Development of an energy digital twin from a hotel supervision system using building energy modelling

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Development of an energy digital twin from a hotel supervision system using building energy modelling

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Abstract. In this work, the utilization of the supervision system of a five-story hotel located in Northern Italy as tool to calibrate and validate a building energy model (BEM) is evaluated. The BEM is created using the TRNSYS simulation environment with the aim to develop a digital twin, to study the energy consumption of the building-HVAC system. The procedure for the supervision system preparation and the data analysis procedure is presented. The digital twin is then used to compare two control strategies for the thermostats' control during summer to increase the energy efficiency of the building-HVAC system, and to use the heat storage properties of the building envelope to shift and shave the peaks of power demands. Control rules that allow a better match between electrical energy demand and availability, developed, and tested using the BEM, are pursued with the final goal to prepare the inclusion of the hotel in a smart grid. The building is modelled using TRNSYS Type 56 as a multi-zone building, with 96 thermal zones while the building monitoring is performed during the summer season from June to October 2022.

1. Introduction

To reduce buildings' operation footprint and energy consumption, many efficiency measures can be implemented, like the reduction of energy losses through the building envelope and the utilization of renewable energy, that are mostly fluctuating and not constantly available. The implementation of energy storage systems could reduce the impact on existing utilities, but they are often expensive. Another solution is to connect the utilities of prosumers to other consumers to match the energy demands with the production. Both principles are then applied in smart grids. To ease this process it is crucial to increase the flexibility of the energy demands, in order to match the offer. In this context, transient building energy simulation methods that are used to evaluate energy consumption and occupants' comfort, could be now used to evaluate the heat storage capacity of buildings, and the flexibility under the variation of energy availability. When the involved buildings are low-energy demanding it is possible to store energy changing the temperature of the thermostats [2], shifting or shaving the peaks of the heating or cooling loads. These strategies require a deep knowledge of the thermal behaviour of the building and of the energy grid, that can be acquired with monitoring and calibrated models.

1.1. Digital Twin and Building energy modelling

In a recent review [1] on research works on Digital Twin (DT), the authors reported only few applications in building energy management, concluding that it is still novel topic. Furthermore,

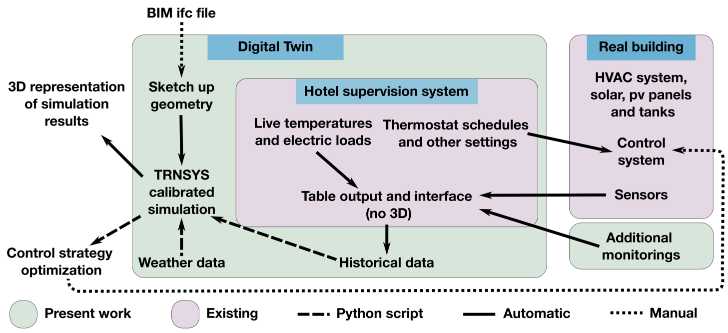

Figure 1. Procedure followed for the definition of the digital twin, starting from the supervision system. The arrows show the automatization stage of the connections, from manual to automatic (already implemented in the used solution).

the use of different BEM techniques are reported, not only transient energy simulations but also machine learning and artificial intelligence, that are used to interpret measured data and to generate behaviour predictions. The main unknown in buildings, especially in hotels, is occupants' behaviour, not only due to the natural ventilation due to window openings, but also to heat loads from occupants and changes they do on thermostat's set point. Confirming the relevance of this aspect, the authors of [3], using EnergyPlus building simulations, showed that the installation of occupant presence sensors in guest rooms and common spaces could reduce relevantly the energy consumption. On the other hand, the authors of [4] monitored four guest rooms defining correlations between the outdoor air temperature and the room air temperature. A thermal comfort survey on the occupants is also performed, concluding that also the temperature at the check-in is relevant on the perception of comfort of the guests, meaning that changing the thermostat settings when the occupants are not present could be perceived as a reduction of comfort.

