Thermal Behavior of a Seasonal Building

Extended Abstract of the Thesis to obtain the Master of Science Degree in
Physics Engineering

Joana Margarida Vieira Batista

Physics Department, Instituto Superior Técnico

Supervisor: Prof. Doutor Luís Filipe Moreira Mendes

Supervisor: Prof. Doutor Pedro Miguel Félix Brogueira

Abstract

In this dissertation, the starting point was a real building occupied 1 weekend every 15 days during the heating season, in Sesimbra, Portugal. Recurring to the TRNSYS software, it was possible to simulate this case study and compare it to other cases, varying the occupancy schedule and the building materials, in order to understand the way those changes affect the thermal comfort of the occupants.

It was defined three different buildings to be simulated: one similar to the real example, with a medium thermal inertia, and other two with low and high thermal inertias associated. The main focus of this work was during the heating season, for which they were tested different heating temperatures. Later, it was also determined the thermal behavior of each building during the cooling season. Low thermal inertia buildings are not part of the Portuguese building culture, but this study shows that they could represent an advantage for short period occupancies. In contrast, during warmer seasons, for the same occupancy profile, there are more advantages on the buildings with higher thermal inertia associated.

With these results, it is possible to conclude the best heating temperature for this building and also the best construction material to be implemented for these occupancy patterns.

Introduction

When a building is projected, it is expected to be occupied almost every day. However, sometimes a building is classified as seasonal and for that reason has an intermittent occupancy (that occur for a short period of time and with high time intervals between other occupancies). In this case, some construction and architectural methods can be inappropriate in providing thermal comfort to the building occupants.

There are not many studies relating the thermal comfort of the occupiers of a building with the occupancy schedules and different thermal inertia patterns. Tuohy and al.[3] concluded the effect of building thermal mass depends on the insulation of that building, weather conditions and occupancy schedule. They simulated two types of buildings with low and high thermal inertias. For each type, it was studied the impact of different occupancies and insulations. The results showed that high thermal inertia buildings need more energy to heat the air. During the cooling season, the high thermal inertia was better to ensure comfort conditions for its occupants. It was also studied the impact of the shading in the room, that revealed quite effective in lowering the temperature inside the building. Different occupations in the building have shown that the high thermal inertia building can keep the temperature for more time. There are some studies that have different statements when comparing two buildings with different thermal masses. For example, Finney [4] concluded with his work that a building with higher thermal inertia will need more 10% more energy. On the other hand, the CIBSE [5] guide reports an increasing of 10% on the thermal inertia demand. Due to the complexity of these studies, it is hard to achieve an overall conclusion. Because of it, each case study should be strictly detailed.

The starting point of this study is a real building used to create a model for the simulations. Then, the model is validated changing the construction materials of the building, and changing also some relevant parameters in the simulation – Convective Coefficient and Time base of the wall. Studies suggested these values could change the simulator outputs, but, in this work it is seen not to be relevant. After the validation, it is created more case studies, changing not only the materials of the building, but also setting different occupation periods and different control temperatures of the environment inside the house.

The studies take place during two different periods of the year: January (winter season) and August (summer season).

Thermal Comfort

Among all the existent models to predict the thermal comfort, two models stand out: The Fanger's Model and the Adaptive Model.

The Fanger's model is based on the energy balance between the human body and the surroundings environment. It is one of the most popular models in the determination of the comfort scales and one of the easiest to use, because it can be represented in table or graphic form. According to Fanger, the thermal comfort can be acquired when the heat accumulated in the occupant's body is null.

The Adaptive model considers the capacity of an occupier to adapt himself to an environment. Because of its complexity and subjectivity, it was not considered for this study.

Case Study

The chosen model is a building of two floors, placed in Sesimbra, which the occupants describe as very hard to heat up and feel uncomfortable most of the times during the occupation in the heating season.

To simulate this case study, it was necessary to collect the intrinsic data of the building, and simplify a bit its geometry to simplify the modeling process. The following pictures – Figure 1 and Figure 2- represent the schematics of those two floors of the house that are physically connected with a flight of stairs. The red rectangles represent the radiators of the heating system, the yellow ones represent the heated towel rails used in the toilets of the building, and the blue ones represent the unities of air conditioning.

