFD)”. Each approach leads to some advantages and disadvantages such as the accuracy of the results and the computational runtime. In this context, this research brings out the complementarities of this both approaches by defining a method to evaluate the matching between CFD and multizonal results.

METHODOLOGY

The purpose of this study is to evaluate a case study using CFD and multizonal approaches. Both approaches are confronted with measured results (flow and temperature) and their accuracy is discussed.

The comparison is based on an evaluation of absolute differences and relative errors. But a graphical representation of temperature results is also suggested. This confrontation method superposes the spatial representation of the temperature results of a building section and discusses the spatial match between CFD and multizonal results. This graphical confrontation is suggested in order to bring some nuance to the comparison of the two approaches. This method includes three steps.

The first step is the definition of an “occupied zone”. The idea is that a highest precision in the results must be achieved in the zones highly occupied by the workers and which must, thus, offer thermal comfort to the occupant. Considering the European Standard EN 13779 on Ventilation and Air-Conditioning Systems [1], the occupied zone considered in the study is presented in Figure 1.

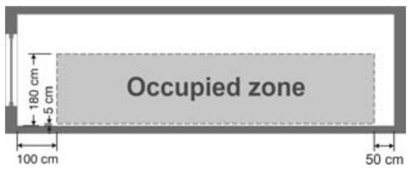

Figure 1: occupied zone considering the EN 13779 norm

The second step of the study is the representation of measured values. Considering the great accuracy of the CFD simulation and the limited number of measuring points, results obtained with the CFD approach were chosen to represent temperatures.

The third step consists in the representation of multizonal results. In order to represent the single value obtained with multizone approaches, an accurate range around this value was defined. Since the objective of this kind of simulation is to discuss thermal comfort, results must allow the identification of the comfort zone such as those described in European Standard EN 15251 [2]. The gap between different comfort zones is one degree. Thus, numerical results with an error less than 0.5° are tolerated in comparison with experimental data.

MATERIALS

Published reference cases

In order to validate the CFD approach for the evaluation of building physic phenomena and to confront the CFD to the multizone approach, we first selected published reference cases to compare simulation results with experimental results of some typical applications in building physics. Details about the selected literature have been previously published [3]. In this paper, only results obtained by Walker [4] thanks to CFD simulations and measurements on a scale model, for an unpartitioned building, with natural ventilation, are considered.

Software

Software used in this research are FLUENT for the CFD approach and TRNSYS17 for the multizonal approach. FLUENT is a widely used software for studies on fluid dynamics while TRNSYS is a well established and validated dynamic multizone software [5].

Case study: an unpartitioned building

For this study, an open-space office building was chosen because this configuration is often encountered in office buildings. Figure 2 shows the geometry of the studied scale model used for the collection of experimental data [4]. A conversion was used to obtain the value at real scale. Table 1 describes the main hypothesis done to run models.

Hypothesis	Walker	Trnsys	Fluent
Boundary temperature [°C]	13	13	13
Air supply temperature [°C]	13	13	13
Internal gain by zone [W]	500	500	500
U wall [W/m²K]	0.39	0.39	Adiabatic
South fenestration by zone [m²]	0.0336	0.0336	0.0336
North fenestration by zone [m²]	0.04788	0.04788	0.04788
Inlet speed [m³/s]	0.1	0.1	0.1
subdivision	-	5 zones	1 244 722 cells

Figure 2 and Table 1: scale model geometry and main hypothesis

The referenced study presented hypotheses used to realize measurements in a scale model and CFD evaluation. Hypothesis for the new CFD model to reproduce Walker's results were available. But, some supplementary assumptions are needed to achieve the multizonal model:

- the simulation time step is 0.1h. The results are examined after a 200 hours long preprocessing period to avoid any impact of chosen initial conditions,

- airflows are evaluated thanks to the Trnflow add-on to TRNSYS. Where air supply is modeled as a fan, openings between thermal zone and exhaust openings are modeled as "large openings" with a constant discharge coefficient of 0.6,

- no solar radiations is considered in the model and external temperature is constant.

RESULTS

Conventional comparison – Flow

In Figure 3 presenting results obtained for multizonal and CFD approaches, we observe that TRNSYS results are consistent with FLUENT for the inlet flow but are not consistent for the outlet flow. Indeed, absolute flow differences are 6 in the south zones and vary between 209 and 220 in the north zones.

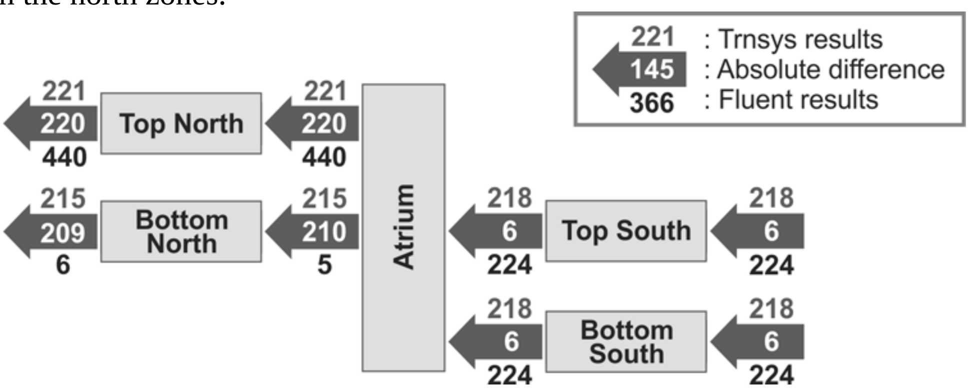

Figure 3:Net flows obtained with CFD and multizonal approaches and the absolute differences between these results

TRNSYS results spread equally the flow between the bottom and top North zone. On the other hand, FLUENT results show a different pattern. Indeed, the net flow mainly goes in the top North zone and almost zero in the bottom North zone.

For the inlet flow, the little difference is due to the density chosen for the incoming air 1.204 kg/m³ for TRNSYS and 1.225 kg/m³ for FLUENT. For the outlet flow, the difference is due to the simulation of the atrium as a unique thermal zone. This neglects the impact of thermal stratification and of the conservation of motion. Indeed, a thermal stratification occurs in such an atrium and the impact of this stratification on the flow direction explains CFD results

Conventional comparison – Temperatures

Figure 4 shows temperatures obtained experimentally by Walker [4], using CFD and multizonal simulations. The atrium temperature was not measured by Walker, however we computed it.

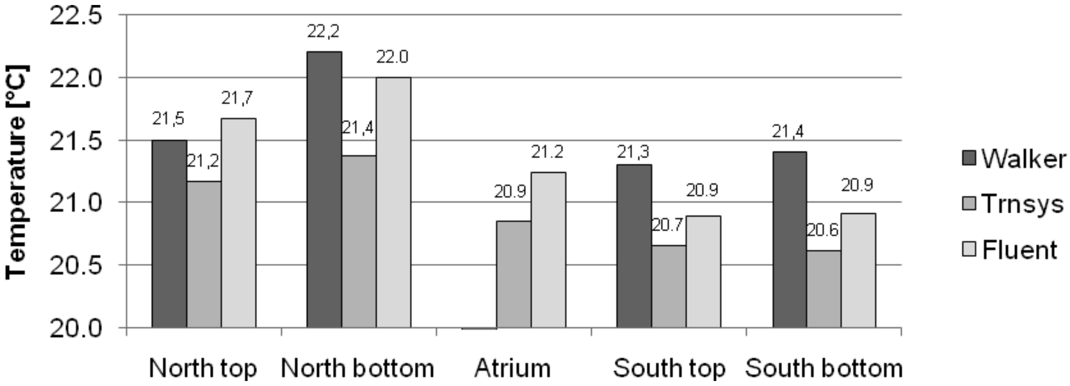

Figure 4: temperatures obtained experimentally by Walker, numerically by CFD and by multizonal.

We observed that temperatures obtained with FLUENT are, for each zone, superior to temperatures obtained with TRNSYS. Moreover, measurements done by Walker are generally superior to results obtained by simulations.

Table 2 presents absolute and relative differences between measurements done by Walker and numerical results (multizonal approach with TRNSYS and CFD approach with FLUENT).

	Absolute difference Walker-TRNSYS	Absolute difference Walker-FLUENT	Relative difference Walker-TRNSYS	Relative difference Walker-FLUENT
Top North	0.33	0.17	2 %	1 %
Bottom North	0.83	0.2	4 %	1 %
Atrium	-	-	-	-
Top South	0.65	0.41	3 %	2 %
Bottom South	0.79	0.49	4 %	2 %

Table 2: absolute and relative differences

Absolute differences between TRNSYS results and measurements vary between 0.33 and 0.83°C. The precision objective: 0.5°C, as explained in the methodology, is not achieved. Absolute values from FLUENTresults vary from 0.17 to 0.49°C. In this case the precision objective is achieved. The relative errors vary from 2% to 4% for Walker- TRNSYS comparison and from 1% to 2% for the Walker-FLUENT comparison.

Graphical confrontation method - Temperature

As explained in the methodology we consider that the acceptable range of accuracy is given by the numerical results +/- 0.5°C. By this way, ranges in the five simulated zones are defined as follow:

Top North :	[20.7°C ; 21.7°C]	Top South:	[20.2°C ; 21.2°C]
Bottom North :	[20.9°C ; 21.9°C]	Bottom South :	[20.1°C ; 21.1°C]
Atrium :	[20.4°C ; 21.4°C]		

Figure 5 illustrates, for each zone:

- the temperature distribution in the central plane of the building obtained with CFD;
- the matching of multizonal results (range of temperature defined above) for each occupied zone (shaded area),
- the matching of multizonal results for each zone (white line).
-

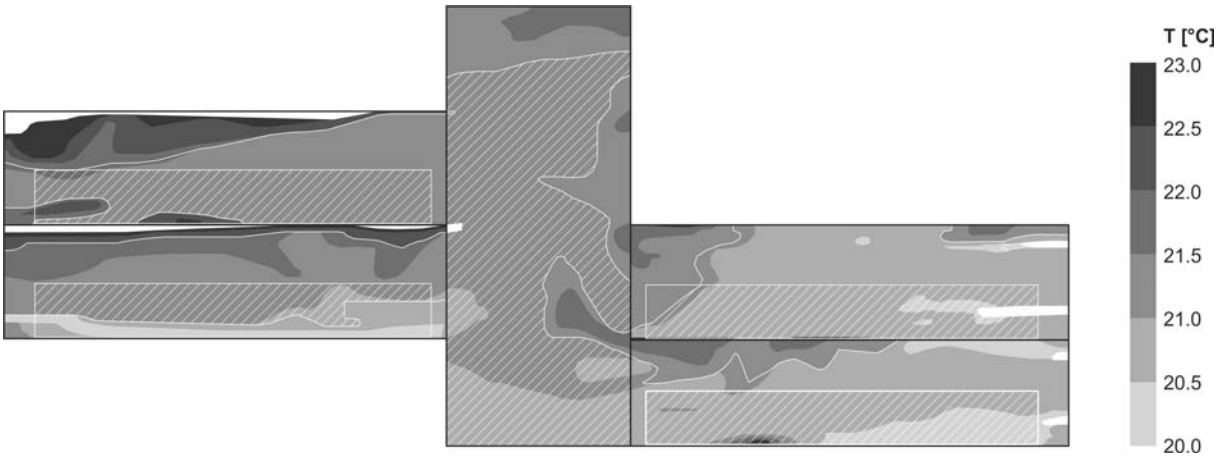

Figure 5: The temperature distribution in the central plane of the building section obtained with CFD and the matching of the multizonal results for each zone (white line) and for each occupied zone (shaded area).

Table 3 provides the percentage of space where the multizonal approach is correct for each zone and each occupied zone.

x %	Total zone	Occupied zone	x %	Total zone	Occupied zone
Top North	66	90	Top South	81	92
Bottom North	68	63	Bottom South	85	100
Atrium	74	-			

Table 3: percentage of matching between the multizonal and CFD results

DISCUSSION

When analyzing absolute differences and relative errors, CFD leads to more accurate results. However by the graphical superposition of CFD and multizonal approaches, the method indicates that the multizonal approach gives matching between CFD and multizonal results for more than 66% for each zone. Furthermore, for the occupied zone, better matching is obtained.

Indeed, for the bottom South zone, multizonal results correspond to 100 % of CFD results in the occupied zone. For the South and North top zones 92 % and 90 %, respectively, of multizone results match with CFD results for occupied zones. However, the bottom North zone presents a different pattern: indeed, only 63% of the multizone results match with the CFD results. The bottom part of the occupied zone is over estimated by multizonal approach. In the case of an office building, this may lead to a thermal discomfort.

In general, better temperature matching is obtained in the South zones where flows were better estimated by multizonal approach.

Despite that, absolute differences between measurements and multizonal approach results are 0.79 for the bottom South zone and 0.83 for the bottom North zone, while the matching in the occupied zone is 100% in the bottom South zone and only 63% in the bottom North zone.

CONCLUSION

Absolute differences and relative errors are efficient tools to discuss mathematical quality of approaches, but do not exactly reflect the pertinence of these approaches. The pertinence that we defined as the ability to give a useful indication for the designer is more efficiently evaluated if approaches are compared for relevant values. Relevant values, when speaking of thermal comfort, are those related to occupied zones and allowing the identification of normatively defined comfort zones.

The graphical superposition of CFD and multizonal approaches allows bringing out some nuances to the comparison of these approaches and improves the appreciation of the multizonal evaluation of the mean ambient temperature.

In fact, for the example presented in this paper, multizonal errors are smaller if compared to measurements in the occupied zone only. Moreover, multizonal approach results are representative of a significant part of that occupied zone. This argues for the pertinence of this approach despite the disappointing values indicated by traditional "error based" comparison.