1.2. Present work

The DT real-time data collection for the present work is provided by the supervision system (a commercial solution) that automatically writes measured data to a database, while the digital representation, that could be used to perform predictions, is a building energy model (BEM) defined in the TRNSYS environment. The setting up of the system is presented in Figure 1. In this preliminary work, the TRNSYS model includes the hotel building envelope, connected to the the guest occupation and the temperature set points of the rooms obtained from the supervision system database. The output of the model is the cooling loads of each thermal zone. Using the room occupation data, it is possible to evaluate other thermostat rules that could reduce cooling loads maintaining the comfort of the occupants. The developed control rules can then be set using the supervision system acting as a control of the hotel HVAC system. The preparation of the TRNSYS input data from the database is done with python scripts, like the definition of the weather file obtained from a weather station. The ifc BIM file is used as underlayer for the manual definition of the building geometry in SketchUp and automatically converted in the BEM model with the plug-in Trnsys3D. Future work will also include the generation of optimized control rules with python scripts that will be set up in the supervision system manually allowing to evaluate the effectiveness of the strategies. The BEM is not connected to live data and at the moment and it could be used only with historical data.

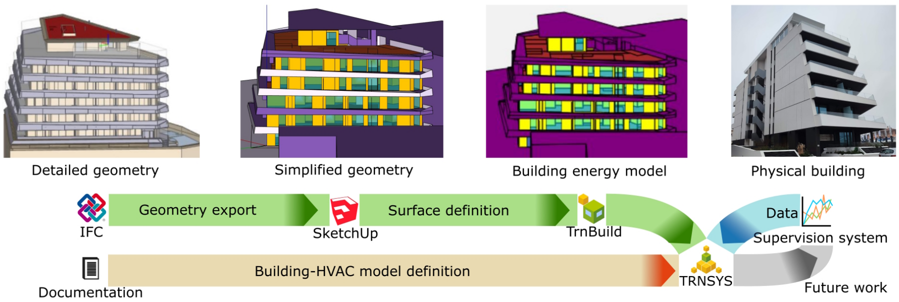

Figure 2. Workflow followed for the definition of the building energy model in the TRNSYS simulation environment.

2. Materials and methods

This work presents the early phase of the development of digital twin (DT) of a hotel building-HVAC system. The idea is to utilize the already implemented supervision system (requiring as small as possible modifications in the hotel's monitoring sensors), to build a continuously calibrated energy model of the hotel on TRNSYS simulation environment to develop thermostat and HVAC settings to reduce energy consumption and to improve the energy flexibility.

The building is a 5 storey seasonal hotel located in a seaside location with a total floor surface of 1600 m^2, an internal volume of 4300 m^3 and a external surface-volume ratio of 0.44. The hotel is a new construction with a high-efficiency envelope (wall thermal transmittance U_{wall}=0.20 W/m^{2}K and windows thermal transmittance U_w=1.30 W/m^{2}K), open to guests for the first time on the 7th of June 2022. Two air-water heat pumps provide heating and cooling for the fan coils in every guest room and for the AHU. The hotel is equipped with a set of photovoltaic and thermal solar panels not yet functioning. This study focuses on the estimation of the cooling demands of the guest rooms in the period from the 7th of June to the 5th of November in order to develop HVAC control strategies to better exploit the self-produced energy.

2.1. Building monitoring and modelling

The current supervision system measures all the room temperatures in order to guarantee the guests' comfort and allows to set a temperature set for every hour of the day, for checked-in and vacant guest rooms. The supervision system is connected to a computer at the reception, allowing the hotel staff to pinpoint every HVAC malfunction in the rooms. The system also tracks the key operation of the rooms' doors and shows if the rooms are occupied. It also allows to track the overall energy consumption of all the systems in the building. Eventually, other sensors could be connected and monitored by the system, extending its capabilities.

The BEM definition is described in Figure 2. The BEM geometry is defined using Trnsys3D plug-in and the software tool SketchUp 2017. The geometry is imported from the IFC file in SketchUp and used as underlay to manually draw the BEM surfaces. A thermal zone is defined for each thermostat in the building, for a total of 94 zones including 34 guest rooms with restrooms and common zones. Then the building envelope properties are defined in TRNBuild, the internal gains (occupation, illumination and electric devices) are defined as schedules.

The occupation and illumination schedules are obtained for each guest room from the supervision system room key operation record. This is one of the uncertainties of the model: knowing the key operation time does not provide an accurate record of the room occupation and the number of people in the rooms. The occupants' loads are set to 115 W/person, while the illumination load is defined by the lighting devices installed in every room. The infiltration is set constantly to 0.5 ACH in the guest rooms and to 1.5 ACH in restrooms. The weather file used in the simulations is measured at about 10 km away from the building location and is kindly supplied by ARPA FVG (OSMER). The solar radiation is calculated by Type 56 ideal sky model and does not take in account cloud cover.

