ACHIEVING THERMAL INERTIA IN LIGHTWEIGHT CONSTRUCTIONS

Pedro Silva – psilva@civil.uminho.pt
Luís Bragança – braganca@civil.uminho.pt
Manuela Almeida – malmeida@civil.uminho.pt
University of Minho, Civil Engineering Department
Campus de Azurém, 4800-050 Guimarães, Portugal
Paulo Mendonça – mendonca@arquitectura.uminho.pt
University of Minho, Architecture Department
Campus de Azurém, 4800-050 Guimarães, Portugal

Abstract. *The aim of the present work is to improve the thermal performance of lightweight constructions making use of Phase Change Materials (PCMs). Typical lightweight constructions have lack of thermal inertia. The use of PCMs can remediate this problem and improve the building thermal performance. However there are few studies specifying the correct PCM to apply in each situation and the optimal quantity to use. In the present case, it was used a natural PCM – Coconut Oil, placed in plastic containers in the floor. For the study it was used the Test Cells built in the University of Minho. There were carried out several experiments with Coconut Oil, reproducing different thermal storage situations, from the total absence of this material (reference lightweight solution) to the application of all the available PCM. It was concluded that the introduction of PCMs improved substantially the Test Cell thermal inertia, but it would be necessary to also implement some modifications in the South façade (reduction of the glazing area and introduction of more thermal mass) in order to improve the overall thermal performance. Before the introduction of these modifications in the Test Cell, the Program VisualDOE was used in order to forecast the performance of the Test Cell and to optimize the final solution.*

Keywords: *Lightweight construction, thermal inertia, energy simulation, test cells*

1. INTRODUCTION

The reduction of weight in buildings – lightweight construction - is a technique used to reduce the environmental impact of the building and it can also bring advantages in economical terms. The lack of thermal mass in lightweight buildings results in an insufficient thermal inertia and thus problems in terms of thermal comfort and higher temperature oscillations.

In order to face these problems, it is possible to introduce materials with specific thermal storage properties, increasing the thermal inertia, without significantly increase the weight of the building. This can bring advantages in both environmental and economical terms, particularly by an ease application in lightweight constructions and in existing buildings with small thermal inertia.

. Lightweight thermal storage can be achieved using the latent heat of certain substances – PCMs (Phase Change Materials). In order to use this property for thermal regulation, these materials should change their phase at temperatures near the comfort temperature – between 18 to 25ºC (Mendonça, 2005).

2. CASE STUDY

This research was focused on the study of the optimal quantity to be applied of a chosen PCM, in a lightweight construction with no thermal inertia. The PCM selected for this study was Coconut Oil, not only because it is a natural material but also because its phase change is inside the comfort temperature range.

The PCMs can be placed in containers, mounted as units with proper support or absorbed in conventional materials, in microcapsules. In the present study, the PCMs were placed in plastic containers in the floor, as it can be seen in Fig. 1.

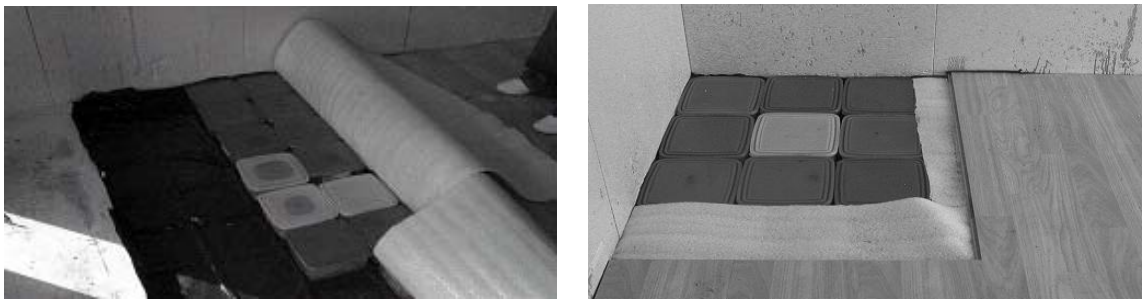


Figure 1 - Placing the containers with coconut oil and final aspect of the floor.