ACKNOWLEDGEMENT

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MODAL ARCHITECTURE: AN INTEGRATED APPROACH TO BUILDING INFORMATION MODEL, SIMULATION BASED DESIGN AND LEED ENVIRONMENTAL RATING

LAC – Leed's Automatic Credit Check - Plug-in

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ABSTRACT

The most sophisticated international systems of environmental certification –such as LEED, BREEM and GREEN STAR, consider building processes and building life cycle. They estimate the building sustainability level not only on the basis of the "static" performance, but they take into account the "dynamic" process of production, employment and disposal.
Therefore, a correct planning methodology should be able to observe the multiplicity of parameters on a horizontal path that gives the same weight to environmental issues, energetic efficiency, construction processes, costs and materials. Making an effort to relate since the beginning the parametric planning with the sustainable approach, and relying on a comprehensive simulation tool may be an effective solution to control the dynamic planning process, optimizing the project in real time.

This paper presents the synthesis of a protocol finalized to the sustainable design process including a wide range of aspects (space, energy, environmental rating) and controlling lots of variables.
Introduction confronts the ordinary design approach with ours process proposed; Method describes the practical job organization in the BIM ambient; Results defines the work articulation subdivided in 6 phases and, like example, the main first phase structure called *Outside* ; Discussion concludes with the typical LEED credit calculation through the LAC application (Leed Automatic Credit Check), studied for the *Allplan* parametric software.
The LAC - developed by a work team that included designers, technicians and programmers - represents an advanced tool to construct a coherent computerized language which may improve communication between the parts involved in complex building processes, unifying different codes in a single integrated system.

INTRODUCTION

The design praxis, could be seen subdivided in two aspects that we can define *process* and *tools*, with different development levels and structures. For example, if we consider three fundamental topics in the planning like *space, energy and environmental rating*, they're usually distributed along a linear process, where one follow the other like a train on the railway. In this case, also we use sophisticated software and computers, we cannot guarantee however a simple interactions between different parts and solutions. But if the *linear path* evolves in a *spiral path*, we can observe that the main aspects return more than one time during the process, provoking natural interferences to every inner passage towards the center, that represents the right balance between many requirements.

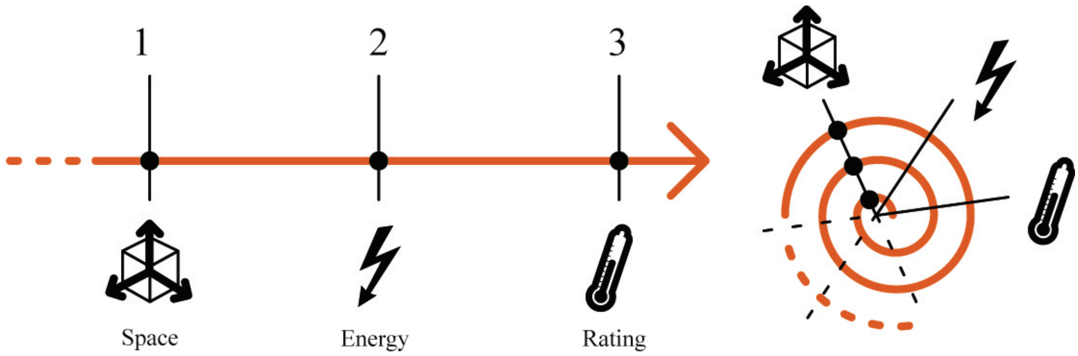


Figure 1: The linear ordinary design process confronted with the Spiral Path that allows interferences and optimizations

So, objectives and constraints for the project aimed at environmental sustainability are identified, and the design variables are defined and controlled since the beginning of the process, through the SBD methods (Simulation Based Design) and accordingly optimized.
We have called this approach "*Modal Architetcture*".

METHOD

The starting point of the Modal Architecture methodology is a simplified three-dimesional inner spatial model (Core), which satisfies the initial design requirements through an advanced parametric software (Allplan by Nemetschek).
Around the Core we can construct the information database, that we can upgrade during the design process, intimately connected to different software to control energy values, light performances, sustainable choices in bi-directional links with the spatial structure .
From the beginning until the end, data are closely linked in a dynamic structure in a Building Information System (BIM), that represents the elastic platform where the designer can put and extract every kind of information.

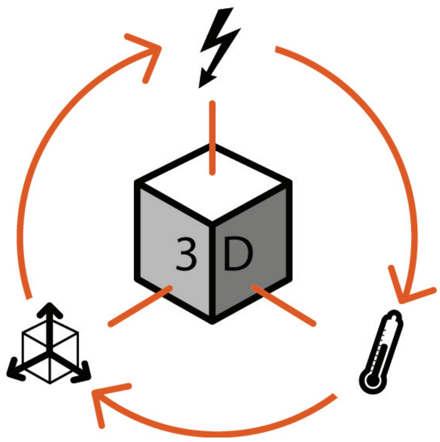
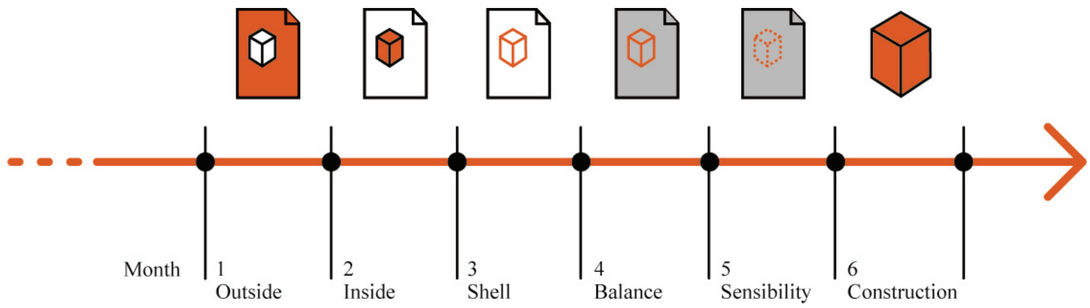


Figure 2: The BIM platform, necessary to organize around the parametric 3D model the different data set (IN-OUT)

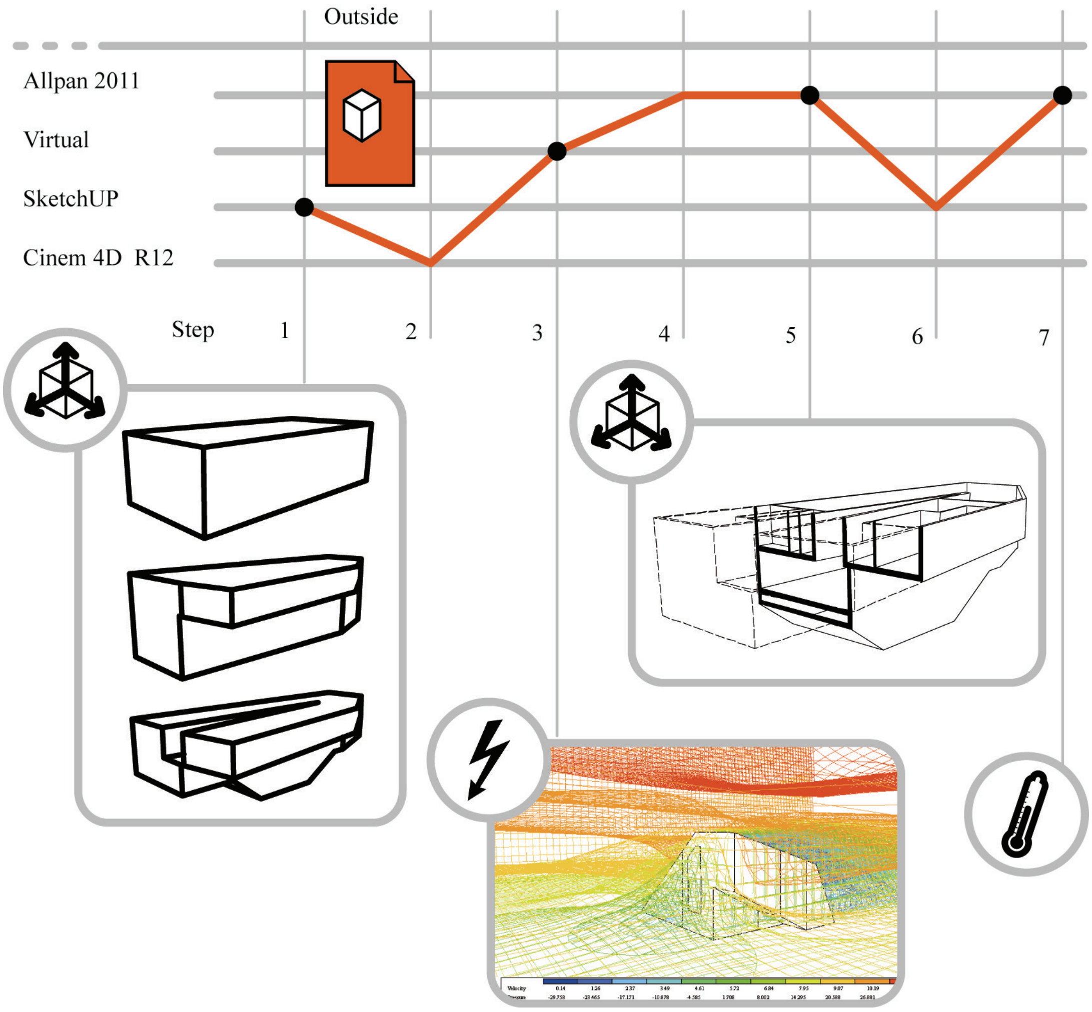
For every architectonic progressive step, we can verify in real time how the different environmental performances evolve, until to arrive to the better configurations or the hightest LEED's score as possible. In the same way, if we modify for example the energetic data, we can observe how the spatial distribution change consequently.
In the Modal approach, the environmental rating don't arrives at the end of the process, but in-itinere during the creative activity, measuring the architectonic space with the sustainable meter, in a holistyc and organic vision, exactly how the real spatial experience is.

RESULTS

At the opposite of the classical design way, where we define plants, prospects and sections and after develops the 3D model, in the BIM ambient we build the virtual model before and then we extract every information in graphical or alpha-numerical format.
Into this specific perspective, we have organized the *modal* workflow from the general to the detail in a deductive form, articulating 6 phases from the *Outside*, passing to the *Inside*, the *Shell*, the *Balance* between Out-Inside, the *Sensibility,* and arriving to the *Construction*.



The first phase's output will be the input for the following, developing alternative scenes.
The parametric flexibility, reflecting his nature, will allow a wide range of possible jump between all the phases, facilitating the verifications every time that could be necessary.



Figures 3-4: The six Modal's main phases and the first phase's steps example (Outside).

Every phase has some steps that describe the sequential passage in many different software. The diagram on the top of the 4^{th} figure represents the "*pentagramma*" where we can read the step and the correspondent software used to upgrade the model, increasing the information contents in.
Bottom, the same picture show some critical passages of the first phase, regarding the architectonic *Outside* control, where we can define in many iterances:
1_alternative envelopes with constant fixed volume (Sketchup)
3_external air flows and sun incidence on the surfaces (Virtual Environment IES)
5_optimization in a parametric entity and plants-section extraction (Allplan Nemetschek)
7_site sustainability measured with the LEED protocol(LAC tool for Allplan)

DISCUSSION

LEED is the most advanced international environmental rating system developed by the Green Building Council USA, but in the *Modal* approach we use his protocol like a simple design guide, that returns in many steps during the verification process.

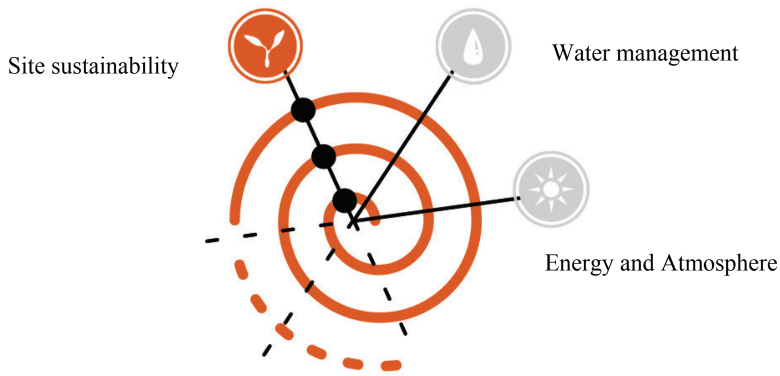


Figure 5: The LEED credits in the Spiral path application where are shown the successive deepenings

The protocol is organized in 7 main sections (*Site, Water, Energy and Atmosphere, Materials and Resources, Indoor quality, Innovation, Regional priorities*) with relatives credits which correspond more than 100 score, and it releases 4 different certification levels (*Base, Silver, Gold, Platinum*).
Using the credits from the beginning, the control possibilities are implemented with the LAC tools that we have realized, that allows a total graphic integration in the same design ambient.
For example, the following figure 6 describe the sequence in the *Site Selection* evaluation (*Site Sustainability section, credit 1, 1 point*), where the green soil percentage is putting in relation with the build soil, to define a right balance and to obtain the point.
The easy steps are:

1. Open the *Site Sustainability* directory, where are available specific graphic *assistants*
2. Select the *green restored* button to describe the planned green areas, then the grey button to define the *building footprint*, and at last the white button for the total site boundary
3. Immediately, appears the synthesis table where is shown data and the credit calculation
4. If you don't have caught up the score, you can modify the design in graphical way, and thanks to the Allplan's parametric engine, you can see in real time how the data set upgrade until are verified the correct condition.

Concluding, Modal approach and LAC plug-in demonstrate how is possible syntonize process and tools if they're thoughts like *open systems, ready to use and reversible*.
Probably exactly a good architecture could be.