Figure 1 Schematic of the Ground Floor

Figure 2 Schematic of the First Floor

An important factor during a building simulation is the surroundings and the environment in which it is located. The building isn't influenced by the shade of other neighbor buildings, but near it are planted some pine trees of height about 20 meters that could lay in some of their branches in the roof. Because there are no weather files available for this specific zone, it was necessary to find an available meteorological file compatible. The chosen one was the file for Lisbon which is referred in RCCTE to have similar characteristics with the real case of Sesimbra zone. A field that is completely crucial when simulating a building is its construction in terms of materials. On the ground floor, the walls are made of brick with an air space of 6 cm depth. On the first floor, the air space was placed by an insulating material of the same thickness – Extruded Polystyrene. The roof is made of tile and is insulated with a layer of *roofmate*.

Simulations

By doing the simulation of the case previously described, the goal was to understand if the real situation matched with the developed model in order to validate the model for further analysis.

Because the case was very complex, it was necessary to make some restrictions on the analysis. The simulation period was shortened for the occupation during January. And it only was analyzed the cases for the living room "Sala 1" – described as the one occupied more often.

The parameters intended to study were Air Temperature, Superficial Temperature and PMV- All of them related with the thermal comfort experienced in those spaces.

In this case, it should not be forgotten the occupation schedule of this building that corresponds to a weekend occupation of 58 hours:

- Saturday 10am-1pm: 2 people inside the building
- Saturday 1pm-Sunday 5pm: 8 people inside the building
- Monday till 8 pm: 2 people inside the building

For the simulation, the initial values were - Air temperature of 12ºC and relative humidity of 25%.

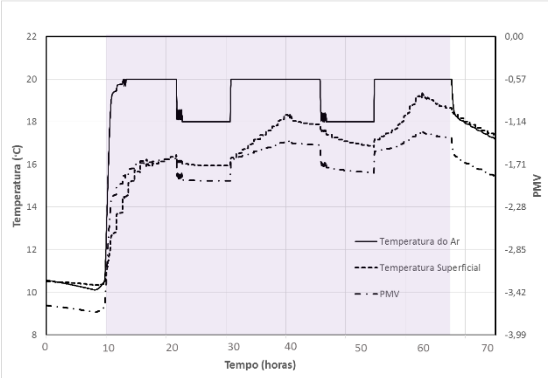

Figure 3 Air temperature, Superficial Temperature and PMV associated to the real building scenario.

The results show a quick response of the air temperature to the heating system – around three hours. However, the PMV is always negative and less than -0,5 (value from which it is considered one be in the comfort zone). As the occupation period runs, the value of this parameter decreases in absolute terms, but they are never enough to guarantee comfort to the occupants of the building.

<u>Other Construction Materials:</u>

As the previous simulation reveals a mismatch of what the building is set to give and what the occupants expect to feel, it is important to study variations of this case study. This could be resultant of an inappropriate temperature set of the building or an incapacity of the building materials to respond to the occupancy periods, as they are short and spaced in time.

For that reason, it was studied the thermal response considering three different types of buildings.

- Low Thermal Inertia Building **(<u>It ≈ 138 Kg/m^2</u>)**
- Medium Thermal Inertia Building **(<u>It ≈ 326 Kg/m^2</u>)**
- High Thermal Inertia Building **(<u>It ≈ 771Kg/m^2</u>)**

To simplify the simulation process, the occupants of the building were reduced to only one during all the occupation period. Also, the thermostat temperature was set to 20ºC all the time.

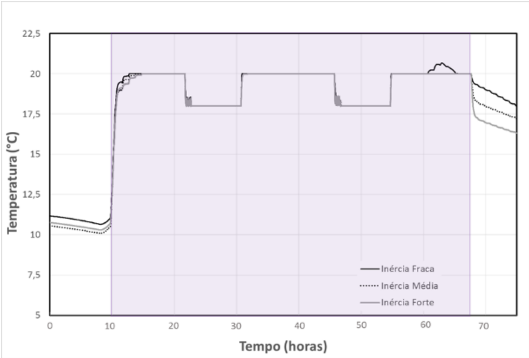

Figure 4 Air temperature profile for each thermal inertia building.

It could be seen in **Figure 4** that all buildings respond similarly to this heating temperature. In the building with low thermal inertia, temperatures decrease more and faster than in the others, as it is more sensitive to temperature change for the air temperature in the living room “sala1”. The data from this essay gives information that not only the high thermal inertia building takes 2 more hours to reach the 20ºC temperature set that the low thermal inertia one, but also that it required more energy for a weekend simulation. The heating system has a good capability to deal with this temperature set, however it was not possible to achieve comfort values (PMV values near zero)- **Figure 5**.