2.2. Thermostat settings

Using the occupation schedules obtained from the supervision system, different thermostat settings are defined:

- MT: as measured by the supervision system, the temperatures are influenced by occupants' behaviour (occupant-based climate control) and by other loads (e.g.. window openings, domestic hot water utilisation);
- PD (PreDefined): as predefined in the supervision system: 24°C if vacant and 22° if rented;
- SB (SetBack): like PD, but setting back to 24°C a rented room after 30 minutes after the occupants left the room;
- LS (Load Shift): like SB, but shifting the loads reducing the temperature to 19°C from 13:00 to 15:00 (when most of the rooms are empty and the PV production is at peak) only in the rooms oriented to South West, where the cooling loads peaks happen at about 17:00;
- LR (Load Reduction): like SB, but increasing the temperatures of 1°C .

The LS and LR settings are relevant to evaluate the energy flexibility of the building, to increase self-consumption and use grid energy at hours with reduced price.

3. Results

The supervision system provided many relevant information necessary to build the building energy model. Figure 3 shows the frequency distribution of the occupation of all the rented guest rooms in August and October. The guest rooms not occupied during the night are probably due to rented rooms that were checked in in the morning. It could be observed that the profiles change according to the month, due to the differences in activities and daylight (most of the rooms are occupied after 20:00 in October, while in August the same happens after 22:00).

No clear correlation between the occupation and the internal temperature was found and the thermostat preferences of the occupants were not recorded by the supervision system, nor the window openings or the usage of domestic hot water. Figure 4 shows in the first plot the temperatures calculated by the BEM in a room facing South-West of the first floor. It is possible to see that the temperature of the setting MT follows the occupation daily pattern with higher temperatures when the room is occupied. The SB setting is defined in order to reduce the cooling loads when the room is not occupied, turning the set-point to 24°C after 30 minutes of vacancy. In the second plot of Figure 4 it is possible to see the cooling loads for the same thermostat settings. The SB setting turns off the cooling most of the time in which the room is empty, while the MT some days reaches 0 kW in presence of the occupant. Considering the Energy cooling demands simulated from June to August the SL and PD resulted respectively 4% and 2.5% higher loads than the MT, due to the fact that the MT is not constrained below 24°C, but often reaches higher temperatures.

As shown in Figure 5, during June, using the LS setting it has been possible to reduce the peak at 17:00 of the rooms facing South-West of the 19% in average, while increasing the total cooling demand of the 3%. When considering the whole building the peak reduction is of 6% with an increase of the cooling demand of the 2%. It should be considered that the LS setting has not been optimized and that a parametric analysis could lead to better results. On the other hand the LR setting obtained a reduction of the 5% of the June cooling demands from the SB setting, while considering the period from June to August, the reduction is of the 12%.

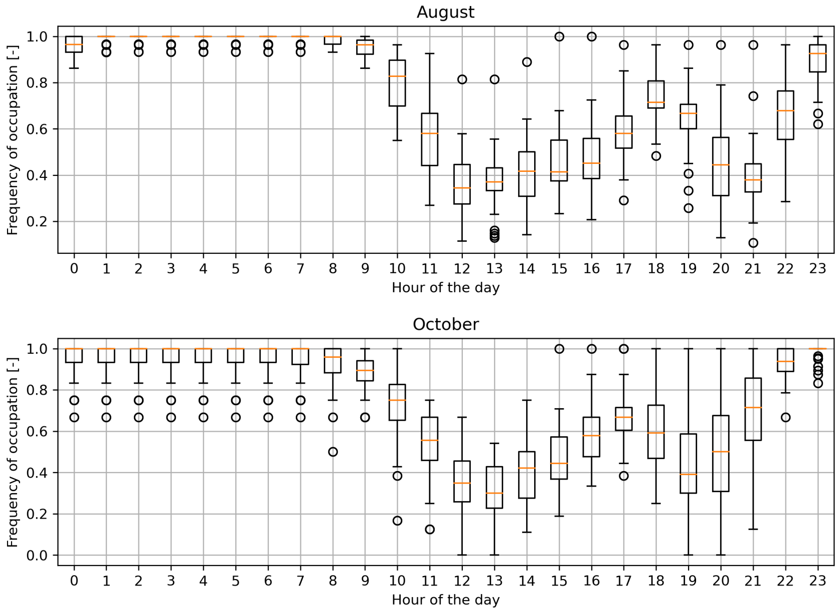

Figure 3. Occupation frequency daily distribution among the hotel rooms in August and October. The circles indicate outliers.

