ÉCOLE POLYTECHNIQUE
FÉDÉRALE DE LAUSANNE

2009-21

LESO-PB

From the neighbourhood to the city: resource flow modelling for urban sustainability

Robinson D.
Haldi F.
Kämpf J.
Leroux Ph.
Perez D. - Raseed A. - Wilke U.

CISBAT 2009
p. 445 -450

2009

FROM THE NEIGHBOURHOOD TO THE CITY: RESOURCE FLOW MODELLING FOR URBAN SUSTAINABILITY

Robinson, D.[1], Haldi, F.[1], Kämpf, J.[1], Leroux, P.[1], Perez, D.[1], Rasheed, A.[1], Wilke, U[1].

1: Solar Energy and Building Physics Laboratory (LESO-PB), Station 18, EPFL, CH-1015 Lausanne, Switzerland

ABSTRACT

Agreed intergovernmental targets to reduce the emission of greenhouse gases due to predominantly urban anthropogenic activities are becoming increasingly stringent; one might even say ambitious. One crucial strategy in achieving these targets will be to improve the efficiency with which resource are consumed with our cities, which now accommodate more than half the global population. An important tool for testing whether governments are on track to reach their targets will be computer models which simulate the energetic consequences of alternative urban planning and design scenarios. In this paper we describe progress that has been made to develop one such tool: CitySim. In particular we describe the graphical user interface with which urban scenes may be described and the solver that simulates the energy flows within these scenes. We also describe work that is both underway and planned to enable users to simulate urban resource flows in a more comprehensive way and at a variety of scales, from the neighbourhood to that of the City.

INTRODUCTION

It is estimated that over half of the global population is now living in urban settlements [1], in which three quarters of global resources are consumed [2]. Energy derived from fossil fuels is key amongst these resources, so that urban settlements are responsible for the majority of greenhouse gas emissions. Given that the G8 countries have recently pledged to reduce greenhouse gas emissions by 80% with respect to 1990 levels by 2050 [3] it is increasingly important that existing urban settlements are adapted and that proposed settlements are designed to minimise their net resource consumption. Software for simulating and optimising urban resource flows will play an essential role in this process. In this paper we describe progress that is being made in one such initiative: the development of CitySim. In particular we describe the current structure of CitySim – it's graphical user interface and solver – and work that is both underway and planned to enable users to simulate urban resource flows in a more comprehensive way and at a variety of scales, from the neighbourhood to the City.

CITYSIM INTERFACE

The Java-based graphical user interface to CitySim enables users to describe and simulate an urban scene according to the following key steps:

- Definition of site location and choice of associated climate data.
- Choice and adjustment of default datasets for the typologies of buildings to be studied.
- Definition of 3D form of buildings; definition of energy supply and storage systems to be modelled; refinement of building and systems attributes.
- Parsing of data in XML format from the GUI to the C++ solver for simulation of hourly energy flows; analysis of the results parsed back to the GUI.

In developing this interface, we have been careful to design a modular platform for straightforward extensibility, in particular to support the future incorporation of modules developed for related open source applications (other 3D modellers, GIS tools etc). In developing the above native features we have focussed the vast majority of efforts in developing an efficient interactive 3D modelling tool which enables users to quickly and easily sketch and visualise building envelopes and with sufficient flexibility that even the more unusual forms may be defined.

In terms of workflow, 3D forms are immediately projected to a default height upon closing a 2D polygon of the floor plan. The height of this solid may then be easily changed. Individual faces of this solid may now be split and extruded along the surface normal, whether negative or positive; although surfaces may also be rotated and then extruded. Ridge lines may also be defined on (originally) flat roofs and the solid extruded from the roof edges to this ridge. Once the user is satisfied the building's constructional, occupational and systems attributes may be refined. The user may also create multiple copies of one or more buildings and drag these to the desired locations. These buildings may then be further transformed and / or rotated...and so on. Although this tool, which is still under development, is no replacement for a general 3D modeller such as Google SketchUp, it is reasonably fit for its purpose of quickly sketching building envelopes for the simulation of urban resource flows – see Figure 1.

