Development of an energy management model for a heating and cooling microgrid in a public building

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Abstract

In order to seriously address the fossil energy use and climate change crises, buildings clearly offer vast potential for reducing the demand for energy and the corresponding greenhouse gas emissions. The sustainability of our society and economy will be clearly based on renewable and highly efficient resources. This implies large scale strategies as the implementation of low-energy buildings (so called nearly Zero-Energy Buildings or nZEBs).

Enhancing the energy performance of buildings through deep renovation is strongly requested. As one of the European Regional Development programs, the IMPROVEMENT project seeks for the integration of combined cooling, heating and power microgrids in zero-energy public buildings under high power quality and continuity requirements. This assessment might help to find out a "common strategy" regarding the Sothern Europe meteorology and stablish regional implementation plans under the common climatology conditions.

The empirical part of the research utilizes Matlab/Simulink environment to carry out simulations and validate whether the proposed Energy Managed System was appropriated for the building's features. Matlab/Simulink allows both dynamic building thermal simulation and multi-objective optimisation, within a single environment.

Key-words: Buildings energy performance; Energy Management Systems, retrofit; nearly Zero-Energy Building (nZEB); Matlab/Simulink; climate zones.

1. Introduction

Over the last years, the European Commission has been following ambitious plans towards the transition to a low carbon economy by 2050. The targets are mainly based on the reduction of greenhouse gas emission (≤40%) and in improve both the energy efficiency (≥30%) and the renewable energy share (≥27%) for the 2020-2030 period, compared to 1990 levels. Worldwide, there have been many attempts to reduce the carbon footprint by integrating Renewable Energy Sources (RES) within the energy generation units, but unfortunately, they will not be sufficient to reach the 2050 objective and there is a need of ensuring the right policies to reach our long-term target.

The complete introduction of the renewable technologies in the grid it is being arduous to achieve due to its natural intermittency. The introduction of Energy Management Systems (EMS) has been relevant to control the gap between energy supply and demand, optimizing the energy costs, increase comfort of living and reducing the greenhouse gas emissions. Thus, there has been a focus on the research of a new generation of EMS to operate buildings according to the local conditions and therefore harness the onsite renewable sources. This thesis is also an attempt to reduce the carbon footprint within the building sector.

2. Model description

The modelling of the thermal energy management system of the case study for space heating purposes has been developed following the dynamic approach, which is based on the analysis of the hourly evolution of the significant status parameters.

The layout of the thermal system (Figure 1), depicts the EMS of the office building that has been built through Matlab/Simulink environment. Four principal sub-systems have been employed for the modelling its thermal performance. These are:

• The *Solar Thermal* system, composed by the collectors, the storage tank and the auxiliary equipment such as the pump.

• The *Room*, which simulates the thermal conditions of the case study by considering the heat gains and losses through the envelope, infiltration and ventilation, solar gains and internal gains.

• The *Fan Coil Unit*, which allows the heat exchange between the Solar System and the Room.

• The *Back-up* unit, that will be activated when the energy provided by the collectors does not meet the thermal needs of the office.

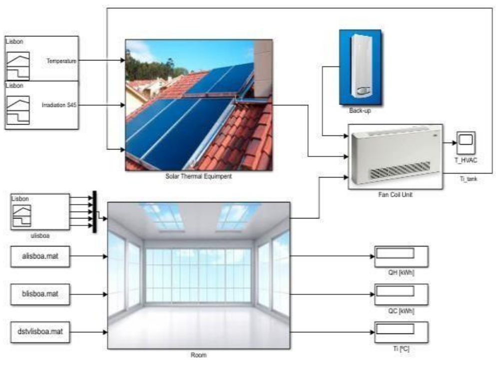

Figure 1 Schematic diagram of the thermal system of the office in Smulink

2.1 Global Irradiation on sloped surfaces

The amount of solar radiation incident either on solar thermal collectors or photovoltaic panels is strongly affected by its installation angle and orientation [1]. Therefore, finding the optimum tilt angle to receive maximum solar radiation on a photovoltaic module is the best way to take full advantage of the solar radiation.

