Impact of occupancy on energy consumption by an educational facility

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Abstract. Building energy simulation models are playing an increasing role in the construction industry and estate services and are constantly being improved. However, the accuracy and usability of simulation results is highly dependent on its inputs, many of which remain difficult to determine. Amongst inputs, the definition of occupant behaviour is recognized to be complex, and generally underestimated and neglected. With the trend towards increasingly energy efficient buildings, a proper representation of occupant presence and activities is becoming crucial in the design of buildings, which need to be comfortable, adaptable and resilient towards variable thermal loads. This paper presents a study of the occupancy of a university building in the UK in order to assess discrepancies between assumed and actual occupancy of the facility. Data has been obtained from a range of sources, including the Building Energy Management System, timetabling, and direct observation. The corresponding occupancy patterns have been simulated using DesignBuilder and EnergyPlus. Results indicate a potential energy saving in the order of 10% for set-up control that matches actual building occupancy more closely than current settings.

1. Introduction

Progress in the field of building simulation has made it a tool of choice in the building design and engineering process (Hensen and Lamberts, 2011). Built on a track record of fifty years of research and development, this technology is increasingly important and popular in the construction industry. Increasingly stringent energy efficiency targets, such as those demanded by the European Energy Performance of Buildings Directive (EPBD) are driving further uptake, whereas the increased use of Building Information Models (BIM) is bridging the gap between different tools by providing a common information repository. However there is still a need to make building simulation more accurate. Significant improvements have already been achieved in terms of fidelity and precision of simulation models, helping the technology to become even more prominent in the design, analysis and maintenance of buildings (Malkawi and Augenbroe, 2004).

Building performance simulation requires a considerable amount of input data. Amongst others this needs to include physical inputs (such as building size, orientation, construction materials, HVAC system size/types, interior and exterior lighting, equipment) and operational inputs varying in time, like occupancy, lighting and HVAC control settings, and plug load profiles. While physical data can be determined with a certain accuracy by using engineering drawings or measurement and observation of the building, other inputs such as control settings and occupancy are more volatile since they can easily vary over time. Understanding these latter factors and how they impact on energy use of a building is crucial to manage the energy efficiency of buildings.

A range of recent research projects shows evidence of discrepancies between the simulation predictions and measured results, discussing what has become known as the 'energy performance gap' (Carbon Trust, 2011; Menezes *et al.*, 2012). An important cause of this gap, especially in buildings for public use, is the fact that the effective future use of the building is unknown at the design stage. Although the energy performance gap needs further research, fundamental causes are likely to be linked with predicting the building occupant behaviour, use and maintenance of the building, rather than problems of design or construction (Korjenic and Bednar, 2012). For a deeper discussion of the gap between simulated and measured results, and the role of issues such as actual weather conditions, modelling errors and uncertainties, see de Wilde (2014).

Due to its complex nature, the influence of occupancy is often under-recognized or misjudged in the design, construction, operation and retrofit of buildings. Especially with regard to public buildings, and specifically to educational ones, the presence of people is extremely variable and difficult to forecast, and requires the use of rather specific quantitative analysis. Occupants interact with the building in both a passive (by contributing a heat load) and active manner (by actively switching equipment and lighting on and off, changing control settings, and opening doors and windows). These interactions all influence the building energy consumption. Unfortunately, predicting the behaviour of people within a building requires long, detailed and precise analysis, so that often the analyst relies on hypothetical or statistics default values for occupation. Since actual occupancy also involves a significant of random behaviour it can be said to be stochastic (Curry *et al.*, 2013). However, efficient energy models require the consideration and combination of all the variables that affect the building. As evidenced by the work of the IEA Annex 66, a deeper understanding of occupancy is a key factor to properly replicate the dynamics that govern energy uses within the building and quantifying its impact is crucial to the design low energy buildings.

2. Aims and Objectives

This paper explores various approaches to capture the occupancy within a university building and compares and contrasts this with the use of typical default assumptions in a commercial software tool. The key factor in this work is occupant presence; occupant actions are not taken into account at this stage. The work aims at exploring the amount of energy that may be saved by using control settings in terms of switching on/off the HVAC system that are more closely aligned to actual facility usage.