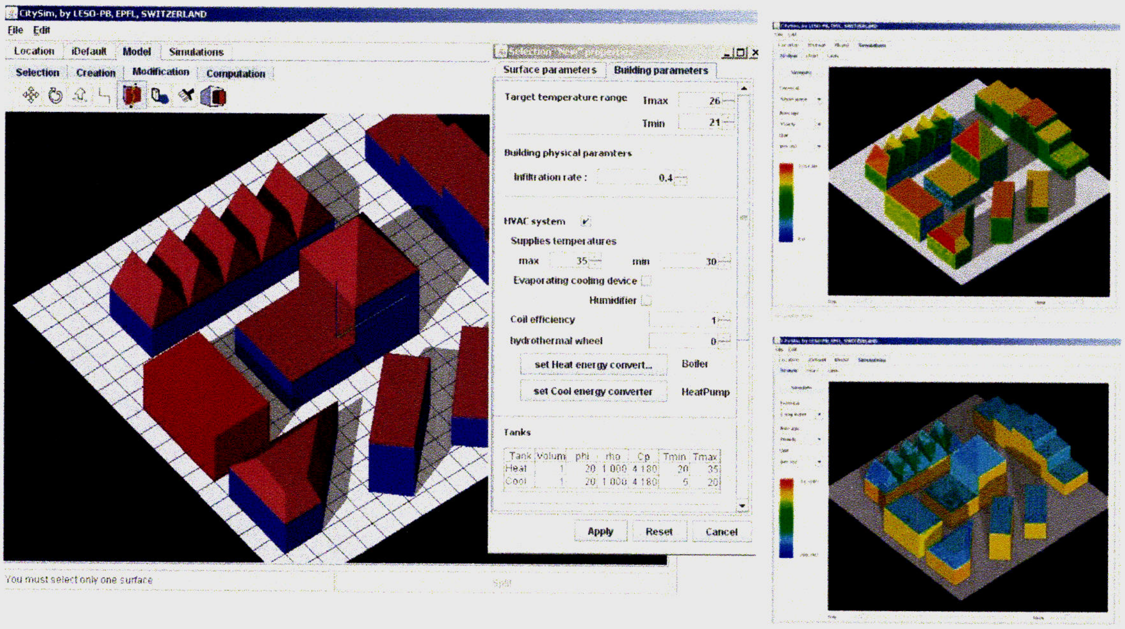

Figure 1: Screenshot of the CitySim GUI: Model definition (left) and results output (right)

Once the user is satisfied a description of the scene may be parsed to the CitySim solver. Upon completion the results from the solver may then be visualised within the GUI. In its present state we may view falsecolour renderings of the scene, for example of monthly or annual shortwave irradiation and line graphs of time against the performance variable of interest, for each building and at the chosen temporal resolution (hourly, daily, monthly).

CitySim Solver

The CitySim GUI writes a description of the user's scene to an XML file, which also contains references to a relevant ASCII climate file and to databases containing descriptions of construction composites and the thermophysical properties of each constituent element; profiles of occupants' presence and associated heat gains as well as profiles of heat gain due to use of lights and appliances and of airflow rates associated with the use of windows. Databases describing the characteristics of heating, ventilating and air-conditioning systems and of energy conversion systems are also referenced; likewise the characteristics of fuels to be combusted.

This data is then read in to the CitySim Solver, written in C++, for the hourly calculation of the building-related energy flows within our urban scene. For this a set of pre-processes are first performed to derive the necessary view information, relating each built surface to the three source of radiant energy (sky, sun and other surfaces), and to construct the matrices which solve for radiant exchanges with these sources. The radiation model is then called, at each time step, to solve the radiation matrix equation for the prediction of the irradiance absorbed by opaque surfaces as well as that transmitted through their glazed parts [4, 5].

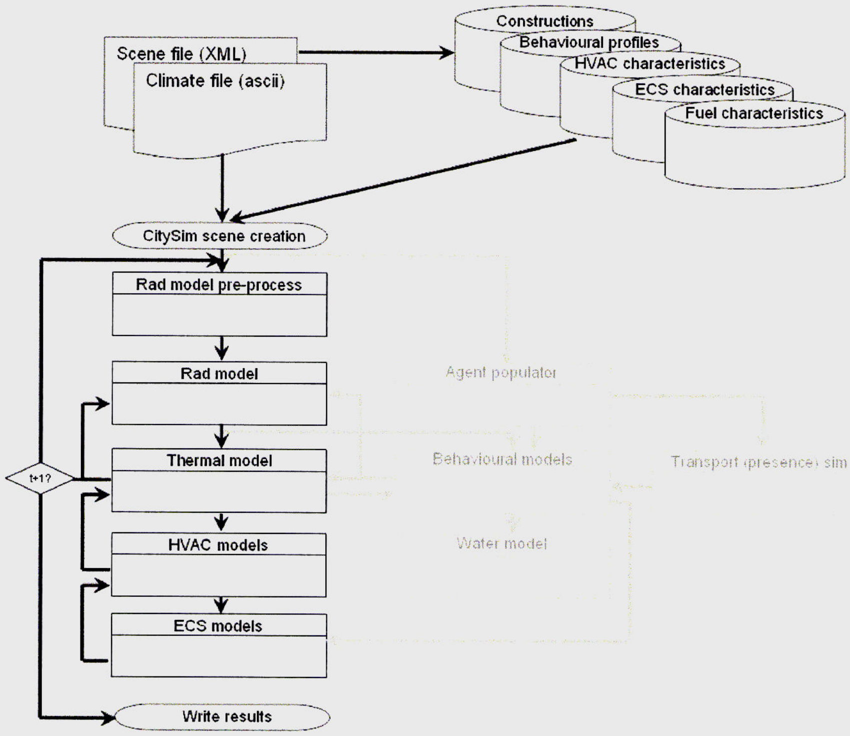

Figure 2: Conceptual structure of CitySim, with planned functionality shown in grey

