Energy and Comfort in School Buildings in the South of Portugal

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Abstract

This work presents a software that simulates the thermal response of buildings with complex topology and evaluates the indoor building climates, namely the thermal comfort and air quality in indoor environments. In this study the implementation of heating, ventilating and air conditioning systems with intelligent control, based on the PMV index. Instead of the traditional control based on the air temperature, the implemented system is based on the PMV index, which is based on the values of air temperature, air velocity, air relative humidity, mean radiant temperature, the clothing level and the physical activity level. This methodology ensures acceptable levels of comfort, for low levels of power consumption.

The program used in this study, developed by the authors, calculates the values of air temperature inside the compartment and conduits, the temperature of opaque and transparent bodies of the building, the mass of water vapor and other gases inside the compartments and pipes, the water vapor on the surface of the building bodies, the water vapor and other gases in the solid matrix of opaque and inner bodies, the relative humidity of the air inside the compartments, the air velocity and the mean radiant temperature inside the compartments.

The university school building analyzed in this work, with three floors and 110 spaces, 122 transparent bodies (windows) and 1516 opaque bodies (interior and exterior walls, floors, roof and doors). The study is carried out both in summer and winter conditions, and the cycle of occupation and the air renewal rate are considered. The heating, ventilation and air conditioning work only when there are occupants in the compartments.

Keywords: Numerical simulation of the thermal behavior of buildings; HVAC systems control; Thermal comfort; Human thermophysiology.

1. Introduction

Energy consumption and thermal comfort are two important aspects to consider in controlling the HVAC (Heating, Ventilating and Air Conditioning) as these are used in buildings, particularly in residential, industrial, educational and other kind of buildings. Therefore, it is necessary to design control HVAC systems with high levels of comfort and energy savings (see as example Liang and Du, 2008, Nassif *et al*., 2008 and Freire *et al*., 2008).

Several sorts of HVAC control systems have been proposed (see as example Liang and Du, 2008). The most frequently used index is the PMV, Predicted Mean Vote, proposed by Fanger (1972), which is a nonlinear function of the following variables: air temperature, mean radiant temperature, air relative humidity, air velocity, level of human activity and level of human clothing. Thermal comfort has great influence on productivity and wellbeing of occupants of a building. The majority of HVAC systems for thermal comfort are based on a single loop or temperature control, or in some cases, a multivariable control loop with air temperature and air relative humidity. However, when it concerns the optimization of thermal comfort, other parameters must be taken into consideration, so that the occupants feel effective thermal satisfaction (see as example Huh and Brandemuehl, 2008). Interactions between people and the thermal envelope are complex and have been subjected to several studies, therefore the thermal comfort takes into account all these topics (see Freire *et al*., 2008).

The control of a HVAC system is difficult to achieve, when is trying to optimize simultaneously the energy consumption of the building and the thermal comfort of the occupants, with acceptable air quality levels. The control strategy of HVAC systems can be optimized (see Wang and Ma, 2008). Control systems based on models and analysis tools are essential instruments to identify problems previously and find some solutions (see Sane *et al*., 2006, Mendes *et al*., 2008, Axley, 2007, Song *et al*., 2008, Redfern *et al*., 2006 and Komareji *et al*., 2008).

Several control strategies were developed in the last years. Several authors, as Yan *et al*. (2008), Hongli *et al*. (2008), Ly *et al*. (2008), Hong *et al*. (2007), Hadjiski *et al*. (2007), Liang and Du (2007), Leephakpreeda (2008) and Donaisky *et al*. (2007) proposed different control strategies.

2. Numerical Model

The program used in this study, developed by the authors, simulates the thermal response of buildings with complex topology and evaluates the average quality of the indoor air. The program was validated in winter conditions in Conceição *et al*. (2004) and in summer conditions in Conceição and Lúcio (2006a). It calculates:

- the air temperature inside the compartments and conduits;
- the temperature of the layers of the opaque bodies of the building (walls, plates, doors, floors, roofs ...);
- the temperature of the transparent bodies (windows glasses);
- the temperature of the inner bodies;
- the mass of water vapor and other gases inside the compartments and the different systems of ducts;
- the water vapor on the surface of the building bodies;
- the water vapor and other gases in the solid matrix of opaque and inner bodies;
- the air relative humidity;
- the air velocity;
- mean radiant temperature inside the enclosures.