3. Methodology

3.1. Case study building

The case study building analysed for this work is selected on the basis of the variety of uses and its role within the University Campus, since it is used for many activities, including non-academic. A great number of variables affect the presence of people, such as special events, number and time of lessons, available time of people, ways to cross the building and allocation of the rooms. All these parameters confirm the difficulty to predict the number of people in a common space for an educational facility. This is the Roland Levinsky Building, a striking building on the campus of the University of Plymouth in the UK. Built between 2003 and 2007, it currently houses the Faculty of Art and Humanities. One of the aspects that contributes to increasing the buildings value within the campus and the whole city is the fact that it is a multi-purpose building, having been realized both for university and public use. In addition to classrooms, laboratories and offices, it contains two large lecture theatres, the Jill Craigie Cinema, three performance rehearsal studios, digital media suites and a public art gallery housing Plymouth's Peninsula of Art, which displays works by students and both internal and invited artists. Thank to this variety of spaces and functions, the building facilitates the interaction of different subjects, and stands out as one of the main cultural meeting points in Plymouth. It has generated significant urban development in the adjacent areas. The building has a gross floor area of 12,660 m^2 distributed over 10 levels. The east side is characterized by a high tower visible from all over the town. The central part of the building, that connects the tower to the west, which consists of two floors, is three storeys high and is characterized by a strong aesthetic impactful central atrium that internally connects the two areas. In addition to the unique geometry that characterizes the building, an important role is played by the materials used. The base of the building is made of slate walls that give the building an important monumentality, alternating with the lightness of the glass walls extending to the upper floors. The most memorable feature of the building is probably the "wrap", a shell made from copper sheets that envelops the building along the west and the east elevation and covers the roof surfaces. While outside shapes, materials and colours are interwoven to create a complex and totally innovative solution, the interior of the building recalls an industrial context, with extensive use of exposed concrete and, again, impressive windows that bring together the different activities within it. The interior spaces are flexible and designed so that they can be varied and adapted according to the different activities carried out within the building.

Figure 1: South facade of the Roland Levinsky Building

3.2. Data collection

A sample of ten rooms was selected for an in-depth study of building occupancy. These rooms were chosen in such a way as to represent a range in functionality and frequency of use, allowing the scaling up of findings in such a way as to estimate indicatively the occupancy of all the rooms of the building, by associating each room to one reference room that has been studied in depth. The following rooms were selected: classroom, studio space, offices with various types of occupants, special event space, a restaurant, and a large classical lecture theatre.

The analysis period covered the fall semester (October-December 2015). As university buildings are also used for additional activities, significant efforts were invested in defining the occupancy scenarios both on weekday and weekends, and in properly considering academic activities and special events days. Some particular vacation days are subject of the analysis as well. This was then scaled up to cover the whole facility. A longitudinal study over three months allowed getting some understanding of discrepancies in student attendance over term.

Three sources of information on building occupancy were studied in order to understand the differences between the timetabling forecasts and the actual use of every room:

University timetable. The university timetable provides online access to the timetable for all individual rooms in the building. This has been taken as reference for the predicted occupancy values. The occupancy has been assumed to make use of all available seats within every room. The timetable includes information on the timing of regular lectures as well as workshops and special events.

Building energy management system. The building energy management system (BEMS) manages the whole HVAC system of the building. It sets temperatures and times of activation and shutdown for each space and allows determination of energy consumption and reporting of the effective internal temperatures at any instant. Therefore, on the basis of these data, it is possible to obtain an additional source of predicted occupancy, namely that which is programmed into the building services.

Manual collection. Data was collected by direct observation of the occupancy of the selected representative rooms within the building, across the fall semester. This data collection involved an hourly observation of the number of people present in these rooms, and was undertaken from 8 AM until 8 PM.

3.3. Dynamic energy simulations

The final stage consists of thermal simulation of the building subject to different occupancy patterns, which allows studying their impact. To this end, two simulation models are used: a DesignBuilder model, created specifically for the purpose of this work, as well as a legacy EnergyPlus model used in earlier research. The use of two models allows cross-comparison and reduces the risk of model bias in the final comparisons.