A simplified thermal model is then called, to predict the energy demands required to maintain a given set point temperature for each zone of each building within our scene [6]. If our zone is mechanically ventilated, then the HVAC models are called to calculate the energy required (the product of mass flow rate and supply-room enthalpy difference) by heating / cooling sources to meet these needs. If there is under-capacity, whether through instantaneous supply and / or the supply of previously stored energy, then a new ventilation supply condition is calculated and the thermal model is again called to calculate a corrected temperature.

If there are no HVAC models then the sum of the demands of each zone is parsed directly to the relevant energy conversion system (boiler, heat pump, co-generation system etc) which may or may not satisfy this demand, so that a corrected temperature may again be calculated by the thermal model (the deficit, currently, being evenly shared between zones). At the moment, the energy consumed by pumps and fans for the distribution of heated / cooler air / water is not calculated explicitly. Rather standard specific power demands are used.

The external surface temperature, predicted by the thermal model, is also used at the next time step to solve for the longwave radiation exchange at each surface, using the view information that was calculated within the radiation model's pre-process (see [7] for a more detailed description of the CitySim solver). The calculation then proceeds, either to the next time step, or to write the simulation results to an ASCII file for analysis within the CitySim GUI.

Forthcoming Models

At the present stage of development, we have a core set of deterministic models that solve for the energy demand from buildings and the storage and supply of energy to meet these demands. At present no account is taken of the stochastic nature of peoples' presence and behaviour, which can have an important impact on both the magnitude and the temporal variation of buildings' energy demands, with corresponding implications for the dimensioning of HVAC plant and the energy conversion systems that satisfy their needs.

In the near future, stochastic models of occupants' presence [8] and their interactions with windows [9], blinds [10] and lights [11] will be integrated within CitySim. Further work is required to develop a convincing model of interactions with electrical appliances though some promising progress has been made by Page [12], Paatero [13] and McQueen [14]. But current work in this expanding field of research tends to model occupants' interactions as being independent of the activities which are being carried out. This may lead to incoherencies – with occupants interacting with several unrelated types of appliance simultaneously (use of a computer whilst cooking) or with possible interactions between types of action being ignored (e.g. cooking and the opening of windows to remove pollutants). To resolve this we intend to add a further layer to our models: predict presence, then the most probable activity and, whilst this activity takes place, the probable interactions which may plausibly take place. For this we will use Time Use Survey (TUS) statistics. In addition to this, recent work at the LESO supports the common sense conclusion that occupants' behaviours can vary significantly, according to their financial means (affecting the ownership of resource consuming appliances), their preferred activities (mentioned above) and their environmental preferences. To account for this we propose to include an 'agent populator' within our solver. By this we mean that we will create a population of individuals and assign to these individuals the key characteristics (some of which are noted above) that seem to drive occupants' behavioural diversity. This Multi-Agent Simulation of occupants' presence and behaviour then provides the opportunity to couple CitySim with a Multi-Agent Transport simulation program (www.matsim.org/).

Other planned developments relate to increasing the scope of our modelling of resource flows and the dependency of these flows on urban climate. In particular we wish to model the demand, storage and supply of water; the demand side possibly by means of a generalised form of appliance model, which considers appliances which consume water, electricity or both. There are many other modelling challenges that we would like to address, but the above (and eventually the coupling of CitySim and MATSim) represent our immediate priorities.

Modelling Scenes of Different Scale

For the modelling of small scenes of a few tens of buildings it is anticipated that the user will rely mostly on native tools to sketch and attribute buildings according to their constructional, systems and occupational characteristics, as described above. But many potential users already have preferred tools for 3D modelling – Google SketchUp for example has attracted a large following of devoted users, and for very good reasons. So work is currently under way to develop routines to support the import of DXF files which may be exported from a third party 3D modeller (and vice versa); likewise Google Earth's KML file format and the emerging CityGML file format which is attracting a growing user base.

But when it comes to large scenes, it becomes unreasonable to expect the user of CitySim to sketch and attribute all buildings to be modelled – which may potentially number several tens of thousand. For this we need to make the maximum use possible of existing sources of data.