The simulation of the model was carried out according to detailed weather data. The data was firstly downloaded from the EnergyPlus website [2] and then utilized to compute, the hourly values of global solar irradiance on a sloped surface of any orientation and slope. These calculations have been carried out through simple Liu-Jordan method [3][4].

Table 1 shows the computed annual global irradiation on a sloped surface facing south for an office in Lisbon, with its respective latitude and the selected tilt angle. Similarly, Figure 2 depicts the computed annual solar irradiation. The hourly values of the annual solar irradiation will be, together with the external temperature, the input variables of the studied solar thermal system.

Table 1 Annual global irradiation, latitude and tilt angle of the study case in Lisbon

Latitude	Tilt angle	Global Irradiation
38.74 º	40 º	671.90 (kWh/m2)

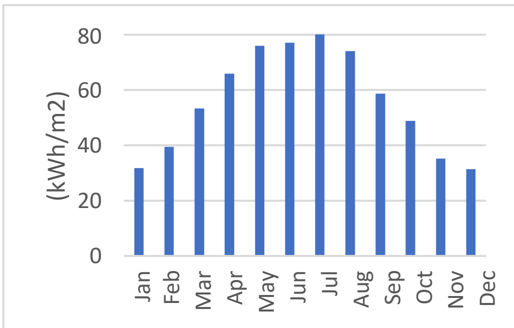

Figure 2 Lisbon's annual solar irradiation

2.2 The Room block

The Room sub-system is based on the solution that Piotr Michalak proposes in [5], which introduces a novel Linear Time-Varying (LTV) simulation model of thermal network of a building. It has been developed through the Simulink S-function stvmgain (i.e. continous time varying matrix gain). Through this function block, it is possible to build a state-space model of the building in the form of state-space matrices with time-varying parameters as inputs. These can be generated according to the user's requirements.

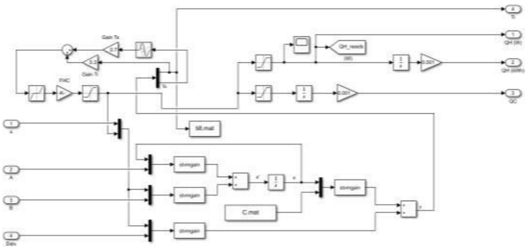

Figure 3 Room's Layout with its inputs and outputs variables

The hourly values of the heating and cooling needs have been calculated through a simple hourly model: the five resistances, one capacitance (5R1C). This model, described in ISO 13790:2008 Standard [6], enables the calculation of the energy consumption and use of the space heating in residential and non-residential buildings. (See Appendix A).

The inputs of the system are:

• The 'u' block, that has been created by means of the Signal Builder Simulink's block, which contains a consecutive sequence (hourly) of the external air temperature (Te), the supply air temperature (Tsup) and the heat fluxes to the internal mass (Φm), to the central node (Φst) and to the internal gains (Φia).

• The A.mat, B.mat, C.mat, Dstv.mat blocks are the system, input, output and input-output matrices respectively, which are composed by the internal thermal capacity of the building and the different transmission heat transfer coefficients within the building (See [5] for full set of equations).

• The Dead zone block allows the temperature control for the heating and cooling, according to EN ISO 13790 requirements. This block is coupled with the gain block FHC, which is used as temperature error gain.

• The Saturation block is used to limit the maximum heating and cooling power.

The outputs of the Room are the heating needs (QH), the cooling heeds (QC) and the internal temperature (Ti).

Both the Room and Solar sub-systems are connected to each other through the FCU which allows the heat transfer process.

2.3 The Solar thermal block

The Solar thermal sub-system has been adapted from [7] where Matteo Dongellini et al. have developed a dynamic simulation of solar thermal collectors for DHW production. The simulation of this model allows the hourly evaluation of the energy collected by the solar panels and the temperature of the hot water produced by the system, that in this case, will be used for space heating through a water-air FCU.