In addition, the software calculates also:

- the incident solar radiation on the outer surfaces;
- the sunlight transmitted through the windows and striking the surfaces of the compartments;
- the heat exchanges by radiation between the outer surfaces of the building and the sky or the surrounding surfaces;
- the radiative exchanges verified between the different compartments;
- the radiative properties of the glasses;
- the coefficients of heat and mass transfer;
- the shape factors inside each compartment;
- the average level of thermal comfort in every space;
- the heating power for the cooling/HVAC system;
- other parameters.

More details can be found in Conceição (2003), Conceição *et al*. (2004), Conceição and Lúcio (2005) or Conceição and Lúcio (2006b).

3. Input Data

This numerical study was performed at the Teaching Complex of Campus of Gambelas of the University of Algarve (see Figure 1). This building is primarily used for school activities.

The simulation presented in this work was held on the 22nd of December, in winter conditions, and on 22nd of June, in summer conditions. In order to take into account the thermal inertia of the building, the previous five days were simulated, and only the results of the last day were considered.

The occupation cycle used in this study considers classes for a period of 1 hour and 15 minutes and 15 minutes pauses. It includes a statistical study of the evolution of the occupation of the different rooms of lectures and theoretical-practical classes, hallways, offices, among others.

As input data for the model, concerning the environmental variables during the days of the simulation, measured values of air temperature, air relative humidity, wind velocity and wind direction were used, whereas the direct and diffuse solar radiation were numerically calculated from a set of empirical equations presented in Iqbal (1983).

The ventilation strategy used in this preliminary work is to maintain a constant renewal rate, all day long, 2.5 renewals per hour. According to preliminary studies in these areas, this value provides a good compromise between air quality and thermal comfort in such spaces.

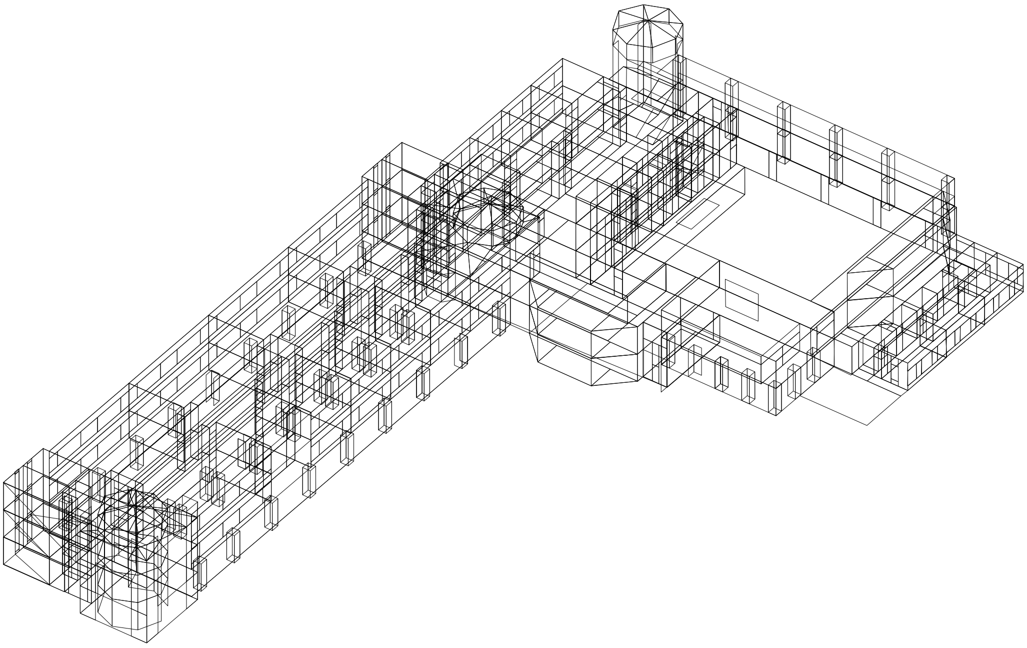

Figure 1 – Scheme of the Teaching Complex.

4. Implemented Control System

The system implemented is designed to control, rather than the traditional value of the air temperature, the PMV index, which is based on the values of air temperature, air velocity, relative humidity, mean radiant temperature, level of clothing and level of physical activity.

This system ensures acceptable levels of comfort according to Category C of ISO 7730 (2005), that is, in winter conditions the heating system is on when the PMV index is lower than -0.7 and in summer conditions the air conditioning system is switched on when the PMV index is greater than +0.7. This philosophy, according to Category C of ISO 7730 (2005), ensures 15% or less of thermally dissatisfied people.