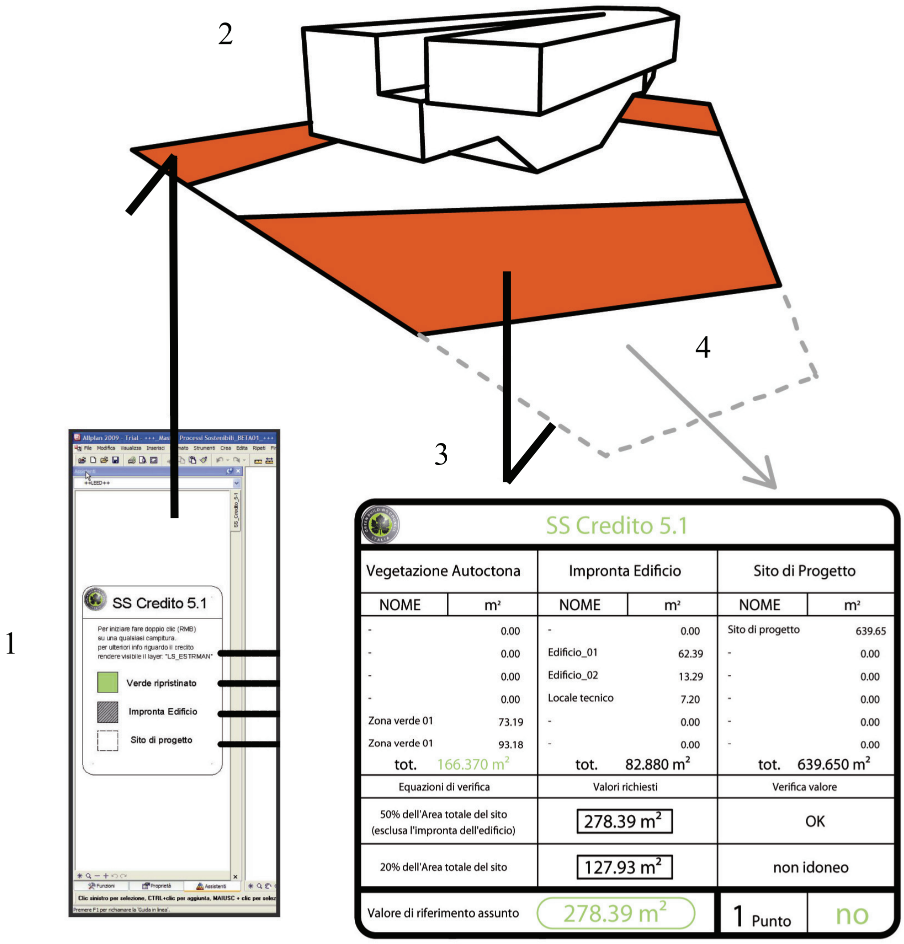


Figure 6: The LEED credit Site selection automatic evaluation whit the Allplan's LAC plug-in

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This paper presents the work that the research team charged by Fondazione per l'Alta Formazione di Feltre (Architecture Department: ABC_Architecture Base Camp) and the Dolomiti Industrial Confederation have started: develop a computerized procedure aimed at the maximum efficiency of sustainable building processes.

This protocol , available today for the professional activities, will be used in the International Master in sustainable constructive processes that will start in autumn, in partnership with the IUAV (Venice Architecture University Institute), to form professional profiles cross-sectional to the currents specializations, able to control the entire design process.

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COMPARISON OF SIMULATION RESULTS WITH MEASUREMENTS OF THE DECTHLON BUILDING OF THE UNIVERSITY OF ROSENHEIM

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ABSTRACT

For a prototype building of a plus energy house, contributed to the Solar Decathlon 2010 by University of Rosenheim [1], attention was paid to the development of an own solar protection system. This system should both meet sophisticated architectural claims, and provide an efficient reduction of the solar loads. Due to the high angle selectivity of the solar shading effect and the dynamic behaviour of the reduction factors (both direct solar transmittance (Te) and total heat gain coefficient (g)), it was a challenge to implement this specific façade system into a simulation environment. This was realized with a modified double glazed façade model of "IDA Indoor Climate and Energy" (IDA ICE). Satisfying correlation of the simulation results with measurements was met by:

- the basic models of IDA ICE
- adapting the simple window in the double façade model with angle dependent Te and g values to consider the complex geometry of the façade
- using the "air gap" in the double façade model to account the convective and emitted heat transfer of the preheating shading device.

The remaining inaccuracies of the results are caused by the simplification of the double façade model. The detailed influence of the secondary heat loads and the viability of the "air gap for double glazed façades" approach has to be investigated in more details and for more critical climate, e.g., during hot periods

INTRODUCTION

Figure 1 : Zigzag shading of the prototype building [2]

The Solar Decathlon provides the opportunity for students to plan and build a plus energy home. More than less 20 Universities take part on every Solar Decathlon competition. The project takes about two years and in the end of this time all participating houses have to build up on a competition area. After one week of contest, which all homes are compared in detail, a winner will be announced. The University of Rosenheim took part in the first Solar Decathlon Europe in Madrid. After the student competition the contributed house was build up on the campus of the University. There was realized five weeks of measurement. With the aim to compare simulation results of IDA ICE with measuring of a real building.

DESING OF EXPERIMENT

To focus the validation to the model of the innovative solar protection, four different measurement periods were recorded. This procedure was chosen in order to isolate the different effects and their contribution to simulation uncertainty. During the first two periods, the solar shading system was inactive and the main heat flows were calibrated, including transmission, convection and radiation, as well as heat storage effects by thermal activation of the building components. After this base model calibration, the shading was added to both the real measured building and the simulation model for the third and fourth period. Thus uncertainties due to an inaccurate base model were eliminated. During period 3 and 4, the main differences between measurement and simulation are therefore caused by the façade model. This enables a detailed analysis of the developed shading model.

The first period – **„Free floating without solar protection“**

The second period – **„Heating without solar protection“**

The third period – **„Heating with solar protection”**

The fourth period – **„Heating with controlled solar protection“**

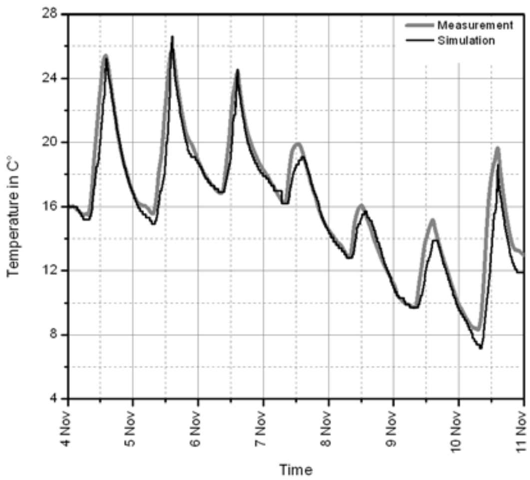

Figure 2: Air temperature of the zone winter garden during the period "Free Floating without solar protection"

Figure 2 shows measured and simulated indoor air temperatures of the zone winter garden in first period "Free floating". A good correspondence between simulation and measurements can be observed. This assures, that the simulation model of the building produces realistic calculation results. Before focusing on the developed shading model (validation periods 3 and 4), we go into the state of the art window and shading models.

STATE OF THE ART WINDOW/SHADING MODELS

The state of the art window and shading models presented in nowadays simulation programmes can be divided into two categories: "Simple" and "Detailed". The two models differ in their way of calcuating the energy transmission through the glazing.

In the simple window model, total solar heat gain coefficient g, direct solar transmittance Te, visible transmittance Tvis, glazing U-value, internal and external emissivity are given as static values. Even if this approximation is completed with (fixed) angle dependence, it may not be sufficient i.e. for coated glazing or slated shadings. In the detailed window model, solar properties are given layer by layer and angle dependence of g, Te and Tvis is calculated from these properties, valid for normal incident angles according to ISO 9050:2003 [3]. For properties for diffuse radiation, the layer properties are averaged over the hemisphere according to ISO 15099:2003 [4]. Unlike the simple window model, the detailed model calculates convection between panes according to ISO 15099:2003, which is particularly relevant for ventilated cavities as spaces between glazing and shading.

The two models differ as well in their way of modelling **shading layers**. In the simple shading model, the (fixed) transmission properties are simply reduced by multipliers (between 0 and 1), when the shading is active. This means, that the angle dependency is not influenced by the shading. In the detailed window model, some typical shading layer types like venetian blinds are available (and calculated according to ISO 15099:2003). However in modern architecture, more and more innovative solar protection systems are used. It becomes more important for the engineer to understand the detailed physical processes in and on the façade. In order to get more realistic results, it is necessery to develop new models or modify existing models to characterize specific systems.

ZIGZAG SHADING (ZZS)

The detailed window model is available in only a view building simulation software. But even with those, models for solar shading systems only cover the classical "Screen" shades or „Venetian Blinds" (lamella system). To have the full flexibility of being able to simulate any innovative system (like the Zigzag shading (ZZS) presented below), a transparent software with adaptable models is needed. Otherwise, it gets either expensive or big simplifications lead to high risks of errors. Often the behaviour of such new facades strongly differs from that of the screen or the horizontal lamella. It will mostly not be sufficient to feed the standard shading models with more or less correct average reduction factors.

Angle Dependent Transmittance

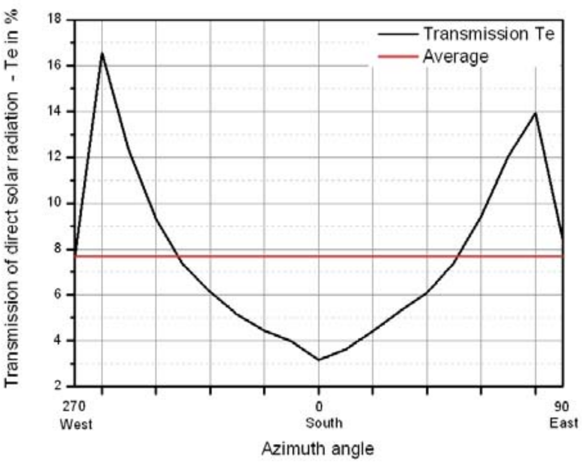

Figure 3: Transmission of the direct solar radiation through the south orientated Zigzag shading at 15. June on the location Madrid

Figure 3 shows the angle dependency of the ZZS, calculated by a daylight calculation (Raytracing) with a 3D CAD model of the Zigzag layer inserted. The characteristic is caused by the geometry of the Zigzag construction, and effects that with sunrise and sunset, a higher percentage of the solar radiation reaches the window by the rhombs. While with a southern solar altitude, almost no radiation passes the shading. Such a shading behaviour can by far not be described by a "classical shading layer" with fixed reduction factor (as we will show with a model comparison further down).

Secondary Heat Loads

Another problem for the simulation of this Zigzag shading is the preheating of the ambient air in the partly enclosed space between the shading layer and the glazing, caused by absorption of the solar radiation on the aluminium surface. This preheating causes so-called „secondary heat loads", reaching the zone by longwave radiation and convection. If the ZZS is closed, solar load is mainly caused by this secondary heat loads [5]. As solar loads (specifically in domestic buildings) always are a non negligible contribution to the total zone heat balance, it can be important to consider these heat loads carefully.

MODEL APPROACH

The first idea was to insert an external shading 3D object for the ZZS into IDA ICE. With this method, it would be possible to consider the complex geomtery and its angle dependent direct solar transmittance, but not the thermal behaviour (secondary heat loads) and the control of the shading. That is the reason why this first idea was rejected. Instead, the problems were solved by the use of the double façade model of IDA ICE. The idea consisted in substituting the external glazing of the double façade with the geometry of the ZZS and in taking over therefore the basic settings (calculation of the secondary heat loads, control etc.) of the façade model.

Angle Dependent Transmittance

For the geometrical representation of the ZZS, the variable for the transmission of the direct solar radiation (FThruDir) was changed in the simple window model. FThruDir is defined as the ratio of the surface of an opening (rhomb) and the surface of an element of the shading (see Figure 4). The variable reflects the window surface ratio "seen" by the sun. This means: If the sun is in the south (normal to the façade), it can only "see" the “element” and the surface ratio is 0, i.e. no solar transmission. If the sun is in the east or the west, it can only “see” the “rhomb” (opening) and the surface ratio is 1, i.e. no reduction of the solar radiation.

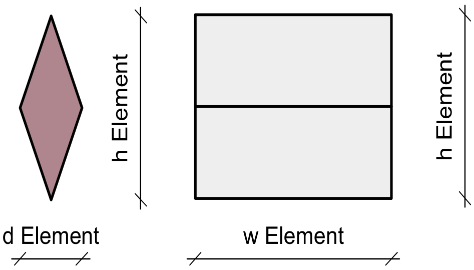

Figure 4: Geometry of "rhomb" and "element"

Formula (1) reflects how the transmission degree of the solar radiation (Te) is calculated in dependence of the solar altitude (azimuth). For solar irradiance nearly parallel to the façade (-90° and 90°), a critical angle is calculated (when the elements start self shading each other - see Figure 3). For the external layer of the double façade, the geometry of ZZS was considered by using the simple window model, completed with equation (1).

$$Te = \frac{rhomb * \sin(azimuth)}{element * \cos(azimuth} = \frac{d\ Element}{2 * w\ Element} * \tan(azimuth) \qquad (1)$$

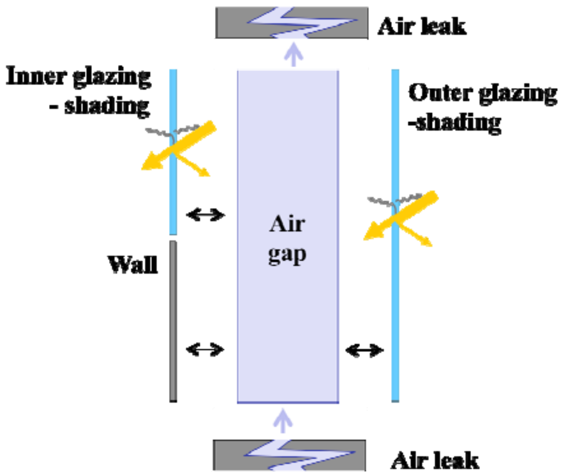

Abbildung 5: Principle of the air gap model for double glazed facades

Secondary Heat Loads

The thermal effects in the space beteween the Zigzag shading and the window are not trivial. It would have exceeded the possibilities of this project to describe in detail the preheating of the air in this space and the massflows from and to the ambient. With help of the model of a ventilated gap between two heated surfaces (developed for double glazed façades – see Figure 5) it was tried to get the simulation results closer to measurements.