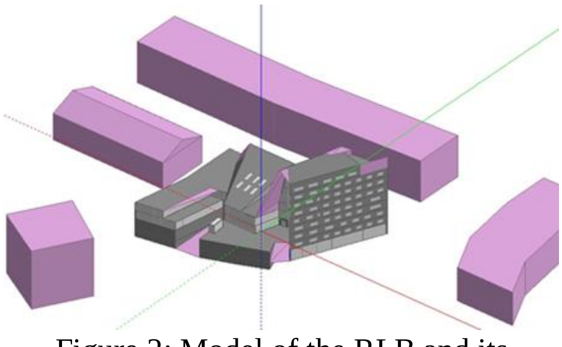

Figure 2: Model of the RLB and its surrounding in Design Builder

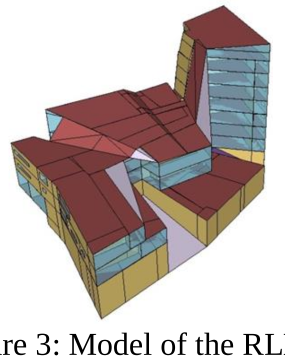

Figure 3: Model of the RLB in EnergyPlus (OpenStudio)

Both models are as faithful as possible to reality in terms of weather file, geometry, materials and constructions. Using the same features for both models allows avoiding influences of these parameters on the final results addressing them only to the occupancy. However, as shown in Figure 1, the DesignBuilder model also contains the surrounding buildings that may have an impact on the studied building. Heating and cooling systems were modelled for the specific rooms studied, while the remaining services were represented by a mechanical ventilation system, controlled according to BEMS settings. Electric equipment (i.e. computer, printers and projectors) within the facility was manually counted and specific values of heat emission were investigated by means of literature. Similarly, approximate values were established for interior lighting. In modelling the occupancy, heat emissions were assumed for adult males at 120W for seated person (i.e. for offices and teaching rooms), 200W for a walking slowly person (i.e. circulation zones and toilets) and 230W for a medium working/eating person (i.e. laboratories, restaurant and rooms used for special events).

In the simulations, three main scenarios were created in order to analyse how occupancy affects energy consumption in different situations. Such schemes were simulated using both the DesignBuilder and EnergyPlus model, by changing schedules for each of them

Default: a base case was defined in the first stage of the simulation strategy to consider the gap between the two models and reality. In DesignBuilder, all the values of occupancy are automatically associated to their own functions as a default; into EnergyPlus standard values are manually chosen. In this first case, the HVAC system is set according to the BEMS.

Predicted: subsequently, the density of people was determined as the maximum number of possible people within a room, provided by the timetable in terms of number of seats, divided by its area. As in the precious case, the HVAC system was modelled according to BEMS settings.

Real: finally, in the last and most significant case, the manual investigation is considered. The occupant density (persons/m^2) was determined considering the peak of the average hourly number of people, considered separately for every room and for weekdays, weekends and special events. The effective occupancy is represented by a percentage number of the aforementioned density. Firstly, the case in which the HVAC system is set according to BEMS is considered. After that, some different assumptions are made with respect to the real occupancy, as shown in Table 1.

4. Results and discussion

This section first analyses the results of the manual data collection of number of people. Further it focuses on the gap between reality and the two energy simulations. Finally, it provides some values in terms of consumptions by varying the HVAC system as a function of the occupancy. Figure 4 and 5 describe the average trend of people of the Career and Employability room, which is a public office and the BEMS settings. Figure 4 shows a regular usage with two peaks, a slight one at 2pm and another at 11am, where the number of visitors is double than the number of working people. Conversely, during the considered special weekend day, which is an Open Day, shown in Figure 5, it is possible to notice a non-regular attendance starting at 9 am, namely the beginning of the event, followed by a gradual decrease. The same graph shows a peak of 63 people, which corresponds to a great contribution of visitors to internal gains. In both cases it is interesting to observe that the schedule time of the BEMS is coherent with the real occupancy.

In the same way, an academic research office has been studied because of the necessity to understand the differences between different kind of offices, namely public and administrative/research ones. According to the results, the BEMS data for operation hours are coherent with the actual occupancy times. Moreover, for this room, the average trend shows a decrease of occupancy corresponding to lunch breaks.