This philosophy also ensures lower levels of power consumption, because the system, in order to ensure acceptable thermal conditions for 15% of people, considers that in the winter people will be uncomfortable with cold and heat, and in the summer people will feel thermally uncomfortable with heat.

The philosophy of control used in this preliminary study considers the HVAC systems (heating, ventilation and air conditioning) switch on and off. However, in future work a new control philosophy will be applied.

5. Results and discussion

To illustrate the methodology, some results obtained in classrooms and offices will be presented in this section. In each situation, spaces facing the west and east are considered.

While the simulation is carried out on a continuous basis, the results shown in the following figures were recorded every two minutes. Any fluctuation of the variables between these moments is not displayed.

In Figures 2 and 4 the evolution of the level of thermal comfort (PMV) and air temperature (Tair) in classrooms equipped with windows facing East (E) and West (W) is represented. The first picture is associated with summer conditions, while the second figure is associated with winter conditions.

The evolution of the thermal comfort level (PMV) and temperature of the air (Tair) in offices equipped with windows facing East (E) are shown in Figures 3 and 5. The first figure is associated with summer conditions, while the second figure is associated with winter conditions.

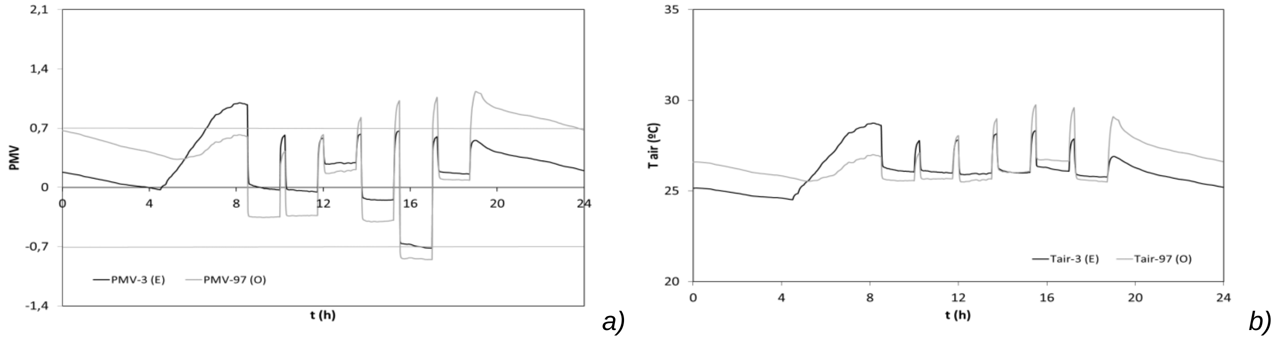

Figure 2 – Evolution of the thermal comfort index (PMV) and the air temperature (Tair) in classrooms with windows facing East (E) and West (O), in summer conditions.

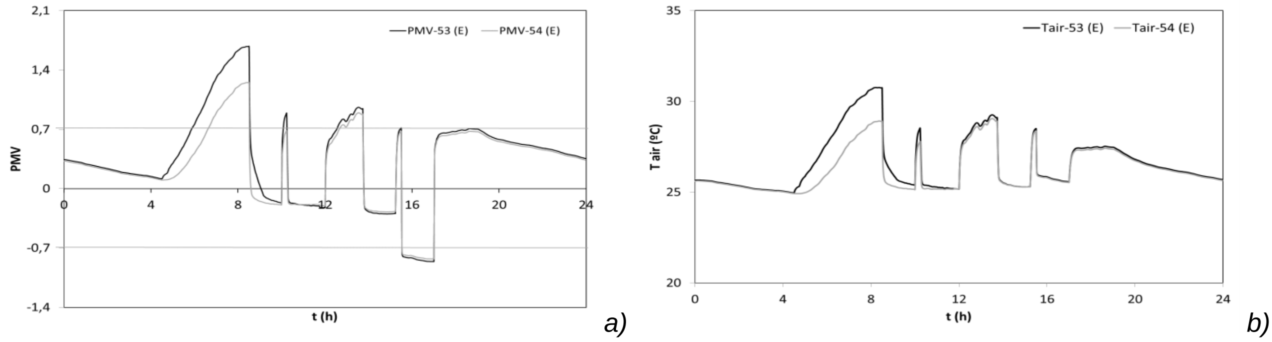

Figure 3 – Evolution of the thermal comfort index (PMV) and the air temperature (Tar) in offices windows facing East (E), in summer conditions.