2.1. Test Cells

This study was carried out in the Test Cells built in the University of Minho. The building has three different Test Cells – Test Cell 1 (TC1) is a passive solar optimized construction; Test Cell 2 (TC2) is a Portuguese conventional constructive solution; Test Cell 3 (TC3) is a super-insulated lightweight construction with a large polycarbonate glazing in the south façade.

There is a sunspace in the south façade, in all Test Cells, as shown in Fig. 2 (Silva, 2006).

The TC3 was designed manly to allow performance tests of new types of façades, but due to its lack of thermal inertia and the existence of a measurement system, this Test Cell was ideal to study the effects of PCMs in lightweight constructions and was chosen for that purpose.



Figure 2 - Test Cells.

2.2. Measurement System

In order to perform the required "*in-situ*" experimental tests, there where installed some sensors and connected to the existent data acquisition system of the Test Cell. The sensors installed were the following (Fig. 3):

- 1 Interior Temperature sensor;
- 1 Interior Relative Humidity sensor;
- 1 Glazing superficial temperature sensor;
- 4 Wall superficial Temperature sensors.

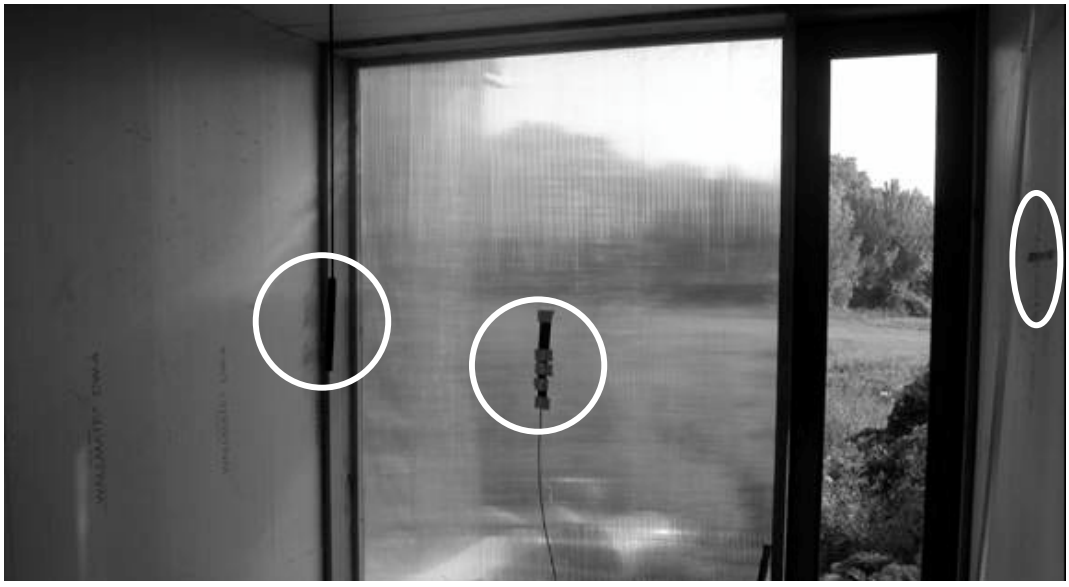


Figure 3 - Test Cells sensors.

As this study intended to optimize the thermal performance of the Test Cell, the interior temperature and relative humidity are fundamental parameters. The superficial temperature of the envelope was measured in accordance with the indications presented in ASHRAE (1997), that indicate the resultant temperature (T_r) as a better parameter to evaluate the thermal comfort than the interior temperature. The resultant temperature is calculated with the use of the interior temperature and envelope superficial temperature, as shown in Eq.(1):

$$T_r = \frac{\alpha_r \times \overline{T}_s + \alpha_c \times T_a}{\alpha_r + \alpha_c} \quad (1)$$

α_r: Radiant coefficient;
α_c: Convection coefficient;
T_a: Ambient Temperature (ºC);
T_s: Mean Radiant Temperature, obtained from Eq. (2):

$$\overline{T}_s = \sum_{i=1}^{n} T_i \times F_{pi} \quad (2)$$

T_i: Internal surfaces temperatures;
F_{pi}: Angle Factor.