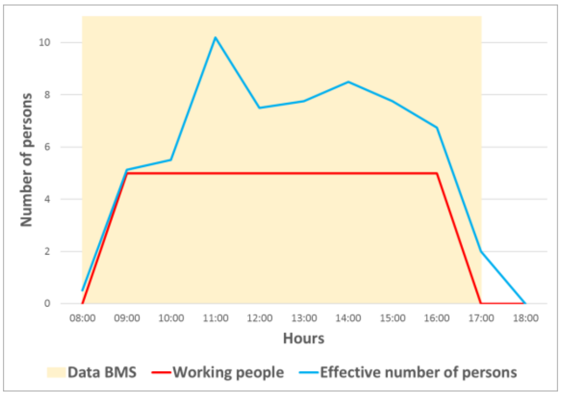

Figure 4: Career and Emloyability – Average of weekdays

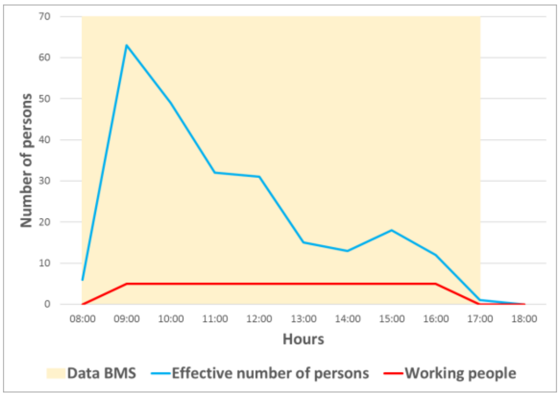

Figure 5: Career and Emloyability – Saturday 10th October (Open Day)

One of the two lecture theatres within the building is studied. This is used in accordance to their particular function, but is also used for public events, in addition to the normal classes. Figure 6 shows a changeable situation in accordance to lessons change. At the end of the day, the room is often used by small groups of people for recreational activities. It can be noticed that the prediction of people expected in the room is overestimated for the whole day. In the same graph, the variation of the predicted average number of people, namely those from the timetable, is due to not forecasted activities in some hours of some weekdays. Considering the average trend, it is possible to observe that the BEMS data are coherent with the predicted occupancy but not with the real observed data. However, considering a specific day, as shown in Figure 7, there is no correspondence between BEMS data and predicted number of people. It is possible to notice a big discrepancy between the effective number of people and both the timetable prediction and BEMS data. Thus a regular rearrangement of BEMS settings would be able to save energy.

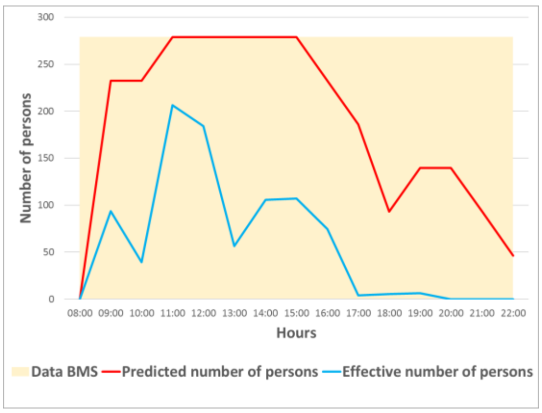

Figure 6: Lecture Theatre 1 – Average of weekdays

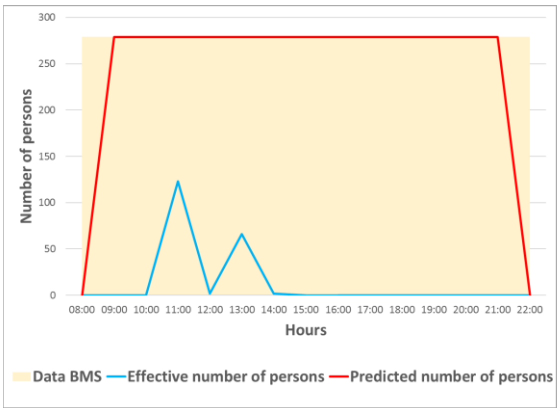

Figure 7: Lecture Theatre 1 – Wednesday 21st October

In Figure 8 it can be noticed that the trend of people within a common teaching room changes over time; this is especially true for Wednesdays. Furthermore there is a marked decrease of the number of people in the middle of the semester, while at the beginning and the final days of the term, they fill the room; this may be due to increased interest in academic information such as grouping for coursework at the start, and exams at the end. Figure 9 shows that occupancy predictions from the timetable are reasonable, and the effective number of hours in which the room is occupied is almost always less than the predicted.

