Proceedings of 7th Windsor Conference: ***The changing context of comfort in an unpredictable world*** Cumberland Lodge, Windsor, UK, 12-15 April 2012. London: Network for Comfort and Energy Use in Buildings, http://nceub.org.uk

COMPUTATIONAL ANALYSIS - Evaluation of the impact of the user expertise on the results of simulation tools

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ABSTRACT

The use of simulation tools has increased over the years due to the requirement of more complex energy analyses. The outputs provided by such tools are quite dependent on the available information about occupancy profile of building and schedules from systems such as: lighting, electric equipment, air conditioning, window openings and others.

It is very important for users to be aware of the limitations and uncertainties regarding the thermal models of each tool when evaluating their outputs. The user should have the expertise to choose the most suitable tool depending on the type of analysis being done.

This paper evaluates the performance of two different buildings, a budget hotel and an office building, located in the city of São Paulo, Brazil. Both buildings characteristics were entered into the simulation tool *EnergyPlus*™. For the office building, comparisons were performed between the actual profile of the energy consumption and their simulation results for evaluating the main parameters that affect the simulation results. For the budget hotel, measured temperature profiles were compared with simulation results, in order to calibrate the model. This calibration is done in order to verify the most appropriate strategies and changes that could be done in the building considering environmental issues.

The comparisons between the acquired data and the simulation results were appraised and the authors analyzed how the results vary depending on how well the building's characteristics were modelled. Some aspects of how to improve the data gathering and model input process were analyzed in order to enhance the reliance of simulation results and therefore reduce errors on forecasting of the thermal behaviour of buildings.

Key word: Building characteristics modelling, thermal behaviour forecast, case studies

INTRODUCTION

Malkawi & Augenbroe (2004) infer that the term building simulation is quite wide and it varies from mass flow and energy balances, going by structural durability, aging and construction site. The first developments of simulation tools appeared in the 1960´s and 1970´s, focusing on energy performance of the building envelope and expanding to the lighting systems, air conditioning, heating, ventilation and others. Nowadays, this range was enlarged for analyses that evaluate coupled heat and mass transfers, acoustics, control systems and several combinations of simulations of urban climates and microclimates.

The main uses of simulation tools are presented by Hong et al. (2000), i.e.:

- Evaluation of cooling and heating loads of building constructions: peak values and daily/annual profile of the cooling and heating loads are the basis for sizing and selection of air conditioning systems, heating, ventilation and refrigeration;
- Analysis of energy performance of buildings for design and retrofit: simulation tools can offer the profiles of energy consumption of the building and the performance of the main systems in nominal and partial load;
- Support for the design of the building energy management and control system: these systems monitor, control and supply reports on the performance of several systems of the building. Using the simulation tools, it is possible to evaluate the most appropriate strategies to be used in the building and to consider which parameters should be monitored and controlled.
- Complying with building regulations, codes, and standards: the building simulation can provide information on the energy performance of the building as well as the impact of changes in the design of the building when this building is submitted to certain standards and regulations. Besides, the simulation tool can help in the process of energy auditing, by supplying an energy analysis of the building in its current state (as-built);
- Cost analysis: some simulation tools can provide cost analysis where the utilities tariff structure is simulated. Therefore, it is possible to verify the impact of changes in the design of the building on the operation cost;
- Analysis of passive strategies: simulation tools allow to evaluate the impact of passive strategies (i.e. controlled shading, natural illumination, etc.) in the energy performance of the building;
- Use of Computational Fluid Dynamics (CFD): this type of tool allows studies of urban and indoors microclimates, ventilation of constructions, safety in fires, etc.

The choice of the tool can be quite difficult and it should take into account the following aspects (Hong et al., 2000):

- Need or purpose: the understanding of the nature of the problem to be solved is very important. The choice of a more powerful tool than necessary can lead to high and unnecessary costs, besides taking the risk of increasing the possibility of larger mistakes in the use of the tool due to its high complexity;
- Costs: the evaluation of the cost of the simulation tool should include the costs of acquisition of the tool, the cost of its updates and its maintenance cost as well as the costs of the platform in which the tool has to operate and the training costs;
- Facilities: the user should choose the simulation tool that can be implemented in the available computation facilities.