The following main inaccuracies could get relevant together with this model approach:

- The air gap is always present in the model, even when the shading is inactive.
- The air leaks between the ambient and the gap are in reality not on bottom and top (as assumed from the model), but distributed over the whole external surface. The parameter “equivalent leakage area” get physically meaningless and has to be calibrated.
- The Zigzag surface towards the air gap is in reality not flat as assumed from the model

SIMULATION RESULTS

Simulation results, generated with the “Zigzag model” described above, were compared with those, generated with the “state of the art window models”. The goal was of course to get results significantly closer to measurements with the “Zigzag model”. Results from the following models were compared:

> **Zigzag:** This is the model described above. The new model approaches should be evaluated.
>
> **Screen average:** This model describes a simple screen shading with static reduction factors for solar transmittance. Te = 0,078 is taken from Figure 3 as reasonable mean value. This model should represent the ”best reachable with state of the art models”.
>
> **Screen standard:** This model describes a similar simple screen shading with static reduction factors for solar transmittance. This time, Te = 0,22 is taken, as it could be assumed from real measurements with external textile screens [6].

Figure 6 show the room air temperature of the zone livingroom during the period “Heating with regulated solar protection”. The wide grey curve corresponds to the measurements and the slim lines to the simulation results of the different models. The results clearly show that the Zigzag model achieves a better correspondence with the measuring results than the two state of the art models do. “Screen average” has relevant disagreements, which do not remain with the new model approach.

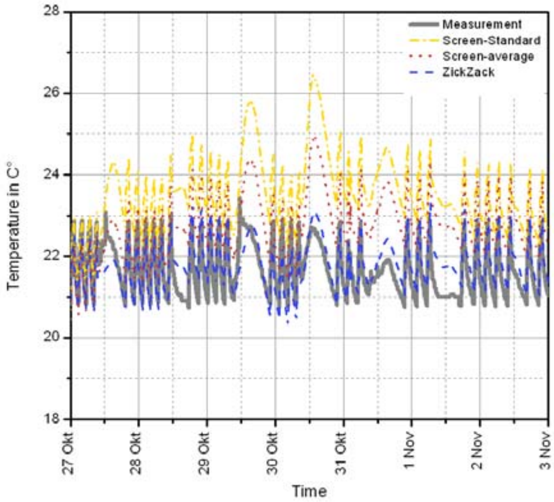

Abbildung 6: Air temperature in the zone "livingroom" during the period "Heat with regulated solar protection"

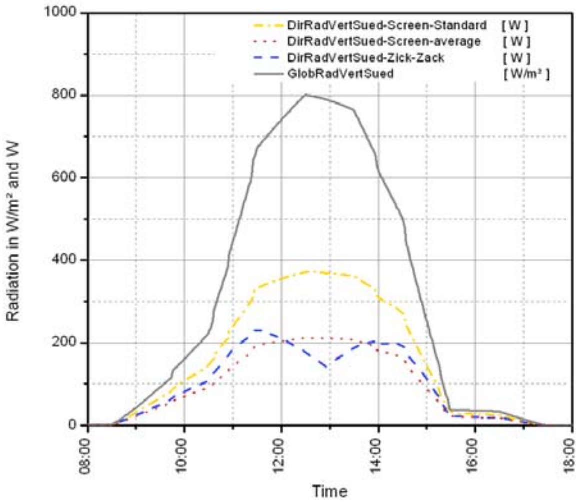

Abbildung 7: Calculated direct solar radidation reaching the zone livingroom through the south facade - 10/19/2010 Rosenheim

For a more detailed analysis of comparison, the direct radiation through the south façade of the building and their impact results can be taken from the figure 7. The dashed curve of the Zigzag shading show a good description of the angle selectivity. The morning (east) and evening (west) peak as well as the total shading at noon are clearly identified. Regarding energy, the direct comparison of the dashed line with the "Screen average" shows a good correspondence. The more exact (dynamic) picture of the temporal distribution by the Zigzag model provides a better accordance with the measurements on days rich in radiation, as seen in figure 6. The weaknesses of the state of the art models can not only be explained with the variable shading reduction factor. The divergences of the shading models also play a role. For example the double façade model compared to the Screen, has a more realistic illustration of the space ventilation between shading and window. The two model ameliorations "angle dependent transmittance" and "secondary heat loads" are not seperated in this model comparison. Some "quick studies" showed that both approaches help to get better results. The remaining differences between simulation results and measurements can probably be explained by the described weaknesses of the double glazed façade approach.

CONCLUSION

The developed model for the Zigzag façade delivers a satisfying correspondence with the measured values. The angle selectivity of the system is well illustrated. It is obvious that the model generates advantages for the calculation of cooling loads and the assessment of comfort conditions compared to state of the art shading models, using a static transmittance reduction factors. The detailed influence of the secondary heat loads and the viability of the "air gap for double glazed façades" approach has to be investigated in more details and for more critical climate, e.g., during hot periods.

The Zigzag shading can be regarded as a "representative innovative façade system". Such systems are often developed to get non standard solar radiation properties, which are caused by geometrical or strutctural (e.g. reflective surfaces) characteristics. The example presented in this paper shows that specific simulation models are needed to evaluate the relevant effects of innovative shading systems. To get such models with practicable effort, it was advantageous to profit from a well developed building simulation tool with flexible equation–based component models, as IDA ICE is providing with either the Neutral Model Format (NMF) or modelica.

ACKNOWLEDGEMENTS

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PARAMETRIC SCRIPTING FOR EARLY DESIGN PERFORMANCE SIMULATION

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ABSTRACT

The research presents the potential of a new design approach prevalent among architects to address the notoriously difficult early design stage building performance assessment. Through the use of computer code (e.g. *scripting*), designers are becoming more and more able to automate the geometric description of architectural form. By extending this paradigm to Building Performance Simulation (BPS), it becomes possible for a non-expert user to generate sufficient construction details and building usage information to run full-featured BPS tests. Although limited in their relevance by the users' lack of expertise, such tests can provide early insight in the influence of key parameters on the overall performance. When the scripting approach additionally provides an opportunity for real-time parameter update (e.g. *parametric scripting*), parameter space can be extensively explored allowing designers to easily modify simulation information for interactive comparison of design alternatives.

In the paper, the authors present the approach by describing an experimental toolset taking the form of a parametric scripting engine with a set of interfaces to validated expert-level BPS tools, and explain how the toolset integrates into the design process. The potential of the approach for performance assessment is demonstrated through a simple housing case study addressing daylighting, thermal gains and natural ventilation questions. These inherently conflicting aims can be tested for a given set of design constraints, allowing the designer to make informed choices between differing design solutions.

This new design paradigm is relevant in terms of next generation BPS tool development by providing an alternative to current user interfaces traditionally difficult to learn. It also questions the current role definition between BPS expert and designer in transferring a significant part of simulation information definition to the designer, possibly to the benefit of both parts. Last but not least, the approach enables the early assessment of building performance even in the case of partly undefined designs.

INTRODUCTION

The field of architectural design research and practice has lately witnessed the growing use of *scripting* - the use of computer code instructions (possibly visual) to define architectural form - and *parametric design* - maintaining a dynamic link between parameters and their use in form definition, enabling real-time continuous parameter space exploration. This trend has received few attention from the building physics community, possibly due to its propensity to produce designs less concerned by performance than impressive smooth shape. The research presented here demonstrates, through the development of a scripting design framework, how this designers' interest to define form through computer code provides an innovative context to address open research questions relative to non-expert usage of Building Performance Simulation (BPS) [1].

In the context of parametric scripting, notions such as design alternatives comparisons, detail generation to populate simple massing studies, or data interoperability are considerably facilitated by automatic production, modification, or translation of model information with the help of code instructions. Scripting thus bears the ability to provide a different point of view on the nature of an easy-to-use BPS interface, the debate about using simplified tools versus subsets of full-featured tools, or the difficulty to define physical information at design time; topics identified as of importance for the use of BPS tools in the early design stage [2,3].

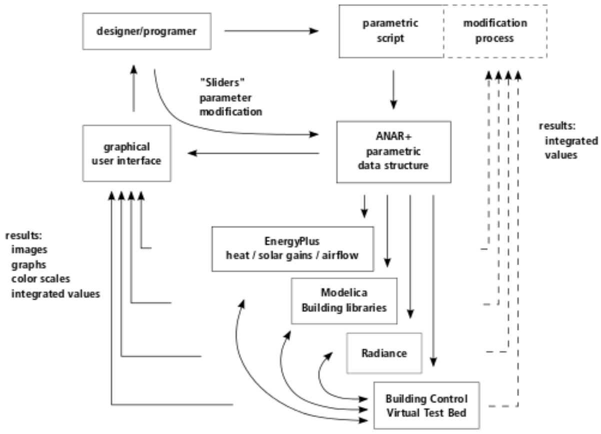

Figure 1: Scripting/simulation framework schema

METHOD

The research presented here proposes a prototype framework meant to represent a proof of concept of the potential of parametric scripting in the context of early design performance assessment. This framework builds on an open source parametric scripting modeling tool developed by the authors and used in architectural design studios [4]. Its main characteristic is to concentrate on geometry definition through written code instructions (the *parametric script* of Fig. 1). The graphical user interface allows continuous alterations of parameters through *sliders* (as presented in Lagios et al [5]), whereas topological transformations must happen through code modifications. This approach decouples definition from representation and forces the designer to “think before modeling” [4].

The geometric framework is extended by defining sets of higher level functions (e.g. an Application Programming Interface) that provide interfaces to several expert-level BPS software. Among several possibilities, the whole building simulation EnergyPlus and the physically realistic light simulation Radiance were selected. Further work will include the Modelica-based libraries Buildings [6] and BuildingsPhysicsLibrary (a hygro-thermal multizone building model [7]). Finally, an interface to the Building Control Virtual TestBed [8] allows to put previous software in interaction for innovative control modeling (Fig. 1).

Similar to the Animated Building Performance Simulation approach presented in [5] extended to thermal and airflow modeling, the tool runs daylighting, thermal, solar gains and airflow simulation through automatic production of simulation input files from the geometric description. Thank to the parametric capabilities of the underlying geometric engine, it provides the opportunity to systematically explore daylighting and thermal performance of strongly differing design alternatives as often required in early design stage. Input physical parameters are defined by default values, which can be easily redefined either through compound functions (e.g. *setAirTightnessLow()*) or directly accessing specific parameter values (e.g. *setCrackAirFlowExponent(0.667)*). Results may either be graphically represented (Fig. 1, left) or fed back if the parametric script contains the definition of a modification process according to performance (Fig. 1, right).

Such type of interfaces potentially provide full access to the capabilities of the several BPS while allowing simple early performance testing. Source code availability further allows tool extension by interested/advanced users through aggregation of common operations in code functions or objects, which bear the additional advantage to be reusable in future designs.

RESULTS

As an application demonstrating the potential of the approach, the research considers a 5-level housing building case study, in an urban context typical to Berlin (Germany), with continuous square blocks and backyards (Fig. 2). Form and detailing is not fully agreed upon and may be changed within constraints provided by local regulations. For instance, facades may include oriels, similarly to existing buildings from early 1900, whose maximal allowable size depends on the street width.

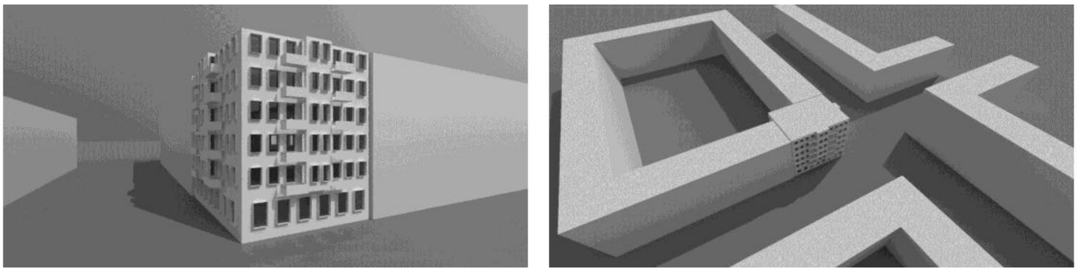

Figure 2: Typical Berlin-located 5-level housing case study and its urban context

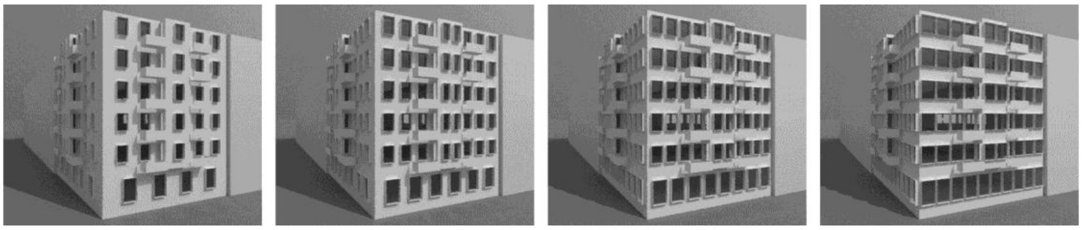

Figure 3: Variation of glazing proportion from 20% to 50% (left to right)

A

```
// ENERGYPLUS ----------------------------------------------------------------------->
EnergyPlus.setVentingMode(building.objEnd(), EnergyPlus.OPENTEMPERATURE);


EnergyPlus.setName(building.objEnd(), "zone"+b+i);
EnergyPlus.setControl(building.objEnd(),"naturalTempSchedule" );
EnergyPlus.setSchedule(building.objEnd(),"naturalTimeSchedule");

// all to default

for (int o=0; o<zone.numOfFaces()-2; o++) {
    f = building.objEnd().face(o);
    EnergyPlus.setName(f, "exterior_wall"+o+"_of_zone"+b+i);
    EnergyPlus.setConstruction(f, "exterior wall construction");
    ALL_EXTERIOR_WALLS.add(f);
}
```

Figure 3: JAVA code defining EnergyPlus information

parametric description expressing the constraints chosen as relevant by the designers is coded, with needed detail and material definition generated through code instructions (Fig. 4). Such details are not meant to be definitive: the use of code enables a simple method definition to initially populate the geometry, with subsequent change or refinement only requiring method adjustment. Differences in detail and geometry needs between BPS tools can be taken into account, such as the merging of windows sharing the same wall to fasten EnergyPlus computations. Example of possible variations are depicted in Figs. 4 to 6. Results presented below focus on the influence of glazing variation.