The inputs of the Solar sub-system are the external temperature and the hourly solar radiation within a reference year. The outputs of this sub-system are two: the warm water that goes to the FCU and the cold brine that comes back to the collectors.

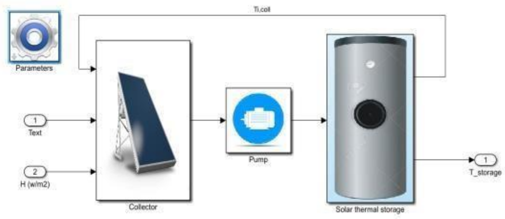

Figure 4 Layout of the Solar thermal sub-system

The sub-blocks that compose the Solar thermal sub-system are the following:

- The Collector block is a simulation of the solar thermal collectors' performance that constitutes the heating system.
- The Pump block contains the pump governing equations that compute the fluid temperature raise caused by de pump itself and its electrical consumption.
- The Solar thermal storage block evaluates the thermal loads within the hot water storage tank. The storage tank connects

the Solar thermal and the FCU sub-systems through a water mass flow that has been heated up by the solar collectors and stored until needed.

Separately, there is an extra block within this category, called the Parameters block, which contains all the values of the main physical and geometrical properties required in the modelling. These can be changed within the same model to simulate different scenarios.

2.4 The FCU block

The FCU sub-system simulates the performance of a Fan Coil Unit through a cross-flow heat exchanger, which allows the heat transfer process between the collector's working fluid (water) and the air mass flow of the room. It is assumed that the heat exchange is based on the specific heat of the fluid with less heat exchange (i.e. the air) and depends on the temperature difference of both fluids of interest with a certain efficiency. The general equations of the process are depicted in Figure 5.

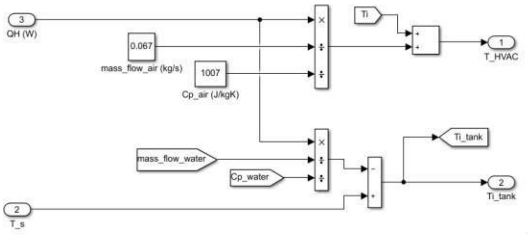

Figure 5 Layout of the FCU sub-system

Associated to this subsystem we find the back-up unit, which will be switched on if the heat provided by the collectors is not enough to meet the thermal requirements of the office. It works by means of an electric heater (COP=1). This operation is supervised by a controller characterized by an on-off logical control that is implemented within the block.

3 Results and discussion

This section shows the results of the different sub-systems working as a grouped model. All the simulations have been performed within Matlab/Simulink environment. Within the original document [8], the simulations are carried out in identical conditions for the three studied European cities, while here only the results for Lisbon case study are presented. The results obtained from simulations were performed to determine if the originally proposed thermal system is suitable for study case.

3.1 Heating needs

Following the 5R1C method as mentioned in section 2.1, Figure 6 depicts the instantaneous power requirements to be supplied to the office for space heating. It can be appreciated how the thermal performance of the office only requires heating during the cold seasons that is, from November to mid-April in the case of Lisbon.

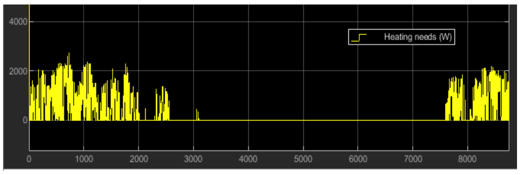

Figure 6 Lisbon instantaneous power needed for heating purposes

3.2 Available thermal power

Figure 1 shows the annual useful thermal power collected by the solar panels in Watts. These values are obtained by means of two flat solar thermal collectors connected in series with an absorver surface of 4 m^2 each. The useful thermal power curve for this case study presents itself as a very interesting curve since most of the values are between the 1000-2000 (W).