Crawley et al. (2005) compared 20 tools for energy simulation of buildings, presenting a brief history and description of each program. The authors comment that one of the main difficulties in the accomplishment of the comparisons is that there is not a common language to describe the characteristics of each tool. The authors emphasize that the professionals that get involved in energy building simulation should frequently use more than one tool, so one tool complements the deficiencies of the other tool.

THE ROLE OF THE SIMULATION EXPERT

Based on this scenario, the role of the simulation expert is quite relevant and critical. During the process of construction of the model into the simulation tool, the expert has to support his/hers work on the expertise of several professionals such as architects, mechanical engineers, electrical engineers, etc. Depending on the simulation tool, the input data process demands a large amount of data and the simulation expert might not possess all the required expertise for a complete definition of the parameters related to the building simulation and its subsystems (air conditioning, lighting, envelope, etc.). Thus, the data input should be made in a collaborative form. The simulation expert should consult several specialists on the systems of their expertise and the simulation specialist must translate this information to accomplish the input data in the simulation tool (cf. Donn et al., 2009).

Besides the capacity of interacting with other specialists, the simulation expert should have a deep knowledge of the models, equations and hypotheses used in the simulation tool. The knowledge of the building performance, types and operation of air conditioning systems, lighting and other equipments are important elements so that the model implemented in the simulation tool corresponds the closest possible to the analysed building.

Kaplan & Caner (1992) conducted a study in which it was requested for several simulation specialists (with different training/experience levels) to simulate the energy behaviour of existing small and large office buildings. The specialists had no access to the electricity and gas bills of the buildings, and therefore, they had not the possibility of performing a model calibration to adjust the model for a better representation of the energy performance of the actual buildings. The difference between the actual and the simulated energy consumption varied from ±66% to 127% for the small building offices and from ±37 to 120% for the large ones. These results demonstrated that the simulation expert must always accomplish a model calibration, not only in the case of existent buildings but also for the simulation of new constructions. For new constructions, the expert's knowledge and experience can alert him/her for eventual unlikely simulation outputs, indicating some problems in the simulation model.

UNCERTAINTIES OF THE SIMULATION PROCESS

The simulation tools are characterized by the translation of the behaviour of a phenomenon (energy performance of buildings) through equations and hypotheses that generate the so called model. The model is a representation of the actual phenomenon and for being a representation, it is associated to a level of uncertainty between the actual phenomenon and the model (see Fig. 1).

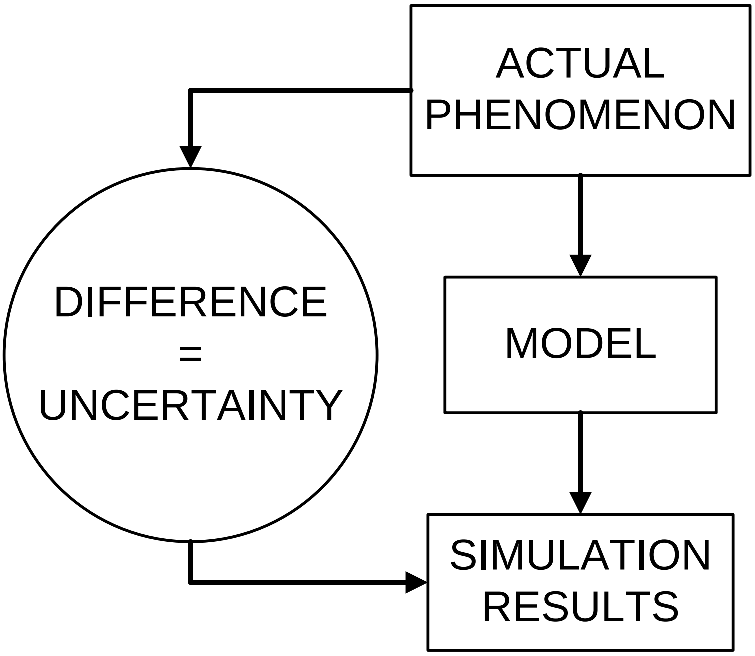

Figure 1. Representation of the model and actual phenomenon

(adapted from Malkawi&Augenbroe, 2004).