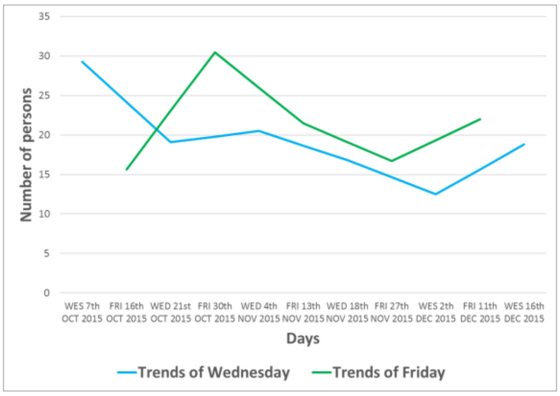

Figure 8: Teaching room 209 –
Trend of effective people

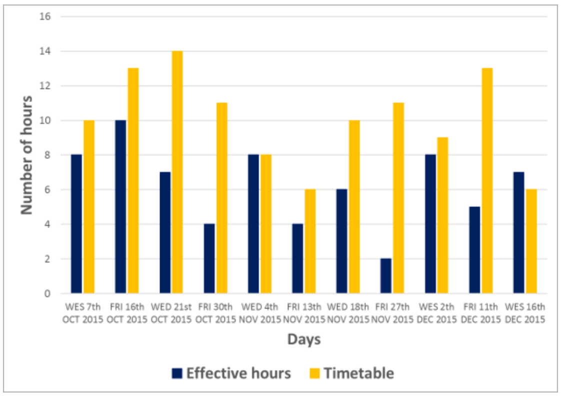

Figure 9: Teaching room 209 –
Number of hours with occupied room

Figures 10 and 11 show the trend of a particular room, which is mainly used for workshops and practical independent activities, rather than lessons. It is possible to notice how the occupancy increases in the third week of each chosen month. This seems to indicate that the room is more occupied in days close to academic deadlines, which are normally set in the last week of each month. Accordingly, during the first week of the month, only few students are in the room. By looking at the hours effectively occupied and the expected ones from the timetable, the gap between reality and prediction based on university events can be appreciated.

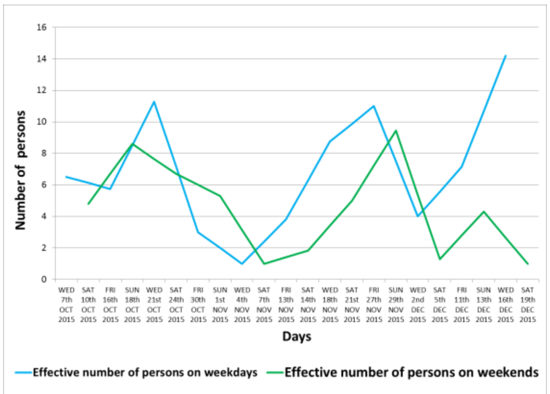

Figure 10: 3D Design studio 211 –
Trend of effective people

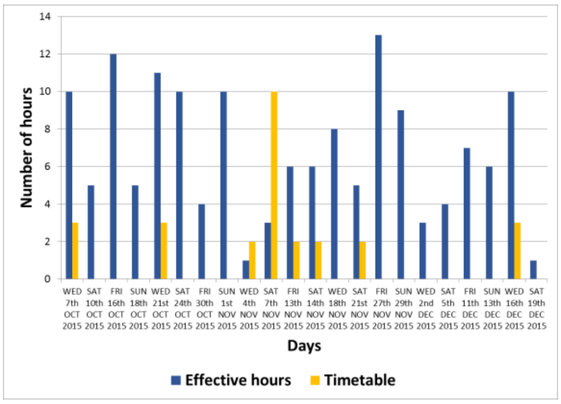

Figure 11: 3D Design studio 211 –
Number of hours with occupied rooms

Table 2: Simulations results and evaluation of different solutions of occupancy

	Occupancy	HVAC system	Lights	Electric Equipment	Design Builder			EnergyPlus		
					Electricity	HVAC system	Total End Uses	Electricity	HVAC system	Total End Uses
1	Default	According to BMS	Default	Default	1271607	317662	1589269	917312	308040	1225352
2	Predicted	According to BMS	Default	Default	0,00%	+11.43%	+2.29%	0,00%	+5.71%	+1.44%
3	Real	According to BMS	Default	Default	0,00%	-4,44%	-0,89%	0,00%	-3,43%	-0,54%
4	Real	According to BMS and when at least one person occupies the rooms	Default	Default	0,00%	+31.58%	+6.31%	0,00%	+24.33%	+6.12%
5	Real	When at least one person occupies the rooms	Default	Default	0,00%	+6.32%	+1.26%	0,00%	+5.98%	+1.5%
6	Real	When at least one person occupies the rooms - without weekends	Default	Default	0,00%	-2,64%	-0,53%	0,00%	+2.04%	+0.51%
7	Real	When at least 5% of the people avarage peak occupies the rooms	Default	Default	0,00%	-2,79%	-0,56%	0,00%	-3,05%	-0,77%
8	Real	When at least 5% of the avarage peak of people occupies the rooms - without weekends	Default	Default	0,00%	-9,32%	-1,86%	0,00%	-8,34%	-2,10%
9	Real	When at least one person occupies the rooms	When at least one person occupies the rooms	Default	-0,87%	-8,22%	-2,34%	-2,18%	-4,25%	-2,70%
10	Real	When at least one person occupies the rooms	When at least one person occupies the rooms	When at least one person occupies the rooms	-9,91%	-7,82%	-9,49%	-13,14%	-3,76%	-10,78%