Daylighting

Varying facade glazing proportion from 20% to 50% (Fig. 3), daylighting availability is analysed for specific solstice days and intermediate sky using Radiance falsecolor inside renderings (Fig. 7). Such renderings can be produced interactively to understand specific parameter influence, while code instructions may systematically explore parameter space. Note that the potential of the approach is here only sketched, proper analysis calling for state-of-the-art dynamic daylight analysis [9].

Thermal Gains

The same approach in detail generation is used to drive EnergyPlus whole building simulations, this case being more demanding since thermal analysis requires zone definition, operation schedules and boundary information in addition to materials and geometry. Again results can be produced interactively for different variants with simulation time depending on number of zones and level of detail. In the case study, only solar gains are taken into account to estimate the extent of heating/cooling periods. The influence of glazing proportion increase on indoor temperatures clearly calls for appropriate shading and/or cooling strategy to avoid overheating (Fig. 8, top).

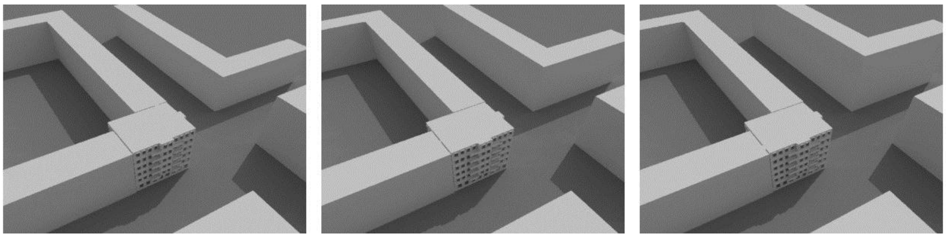

Figure 5: Variation of south-west building height from 20m to 30m

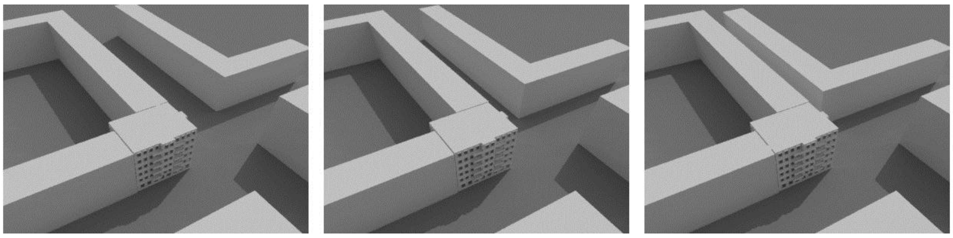

Figure 6: Variation of south street width from 25m to 5m

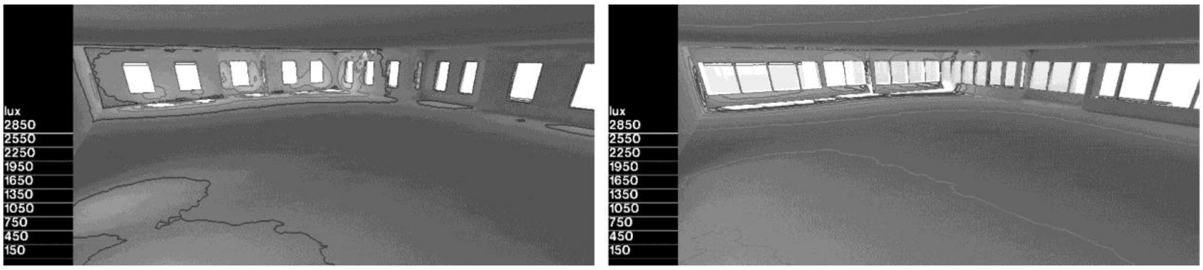

Figure 7: Inside false-color views for glazing proportion of 20% (left) and 50% (right) (third floor, summer solstice, intermediate sky, radiance parameters: -ab 5, -aa 0.08, -ar 512, -ad 1024, -as 512).

Natural Ventilation

As an additional level of inquiry, airflow network modeling is used to assess the potential of a given variant for passive cooling in summer. The parametric framework automatically produces airflow network parameters and topology for thermal co-simulation with EnergyPlus [10]. Only buoyancy effects are modeled given the difficulty to compute accurate wind pressure coefficients with the considered geometry variability [11] and ventilation is allowed from the evening on through the night. Results clearly show that night ventilation is able to counter-act solar gains by shifting the temperature spectrum towards cooler values and thereby increasing the amount of comfort hours (Fig. 8, bottom).

However, the window control model implemented in EnergyPlus inherently suppose automation, whereas user action on window has an effect on comfort temperature itself, as demonstrated by field studies [12]. To take this into account, the framework uses the *Building Control Virtual Testbed* (BCVTB) [8] in interaction with EnergyPlus to explore the potential of user-driven natural ventilation. A probabilistic model is defined in which users may open windows if the outside temperature helps in reaching comfort temperature or may close otherwise (Fig. 9). Given the stochastic nature of the model, users may leave windows open even in adverse conditions. The annual cumulated inside temperature differences between user-driven ventilation and automated night ventilation show that such a user behaviour --- if realistic --- would perform better on overheating, but may increase heating needs through inertia in window operation (Fig. 10). For validated realistic office user behaviour, one may implement the model from [13].

DISCUSSION

The work presented demonstrates the potential of parametric scripting in defining and analysing early design variants. By putting several BPS in interaction, the approach is also able to overcome tool limitations. This research complements similar work on daylighting by focusing on thermal behaviour for passive cooling strategies and actually represents a potential candidate to support the workflow wished by Reinhart and Wienold in [9].

As additional work, the evacuation of pollutants through natural ventilation will be assessed through an available BCVTB interface to Modelica (Fig. 1, [6]), which will provide ways to compare results between similar modeling tools to increase confidence on results. It will also enable problem-specific tuning of accuracy versus computational complexity to discriminate initial explorations needs to latter in-depth analysis. The feedback of performance results on form definition (Fig. 1, right), not addressed in this paper, will also need further research.

In the BPS community, the use of modular open-source tools such as BCVTB or Modelica addresses needs to test novel non-standard engineering solutions. Correspondingly - and despite the presentation of a standard case-study - the framework is meant for assessing the performance of non-standard architectural solutions. Subsequent work will thus concentrate on non-standard housing typologies.

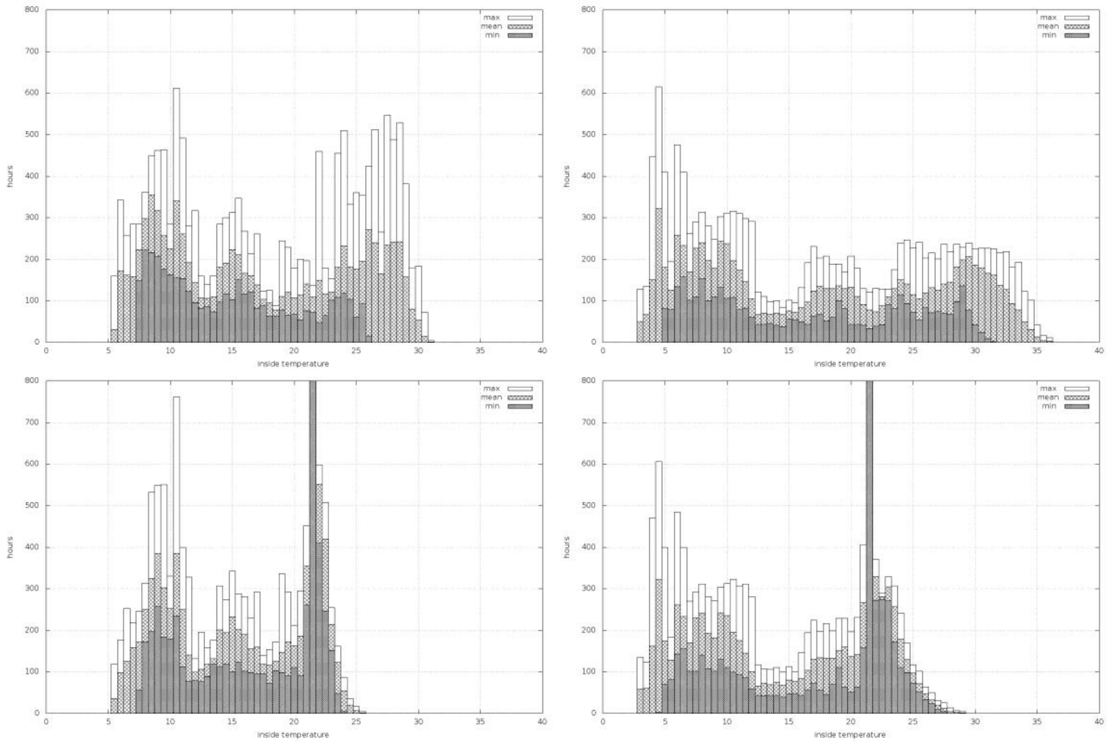

Figure 8: Annual cumulated inside temperature profiles for 20% (left) and 50% glazing (right). (top) non-ventilated building (bottom) passive night cooling (maximum, minimum and mean over all floors)

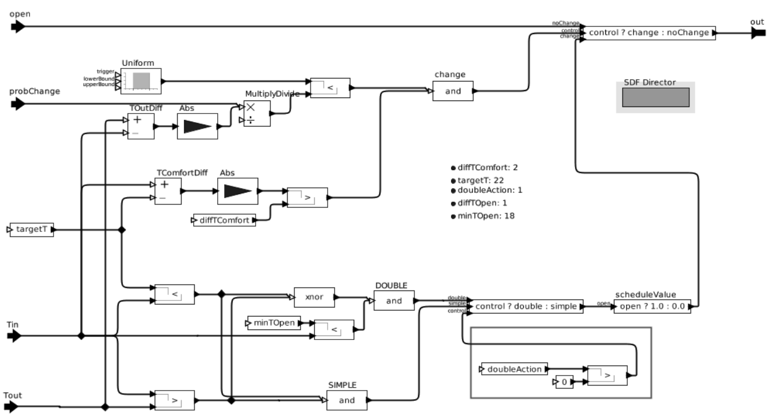

Figure 9: Probabilistic user model implemented in BCVTB

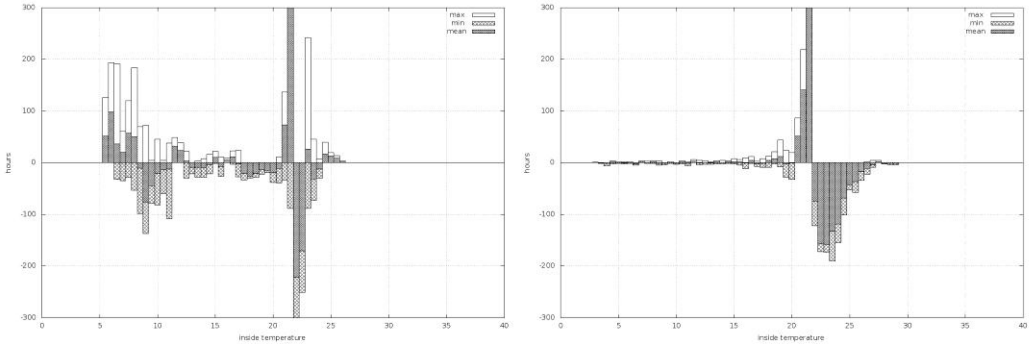

Figure 10: Difference between annual cumulated inside temperature profile with user controlled natural ventilation and automatic night ventilation. (maximum, minimum and mean over all floors)

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DIAL+*SUITE*

A COMPLETE, BUT SIMPLE, SUITE OF TOOLS TO OPTIMIZE THE GLOBAL PERFORMANCE OF BUILDINGS OPENINGS

Daylight / Natural Ventilation / Overheating Risks

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ABSTRACT

Estia SA in collaboration with the Laboratory of Urban Architecture and Energy Reflexion (LAURE/EPFL) has developed a suite of software tools aiming to assess in one row :

- Daylighting autonomy : **Dial+*Lighting***,
- Natural ventilation throughout windows : **DIAL+*Ventilation***,
- Thermal dynamic behaviour for winter or summer conditions : **DIAL+*Cooling***.

These three software modules are really user friendly and the implementation of original fuzzy logic rules makes the input easy and reliable. Furthermore, graphic outputs, and commented diagnosis with hints are provided in order to enable the designer to optimise his case-studies. It is then possible to get to the point directly, by asking to the user only for about 20 % of the effort required usually by the use of complex simulation tools.

This is a new possibility for the building designer to optimise both natural lighting and summer comfort (natural ventilation and overheating risk)

This paper presents the main features of the daylighting module and introduces briefly the ventilation and overheating modules.

INTRODUCTION

If we look to the building market evolution during the last decade, we can see that «Very low energy » buildings are no longer considered as «pilot projects». For instance, in Switzerland, the performance of «Low Energy » buildings corresponds to the minimal requirements of the national standard and the label «Very Low Energy» building (passive house) becomes mandatory for most public buildings. In this context, most of the efforts focus on the optimization of the thermal behaviour of buildings for winter conditions but very often, the questions of lighting and summer comfort are neglected in the design process.