The angle factor can be obtained using the charts produced by Fanger (1982), that take into account the position and orientation of a person inside the room. An example of these charts is presented in Fig. 4.

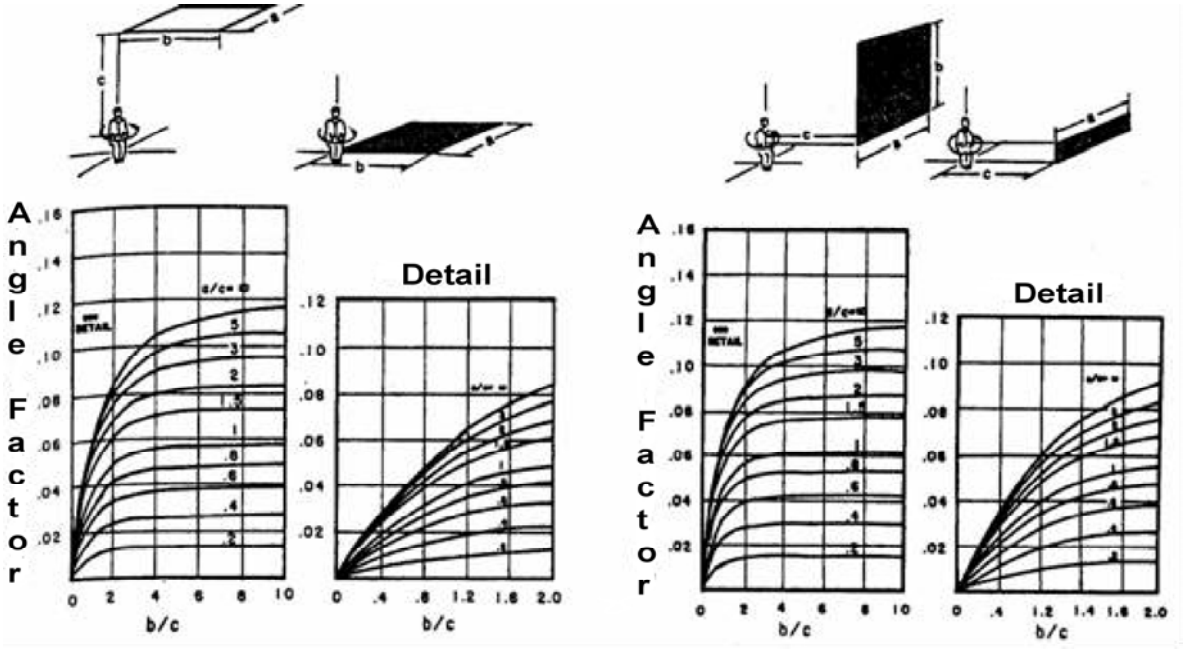


Figure 4 – Average value of the angle factor between a seated person and a vertical or horizontal surface, when a person can be rotated in a vertical axle, Fanger (1982).

3. "*IN-SITU*" EXPERIMENTS

In this study, in order to identify the optimal quantity of PCM to use in a lightweight construction, there were performed four main experiments with different quantities of Coconut Oil applied in TC3:

1. Total absence of PCM (reference lightweight solution) – the values were measured from 2 to 4 of October in 2003;
2. 100kg of PCM applied only in the floor – the values were measured from 27 to 29 of September in 2004;
3. Intermediate situation with 100kg of PCM in the floor plus 100kg in containers placed inside the room – the values were measured from 21 to 23 of September in 2004;

4. 100kg of PCM in the floor plus 200kg placed in containers inside the room (corresponding to the application of all the available Coconut Oil) – the values were measured from 17 to 19 of September in 2004;

