EVALUATION AND OPTIMIZATION OF RENEWABLE ENERGY IN THE "QUARTIER NORD": OBJECTIVE ZERO-POWER

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ABSTRACT

Buildings account for almost 40% of energy consumption in European countries and hence are responsible for a significant part of greenhouse gas emissions. Recent regulations and standards (Minergie, Minergie P, etc.) are strongly encouraging more sustainable buildings by decreasing energy consumption and integrating more renewable energy sources. It is essential, in such a context, to evaluate the performance of buildings and to determine how relevant are the integration of renewable energies and how their implementation can be improved in order to give full autonomy to such a district (towards zero power districts).

In order to achieve this, it is here proposed to use building energy simulation tools to simulate the heating and cooling energy demand. First Energy Plus is used to simulate the demand with a detailed geometrical model of the STCC. Although the results did not give good agreement when compared with a set of measured and recorded data, they corresponded to what has been expected from the Minergie standards. The geometrical model is then simplified and used as input for simulations with both CitySim and Energy Plus. The differences between both models are considered to be acceptable (15%). Finally, the evaluation of the potential for the integration of renewable energy and storage capacity is done with CitySim.

This work is expected to provide a methodology which could be used in the evaluation of building energy use and help with the integration of renewable energy at a neighbourhood scale along with the dimensioning of the energy storage. Furthermore we gave a quantitative analysis of the differences between the two models. It is thus proposed in future work to couple both models using a co-simulation technique, to take advantage of the performance of CitySim and Energy Plus models and to include processes at different scales.

Keywords: building energy simulation, CitySim, Energy Plus, renewable energy, storage, zero-power district

INTRODUCTION

The recent Intergovernmental Panel on Climate Change[1] again highlighted the need for a drastic change in national and international policies regarding the mitigation of climate change due to greenhouse gas emissions. Buildings account for almost 40% of energy consumption in European countries and hence are responsible for a significant part of greenhouse gas emissions (around 23% for France[2]). Recent regulations and standards (Minergie, Minergie P, etc.) are favouring more sustainable buildings by decreasing energy consumption and with the integration of more renewable energy (RE) sources.

New strategies are however needed to develop and build more sustainable quarters / neighbourhoods. In order to reduce the energy consumption and greenhouse gas emissions, which usually comes from centralized energy system, communities are encouraged to install more RE. However these RE are often intermittent and are not available when most needed (e.g. heat from the sun during winter months). Storage should thus be used as a complement to reach these requirements. Determining the size of the storage and the RE installation capacity is a tedious process which can only be handled by using numerical software.

Such tools are often used, before renovation and construction, to determine what kind and type of strategies are needed to achieve the desired objectives (both for demand and installation of RE). Models working at different spatial scale have been developed and used in the past. On the one hand at the building scale, models such as Energy Plus[3] are frequently used. However these models do not consider the surrounding neighbourhood which can have a significant influence on the energy balance of the building. On the other hand at the neighbourhood scale model such as CitySim[4] or Envimet[5] have been used. These models give a more realistic representation of the surrounding but however do not have a very detailed description of the considered building.

We hence propose to evaluate with a quantitative analysis the difference between two models working at different spatial scales. We used the Energy Plus model and the CitySim software for the simulations. The idea is to prepare both models for a future co-simulation, as multi-scale modelling could be used to simulate a building at both scales in order to improve results.

In the framework of this study, we focused on one of the landmarks of the Ecole Polytechnique Fédérale de Lausanne (EPFL): the SwissTech Convention Center (STCC). In a first step, we collected data / information on this building. We then developed a detailed model representing the real geometrical and technical characteristics of the STCC to be used as input for simulation with Energy Plus. These results are then compared with measured data. In a third step, we then “simplify” this model so that it can be used in both CitySim and Energy Plus. CitySim is then used to evaluate the renewable energy integration capacity as well as the need for storage, to decrease the dependence on centralized energy systems.

This paper is divided as follows. In this Method section, we give a brief overview of how we used the Energy Plus Open Studio plugin to draw the detailed model of the STCC and how we then simplified it. We also describe how we use a simple methodology to calculate the storage need. In the Results section, we describe the results obtained from both models, the storage need and renewable energy integration in the Quartier Nord. Finally, we discuss the results and conclude on the main outcomes of this study.

METHOD

Geometrical data

To build a coherent model and as close as possible to the actual STCC building, we collected data from the Department of Infrastructure of the EPFL (DII). The data obtained corresponded to the technical details of the building as described by the architects and engineer. However, due to some discrepancies between some of the administrative documents, part of the data (total volume, window glazing / frames …) was considered to be incomplete or incorrect.