However, if we want to make buildings consuming less than 50 kWh/m^2.year (primary energy), the lighting performance issue becomes very important.
Let's imagine an office room (500 lux requested on the work plane), equipped with high efficiency luminaires fitted with fluorescent tubes (average power = 10 W/m^2). Let's consider standard opening hours (8 AM-6 PM, 5 days/week). A 50% daylighting autonomy leads to an annual final energy consumption of 13 kWh/m^2.y (final energy), which means 32.5 kWh/m2.y (primary energy, conversion factor 2.5 for electricity).

This simple example shows that lighting could easily represent more than 50% of the total energy consumption of "Low energy" buildings!
The question is similar with summer comfort and the potential for passive cooling using natural ventilation. Although many simulation tools do exist, it appears that they are often too complex to be useful in the early design. Simplified softwares, dedicated to the optimisation and the control of natural lighting and passive cooling, are more and more necessary.

1 DIAL+*LIGHTING*

It is thus of very high importance to provide designers with conception tools that helps them to optimise their projects. Furthermore, it is essential that these tools are flexible enough to be used in the early stage of the design process. Another important point is to be sure that people who are in charge of the building performance control (state services, certifying bodies) are able to use the same tools. We also have to keep in mind that both “designers” and “controllers” are usually generalists and cannot spend much time to learn and use complex tools.

DIAL+*Lighting* is a continuation of the software DIAL-Europe[1] conceived, designed and realized at the beginning of 2000s within the framework of the “European Integrated Daylighting Design Tool, DIAL-Europe Project” by the following partners:

- Cambridge University Technical Services Limited,
- Ecole Polytechnique Féderale de Lausanne,
- ESTIA SA,
- Fraunhofer-Gesellschaft zur Forderung der angewandten Forschung c.v.d
- The Netherlands Organisation for Applied Scientific Research

When launched in 2003, DIAL-Europe was the first daylighting software dedicated to “non specialists” and it had been very welcomed either by academic institutions and architects.
In spite of a very poor marketing approach, the software had a particular success in France where it is still in use to fulfil the requirements of the HQE® method (daylight factor calculations). The simplicity of use was certainly one of the main reasons of the success.

The first challenge of the new DIAL+*Lighting* module was to allow the description of more complex shapes (DIAL-Europe was only available for shoe-box room shapes) so as to be able to solve 95% of the “real life” situations. The second challenge was to keep the input procedure as “fluid” and intuitive as possible in order to satisfy non-specialists and/or occasional users.
We first made the choice to maintain a “path” description mode as originally in DIAL-Europe. It means that instead of relying on a classic menu approach (the user has to search into popup menus to discover all the software possibilities), we guide him through successive windows focusing on each of the key design parameters.
We think that this way offers good guarantees regarding the accuracy of the description (less input errors) and also enables the user to improve his understanding on what is important.

Room geometry

To describe most of usual geometries, the user can choose between three generic plan shapes : Rectangle, L-Shape and Trapeze. Each room can be fitted with a single or double sloped roof. Finally, parallelepipedic obstacles can be placed inside the room in order to represent either rough furniture, vertical partitions, intermediate floors or even “blind zones”.
This combination allows the user to describe 95% of the rooms with an appropriate level of precision.

External obstructions

In addition, outdoor fins and blind systems can be described to take into account the light absorption and/or reflection.

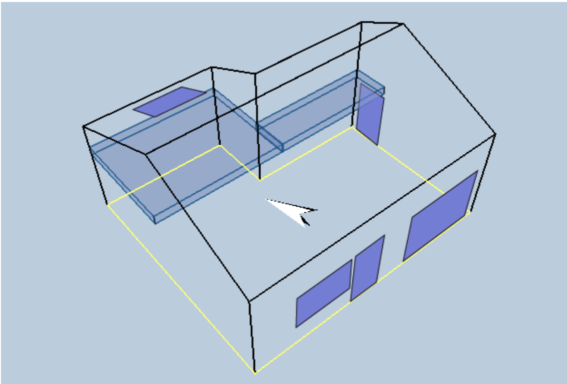
[1] DIAL-Europe : www.ibpsa.org/proceedings/BS2003/BS03_0421_426.pdf

Calculations

DIAL+*Lighting* can run simulations with Radiance[2] and Phanie[3]. Daylight factor calculations are made with CIE overcast sky and daylighting autonomy values are either derivate from the cumulative distribution of outdoor diffuse illuminance of the selected location, according to corresponding orientation factors (Meteonorm data), or calculated from cumulative distribution of skies luminances (Satellight data).

We have made the choice not to provide 3D images but to focus on the results (work-plane or any other room surface) in order to go straight to what is really useful to fulfil standards and norms.

This leads to fasten the simulations and allows this software to be used as real “production tool” for both design and control purposes.



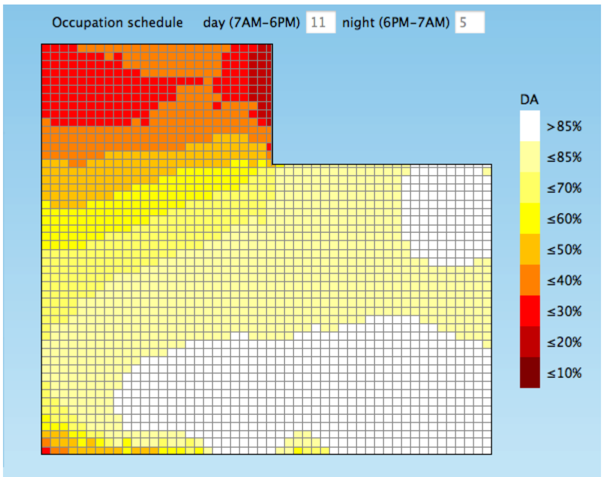


Figure 1 : Daylighting autonomy on the floor of a given indoor space.

Diagnosis

As function of the result, DIAL+*Lighting* may point out the design weakness in order to prompt the user to optimise the daylighting performance. This facility is based on fuzzy-logic rules[4].

Artificial lighting calculations are made using “generic” luminaires (IES distribution functions).

Illuminance values are processed on the different walls in order to check whether the dimensioning (number of luminaires, power, etc.) fulfil the requirements. According to the daylighting autonomy and the lighting commands, DIAL+*Lighting* estimates the annual electric consumption.

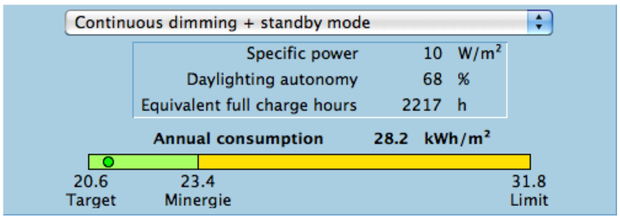


Figure 2 : Screen copy of the electric lighting diagnosis with the estimation of the annual electricity consumption according to the daylighting autonomy of the room (SIA 380/4).

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[2] Greg Ward. The radiance synthetic imaging system : http://radsite.lbl.gov/radiance/

[3] CSTB : Acoustic and lighting department http://dae.cstb.fr/en/webzine/preview.asp?id_une=46

[4] PAULE, B. Application de la logique floue à l'aide à la décision en éclairage naturel. PhD EPFL, no 1916 (1999).

2. DIAL+*VENTILATION*

DIAL+*Ventilation* is a module that allows the user to calculate the air-change potential due to natural ventilation. Depending on the opening characteristics and, the indoor and outdoor temperatures, the software calculates the neutral level and gives the instantaneous air-flow crossing the opening. Furthermore, it calculates, for a given condition, the time requested to renew the indoor air, which indicates the natural ventilation potential of the window.
This feature is very useful to make a sound design of the openings and can be particularly interesting for school and educational rooms.

Figure 3 shows that the ventilation potential depends on the window characteristics and the outdoor temperature.

- The yellow plane indicates the position of the neutral level (air pressure).
- We can see fresh air entering the aperture and warm air exiting the room

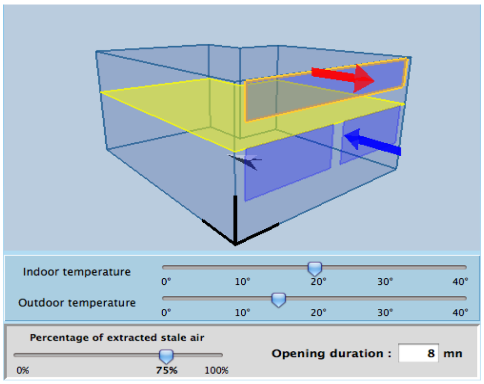


Figure 3 : Screen copy of a natural ventilation analysis.

3. DIAL+*COOLING*

If the user wants to calculate the evolution of the room temperature during a typical period, he just has to describe the composition of the walls, floor and ceiling, to indicate which wall is on contact with the exterior and to enter the insulation position and thickness. The wall composition and thermal mass of the room are taken into account in a physical based aspect.

The user can define easy-to-understand strategies to optimise the thermal comfort:
1) A max radiative power on the window from which shadings are considered as closed
2) A min inside temperature from which the shadings are considered as opened
3) A natural or mechanical night cooling ventilation during the hot season
4) A reduced ventilation during unoccupied periods

Tree different modules make the calculations.

Solar gain.
Depending of the geo-localisation of the project, the sun position is calculated for each time step. The software calculates the radiative power on each wall and roof as a function of the horizontal diffuse radiation and the normal direct radiation corresponding to the climate conditions. Overhangs and fins as well as horizon are taken into account for the calculations.

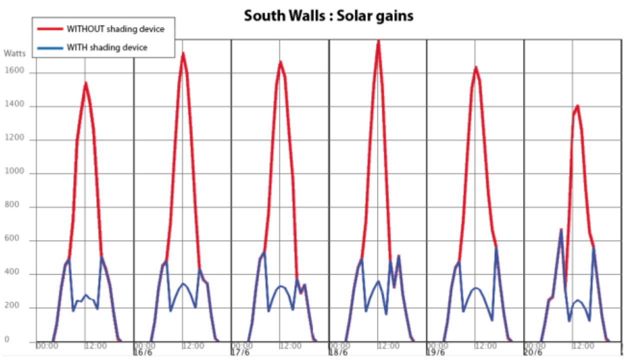


Figure 4 : illustration of the solar gains calculation with and without shading devices for 6 consecutive sunny days in Geneva.

Internal gains.
Standard profiles of more than 20 rooms categories are stored in the software. The user selects the category and then the qualitative qualification for Occupation, Electrical power (excluding

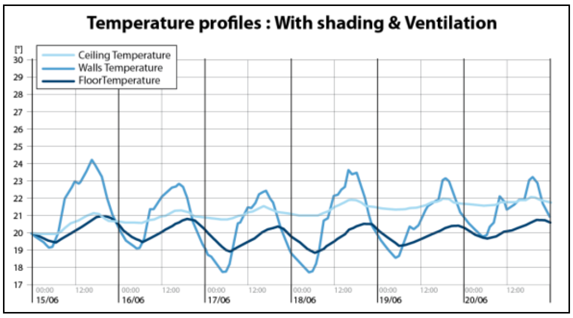
lighting) and installed lighting power. The total internal gains are then calculated and split into radiative component (for the wall) and convective component (for the air)

Ventilation.
The potential air-flow is calculated at each time step with the difference between inside and outside temperature. This allows the user to calculate real natural ventilation air-flow which can be useful for night-cooling
The user can view the results for each hour of the simulation. The available outputs are:

- Operative temperature of the room
- Air temperature of the room
- Surface temperature for each wall, roof and floor
- Internal gains
- Solar gains through each wall and roof

Overheating risks.
Moreover, temperature data are collected in order to evaluate overheating risk. The user can define the comfort zone and the software calculates the number of hours over or under this zone. Figure 5 shows an example of dynamic calculation of the temperature of the indoor surfaces for a given office room located in Geneva with the following characteristics :

In that case, the sound strategy for both shading device and night ventilation allow to reduce the overheating risk for the same office room. Thanks to these calculation facilities, the user is able to modify the design of his project in order to optimise both comfort and performance.



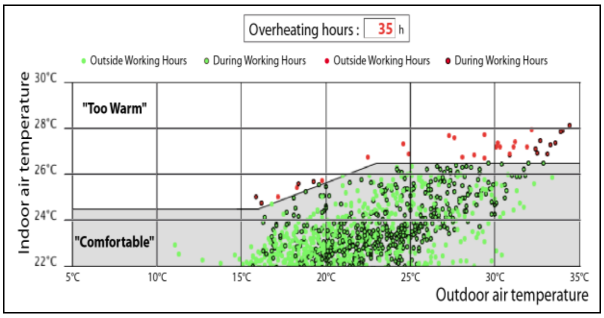


Figure 5 : Outputs of the DIAL+COOLING module

LEFT : Example of Evolution of indoor temperatures with appropriate shading device and night ventilation strategies

RIGHT : Example of cumulative distribution of indoor air temperature with appropriate shading device and natural ventilation strategies.

CONCLUSIONS

This quick overview of the DIAL+*Suite* shows that the combination of the three modules (Lighting, Ventilation & Cooling) gives a unique opportunity to have an overall approach of the aperture design.
Thanks to its simplicity of use, we believe that it is possible to take into account this problem in the early stage of the design.

We also think that DIAL+*Suite* is suited to a large range of “non-specialist” users and thus, will favour the emergence of successful solutions dealing with “Very Low Energy” buildings labels.
We already work on the adaptation of this tool to different standards and regulations in force, so that it can support the policies of reduction of energy demand and greenhouse gas emissions, while guaranteeing an optimal comfort to the building users.