Waltz (2000) pointed out that the simulation results of a modelled building does not forecast the energy consumption with lower uncertainties than 5%, comparing to the energy consumption of the actual building. It should be reinforced that a good specialist in simulation should be able to reach the level of uncertainty from 5 to 8%. Over detailed building geometry or even the use of sub-hourly interval for the output results affect very little the level of uncertainty of the simulation results. Therefore, the level of details in the model should be compatible with the occupation type and use of the building. As a result, for a small office building (up to 2,000 m^2), there is no need to obtain profiles of energy consumption every 15 minutes. For buildings with more than 10,000 m^2, it might be necessary the installation of dedicated energy meters in certain systems (for instance, air conditioning systems or elevators) for one to two weeks in order to evaluate properly evaluate the profile of energy consumption of the analyzed building.

Liu & Liu (2011) highlighted that, due to the increasing use of building energy simulations for evaluating the effectiveness of the energy conservation retrofits, calibration of simulation tools against measured data has been recognized as an important factor in substantiating how well a model represents the characteristics of an actual building.

Kaplan & Caner (1992) reinforced that the simulation tools have limitations regarding the evaluations of absolute values of the simulated results. Hence, it should be emphasized that the results of a simulation to evaluate the measures for reduction of energy consumption should be made by comparing the results of a simulation of a baseline building in the same occupation and climate conditions.

SIMULATION TOOL

EnergyPlus$^{\text{TM}}$ (USDoE, 2005) was used for the building simulation in this study. *EnergyPlus*$^{\text{TM}}$ is a robust building simulation tool that allows the user to implement the geometry and materials of the building as well as its internal loads and HVAC systems characteristics. It allows the user to set two kinds of simulation: a design-day and annual simulation. For the latter, a weather parameter profile should be provided in which the main parameters (dry/wet-bulb temperature, direct/diffuse solar radiation, wind speed/direction, etc.) are given in an hourly basis and the software can provide an annual profile of several outputs (cooling/heating loads, zone temperature, building energy consumption, etc.). For the design-day simulation, the user should supply a group of parameters such as maximum and minimum dry-bulb temperature, wet-bulb temperature when the maximum dry-bulb temperature occurs, wind speed and direction, etc. for a single day. *EnergyPlus*$^{\text{TM}}$ can provide for single day simulation the same outputs mentioned for the annual simulation.

CASE STUDIES

In order to illustrate the concepts presented previously, two case studies were presented in this paper which the simulation results obtained from the use of a simulation tool called *EnergyPlus*$^{\text{TM}}$ are compared to the actual data from two types of buildings: a university administration building and a budget hotel, both located in the city of São Paulo, Brazil.

BUILDING DESCRIPTION

University Administration Building

The Administration Building of the University of São Paulo has two blocks with six floors each (Fig. 2), with a gross floor area of 3000 m^2. Both blocks are oriented 43° northwest and most of the building occupancy occurs between 8:00 and 18:00 with a building population of almost 1000 employees. Based on walk-through surveys on the building, an evaluation of the maximum and minimum values assumed for the internal loads in this study are shown in Table 1.

Table 1. Internal loads of the University Administration Building.

Internal load	Minimum value	Maximum value
Occupancy	110 persons	1008 persons
Lighting	10 kW	82.8 kW
Electrical equipment	8 kW	57.6 kW

Figure 2. Front and rear side of the University Administration Building.

The building air conditioning system is composed by unitary window-type and split air conditioners spread along each floor and individually controlled by the users. Several inspections were made in order to evaluate the different types of internal loads (lighting, computers and occupancy) and their schedules. It should be pointed out that there were no historical records of occupancy profile in this building. Thus, some assumptions related to this profile were made in this case study. The schedule for lighting, equipment and people was assumed to have the same pattern of the energy demand profiles. These profiles were evaluated by the building energy monitoring system. Another important assumption is the use of an average coefficient of performance (COP) for the unitary air conditioners. This was done because the air conditioning equipments were acquired in different periods and it was practically impossible to define a COP for each equipment, unless a full performance evaluation for each equipment was carried out. Based on inspections and previous calculations; it was possible to evaluate an end-use breakdown of the building (Fig. 3).