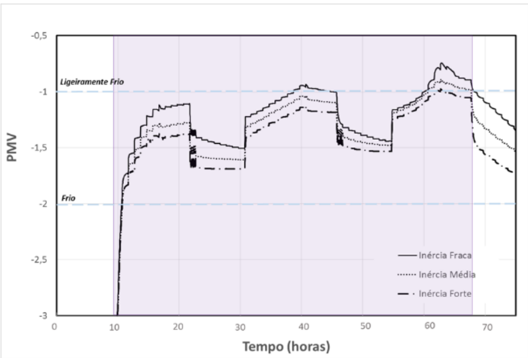

Figure 5 PMV profile for each thermal inertia building.

Varying the Convective Coefficient:

The convective coefficient considered by the simulation software have been studied and compared to real model values. Khalifa and Marshall [17] found for a heated room space a convective coefficient 1,7 times bigger than the considered one in the simulation. Because of the similarity of this specific case and the ones considered in this work, it was necessary to check the impact of that change in the convective coefficient. The results found for this model were quite negligible. In terms of temperature, the differences between cases were of 0,18ºC for the low thermal inertia building and 0,41ºC for the high thermal inertia building. On **Table 1** there are listed the differences in terms of energy for the cases of the low and high inertia buildings.

Energy Differences		
Thermal Inertia	**Absolute Value (kW.h)**	**Percentage (%)**
Low	22,27	3,4
High	3,19	1,3

Table 1 Energy differences for the two convective coefficient.

Applying different Wall Timebases:

A wall timebase is used for TRNSYS software to calculate the coefficients related with the thermal behavior of a wall. Because there is no determined relation between the construction material and the wall timebase, it was used the predefined values of TRNSYS – 1 hour. However, tests were made in order to ensure that value were not unappropriated.

Energy Differences		
Thermal Inertia	**Absolute Value (kW.h)**	**Percentage (%)**
Low	0,23	0
High	0,24	0,1

Table 2 Energy Differences for the two timebases.

For the case of the low thermal inertia building, it was considered a timebase of 12 minutes and for the high thermal inertia building a timebase of 4 hours. The differences observed were very small – for the air temperature there was a difference of 0,85ºC, and for the surface temperature, a difference of 0,57ºC for the low thermal inertia building and

0,42ºC for the high one. On **Table 2** are listed the differences in terms of energy for that both cases.

Changing Set temperatures

The previous simulations have shown the heating system was enough to heat up the air temperature in the room to 20ºC. However, that temperature, was not sufficient for the occupants to feel comfortable. For that reason, it was necessary to estimate the reference temperatures for which the PMV value was almost null (value lower in absolute number than 10^{-2}).There were found three different temperatures, one for each building case:
25,13ºC (low thermal inertia building), **23,94ºC** (medium thermal inertia building) and **25,66ºC** (high thermal inertia building).

The next simulations were made with the previous indicated values of reference and other two values of **20ºC** and **23ºC**. In those cases, not only was studied the difference between the building materials, but also the response to more given occupancy periods.
The new periods of occupancy were defined as:

- one weekend of 58 hours (like the previous period considered) but on a weekly basis,
- Combination of an everyday standard occupancy with the same 58 hours period biweekly.

In all simulation sets, there were similar conclusions, regarding the different building materials. It is easier to reach the air temperature when the building has lower thermal inertia. Also the superficial temperatures increase faster than the ones in the building with medium and high thermal inertia. As the occupancy is more regular, not only the temperature behavior tends to be similar, but also, the impact of the superficial temperatures becomes bigger as higher is the thermal inertia of the building. In general, the number of hours the occupant spend in thermal comfort increases in high thermal inertia buildings for more regular occupations.
The temperature set of 20ºC is not enough to lead the occupant to thermal comfort in any of the buildings considered, or any occupancy studied. On the other hand, for a more regular occupancy and a temperature set of reference, in the high thermal inertia building the values of PMV slightly pass the comfort zone to positive values. That means the occupant in this context could experience warm.
With the temperature set of 23ºC, it is possible to achieve satisfactory values of comfort during the occupations except for the high thermal inertia building when simulating a biweekly occupancy. (only 11 hours of comfort out of 58 hours)

Behavior during the summer:

The main goal of this topic is to compare the response of each building during the summertime.