SOFTWARE

		Available languages ☒ **Français** ☒ **English** ☒ **Deutsch** ☒ **Spanish** ☒ **Italiano** ☐ **……….**
Editor Estia SA PSE-EPFL CH-1015 Lausanne Switzerland	***Distributor*** Estia SA PSE-EPFL CH-1015 Lausanne Switzerland	***Price*** Lighting + Ventilation : 1200,-€ Cooling + Ventilation: 1200,-€ DIAL+ Suite : 1400,-€

Description

The DIAL+ suite allows the user to evaluate the **global energy potential of windows** in the very early design stage, thanks to the 3 following modules:

- **Dial-Lighting :**
  - Radiance simulations (daylight factor and daylighting autonomy values)**.**
  - Annual electric consumption due to artificial lighting according to SIA-380/4
- **DIAL-Ventilation :**
  - Air flow due to natural ventilation throughout windows.
- **DIAL-Cooling** :
  - Thermal dynamic behaviour of a room (hourly step).
    (evolution of the indoor temperature according to the thermal mass, the solar gains, the internal loads and the shading and ventilation strategies)
  - Number of overheating hours according to SIA-180/1

These software modules are really **user friendly** and the implementation of original fuzzy logic rules makes the **input easy and reliable**.

Furthermore, these tools provide a linguistic diagnosis that helps the designer to **optimise the performance**.

It is then possible to get to the point directly, by asking to the user only for 20 % of the effort required usually by the use of complex simulation tools

This is a new possibility for the building designer to optimise both passive solar heating and cooling (30% of economy in summer and in winter), as well as natural ventilation (50 to 100% energy savings for ventilation energy) and natural lighting (30 to 70% energy savings for electric lighting).

Technical Data

Operating System ☒ **Windows 2000/XP** ☒ **Mac OS/X** ☒ **Windows Vista** ☒ **Mac + SoftWindows** ☒ **Windows 7** 32bit ☒ **Windows 7** 64bit ☐ **LINUX** ☐ **Others ………………………………………………………**	***Processor***
	Required memory **512 Mb**
	Required disk space **100 Mb**

SOLAR RADIATION AND UNCERTAINTY INFORMATION OF METEONORM VERSION 7

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1: Meteotest, Fabrikstrasse 14, CH-3012 Bern, Switzerland

ABSTRACT

The solar radiation database and software meteonorm is widely used for solar thermal, PV and building simulation in form of stand alone software or included in the most common simulation software (like PVSyst or Polysun). Version 7 appeared in June 2011. This article shows the news concerning the solar radiation database as well as the uncertainty and trend information. Uncertainty of the yearly values of global, direct normal radiation as well as radiation on inclined planes will be given. Uncertainty is an important information for planners. Up to now this information hasn't been included in common solar radiation databases. The variation of uncertainty throughout the world is quite big.

The solar radiation database includes the new main time period of 1986 – 2005 (totally 1942 stations). Like this the recent global brightening trend (mostly visible in Europe) is included in the data. Additionally the satellite based information has been updated as well. For Europe and Northern Africa new high quality and high resolution satellite data (2 km) are available for the period 2004 – 2010 (based on Meteosat satellite images and prepared by MeteoSwiss).

The calculation of the total uncertainty values of global radiation are based on the uncertainty of ground measurements and the uncertainty of the interpolation.

The uncertainty of the ground measurements ranges between 2 and 8%. In Europe most stations are lying between 2 and 4%. The interpolation of the ground data is modelled with help of the distance to nearest station and the uncertainty of the ground measurements. An area wide calculation of the uncertainty couldn't be done as there are too few stations in some regions. At a distance of 100 km the uncertainty (relative root mean squared error) is generally at 6%.

The uncertainty of satellite data is modelled in dependence on the latitude and the albedo. The higher the latitude and the higher the albedo (e.g. salt lakes in deserts or snow rich mountains) the bigger the uncertainty. The value of the uncertainty is ranging between 3 and 6% for Europe and Northern Africa (Meteosat high resolution area) and 4 and 8% for all other satellites.

The uncertainty of the beam and the radiation on inclined planes is depending on the uncertainty of the global radiation. Typically the uncertainty of the beam is twice as high as the global radiation.

Additionally the trend of the last 20 – 30 years for the nearest long term measurement site is given.

INTRODUCTION

The solar radiation database meteonorm is widely used for solar thermal, PV and building simulation in form of stand alone software or included in the most common simulation software (like PVSyst or Polysun). Version 7 appeared in June 2011. This article shows the news concerning the solar radiation database as well as the uncertainty and trend information.

Uncertainty of the yearly values of global and direct radiation as well as beam radiation will be given. Uncertainty is an important information for planners. Up to now this information hasn't been included in common solar radiation databases. The variation of uncertainty throughout the world is quite big.

SOLAR RESOURCE DATA

The solar radiation database includes the new main time period of 1986 – 2005 (totally 1942 stations). Like this the recent global brightening trend (mostly visible in Europe) is included in the data. The most important source of radiation data is the Global Energy Balance Archive (GEBA, https://protos.ethz.ch/geba). This database is also used to extract uncertainty information (770 stations are used for this).

Interpolation of global radiation data is based on a mixture of ground measurements and satellite data. The satellite based information has been updated as well. For Europe and Northern Africa new high quality and high resolution satellite data (2 km) is available for the period 2004 – 2010 (based on Meteosat satellite images and prepared by MeteoSwiss). This database has been specially adopted for regions with relatively frequent snow coverage and levels of high albedo (mountains, northern regions as well as salt lakes in deserts) taking also infrared channels into account.

Additionally three IPCC [1] scenarios enable the calculation of typical years also for future periods (until 2100).

METHOD

The calculation of the uncertainty values of global radiation are based on the following three points:

- Uncertainty of ground measurements (measurement itself and long term variability of local climate)
- Uncertainty of interpolation (interpolation of ground measurements and uncertainty of satellite based data)
- Uncertainty of the splitting into diffuse and direct radiation and inclined planes

The uncertainty of the ground measurements (U_q) is based on the values of 4 parameters, which have been classified (Table 1).

		Low quality	**Mid quality**	**High quality**
	Value	1	2	3
1	Duration	< 10 years	10 – 19 years	>= 20 years
2	Std. deviation	> 7 W/m^2	4 - 7 W/m^2	< 4 W/m^2
3	Trend	> 6 W/m^2 decade	3 - 6 W/m^2 decade	< 3 W/m^2 decade
4	Up-to-dateness	End < 1980	End 1981 - 2000	End > 2000

Table 1: Uncertainty parameters of the ground measurements.

The values (1 – 3) of the quality levels of the four parameters are summed up, weighted and added to the standard deviation (Sd_m) of the long term means (10 or 20 years) to get the uncertainty of the ground measurements (U_m) with equation 1:

$$U_m = Sd_m + \frac{12 - \left(\sum U_q\right)}{3} \qquad (1)$$

The uncertainty of the interpolation ($U_{i,g}$) of ground stations is modelled with help of the distance to the nearest station. An area wide calculation of the uncertainty couldn't be done as there are too few stations in some regions.

The uncertainty of the interpolation of satellite data (U_{sat}) is modelled in dependence on the latitude and the albedo. The higher the latitude and the higher the albedo (e.g. salt lakes in deserts or snow rich mountains) the bigger the uncertainty. Additionally the spatial resolution and the quality of the used satellite source are considered.

If both satellite and ground are used then the weight *a* is used, which depends on the distance from the nearest ground site (2):

$$\begin{aligned}
&U_i = a \cdot U_{sat} + (1-a) \cdot U_{i,g} \\
&\text{if distance} < 30 \text{ km} \\
&a = 0 \\
&\text{if distance} >= 30 \text{ and distance} < 200 \text{ km} \\
&a = \frac{\text{distance} - 30}{170} \\
&\text{if distance} >= 200 \text{ km} \\
&a = 1
\end{aligned} \tag{2}$$

The calculation of the combined uncertainty (U_t) is depending on the situation (equation 3 or 4). The interpolation and ground measurement uncertainty is assumed independent.

- No interpolation:

$$U_t = U_m \tag{3}$$

- With interpolation

$$U_t = \sqrt{U_m^2 + U_i^2} \tag{4}$$

The uncertainty of the beam and the radiation on inclined planes is depending on the uncertainty of the global radiation. With help of 13 sites with high quality and long term global and direct measurements (mainly BSRN sites) a model based on uncertainty of global radiation has been made.

RESULTS

The uncertainty of the ground measurements ranges between 1 and 10%. In Europe most stations are lying between 2 and 4%. The stations with lowest uncertainty found are Malin Head (Ireland), Innsbruck (Austria) and Lichinga (Mozambique) with 1% of uncertainty. The stations with highest uncertainty are Mocamedes (Angola, 7.1%), Pleven (Bulgaria, 7.6%) and Hirado (Japan, 10.1%). Those uncertainties are based on quality (technique, duration) as well as on climatological reasons.

For ground interpolation at a distance of 2 km the uncertainty is at 1% and at 100 km the uncertainty is generally at 6% (Fig. 1). For distances bigger than 2000 km the uncertainty is set constant at 8%.

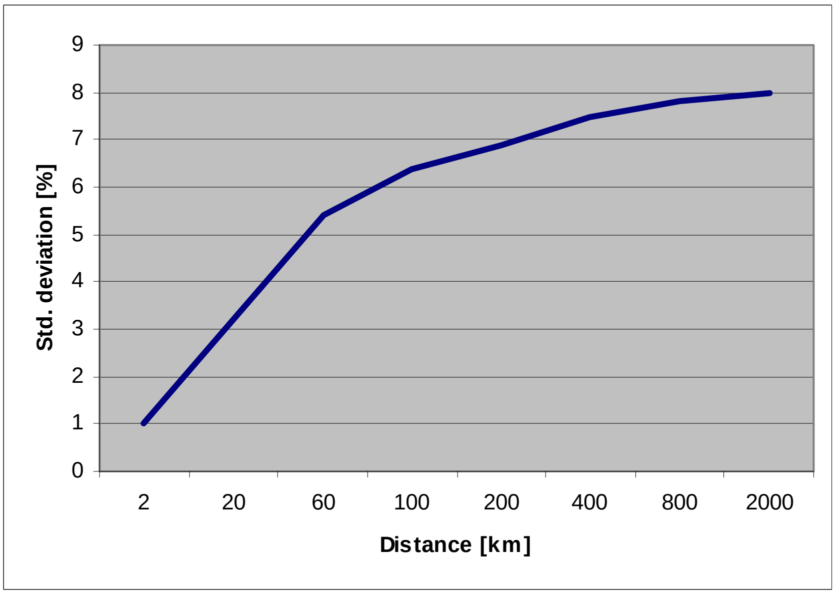

Figure 1: Uncertainty of interpolation of ground measurements vs distance.

The value of the uncertainty for satellite data is ranging between 3 and 6% for Europe and Northern Africa (Meteosat high resolution area) and 4 and 8% for all other satellites (Fig. 2).

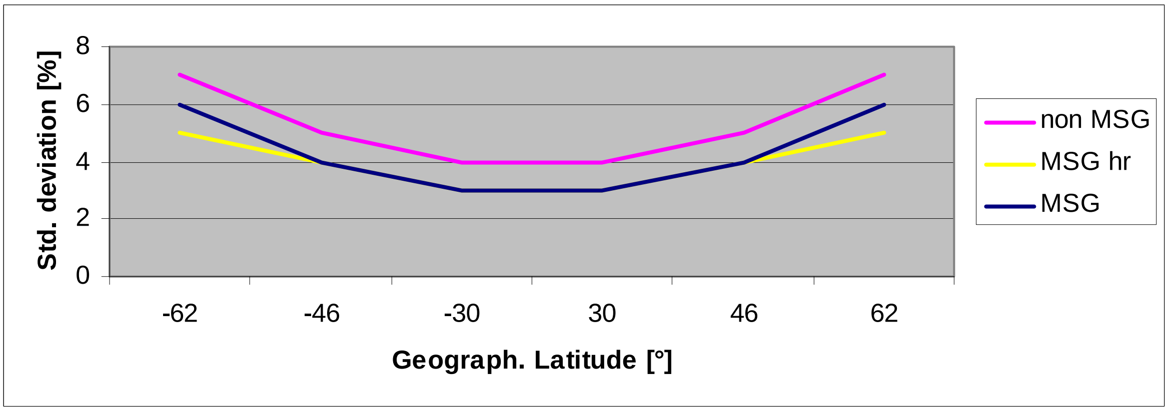

Figure 2: Uncertainty of satellite data in dependence of latitude and source of satellite. MSG= Meteosat Second Generation, hr = high resolution area (Europe).

For areas with high albedo values (yearly means of $\rho > 0.2$) the uncertainty is enhanced based on equation (5):

$$U_{sat,alb} = (\rho - 0.2)\frac{0.14}{0.6} \tag{5}$$

This addition is lowered for Europe due to the fact, that in this region high albedo is considered in the new satellite model from MeteoSwiss.

Typically the uncertainty of the beam (U_{dir}) is twice as high as the global radiation (6):

$$U_{dir} = 3.5 + 2 \cdot (U_t - 2) \tag{6}$$

The uncertainty of the radiation on inclined planes is dependent on the uncertainty of the horizontal radiation and the plane inclination (β) and is defined by the following equation (7):

$$\begin{aligned} &U_t < 2 \\ &U_{incl} = U_t + \sin(\beta) \\ &U_t \geq 2 \\ &U_{incl} = U_t + 0.6 \cdot (U_t - 1) \cdot \sin(\beta) \end{aligned} \qquad (7)$$

To conclude the findings the overall uncertainties of meteonorm values have the following ranges:

- Global radiation: 2 – 10%
- Direct normal radiation: 3.5 - 20%

Typical values for European sites are:

- Pully, meteo station, Switzerland: 2% for global radiation, 4% for direct radiation
- Olten, interpolated site, Switzerland: 3% for global radiation, 6% for direct radiation
- Madrid, meteo station, Spain: 2% for global radiation, 4% for direct radiation
- Pleven, Bulgaria, meteo station: 8% for global radiation, 15% for direct radiation

We have to bear in mind, that also the uncertainty modelling has uncertainties (which haven't been estimated yet).

REFERENCES

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SOFTWARE

meteonorm version 7		***Available languages*** ☒ **Français** ☒ **English** ☒ **Deutsch** ☒ **Spanish** ☒ **Italiano** ☐ **……….**
Editor **Meteotest** **Fabrikstrasse 14** **3012 Bern, Switzerland**	***Distributor*** **Meteotest** **www.meteonorm.com**	***Price*** **CHF 650.—** **Updates: CHF 250.—**

Description

meteonorm has been proofed as a worthwhile tool for many people dealing with solar energy and building simulation since 26 years. In June 2011 the version 7 of the software has been published. The most important features are described here in the following.