The results of these "in-situ" experiments are presented in Fig. 5 to Fig. 8:

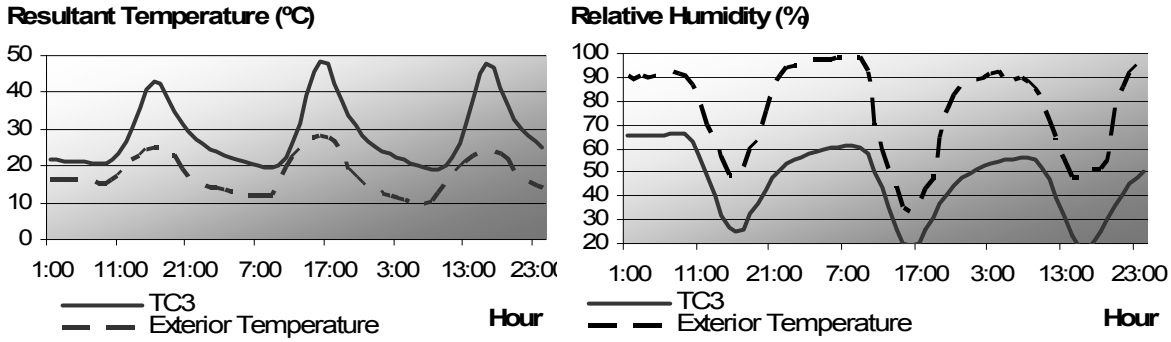


Figure 5 – Resultant Temperature and Relative Humidity in Test Cell 3 - Experiment 1 - Total absence of PCM.

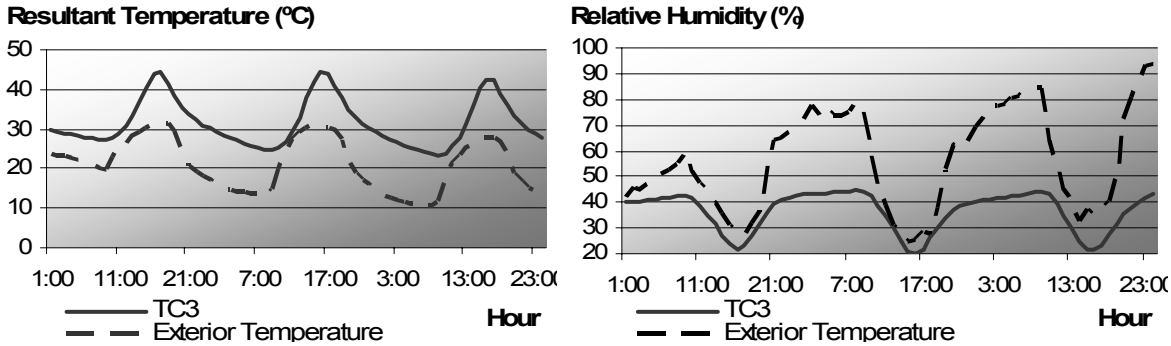


Figure 6 – Resultant temperature and Relative Humidity in Test Cell 3 - Experiment 2 - 100Kg of PCM applied in the floor.