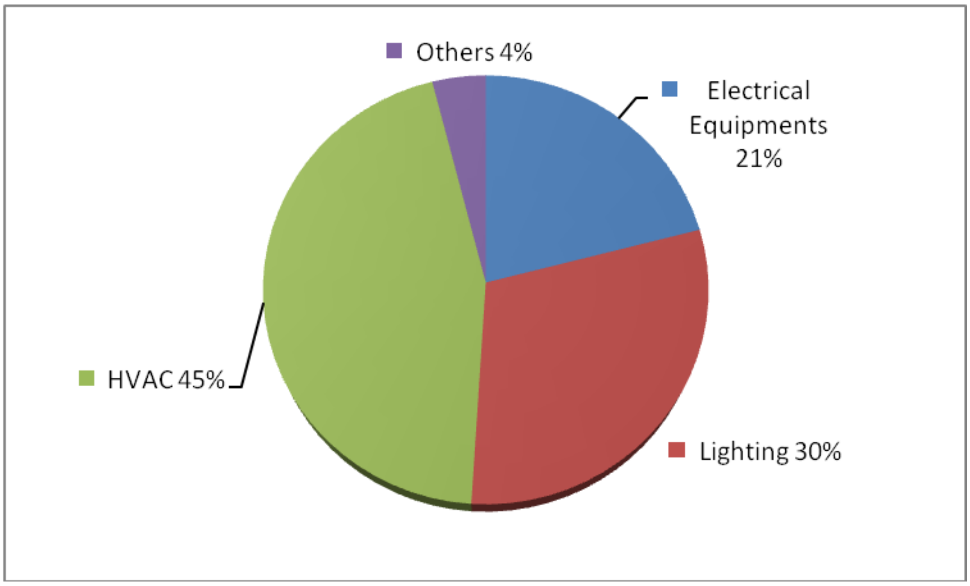

Figure 3. Administration building end-use breakdown.

Budget hotel

The budget hotel has 8 standard floors and a total of 144 units distributed between two facades. Each floor has 10 units facing 215° Southwest and 8 facing 35° Northeast (Fig. 4).

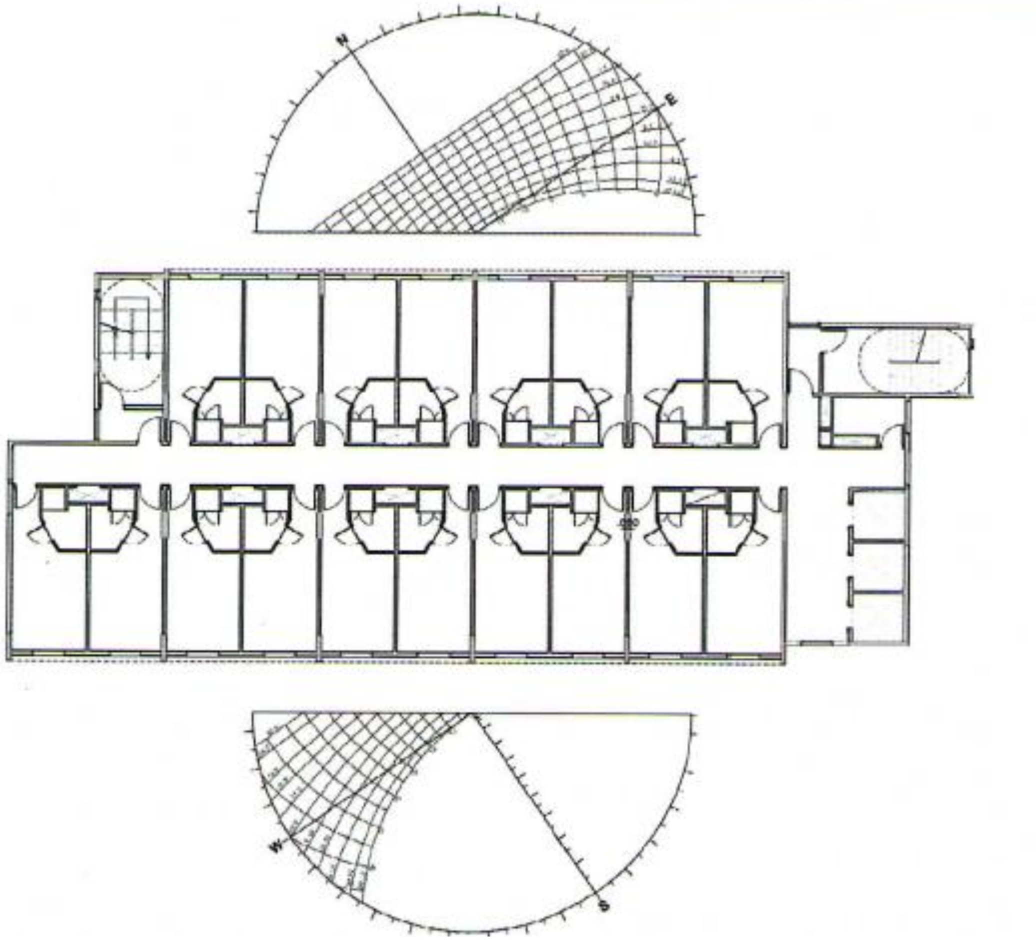

Figure 4. Budget hotel floor plan.

