

# Thermal Performance of Residential Buildings with Large Glazing areas in Lisbon- Modelling and Validation

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**ABSTRACT:** *This work aims to demonstrate the parameters of both major and minor influence on the thermal performance of units with large glazing areas, whether with one face or two exposed. The study was developed after a two year monitoring campaign in a group of 23 building apartments (the units have more than 60% of the main façades in glazing). The main goal was to carry out a representative model that can be validated by the experimental results in order develop a set of parametric studies for the Lisbon Climate. Part of the modeling included the development of detailed and simplified geometrical models related to the units selected for the study. Different parametric variations were performed (summer and winter) using the detailed and simplified geometrical models. These took into account the characteristics of each housing unit and the conditions under which they were monitored in summer and winter. The thermal simulation software EnergyPlus (with the calculation model present in this software) was used to simulate all solutions and models. Thus, the study allows not only comparison but also the evaluation and validation of the models.*

**Keywords:** *monitoring, modelling, calibration, parametric variations, heating and cooling seasons.*

## 1. INTRODUCTION

The work includes experimental studies, modeling, simulation, calibration models and parametric variations of residential buildings (multi-family apartments) with glazing areas greater than 60% of the total façade area, and for different solar exposures in Lisbon. These buildings were designed after the implementation of the first Portuguese Buildings Thermal Regulation and they are intrinsically related with the construction and architecture practiced in the last few years. The analysis includes the thermal behaviour of the apartments selected for the study during the summer and winter.

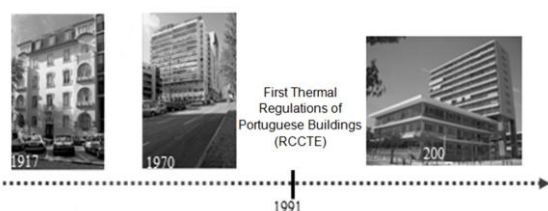


Figure 1: Evolution of glazing areas in residential buildings in Lisbon.

## 2. SAMPLE

For the study in question a group of housing units (23 in total) located in residential buildings chosen among others buildings identified in the Portuguese building stock was selected (see figure below). These buildings are projects developed by Known architects in Portugal and they present important features to this study; in particular the glazing areas (more than 60% of the overall external envelope).

The selected sample includes a range of residential units located in different buildings in the City of Lisbon that show different orientations, locations in the buildings (intermediate floor and penthouse) types of horizontal shading (dimensions), glass protection devices (interior and exterior), types of glass (being the double clear glass the most common for more than 80% of the sample), types of constructive solutions for the interior and exterior envelope (walls, floors and roof – thermal mass and insulation), degree of insulation (normally with 40mm of XPS for most part of sample), degree of natural ventilation, occupation and utilization pattern, equipment (heating system) and others.



Figure 2: Residential Buildings selected for the study (façades in glazing).

## 3. MONITORING

In view of the selected sample a monitoring set was carried out in during both, summer and winter (period of 2007-2009).

Temperature and relative humidity (hygrothermal behaviour - mini dataloggers) sensors were installed in the selected housing units (living room and bedroom). The use and occupancy pattern of the

housing units were also recorded during the measurements, as well as the views of residents through a survey targeting the issues of thermal comfort. Thus, a set of data and other important information were obtained for understanding the thermal behaviour of the compartments of the housing units under study.

While the monitoring was performed the external conditions were obtained from the LNEG Meteorological Station (LNEG-National Laboratory for Energy and Geology, IP) installed in the Solar XXI Building, Lisbon.

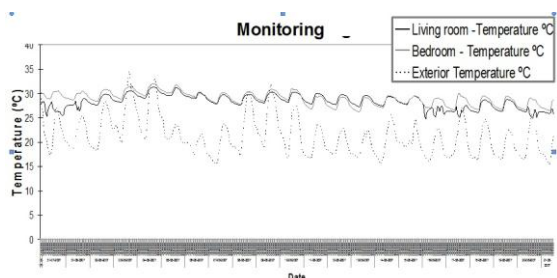


Figure 3: Examples of temperature data obtained during a single monitoring.

The monitoring in situ (situations verified under real conditions) made possible to identify the different effects and influences on the thermal behavior of units located in buildings with such characteristics (large glazing areas).

#### 4. MODELING (GEOMETRICAL MODELS)

Based on information obtained from the housing units selected (H1 to H23), detailed geometrical models were constructed in the thermal simulation software EnergyPlus (E+) The detailed models took into account the features of the housing units and the conditions under which they were monitored during the summer and winter (geometry, orientation, location, construction solutions, pattern of use and occupation, renewal rates by time, equipment...). To insure that the models in question were simulated under the monitored conditions special care was taken to introduce into the thermal simulation software the climatic data (climate file) obtained from the meteorological stations of the National Laboratory for Energy and Geology (LNEG, Lisbon) the same periods of monitoring.

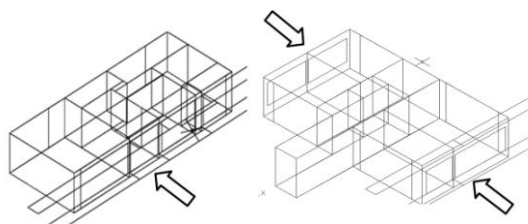


Figure 4: Examples of Detailed Models: 1 and 2 exposed faces.

#### 5. CALIBRATION GEOMETRICAL DETAILED MODEL WITH MONITORING

The following charts show the difference (on average) between the temperature values obtained during the monitoring (summer and winter) with the temperature values obtained with the correspondent detailed models (E+).