Climatological Database:

The database includes now over 8’300 stations. A complete set of 8 basic parameters (global radiation, temperature, dewpoint temperature, rain, days with rain, sunshine duration, wind speed and direction) is available. It contains mainly global radiation data of Global Energy Balance Archive and other parameters of Climatological Normals of 1961-90 of WMO. The climatological means have been updated to 1986 – 2005 for radiation parameters and 2000 – 2009 for all other parameters to include also recent climate change. With help of interpolation tools - also based on satellite data for radiation parameters - the ground data is usable for the whole globe. Meteonorm includes a stochastic weather generator to get typical years for any site.

Generation of future conditions until 2100:

In meteonorm 7 three scenarios (B1, A1B, A2) of IPCC AR4 2007 results are included. Like this it’s possible to calculate typical years also for future periods for any site. The averaged anomalies of 18 available IPCC climate models are used to determine the difference between 1961 – 90 averages and future periods (for temperature, precipitation and global radiation). For future periods the stochastic generation of temperature has also been adopted based on the analysis of future variabilities.

Uncertainty information for any site:

Meteonorm 7 includes now information about uncertainty of the yearly values for radiation parameters and temperature.

Software:

The software has been redesigned totally for version 7 resulting in a more intuitive handling. Additional test reference years are available (sia Merkblatt 2028 data for Switzerland and all tmy3 test reference years of the USA). Software output formats like IDA ICE or DELPHIN have been added. The processing of horicatcher panorama pictures is now included within meteonorm.

Technical Data

Operating System ☐ **Windows 95/98** ☐ **Mac OS/X** ☐ **Windows NT4** ☐ **Mac + SoftWindows** ☒ **Windows 2000/XP** ☒ **Windows Vista** ☐ **LINUX** ☐ **Others ……………………………………………………**	***Processor*** **1 GHz** ***Required memory*** **512 MB** ***Required disk space*** ***800 MB, .NET 4.0 framework installed***

DESIGN SUPPORT TOOLS WITH TECHNICAL, ECOLOGICAL AND SENSIBLE APERTURES IN THE CHOICE OF MATERIALS

Nathalie Tornay[1 et 2] ; Frédéric Bonneaud [2] ; Luc Adolphe [1]
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2 : *PRES – Université de Toulouse – LRA– Laboratoire de Recherche en Architecture, ENSA – École Nationale Supérieure d´Architecture de Toulouse, France*

ABSTRACT

This article concerns itself with the development of support tools for scale designs of materials that incorporate three aspects: the technical aspect, that is implementation of materials; the ecological aspect, with environmental approaches dealing with thermal, acoustic, and visual comfort, the life cycle of materials, etc.; and the sensible aspect, with the willingness to give meaning to the choice of materials, also known as "esthetic value", which is defined in our work as a goal, an aim.

INTRODUCTION

The choice of materials was profoundly changed by the industrial revolution. Scientific and technical advancements developed numerous innovations that caused the number of materials to increase. Today, teams of designers find themselves faced with a broad range of choices, where information is overabundant, where confusion reigns within different selection criteria, where it becomes difficult to understand, with one look, all the materials offered.

Parallel to this, in the past years numerous tools have been developed. Today, the tools are often in software form and principally deal with physical aspects: thermal, acoustic, material footprints, consumption… though sensible characteristics are present in support tools for to-scale architectural design. For example, the analysis of light environments forms the basis of numerous software; others are based on image retrieval for the development of ideas, etc.

In this context, this article deals with the integration of technical, ecological, and sensible aspects of construction materials within support tools for design beginning with referential activities right in the initial phases of designing on a project.

METHOD

The problematic of this article is that it requires significant work gathering information, starting with the data on the treatment of the choice of materials for designers in the architectural literature, both urban and landscape. This topic has been the subject of a doctoral thesis [1]. This article summarizes the foundations of this research, highlighting through its operational aspect the introduction of a design tool.

The first part of this article presents the interests in referential activity to treat questions linked to the choice of materials in the initial phases. This part analyses the needs and supports to adapt referential activity to the scale of the materials.

Starting by defining the needs and supports of referential activity, the two following parts propose a strategy to apply referential activity to the scale of the materials within design tools.

The first concentrates on indexing the data to orient the user in his research; the second focuses on the transmission of knowledge and how-to appropriate for the materials.

Finally, the third part illustrates the established strategies from a suggested design tool called *DILEM'MAterials*.

REFERENTIAL ACTIVITY

Referential activity is part of the processes of formulation [2] and formalization [3] of solutions appropriate to the operational modes of the designers in the initial phases of the project. The objectives of a design tool in the choice of materials are oriented toward the integration of two basic principles: the integration of designer practices and concordance with the criteria for choosing materials.

Definition of needs: the precedents

The precedents are existing projects on the architectural scale, urban or landscape, which illustrate remarkable qualities in the choice of materials. To select these projects, we concentrate on projects presented in reviews or architectural books that integrate the questions of materiality. However, it seems important to us to be aware of keeping an extended range of projects, from the most humble to the most ambitious.

The precedents published in magazines, in professional reviews, in specialized works or presented during exhibitions, conferences, etc. reveal the tendencies, preoccupations, and production issues current to their conceptual, morphological, or again, material choices.

They show an era, with its technical prowess, its ecological choices, and its sensibility. Parallel to this, they influence workers in the design teams like the employers, the employer's assistants, the project managers, etc.

The projects are rich in education opportunities; they were and are the object of different lines of research. In the 1970s, teams of researchers [4, 5], were interested in the issue of analogy at the heart of the design process. Today, the numerous projects rest on referential activity to analyze the phenomena of architectural environments [6, 7]. Others concentrate on the development of rich databases of study cases like Dynamo [8]. In "architecture, the term "reference" is used for the design of "mediation subjects" that help designers to explain their problems and/or imagine solutions [9]."

Definition of support: the images

The images here correspond to the graphical production scale (plan, profile, side, sketch, outline, photograph, etc.). They are about the "fundamental methods of architectural representation" [10] that are able to expand to the scale of urban and landscape construction.

The image does not summarize a visual perception: it reveals information and intentions for construction. Its objective is to permit a view from a distance: a detachment that is essential for making decisions. "The image is an aid for information research, to the scale of the materials, in all phases of the design process. The image plays a key role in design mechanisms, because it is the raw material for creation; it presents a manner of seeing and perceiving a problem; it develops a legacy function in the formation and transmission of doctrines, etc." [11]. The image is only a sample of reality, which remains in the abstract realm due to the lacunal and partial aspect of the sample [12]. In the choice of materials, the representation of reality that gives the image of each material envisioned possesses elements of anticipation (impetus for the research of colors, tints, assembly, etc.) that are the beginning of unresolved activities, in cognitive data (an example of projects that integrate these materials, models, etc.), finally an emotional impact (the impressions, the effects, etc.). The image serves as an intermediary between the abstract and the concrete, where the image synthesizes motive, cognitive, and emotional aspects.

Our proposal, therefore, orients itself towards a research tool for images. As a result, it is necessary to describe an analysis method in these plans to index these images. For that, each precedent is analyzed according to ecological, technical, and sensible criteria. It tries to implement a sorting method, to compare the contents. The group of criteria allows one to manually index each precedent image.

INDEXATION OF IMAGES ACCORDING TO TECHNICAL, ECOLOGICAL, AND SENSIBLE ASPECTS OF THE MATERIALS

The difficulty of this phase is to consider the global criteria (whatever the materials), to avoid the systematic classification by material family (wood, steel, earth construction, etc.) unsuitable in the initial phases. Starting from the most exhaustive bibliographic study possible, containing around a hundred works [1], this article synthesizes the characteristics of the three aspects — ecological, technical, and sensible — of materials to elaborate the strategies for indexing the images of the precedents:

The technical aspect: it is characterized in the literature by the classification of data material by material. It characterizes the use of the materials. We have retained two global criteria of using materials. The first identifies the principles of construction [13] with the homogeneous wall, the brick wall, the half-timbered wall, the wall made with linear elements/layered, the wall with siding, sandwich construction, and the studded wall. The two criteria correspond to the functions of the materials: load-bearing, insulating, and/or protective [14]. Thus, each precedent is listed according to the construction principle and the role of each material used.

The ecological aspect: in the literature, it appears under the form of guides that counsel design teams. We distinguish, on one hand, the environmental approaches that prefer the use of renewable, recycled, or recyclable materials, less damaging to health, and of equal quality, to favor local materials to limit transport and diversify the local economy. On the other hand, the energetic approaches concentrate on thermal and acoustic comfort and the life cycle of the materials. The ecological criteria of the materials are clearly identified; moreover, they are present in existing tools. For our tool, we choose to rely on the two scales studied by the technical aspect, with the thermal and acoustic behavior of devices built from the calculations of the software CoCon [15]; then, the thermal and acoustic behavior and the life cycle of each material according to its function (load-bearing, insulating, protective).

The sensible aspect: it is present in the literature with a willingness to give meaning to the choice of materials. It takes the form of metaphors, of connotations, of sensible approaches (visual, aural, tactile faculties), it reinterprets the use of local materials or refers to building customs. In the bibliographic studies, we are allowed to identify the sensible modes, the meaning of the choice of materials. Different methods of analysis (textual, lexical, etc.) of press articles permit us to characterize the choice of materials, the effects of matter [1], the profiles of the designers [16], etc. Each precedent is then analyzed according to the different methods to identify their issues within the sensible aspect of the materials.

TRANSMISSION OF ECOLOGICAL, TECHNICAL, AND SENSIBLE DATA

The analysis of precedents allows one to illustrate the ecological, technical, and sensible aspects of the materials. In compiling the precedents that present similar characteristics, it is possible to form files to transmit ecological, technical, and sensible data. As well, in adding to the number of precedents, the contents of the files become enriched. The difficulty of this phase is organizing the knowledge and how-to. We have kept three types of files:

Material files: dedicated to one material, they enunciate their characteristics. They deal with the analysis of the precedents classed by material. The files synthesize the ecological approach (examples of treatments respecting the environment that translate to the material scale), the technical approach (use, structure, dimensioning, etc.), and the sensible approach (the different meanings in the choice of materials and the sensible characteristics) of each material studied.

The action files analyze the choice of materials within each precedent. It presents to the user the impact of precedent analysis, of transmitting knowledge and know-how (technical and sensible characteristics, etc.) that can spark ideas. The files constitute a succession of analysis of precedents classed by theme. For example, in the sensible aspect: the temporality, the location, the skin, etc., or for the technical dimension: framing construction, etc.

Finally, the precedent files describe the projects presenting remarkable qualities in the choice of materials. Each precedent is analyzed according to its ecological, technical, and sensible properties.

Moreover, the data on the materials are structured, ordered, and sorted according to different approaches. The material files takes over the classic classification by material family, the action files list the precedent analysis according to themes, so the precedent files form the source of the data used in the material files and the action files.

PROPOSAL FOR A DESIGN TOOL

DILEM'MAterials develops a search engine for information on the materials starting with the image. The navigation in this tool comprises three steps: the choice of an image, the organization of data, and the results.

Step 1: choosing an image

The user is faced with a wall of *images*. The selection of images represents the precedents that correspond to an idea or a concept. The user needs some particular knowledge to start the search. This type of interface is then appropriate to the initial phases of the project. It serves to stimulate ideas.

However, the user has the possibility of restraining the choice of precedents, so the images according to environmental objectives meet five criteria: the life cycle of the materials, the thermal performance, the acoustic performance, the installation, and the density. For each of the criteria, the user checks whichever he chooses.

Step 2: organization of the data

When one or more images are selected, a new page opens and presents all the images appropriate to the selected image(s). The images are classed according to their index, and four categories appear: the materials, the technical aspect, the sensible aspect, and the selected precedents. Each of these categories is proposed according to associated key words: they result from the textual indexation of the images and permit refining the searches.

The parallel formed between the images and key words allows for the adaptation to the advanced levels of the user's project. The more clearly a problem is formulated, on the material scale, the more the information searched should be precise and the number of materials restrained. On the contrary, during the advances phases of the project, the group of key words should appear.

Step 3: results

The results are always organized according to their categories: materials, technical aspect, sensible aspect, or preselected precedents. Also, the user accesses directly the type of information he is looking for.

The results are presented in the form of files: the material files, the action files, and the precedent files. These files are referenced by hypertext links where the precedents are in the center of the system. All the precedent files are linked to the material files that compose the project and the action files that give meaning to the choice of materials. The precedent files form the axis of the navigation system by hypertext links, because it is essential to consider the technical, ecological, and sensible approaches according to the context of each precedent (location, climate, specifics of the site, etc.).

The user forms his own folders where he can record the different files. It is possible to add comments, remarks, questions, etc. These folders form a base to question the choice of materials, to consider the set of impacts of the materials in the project and to pose questions or make ideas come up.

DILEM'MAterials currently makes use of a premier computing model in the forma PHP. It allows one to test the efficiency of the choice of precedent images, the efficacy of their indexation, the presentation of results, etc. The following figure presents the interfaces of the three search stages.

Figure 1: Interface of the three steps of DILEM'MAterials

LIMITS AND DEVELOPMENTS

Our work has shown the different ecological, technical, and sensible characteristics of materials, but more importantly, their interactions. Throughout our research, these characteristics have allowed us to class material data, making evident their numerous links. However, the elaboration of *DILEM'MAterials* is faced with the hard task of project analysis (manual indexation, compilation of precedents classified by theme, etc.) that can take a lot of time. In effect, to optimize the efficacy of the interface and to enrich the data, it will be necessary to multiply the analysis of precedents.

On the other hand, referential activity does not allow us to treat the question of context, of the location of the project by the user (climate, close environment, building customs, etc.). It would be suitable to question oneself on the complimentary modules that integrate site analysis.

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