All units show the same internal layout and are separated by a single corridor that in its Southeast direction reaches the elevator hall, the governance room and one emergency stair. The second emergency stair is located at the opposite side of the corridor.

The majority of the guests at the hotel are business people visiting companies in the south region of São Paulo or attending trade shows. Generally, they remain in the units only during the night (from 19:00 until 8:00) and the units are occupied by one person on average. The design of such type of hotels has as priority the integration of its architecture and strategies to reduce operational costs related to energy consumption, while maintaining the guests' environmental comfort in acceptable levels.

Based on walk-through surveys from similar buildings types, the internal loads assumed in this study were evaluated and the results are shown in Table 2.

Table 2. Internal loads of the budget hotel.

Internal load	Value per unit
Occupancy	1 person (3.31 W/m^2)
Lighting	11.85 W/m^2
Electrical equipment	4.71 W/m^2

Buoro et al. (2005) evaluated the energy performance of a similar hotel, located in the city of São Paulo, where it was found out that the air conditioning system was the major source of energy consumption of the hotel, as shown in Fig 5. The authors verified that the hotel's windows could not be opened and the ventilation was caused solely by the air conditioning system.

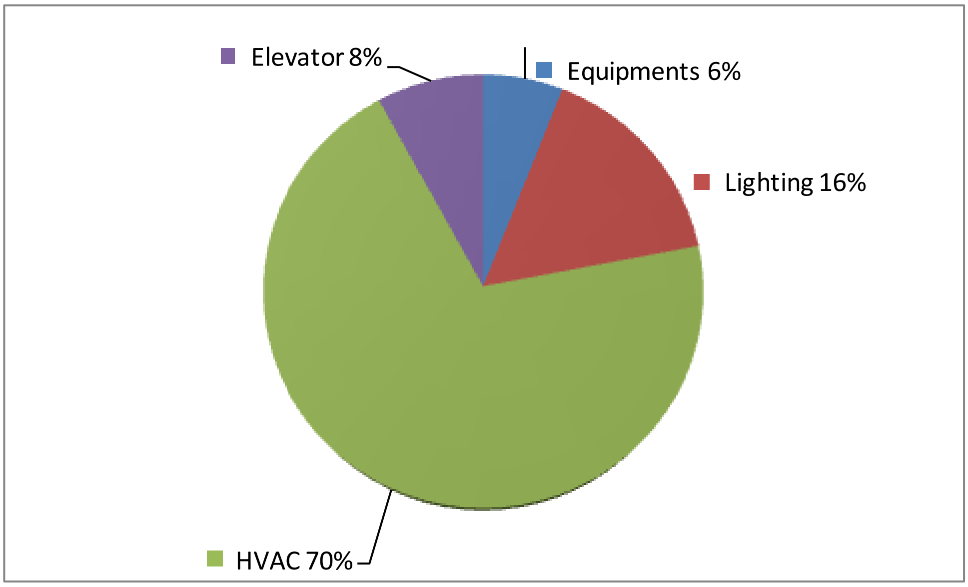

Figure 5: Hotel **e**nd-use breakdown (Buoro et al., 2005)

The air conditioning system consisted of water chilled central equipment with air handling units in each unit, positioned above the bathroom's ceiling and the air return opening was placed above the room's entrance. The units are also equipped with 8 mm thick glass windows with blackout curtains in the room but without *brise soleil*. The window framing allowed an opening of only 20 cm, reducing considerably the potential of the use of the natural ventilation in the units.

Based on the occupation of the hotel, some assumptions were made to try to reduce measurement and modelling errors:

- occupation hours: from 19:30 to 7:30.
- illumination and equipment usage: from 19:30 to 22:30

The measurements were made in two units on the 8th floor, located in the SW and NE facades, for five consecutive days during the summer period. The measured parameters were:

- dry and wet bulb temperature (DBT and WBT);
- mean radiant temperature (MRT);
- relative humidity (RH).