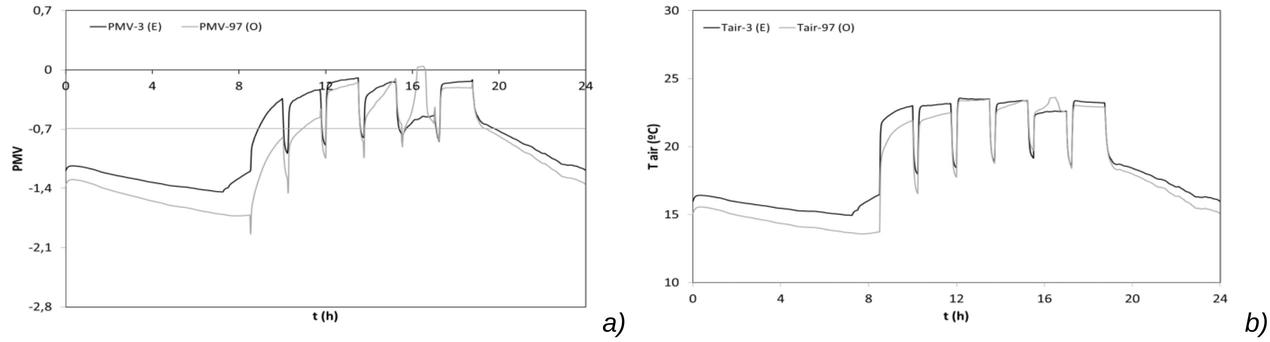

Figure 4 – Evolution of the thermal comfort index (PMV) and air temperature (Tair) in classrooms with windows facing East (E) and West (O), in winter conditions.

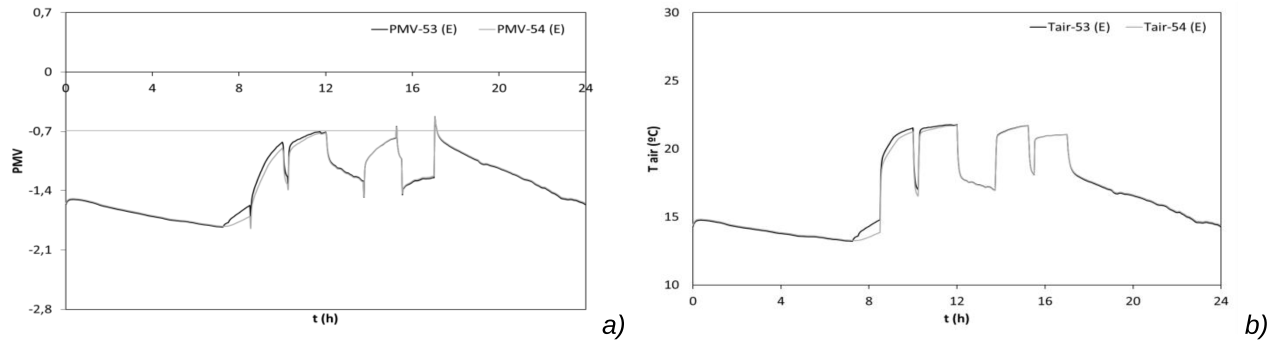

Figure 5 – Evolution of the thermal comfort index (PMV) and the air temperature (Tair) in offices with windows facing East (E), in winter conditions.

According to the results, it can be observed that the PMV index, as a general rule, when spaces are occupied, has values within Category C ISO 7730 (2005). However, in many situations, the results fit into Category B or even Category A requirements.

Although the thermal comfort level remains relatively constant, in general, the value of the air temperature is not constant throughout the day. This also depends on the evolution of the other variables, with special attention to the mean radiant temperature, air velocity and air relative humidity.

6. Conclusions

In this work a software that simulates the thermal response of buildings with complex topology and evaluates the thermal comfort and air quality in indoor environments, for the implementation of heating, ventilation and air conditioning systems with intelligent control based on the PMV index.

According to the results, it can be seen that the level of thermal comfort has acceptable values according to category C. However, in many situations, this level is in accordance with category B or even category A.

In order to improve the performance of HVAC systems with minor fluctuations and lower levels of energy consumption, it is suggested in future works to developed alternative PMV control algorithms.

In future works, in accordance with the obtained results, the geothermal and solar radiation energy sources with PMV control will also be developed.

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