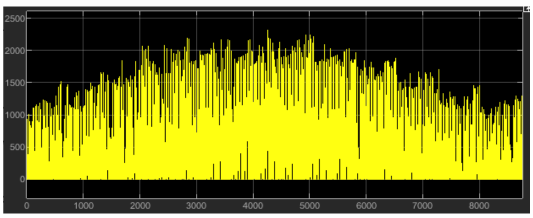

Figure 7 Useful thermal power collected by the solar panels

It can be appreciated how during the spring and summer periods these values are higher, reaching and even overtaking the 2000 (W). During the fall and winter seasons these numbers are clearly smaller, with a range between 500-1300 (W).

3.3 Storage temperature

The next figure represents the water temperature within the storage tank. Under the mentioned conditions, this curve represents the water temperature required for satisfying the energy needs for space heating. As it can be seen, the graph shows the temperature in cumulative values during the months with heating needs while it remains constant (no need of space heating) for the hot months.

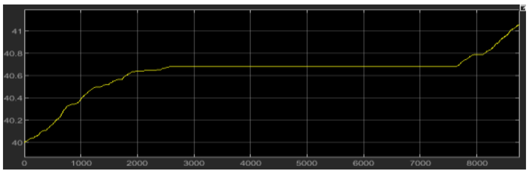

Figure 8 Temperature in the storage tank: Ts (ºC)

3.4 Back-up

While being the sub-systems connected, it is possible to compare the heating needs required in the office with the useful thermal energy provided by the collector. The comparison between these two magnitudes will explain when it is necessary to swich up the back-up unit. The theoretical performance of the back-up unit is shown in Figure 9.

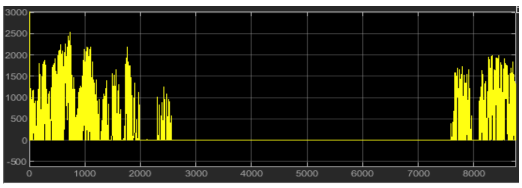

Figure 9 Theoretical back-up power requirements (W)

3.5 The space heating temperature

As the storage tank is connected to a Fan Coil Unit (FCU), the heat within the water is transferred to the air that is going to be supplied into the room through a water-air heat exchange process. Since a very low airflow has been selected for comfort reasons, the temperature range between the office interior temperature and the space heating temperature is considerably large. Thus, for the given conditions, the air supply temperature for space heating purposes is also very high, this is shown in Figure 10.

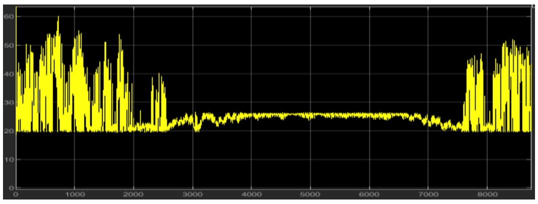

Figure 10 Required temperature for space heating(ºC)

4 Conclusions

In this research, an integrated simulation model of the EMS within an office building was carried out using Matlab/Simulink. This model was then used to predict the thermal performance of a specific office-prototype building in Lisbon. For this purpose, the developed model has been simulated by means of its respective location and weather features.

As far as the model has been developed, the HVAC system can only provide space heating through a Fan Coil Unit (hot air from the heated water by the solar panels) and therefore, the model can only cope with the 'cold-season' heating requirements and not with cooling needs. Furthermore, for satisfying both heating and cooling needs, a heat pump would be needed.

It is concluded that an accurate estimation of the energy needs for space heating to meet the specified comfort targets for winter, requires a detailed hourly simulation (mainly due to the significant daily fluctuations of temperature and solar irradiation). Accordingly, the results strongly depend on the climatic conditions as well as on the configuration of the thermal energy management system. It is hoped that the findings of the present study can help to establish procedures to optimize energy demand and thermal comfort in nZEB buildings in warm regions.

This model highlights the almost continuous need of a back-up unit during the cold months. Taking into account the imposed conditions of using a rather low airflow to heat the office, the supply air temperature in the FCU is very high and this limits the need for back-up action most of the time.