We're very fortunate in Switzerland, in that a great deal of data describing the urban environment already exists:

- **Geometry**: Cadastral data describing the 2D footprint of all (except the most recent) buildings is available from Swiss communes. For the third dimension, LIDAR (Light Detection and Ranging) data describing point heights of solid surfaces are available at fine spatial resolution.
- **Occupation and systems**: The Swiss national Census contains useful information regarding for example the renovation status of a building, the number of apartments it accommodates as well as the occupied floor area, the type of heating system used and its fuel source. The residents' register provides further information regarding the number of building inhabitants as well as some useful socio-economic indicators.
- **Resource use**: Water and district heating and cooling networks tend to be either state owned or operated through a private-public partnership, so that a considerable amount of data is in principle available to help with the calibration of resource flow models.

We are currently evaluating the utility of these disparate sources of data to accelerate the preparation, attribution and calibration of 3D models of urban scenes, possibly supplemented with visual surveys of buildings' characteristics for a representative sample. But our work is not likely to stop here, we may also need to adapt our solver to ensure that the number of computations required to solve our resource flow equations does not entail excessive run times. This is likely to involve refinements to our radiation model (decomposition of our domain into sub-domains of manageable size) and behavioural models (using deterministic profiles or solving explicitly for a sample of inhabitants); the former feature (domain decomposition) may also be exploited to parallelise the solver.

CONCLUSIONS

In this paper we give a flavour of the current capabilities of CitySim, to support the rapid description of 3D urban scenes, the attribution of these scenes according to constructional, occupational and systems characteristics and the parsing of these scenes to a solver which dynamically simulates the building-related demand, storage and supply of energy using a family of deterministic models. We also describe work that is under way to extend both the GUI and the solver of CitySim to enable us to model scenes of varying size, from the small neighbourhood, through the district to the entire city whilst accounting for the stochastic nature of occupants' presence and interactions.

This is an undeniably ambitious programme of work, but we believe that it is crucial to be able to test the effectiveness of design and planning strategies for improving urban sustainability, particularly now that the G8 countries have committed to reducing greenhouse gas emissions by 80% with respect to 1990 levels by 2050. CitySim could play an essential role in helping governments and municipalities to ensure that they are heading in the right direction to meet their targets.

ACKNOWLEDGEMENTS

Financial support from the EU FP6 programme, the Swiss National Science Foundation and the Swiss Federal Office of Energy for the work described in this paper is gratefully acknowledged.

REFERENCES

1. United Nations (2004). Department of Economic and Social Affairs / Population Division. World Urbanization Prospects: The 2003 Revision. New York: United Nations, p.3.
2. Girardet, H. (1999), Creating sustainable cities, Schumacher Briefing 2, Green Books.
3. http://www.treehugger.com/files/2009/07/g8-nations-emissions-agreement.php
4. Robinson, D., Stone, A. (2004), Solar radiation modelling in the urban context, Solar Energy, (77)3, p295-309.
5. Robinson, D., Stone, A. (2005), A simplified radiosity algorithm for general urban radiation exchange, Building Services Engineering Research and Technology, 26(4), p271-284.
6. Kämpf, J., Robinson, D. (2007), A simplified thermal model to support analysis of urban resource flows, Energy and Buildings 39(4), p445-453.
7. Robinson, D., Haldi, F., Kämpf, J., Leroux, P., Perez, D., Rasheed, A., Wilke, U., City-Sim: Comprehensive micro-simulation of resource flows for sustainable urban planning, Proc. Eleventh Int. IBPSA Conf: Building Simulation 2009, Glasgow, UK.
8. Page, J., Robinson, D., Morel, N., Scartezzini, J.-L., A generalised stochastic model for the prediction of occupant presence, Energy and Buildings, 40(2) p83-98, 2007.
9. Haldi, F., Robinson, D., An optimal model for predicting window opening behaviour, Building and Environment (in press).
10. Haldi, F., Robinson, D., Adaptive actions on shading devices in response to local visual stimuli, Journal of Building Performance Simulation (submitted).
11. Reinhart, C., 2004. Lighswitch-2002: a model for lighting and blinds. Solar Energy, 77, p15-28.
12. Page, J. Simulating occupant presence and behaviour in buildings, Unpublished PhD Thesis, EPFL (Thesis No. 3900), 2007.
13. Paatero, J., Lund, p., A model for generating household electricity load profiles, Energy Research 30 (2006), pp 273–290.
14. McQueen, D., Hyland, P., Watson, S., Monte Carlo simulation of residential electricity demand for forecasting maximum demand on distribution networks, IEEE Transactions on Power Systems 19 (2004), pp 1685–1689.