Table 2 shows how occupancy affects energy consumption in different situations through the results of the energy simulations. It allows the understanding of the incidence on electricity, HVAC consumption and total end uses of the variation of different parameters, namely occupancy, set up of HVAC system, lighting and electric equipment. The impact of the occupancy is more evident in Design Builder, while in Energy Plus a more significant contribution in terms of energy consumption is associated to interior lighting and equipment. The first row shows the situation in which just default conditions are considered and the HVAC system works in accordance to BEMS data, in order to compare the gap between the two models without the influence of further assumptions made subsequently. The results show that the model created by means of Design Builder is characterized by higher values of consumptions than the EnergyPlus one. In particular, the raising rate is 27.86% as regards electricity, 3.12% in terms of HVAC consumption and 29.70% for total end uses.

In the two following rows the incidence of occupancy is analysed by considering the predicted number of people according to timetable and the real one measured by means of manual collection. In the first case, the high affluence of people increases the HVAC consumption because the additional energy required for the cooling system exceeds the saved heating energy. Conversely, in the second case, corresponding to the reality, a lower number of effective people decreases the HVAC consumptions due to a significantly lower usage of the cooling system.

As can be observed in the fourth row, the maximum consumption is reasonably obtainable by considering the HVAC system working in accordance with the BEMS and when at least one person occupied the room, namely the maximum usage of the system.

In the subsequent rows the HVAC system working according to the real use of each room; in fact, initially it works when at least one person fills the room, and then when 5% of the average peak of people does it. This percentage is associated to specific time slots, such as the hours before and after classes, offices opening time, cleaning hours, etc, where the rooms are not used for their main purposes. In addition, cases without considering weekends are considered, as happens in the reality. As can be seen, the fifth row is characterized by an increase of consumptions with respect to the basic model. Conversely, the following two rows show a decrease with respect to the default conditions but it increases with respect to the real case. Finally, the seventh case is the only one of these last four mentioned cases that reduces the consumptions.

Regarding the aforementioned considerations, is also possible to notice that electricity consumptions do not vary because lighting and electric equipment have not been changed.

The last two rows consider that HVAC system and lighting and then electric equipment turn on when at least one person occupies the room, thus, it is possible to obtain the best prediction due to a saving of HVAC consumption and electricity as well. In the last case, the higher impact of electric equipment on electricity consumption than lighting is shown.

5. Conclusions

This paper has compared various ways of exploring the effect of occupancy in a university building on the energy performance. The work highlights the discrepancies between the default occupancy values typically used in building simulation tools, occupancy according to timetabling, occupancy assumptions in the BEMS, and actual observation. Deep observation of a representative selection of rooms was scaled up by associating occupancy patterns to rooms with similar functions and features; findings allow a more accurate simulation of the whole building. However, the result of the collection of data has underlined limits in the estimation of the exact presence of occupants within common spaces, such as circulation zones and dining room. Two models were used, one created in DesignBuilder and the other in EnergyPlus. Despite the fact that Design Builder is based on EnergyPlus, it is more immediate and user-friendly. Conversely, EnergyPlus is more systematic and requires more efforts to fill every schedule; however, it allows obtaining a wider number of outputs enabling to check initial hypothesis. The main differences between the results obtained with the two software is due to the different ways in which data are insert. The analysis of different cases made possible to consider all the possible advantages and disadvantages obtainable by varying the HVAC system operation time according to the real occupancy. In particular, the best solution is the one in which the HVAC system works when at least 5% of the average peak of people occupy the room because, since, even if it corresponds to only a slight decrease in terms of consumptions, it guarantees the required indoor conditions for all the rooms during the main activities (both on weekdays and weekends). Results indicate a saving potential in the order of 10% for control regimes that match actual building occupancy more closely than current settings.

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