Energy Plus

Energy Plus[3] is a software developed by the Department of Energy, USA. It works at the building scale and is widely used in the building energy sector both in the private and research industry. One of the main advantages of Energy Plus is that it is has a low simulation time while having a very detailed description of the building. It also contains an exhaustive database for construction materials as well as for the heating, ventilation and air-conditioning (HVAC) systems.

Another one of its advantages is that it has a wide range of compatibility with designing software, including Open Studio. This plugin was used to design the STCC building with as much details as possible corresponding to the actual characteristics of the buildings (see Figure 1).

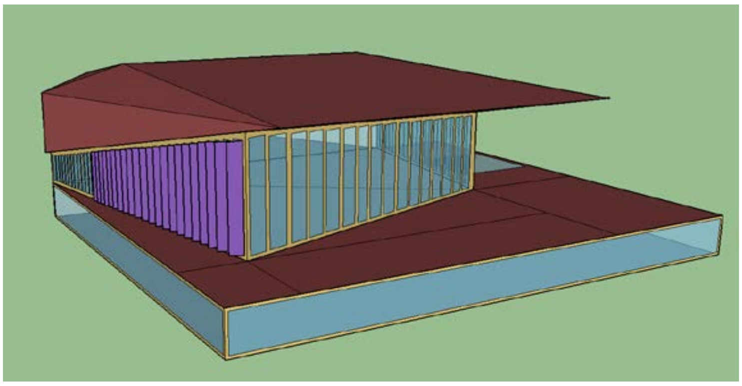

Figure 1: Representation of the STCC with Open Studio

One of the aspects that we have simplified in this representation is the complete description of the HVAC system. The energy system used here is very complex as it uses waste heat water from the EPFL site and also from solar thermal panels installed on nearby buildings. A simplification is thus proposed in the heat network designed for the STCC.

CitySim

CitySim[4,6] is a large-scale dynamic building energy simulation tool developed at the EPFL. The tool includes an important aspect in the field of many buildings simulation: the building interactions (shadowing, light inter-reflections and infrared exchanges). Furthermore, CitySim is based on simplified modelling assumptions to establish a trade-off between input data needs, output precision requirements and computing time.

This thus requires a simplification of the geometrical characteristics of the building under consideration. Based on the first model, we built for Energy Plus, we removed some of the technical details (window frames, Graetzel cells on the west side…) which can be considered to have a minimal impact on the energy consumption or which can be described otherwise. Any simplification done for the CitySim software is also applied to the model used in Energy Plus.

Methodology to evaluate the storage need of the Quartier Nord

The typical building energy consumption and production profiles for a northern European country does not allow for an easy complete integration of RE. It can be noted that during summer months there is a higher production and that if this production can be stored for a couple of months, then it would be possible to use it for the beginning of the winter season as a heating source. The storage thus has the potential to shave off peak RE productions and also decrease the constraints linked to the intermittency of renewable energy sources.

The evaluation of the storage is done as follows. First, we calculate the energy demand and the energy consumption for a whole year. Second, we include renewable energy in the building using only PV panels. We then evaluate what is the surplus electricity (produced – consumed) and how this can be used to heat a water tank ($5m^3$) to store energy for use in future months as a heating source considering heat losses in the tank (to the ground). This is a simplified version of the method used in Guadalfajara et al. (2014)[7].

Monitored data and experiments

For this study, we collected monitored data from the DII regarding the heating and cooling demand. As the STCC has been operational for since July 2014, we run our detailed simulation for only 6 months. These months should be representative of a summer and winter period of a typical year.

As mentioned previously, we run a set of simulations. The first one is done with Energy Plus using the detailed geometrical model and the results are compared with the monitored data. Then we run both CitySim and Energy Plus using a simplified model and when comparing both models, we only use the ideal load, to give a quantitative analysis of the differences between the models. Finally, we include solar PV panels to evaluate the RE integration potential and use a simple methodology to determine the implication of using seasonal storage.

RESULTS AND DISCUSSIONS

Energy Plus simulation comparison with measurements

For EnergyPlus, ideal loads for heating and cooling needs were computed, and the values were divided by 0.8 to get the real consumption as an energy system of 80% efficiency was assumed. The simulation here are done for only 6 months from July to December 2014, as this is the first monitoring period of this newly constructed building.

	DII	**Energy Plus**	**Error (%)**
Heating (GJ)	1395.1	443.9	-68.2
Cooling (GJ)	907.9	1054.2	16.1
Total (GJ)	2303	1498.1	-34.9

Table 1 Difference between Energy Plus and monitored data for 6 months (July to December)

From Table 1 it can be noted that there are significant differences (68%) between the results from the DII and the Energy Plus simulation particularly concerning the winter period whilst during the summer period there is a difference of only 16%, which is slightly above other comparisons done with Energy Plus[8].