In order to keep control of the comfort parameters related to the occupants, a group of occupants were selected based on characteristics such as gender, age, etc. This group was trained for keeping similar activities during the occupation of the units. During the occupation period, each occupant should perform a survey regarding his/her environmental comfort status.

The comfort index used in this study was the adaptive model described on the standard ASHRAE 55 (2004). It was verified that this model had some limitations, especially in the night period, but it was found that it produced the most adequate results.

RESULTS AND ANALYSIS

University Administration Building

The first comparison between the simulated and measured annual energy consumption of the building showed an average difference of 26%, which can be considered extremely high. By comparing the weather tape (from weather file) used in the simulation and measured data provided by a meteorological station located near the building, the profiles of the sky clearness and dry bulb temperature were quite different. Therefore, a modified weather tape was produced based on the actual data and a new simulation was run. This second comparison provided an average difference between the measured and simulated annual energy consumption of the building of 13%. In order to evaluate the reasons for such difference, a closer investigation on the daily energy consumption profile was done and an example of such analysis is shown in Fig. 6.

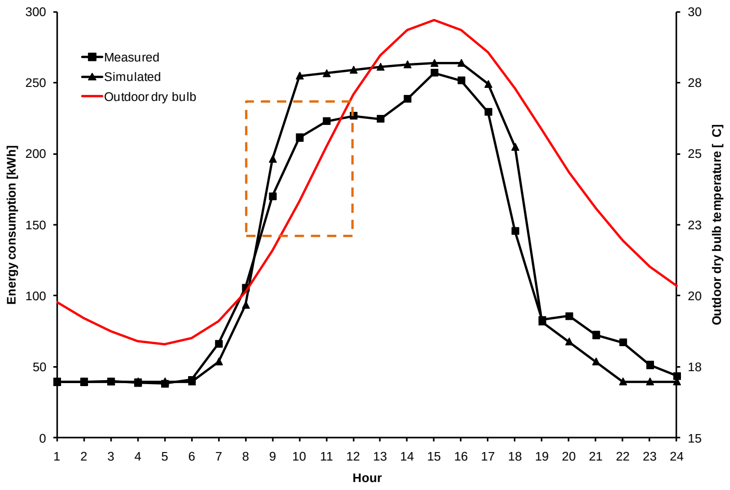

Figure 6. Measured and simulated hourly energy consumption and outdoor dry bulb temperature for a typical summer day (administration building).

The main reason for such behaviour might be explained by the possibility of the occupant of the building individually turning on/off as well as changing the setpoints of the unitary air conditioning systems. Besides, the occupant, when turning off the system, can also open the windows in order to achieve thermal comfort. Based on interviews with the occupants of the building, it was also found out that some of them, even in the summer, use the air conditioning in the ventilation mode, which promotes lower energy consumption. The building model was set to keep the windows closed during all the day and the air conditioning is set only to work during the occupation hour. Since the building allows a large heat gain from the windows, simulated results overestimated the cooling load, consequently, increasing the energy consumption of the building. The aspects mentioned before are quite difficult to be evaluated by the simulation expert and, consequently, for the purposes of this study, the calibration of the model was done in order to reduce the uncertainties between the actual building and its model. After the calibration was performed, the uncertainty level wasn´t modified and the level of 13% found previously was maintained.

A second comparison was also done using the calibrated model. A set of parameters was modified in the calibrated model in order to evaluate the impact of such modifications on the energy consumption of the building. The chosen parameters were the main ones that the simulation expert has to evaluate from walking-in tours and/or interviews with other experts. For this analysis, a variation of ±20% was imposed on each parameter and the results were compared with the results of the calibrated model (see Tab. 1)

Table 1. Variation of energy consumption of the calibrated model.

Parameter	Variation of the energy consumption of the calibrated model [%]
Number of occupants	±6.2
Lighting power	±12.4
Electrical equipment power	±10.6
Air conditioning COP	±4.3

One can observe that the internal loads related to lighting and electrical equipment promote greater impacts than occupancy and the COP. The variation of such parameters has two effects: the first is direct variation of the installed building power because those loads represent 51% of the total energy consumption of the building. The other one is related to the increase in the heat gain which impacts on the energy consumption of the air conditioning systems. That means that, the simulation expert should pay an extra attention to such parameters when simulating building with high electrical internal loads.