Considering that the model provides an accurate calculation of both energy needs and solar radiation on inclined surfaces, possible improvements should be made to both the solar thermal and the FCU sub-systems more adjusted to specific needs.

It can be stated that the main disadvantage of using solar energy for heating is that the main heating demand occurs during a few months of the year and these coincide with the months with less solar radiation, which limits the performance of these installations and evidences the back-up requirements. This is one of the reasons of why it is very common to share the use of the mentioned systems together with the production of DHW, with the appropriate control systems that prioritise the most convenient use in each case.

5 References

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3 Apendix

Appendix A: 5R1C model

The five resistors and one capacitor model is one of the simple hourly methods given by the EN ISO 13790 standard. It appears as an alternative to the monthly method with the main advantage that the hourly time intervals enable direct input of hourly patterns with the same level of transparency and robustness. This method, as well as other models of similar complexity, uses an hourly time step and allows all building and system input data to be modified each hour using schedule tables.

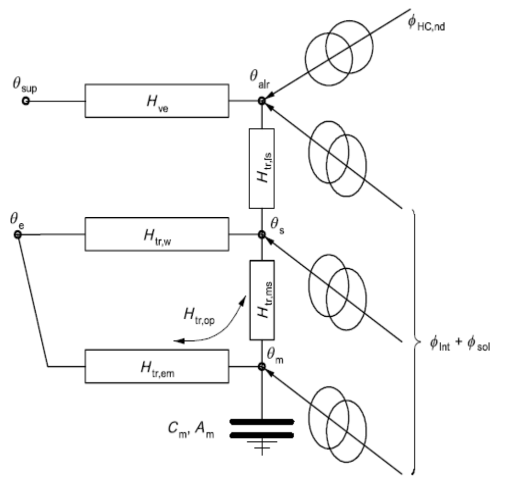

Figure 11 Five resistances, one capacitance (5R1C) model; EN-ISO 13790 standard

The calculation method of this model makes a distinction between the internal air temperature and the mean temperature of the internal surfaces which enables thermal comfort checks and increases the accuracy of accounting the solar, lighting and internal heat gains.

The building elements are discretized into a set of nodes connected by thermal resistances and capacitance. These parameters can be identified analytically, by model order reduction or by tuning the model to a temperature and energy consumption dataset.

Table 2 Nomenclature and units of the main heat transfer variables

$H_{tr,op}$- Transmission heat transfer coefficient of the opaque building elements, (W/K)
$H_{tr,em}$ *and* $H_{tr,ms}$- Transmission heat transfer coefficients of the external and internal part of $H_{tr,op}$, respectively, (W/K)
$H_{tr,is}$- Transmission heat transfer coefficient between the air node T_i and the surface node T_s, (W/K)
$H_{tr,w}$- Transmission heat transfer coefficient of doors, windows, curtain walls and glazed walls, (W/K)
Hve- Transmission heat transfer coefficient of ventilation air, (W/K)
C_m- Internal thermal capacity of the building, (J/K)
A_m- Area of the thermal mass, (m^2)
$\Phi_{HC,nd}$ - Actual heating or cooling need, (W)
Φ_{sol} *and* Φ_{int}- Heat flow rate from solar heat sources and nternal heat sources in thebuilding respectively, (W)
θ_{sup} *and* θ_{air}- Supply air temperature node and internal air node respectively
θ_s *and* Θ_m- Central and internal mass nodes respectively

The nodes are used to evaluate the needs to be supplied to or extracted from and to compute de heating and/or cooling energy needs to maintain the set-point temperature.

The heat transfer by ventilation (Hve) connects the supply air temperature node (θsup) with the internal air node (θair), from which is possible to compute the actual heating and cooling needs.

The coupling conductance (Htr,is) links the air and central nodes. The heat transfer by transmission is split into the glazed elements (Htr,w), taken as having zero thermal mass, and the opaque builiding elements (Htr,op), containing the thermal mass which is successively split into two parts: Htr,em and Htr,ms.