However, if we look at the energy consumed per m^2, over one whole year, it can be highlighted that the values obtained from the Energy Plus simulation (39 kWh/m^2) seems to in agreement with the Minergie Standard[9] (40 kWh/m^2). This then raises the question of the behaviour of the control system as well as of the occupants in the buildings. But as mentioned before this was the first 6 months of monitoring and of occupancy of the building and it is hence very likely, according to the DII, that the building is not functioning at its optimal capacity.

Comparison between CitySim and Energy Plus

In this second phase, we simplified the model so that its representation in both CitySim and Energy Plus are as close as possible. The model is then run over a whole year, without internal gains from equipment and occupants and the results and differences between both software are given in Table 2.

It should be noted here that this is the ideal load needed to heat and cool the building. It can be said that over all the precision of the Energy Plus is slightly decreased as there is a slightly higher energy consumption. There is a difference of around 22% between the energy consumption between CitySim and the Energy Plus simulation. It should also be highlighted that these differences (not shown here) are similar for the both the heating and cooling period. Through some sensitivity analysis that we have conducted we have shown that Energy Plus seems to have higher solar gains inside the building as compared to CitySim. Additional tests are required here to determine the cause of such differences but as this is not the purpose of this paper, it will be addressed in future work.

	CitySim	Energy Plus	Error (%)
Total (GJ)	2253.8	1837.5	22
Energy Per Area [kWh/m^2]	62.6	51.0	

Table 2: Difference between Energy Plus and CitySim

Renewable energy integration and storage needs

To estimate the renewable energy potential, solar PV panels are integrated to the STCC and a simulation is done over a whole year. From Figure 2, it can clearly be seen that the summer production is much higher than the winter, while the consumption appears mainly during the winter, due to the heating demand.

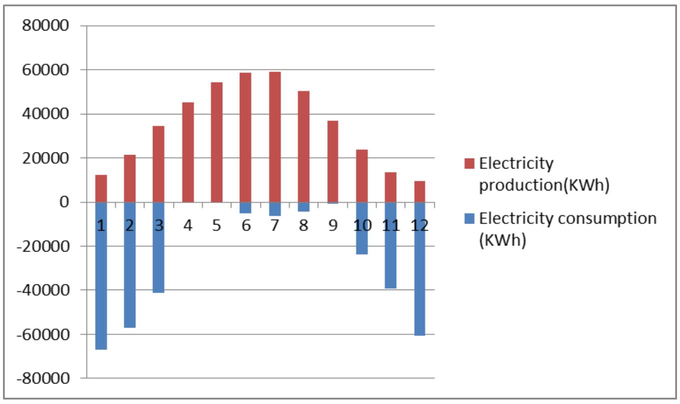

Figure 2: Estimated energy consumption and production

It is thus proposed to use a simple methodology to use this excess summer heat, to heat an underground water tank (with an average yearly ground temperature at 10 °C) of 5m^3 (5000L). In this study, we consider the heat losses to the ground and in the tank but we make the calculation over a whole month. Besides we consider that the accumulated temperature and energy for the first month of the year is equal to the last, so that there is not yearly accumulation.

Table 3 shows the accumulated temperature in a hot water tank. It can clearly be noted that when using such a tank and a system, it is possible to heat a water tank to almost 44 °C. This excess heat can be used thus in the first winter months for heating purposes. It is most likely that additional heating surfaces are needed in order to reach the minimum temperature required for domestic hot water.

Month	1	2	3	4	5	6	7	8	9	10	11	12
Acc. Temp (° C)	30	30	30	32.2	34.7	37.3	39.8	42	43.7	43.7	43.7	30

Table 3 Energy production, consumption and surplus used to heat boiler

CONCLUSION

This study was conducted to analyse the influence of integrating renewable energy in a building to make it autonomous in terms of an energy point of view. Furthermore, we use two distinct models Energy Plus and CitySim to evaluate the energy consumption of a landmark building of the EPFL campus.

First a comparison between Energy Plus simulation and monitored data was conducted. This comparison highlighted the need to account for the user behaviour and other external factors when using building energy simulation tools.

Secondly, we simplified the geometrical model and compared simulation between CitySim and Energy Plus. Although both models gave satisfactory results, it was noted that there could be some significant differences between the ways solar gains are calculated in both models.

Finally, RE sources were integrated and an analysis was conducted to estimate the possibility of using seasonal storage. It was demonstrated that using a simple methodology, the accumulated temperature in the water storage tank can be calculated. More explicit calculation should be done to improve these calculations.

Further works are needed to investigate more in details the reason why CitySim and Energy Plus have some discrepancies. Additional studies should be performed to optimize the actual capacity of the water storage size as well as the possibility to using solar collectors. Besides, this study has now prepared the framework towards co-simulation between the two models working at different spatial scales.

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