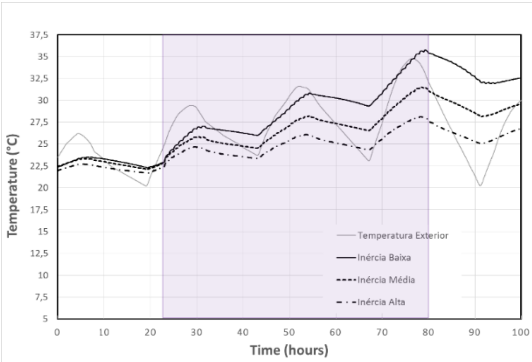

Figure 6 Temperature profile during the summer without any cooling system.

The temperature profile is different from case to case. The low inertia building has higher temperature variation than the others, In this case, because the high thermal inertia building offers more resistance to exterior temperature changes, it keeps a bland temperature inside during all the occupation. Without any cooling, 45% of the time is spend in comfort, in contrast with 5,7% and 6,9% of the low and medium building, respectively - Table 3. As it was previously done for the winter case, it was determined a reference temperature for each building by setting a cooling system to 18ºC and calculating the average of the air temperatures for each PMV value between -10^{-2} and 10^{-2}. The thermal behavior was similar for the occupations biweekly and weekly. It is more difficult to cool the low thermal inertia building, when it's warm outside the building.

Thermal Inertia	Comfort (hours)	Discomfort (hours)	PMV.h (hours)
Low	3,3	54,7	89,48
Medium	4,05	53,95	59,48
High	25,89	32,11	26

Table 3 Comfort Parameters for the summer case without cooling.

On the other hand, the high thermal inertia building doesn't need cooling at the initial moments of occupation (then, the room starts to heat and the temperature exceeds the cooling temperature). For that reason, the energy demand for the weekend is much lower for the high thermal building. For frequent occupancy, the high thermal inertia building also starts to need cooling right in the initial hours of occupancy.

<u>Comparison between Reference Temperatures for the Summer and Winter Scenarios:</u>

On the biweekly occupation one can observe a correlation between the Comfort hours and the building's type of inertia. For the winter scenario, the stronger the inertia is the smaller is the comfort hour's timeframe. On the other hand, in the summer scenario, as the thermal inertia is stronger, the comfort hours timeframe is extended. The average value, dotted line in black, suggests the building with low thermal inertia might present the most suitable solution annually - Figure 7.

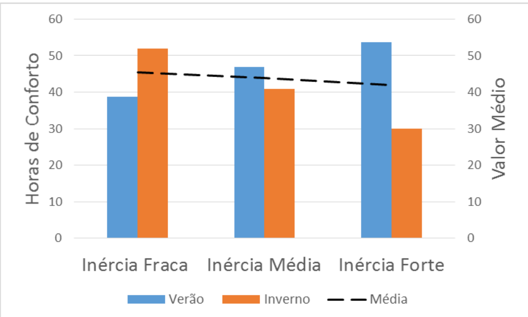

Figure 7 Comfort Hours for a biweekly occupancy schedule (winter and summer)

For the PMV.hour value, Figure 8 one can observe that globally the building the building with higher thermal inertia is less favorable, when considering both summer and winter into account. The average value for this building is approximately 5 hours higher than the average value of the building with lesser thermal inertia (where the users will have a more pleasing thermal experience).

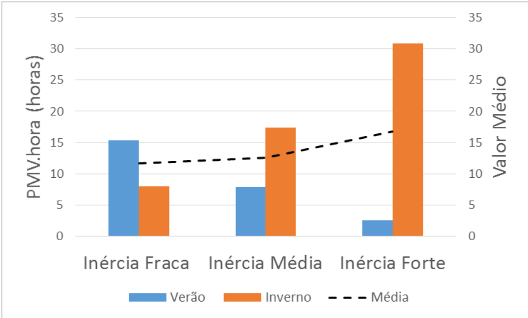

Figure 8 PMV.hour for a biweekly occupancy schedule (winter and summer)

For a weekend occupancy pattern every week along the year, the building with average thermal inertia is more advantageous, in terms of average number of comfort hours, for the reference cases of summer and winter temperatures. In the summer the comfort hours are higher for higher thermal inertia, but in winter it is the other way around, the higher the thermal inertia the lower the comfort hours.