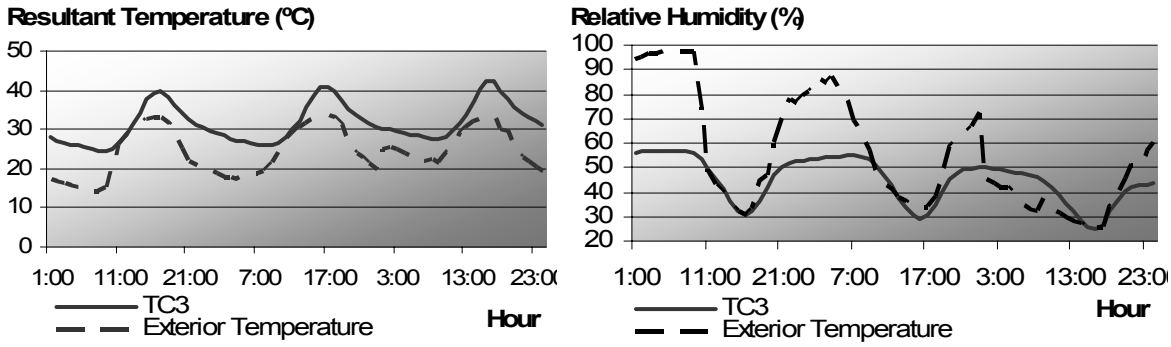


Figure 7 – Resultant temperature and Relative Humidity in Test Cell 3 - Experiment 3 - 100Kg of PCM applied in the floor plus 100Kg placed inside the room.

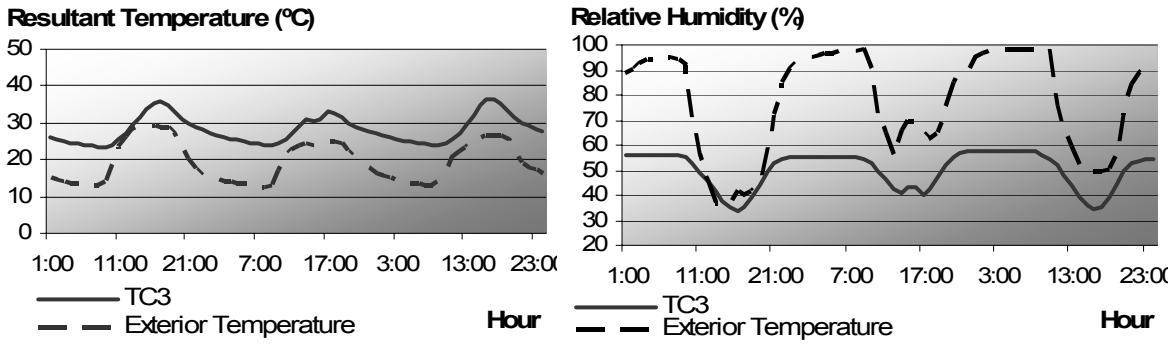


Figure 8 – Resultant temperature and Relative Humidity in Test Cell 3 - Experiment 4 - 100Kg of PCM applied in the floor plus 200Kg placed inside the room.

From the charts comparative analysis, it is possible to conclude that with the introduction of the Coconut Oil there was a reduction in the interior maximum temperature, especially in experiments 3 and 4. However, the maximum peak temperature, in all cases, is above the maximum exterior temperature, mainly due to the excessive heat gains from the south oriented sunspace, in use without any special treatment. But, it can be observed that in the experiment 4 (TC3 with 300kg of Coconut Oil), the difference between the maximum exterior and interior temperatures is 8ºC, considerably lower than the difference observed in experiment 1 (TC3 without any Coconut Oil), that is 20ºC, what shows a good improvement in the thermal performance of the Test Cell by the application of the Coconut Oil.

It was also verified a reduction in the daily thermal amplitude as it was introduced more PCM. This fact is in accordance with the thermal inertia increase verified in the TC3.

On the other hand, there is a significant reduction in the TC3 relative humidity, even with small quantities of Coconut Oil. The high level of relative humidity measured in experiment 1 can be a discomfort factor for the users due to a higher difficulty in body transpiration and it can also contribute to the degradation of the construction materials.

From these experiments, it was also possible to conclude that the best solution in terms of cost/benefit is the experiment 3 since the improvement verified from experiment 3 to 4 was very low when compared with the cost associated to the use of more 100Kg of PCM.

However, for the reasons explained before (excessive solar gains), in this test cell, it was not possible to obtain an optimal solution in terms of thermal performance. So, it was decided to use a simulation tool to continue this study, to test new solutions and to determine the required modifications in TC3 in order to get a better thermal performance.