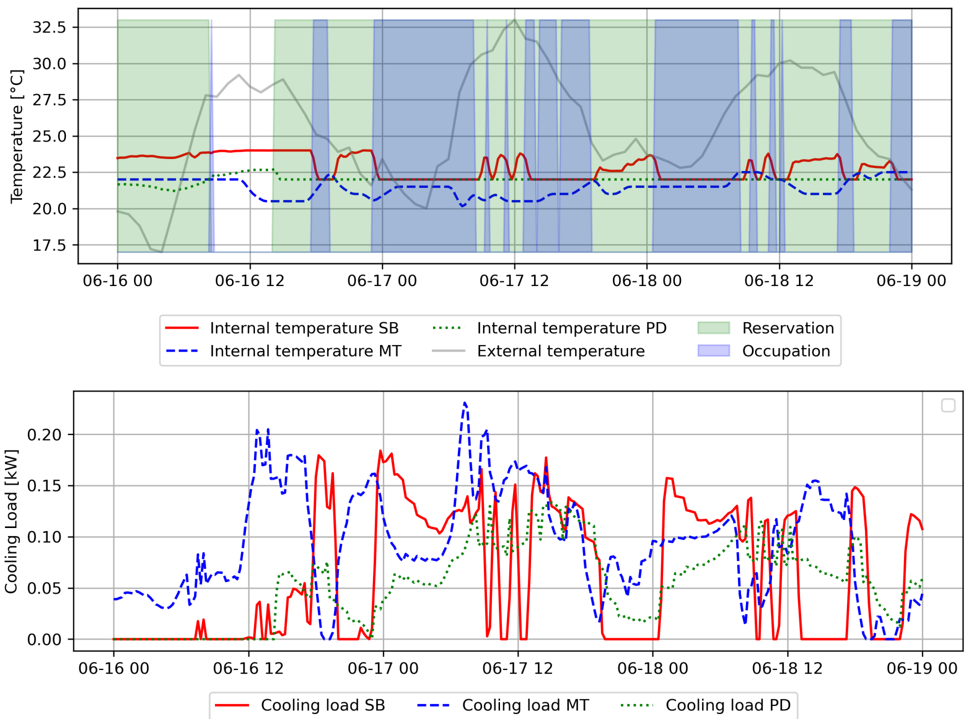

Figure 4. Temperatures and cooling loads calculated for the MT, PD and SB settings for a guest room of the first floor facing South-West from the 16th to the 19th of June.

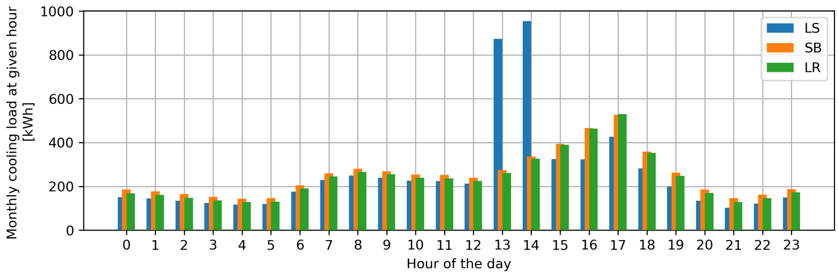

Figure 5. Total cooling load from the 6th to the 30th of June at each hour of the day calculated with the LS, SB and LR thermostat configurations for the rooms facing South-West.

4. Discussion and conclusion

The hotel supervision system resulted as a good starting point to build a digital twin of an hotel building-HVAC system. Unfortunately, the measured data is not enough to complete the calibration and validation of the full building-HVAC system model. Moreover, without the measures of the relative humidity it is also not possible to evaluate the thermal comfort of the guests. The limitations encountered during the presented analysis showed that, to perform a complete calibration of the model, the monitoring system should also record the HVAC system terminal units in every room and their thermal fluxes. With such information, the final digital twin could be calibrated periodically and provide information to find systems malfunctions in advance. Nevertheless, the available system allowed to complete a relevant analysis of the building envelope, computing estimations of the cooling loads in different thermostat scenarios. Comparing the thermostat settings with the measured temperatures allowed to find settings that could lead to lower energy consumptions and moderate peak shifting, relevant for a future connection of the building to a smart grid. The future steps of this research will be to perform a parametric analysis to identify the most appropriate settings, and to verify their efficiency of the real building, comparing them to the ones obtained in the simulation.

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