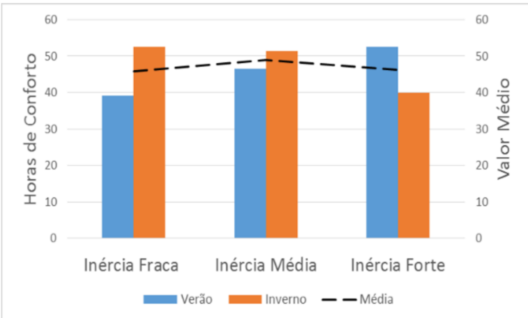

Figure 9 Comfort Hours for a weekly occupancy schedule (winter and summer)

The mean value of PMV.hour -Figure 10- is the highest for the building with lower thermal inertia, which indicates that, for a more global case, the total degree of comfort would be minor than in the other cases.

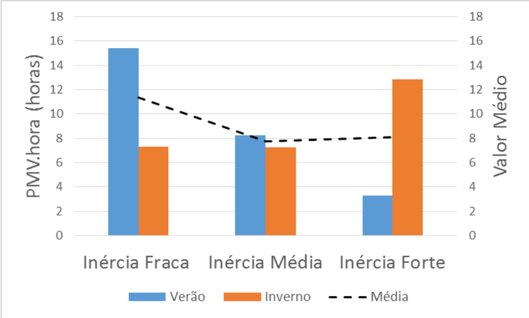

Figure 10 PMV.hour for a weekly occupancy schedule (winter and summer)

For a continuous occupancy pattern, the building with highest thermal inertia stands out, for the average value between winter and summer and for the increase of comfort hours in both seasons -Figure 11.

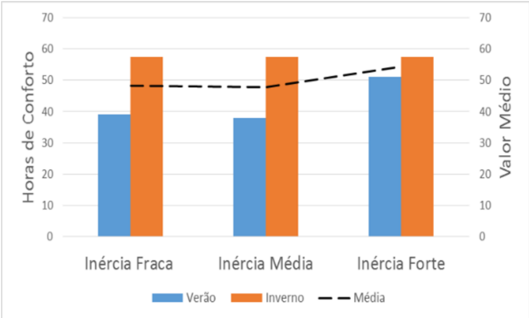

Figure 11 Comfort Hours for a "continuous" occupancy schedule (winter and summer)

When analyzing PMV.hour, in Figure 12, one can conclude that the building with low thermal inertia is in worst position than the other two, since the occupant will experience a higher degree of thermal discomfort.

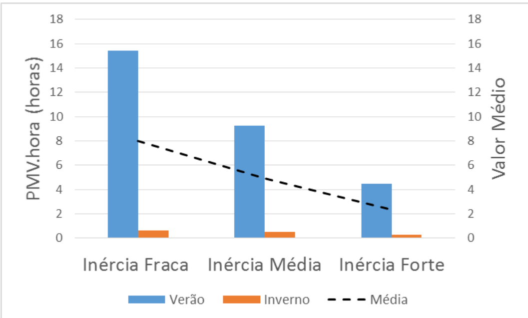

Figure 12 PMV.hour for a "continuous" occupancy schedule (winter and summer)

Conclusions

This project was developed around the determination of thermal comfort of the occupants of a given building, taking into account the construction material, the occupancy pattern in the building along the year as well the heating/cooling criteria.

A real case was used as starting point, a building in the region of Sesimbra, with a weekend occupancy pattern every other week (58 hours stay). Given that the real case was considerably complex in terms of the building's topology, the simulation focused primarily on the most used division – the main room ("Sala 1"). Not only this division was reported as being the most frequented, but it also has a thermostat that regulates the whole building's temperature based on this room's temperature.

As a first step, the model was validated comparing the simulation results with the occupant's description of the building's thermal behavior. It was also tested the impact of using different construction materials, the impact of changing the convective coefficient and the time base of the wall in the simulator.

Then, there were made some simulations for different temperature sets and occupancies. The conclusions are presented by occupation:

<u>Biweekly Occupation</u>

This was the most seasonal scenario studied. Several temperatures and thermal inertias were tested, and for the 58 hour period analyzed during winter season, it was observed that buildings with lower thermal inertia are more advantageous, both in terms of comfort period and in temperature and energy response. The gathered data allows to conclude that the higher the thermal inertia of the building, less advantageous it is when occupied in short periods spaced in time during the winter season.