Budget hotel

The first comparison on the budget hotel case study (room unit) was between the profiles of measured dry bulb temperature and mean radiant temperature inside the unit during the occupation period, shown in Fig 7. One can notice that both temperature profiles had a small increase in the afternoon period, before the beginning of occupation period of the unit (19:30h) and the lights are turned on. Even though the units are located in opposing facades (NE and SW), the differences found between the profiles of the two units (both dry bulb and mean radiant temperature) are negligible (less than 0.6°C). This can be explained by the high thermal inertia characteristics of the building construction coupled with a small windows-wall ratio (wwr) of 0.23. In addition, two other factors contributed to these results: the small window openings and a low windows solar factor of 0.35. These factors reduced the heat gains provided from the external solar radiation. Therefore, it can be implied that the heat gain from internal loads and air circulation were the main factors to affect the thermal comfort conditions in the units.

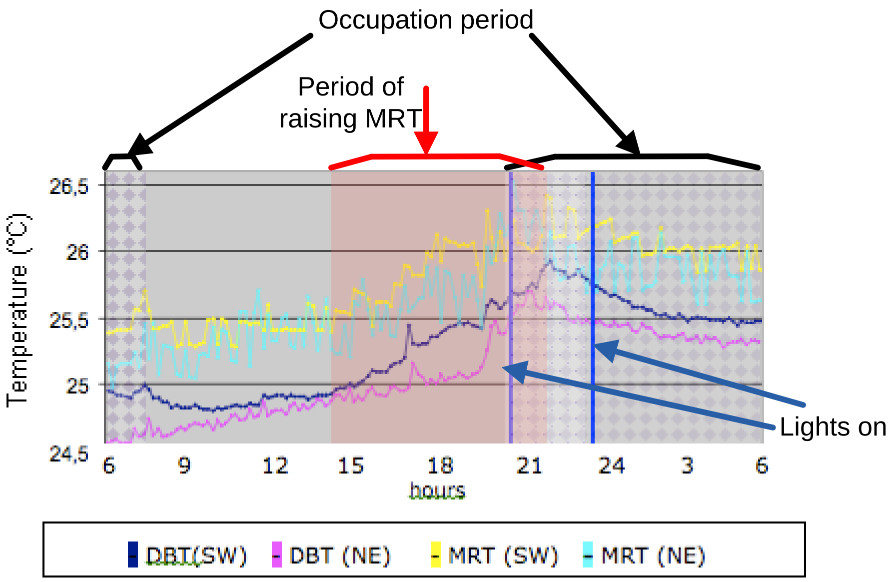

Figure 7. Measured dry bulb and mean radiant temperatures profiles of the SW and NE units of the budget hotel.

Considering this previous analysis, a comparison between the dry bulb and mean radiant temperatures profiles was made and Fig. 8 shows a typical result of such comparison. One can observe that the simulated mean radiant temperature (indicated as MRT) for both units followed the behaviour of the measured profile (indicated as EMP-MRT).

The manipulation of the climate data from the software was another important element in the convergence of the modelled and actual results. The simulated model used the data set from the software based on the USA Governmental Department of Energy (DOE) with the exception of the measured period and a 10 day margin. The climate data were then manipulated to consider climate external temperature from the same period measured inside the unit. Weather data for this period were gathered from a climate station located in the campus of the University of São Paulo. This climate station is maintained by the Institute of Astronomy, Geophysics and Atmospheric Science of São Paulo University (IAG) that provides climate parameters with fair accuracy.

The model calibration was then made in order to conciliate the infiltration and ventilation rates, as well as to converge the inside temperature simulated to the real ones, as shown in Fig (8).