4. TC3 PERFORMANCE SIMULATION

In order to test new design solutions in TC3 that could result in a good thermal performance of this Test Cell, it was employed the simulation tool VisualDOE v3.1 to this case study. This tool was chosen due to its calculation engine – DOE2.1E – and the simplicity of the buildings performance evaluation (Green Design Tools, 2001).

Before the simulations were made, it was necessary to create and calibrate a model that would represent the Test Cells. For the model calibration, the reference configuration for the TC3 was the one presented in experiment 2, due to a more comprehensive availability of experimental data in this configuration.

For each one of the design solutions studied, the performance evaluation was based on an hourly evaluation for a whole year.

4.1. Model Calibration

A model representing the Test Cells was created in VisualDOE (Fig. 9) and calibrated by two main steps:

1. Calculation of a climatic file with the appropriate weather conditions for the TC3 – this step was done following the same procedure as the one presented in Silva *et al* (2006) and Buhl (1999);
2. Adjustments in the model properties by comparing the TC3 interior temperatures obtained with the model and the ones measured "*in-situ*".

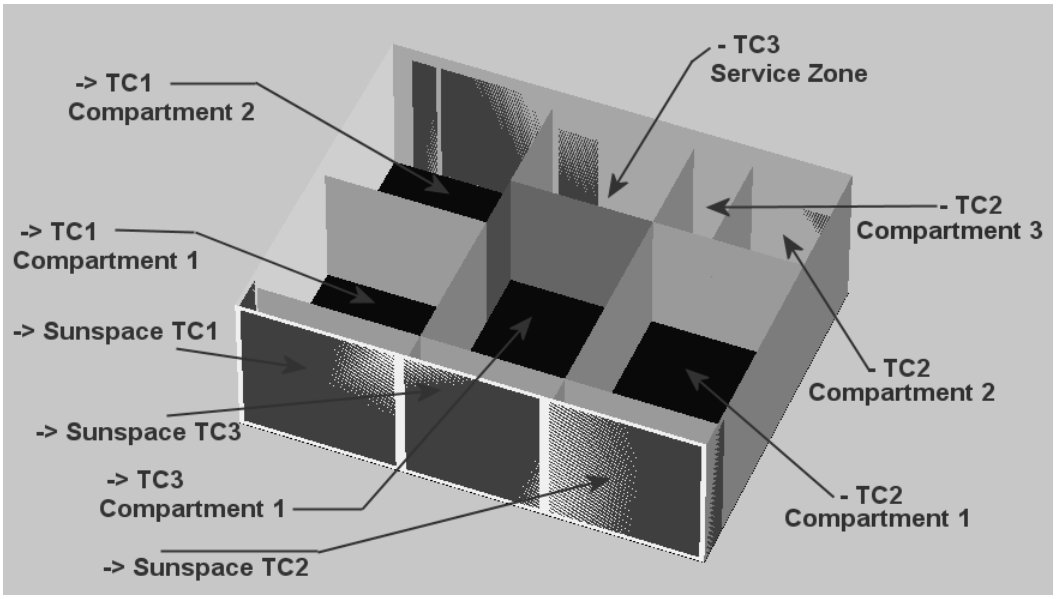


Figure 9 – Test Cells model.

4.2. Results

Using the calibrated model of TC3, made with VisualDOE 3.1, it was predicted the annual energy consumption of TC3 with the different configurations corresponding to each of the four previous experiments. The results obtained with VisualDOE are presented in Table 1:

Table 1. TC3 annual energy consumption

TC3	Energy Consumption (kwh/m^2.year)		
	Heating	Cooling	Total
Experiment 1	46.9	54.8	101.7
Experiment 2	37.3	42.6	79.9
Experiment 3	30.4	33.2	63.6
Experiment 4	28.2	31.7	59.9

These results corroborate the assumptions already made with the "*in-situ*" experiments, like the increase of the thermal performance of TC3 as it was added more Coconut Oil and the small difference observed between the test Cell performance in experiments 3 and 4.