For example, for the same temperature of 23ºC one can observe that the building with high thermal inertia takes an additional 20 hours to be heated relatively to the building with mid-range thermal inertia. In terms of energy consumption, the building with high thermal inertia takes up almost twice the energy as the building with low thermal inertia.

In the summer scenario, the results invert – the buildings with higher thermal inertia become more advantageous given that they are less sensible to external temperature fluctuations. It is worth mentioning that for the simulation where no air-conditioning was used during the summer season, the buildings with strong inertia assured way more comfort hours than the mid-range and low inertia buildings studied.

For the simulations where an air-conditioning system was included, one can conclude that the building with high thermal inertia doesn't need to recur to such system in the beginning of the occupancy, since the main room temperature is still bellow the threshold temperature to kick-start the air-conditioning system. This way, the total energy expended in a 58 hour period during summer is way smaller for buildings with high thermal inertia, than their counterparts with lesser thermal inertia. Since a low thermal inertia is related to less resistance to temperature changes in the interior of the building, the building with low thermal inertia heats up dramatically during the summer, in some cases reaching above 27ºC and presenting higher PMV values – being way less comfortable for a summer occupancy pattern.

The last analysis consisted on the comparison between the comfort parameters for winter and summer and for each type of building. Taking the average between the results for winter and summer seasons, one can conclude that the building with low thermal inertia is more advantageous for a biweekly weekend occupation, since it presents a higher average value of comfort hours, but also because it has a lower PMV.hour value (parameter which represents the degree of discomfort of the occupants). This conclusion assumes that the occupancy pattern is equal between winter and summer.

This way, once one person wants to construct a building for short and spaced in time occupancies, it should take into account that the low thermal inertia building should be the best option for this type of weather conditions.

Weekly occupation

For this scenario the comfort periods of the building with medium inertia and low inertia converge. In the simulations with the reference temperatures for winter, the comfort period is only 1 hour higher for the low inertia building when compared with the mid-range one. A weekly occupation of 58 hour periods is frequent enough to allow for the buildings with higher thermal inertia to present some "memory" of the previous occupation, whilst for buildings with low thermal inertia that is not the case. The building with low thermal inertia starts from a lower temperature, and the one with highest inertia starts from a higher temperature (both air and superficial temperature), which leads to lower PMV values in absolute terms.

In the summer season this type of weekly occupation reveals even stronger advantages for buildings with high inertias, either in higher comfort periods or in lower energy consumptions. The building with low thermal inertia presents significantly lower comfort hours. From the results it can be said that the most suitable building for a weekly occupation during weekends is the one with average thermal inertia.

Continuous occupation

For a regular occupation the simulation shows that it is easier to assure more comfort time in the winter scenario than in summer, regardless of the building construction materials and its inertia. In the winter season the building with higher inertia is more suitable since it storages heat from previous occupancies, allowing it to more easily reach the comfort parameters at any given time. But in terms of energy consumption this building is the more demanding one.

When looking at the summer season, the building with higher inertia consumes less energy than its counterparts. The discomfort index in the building with low inertia is quite considerable, therefore it is not recommended for a continuous occupancy during summer. The average values between summer and winter shows the advantage of the building with high thermal inertia. Although the number of comfort hours is similar between buildings, the difference resides in the type of discomfort that is felt by the occupants (given by the average value of PMV.hour).

Final Considerations

Lastly, one can conclude that there is no general building solution (with limited energy) that maximizes comfort in all situations. It all depends on the intended usage of the building along the year, the thermal inertia of the building and even the type of occupants and their activities. In the circumstances of the real building that supported this study, a solution would be to construct the building with less thermal inertia. Nevertheless, this conclusion should be validated with an actual construction of the building. This study presents similar conclusions in qualitative terms to the ones found by Tuohy [3], namely in the better suitability of the building with high thermal inertia for summer occupancies, and the building with low inertia for short winter occupancies.

There's still the problem of the lack of significant comfort periods in the initial real scenario. This work concludes the temperature that ensures it the best is 23,94ºC. For future progress of this work, this temperature should be tested in the real building.

Because of the high quantity of cases and parameters considered, the simulations were restricted to only two period cases – January (winter) and August (summer). For support the obtained global considerations, it would be necessary to map yearly simulations in order to have more complete data about each studied case. It would also be interesting to test this model for other weather files in Portugal and check if there is any region where these considerations cannot be formulated.

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