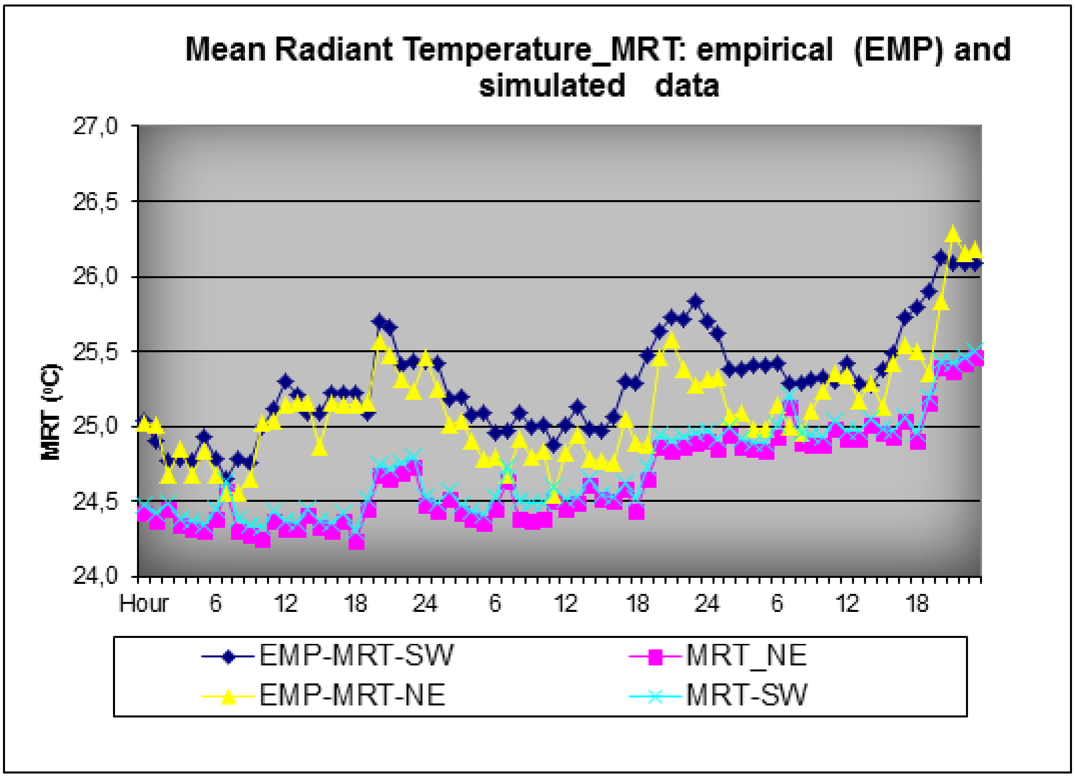

Figure 8. Hourly Empirical (EMP) and simulated data from indoor mean radiant temperature (MRT) during one summer day (budget hotel).

As suggested by Mui & Chan (2006), the building model calibration considers the minimum ventilation level to cope with the level of CO_2 in the air and the user´s environmental comfort. They highlighted the importance of the equilibrium among energy consumption, air quality and pollution levels. So, in order to reduce the mean radiant temperature standard deviation to 0.3, the model infiltration rate was reduced to 50% of the initial value. The ventilation rate was also kept at 1 air renovation per hour in order to maintain an adequate CO_2 levels for the unit and its internal conditions.

CONCLUSIONS

This paper provides a comparison of the thermal and energy behaviour of two different buildings both located in the city of São Paulo, Brazil. The first one was the Administration Building of the University of São Paulo where the occupants have an important role in the thermal behaviour of this building. This influence is related to the fact that the operation of the unitary air conditioning systems as well as the opening of the windows during a typical day is controlled only by the occupants. This situation provides a great challenge for the simulation expert that can be overcome by more detailed walk-through surveys and interviews with the building occupants in order to obtain more accurate information about the building operation. The second building was a budget hotel where the combined influence of the high thermal inertia walls and low wwr/solar factor windows reduced significantly the influence of the building orientation into the evaluation of its thermal performance. The simulation expert should, when performing the energy simulation of buildings with those characteristics, evaluate carefully the internal loads as well as the ventilation and infiltration rates in order to guarantee a fair prediction of the thermal behaviour of those types of buildings.

Finally, the reduction of the level of uncertainty of the results obtained in energy simulations should focus on the detailed survey of the characteristics of the building and its operation, the correct choice of the simulation tool and the use of this tool by an experienced professional and an expert of such tool. The simulation expert should be able to detect, recognize and avoid simulation errors based on his or her knowledge of the building elements.

ACKNOWLEDGEMENT

The authors acknowledged the support from CAPES for founding Anarrita Bueno Buoro in her PhD research in the Mechanical Engineering Department of the University of São Paulo. The authors also acknowledged the support from FAPESP for founding the authors to attend the conference and present this paper.

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