To continue the study, some design modifications were made in the configuration of TC3, based on experiment 3 (optimal solution in terms of PCM application), in order to achieve an optimal design configuration for the Portuguese climate, in lightweight buildings with the introduction of PCMs:

- First alternative – introduction of a second sheet of polycarbonate (in order to increase the thermal resistance of the envelope);
- Second alternative – reduction of the glazing dimension from 2.7m height X 2m width (5.4 m^2) to 1.5m height X 1.4m width (2.1 m^2) and replacement of the polycarbonate by

double glass (so that the daylighting availability do not suffer a significant reduction, as the solar factor of the double glass is higher than the one of the polycarbonate).

The results obtained with these design modifications are presented in Table 2:

Table 2. TC3 annual energy consumption after design modification

TC3	Energy consumption (kwh/m^2.year)		
	Heating	cooling	Total
1st Alternative	26.5	15.0	41.5
2nd Alternative	20.7	9.4	30.1

From the optimized design alternatives simulated with VisualDOE, it can be said that both the alternatives result in a better thermal performance than the initial one. However, the 2nd alternative corresponds to a much better performance and it can be concluded that this is an optimized design for a lightweight construction with the inclusion of PCMs.

For this situation, this design resulted in a higher thermal inertia and the maximum interior temperatures are, in general, lower than the exterior temperature, in opposition to what happened in the experimental test, as mentioned earlier. In Fig. 10 it is presented the simulated TC3 interior temperature and the outdoor temperature for the same period of the experiment 3 – from 21 to 23 of September in 2004.

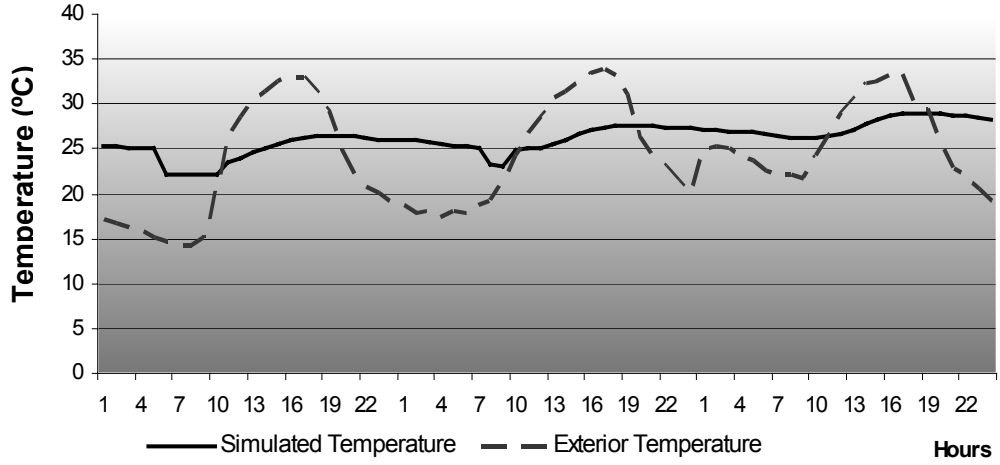


Figure 10 – TC3 simulated interior temperature for the 2nd design alternative.

As it can be seen, now, with the reduction of both heat losses and solar gains, the lightweight Test Cell with the incorporation of PCMs shows a good thermal performance, with low energy consumptions and with almost steady indoor temperatures, around 25º C, even when the exterior temperature goes to 34º C.

5. CONCLUSIONS

With this study, it was proved that, in mild climates like the one in Portugal, the incorporation of PCMs (Coconut Oil) in lightweight constructions, can lead to a very good thermal performance of the building. However, it was also proved that the increase of the thermal inertia with the incorporation of PCMs is not enough if not associated with an optimized design of the envelope. For this situation, it was observed that the solution with PCM and optimized envelope, showed a thermal performance 70% better than a typical lightweight solution, both in terms of energy consumption and temperature swing.

5.1. Acknowledgements

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