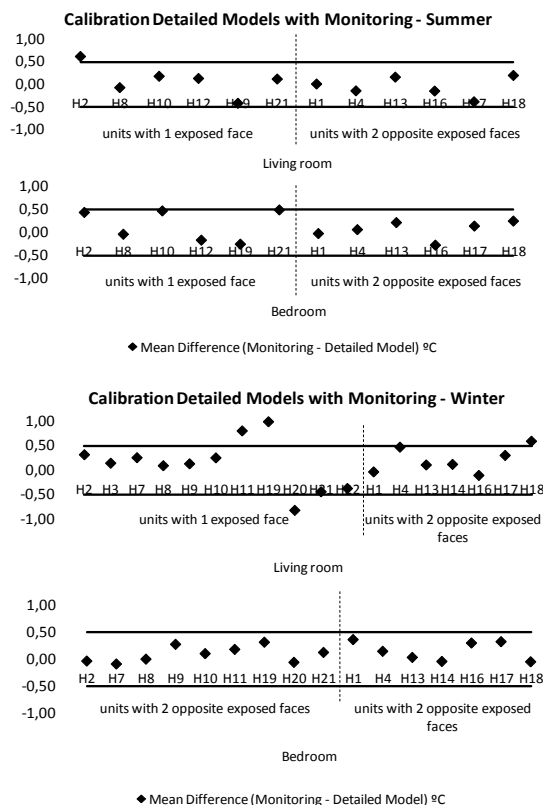


Figure 5: Calibration Detailed Models with Monitoring (summer and winter).

The difference between the temperatures obtained during the monitoring and those obtained through simulations (during the seven days selected to represent the summer and winter season) did not exceed  $\pm 0.5$  °C for most of the housing units (numbered and represented in graphs with H1...23). The manufacturer of the equipment uses a margin of error of + or - 0.5 °C and that the weather station is not located exactly on the building site studied. Thus, taking into account the above observations and the mean differences obtained in both seasons (monitoring and simulations), the results in terms of calibration can be considered satisfactory.

#### 6. GEOMETRICAL DETAILED MODELS AND GEOMETRICAL SIMPLIFIED MODELS

Taking into account the different housing units selected and their typologies, a study was conducted to simplify the detailed models, resulting in two simplified models: a Simplified Model 1 (with one face exposed) and Simplified Model 2 (with 2 opposite faces exposed).

In order to be calibrated, the simplified models were verified in two phases.

In the first phase: they were submitted to the same conditions in which some of the detailed models were simulated. Simplified Model 1 was compared with detailed models of H2, H9, H8, H12, H19, H22, H20, H21, H10, and simplified Model 2 was compared with detailed models H1, H18, H13, H14, H17 and H16.

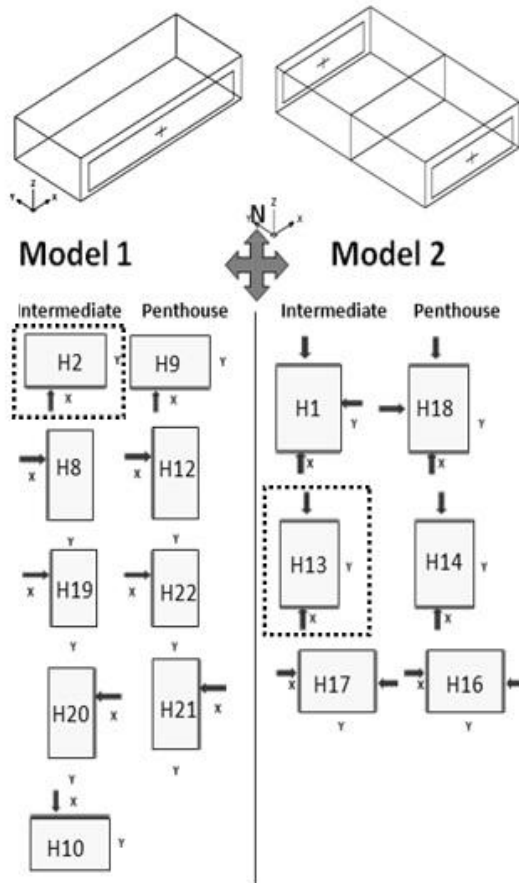


Figure 6: Scheme: simplified models 1 and 2 obtained from the detailed models.

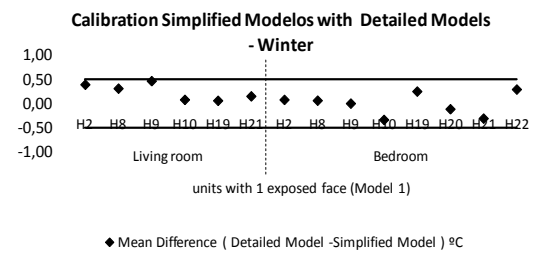
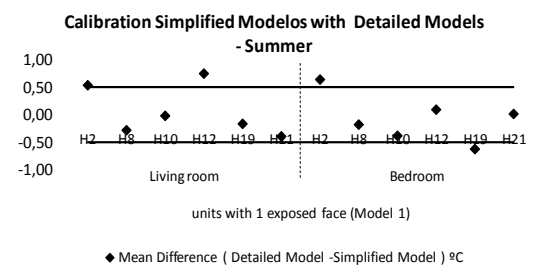
In the second phase: both geometrical models, the detailed models and the simplified models, were submitted to the same parametric variations (summer and winter) in order to verify that both responded to these changes in a similar manner. To accomplish this, the detailed Model of the H2 together with the Simplified Model 1 (corresponding to H2) and the detailed Model H13 with Simplified Model 2 (corresponding to H13) were selected. Different parametric variations were applied on these, such as: different values of ACH (air change per hour), types of protection (interior and exterior), types of windows, insulation, and type of exterior walls.

### 6.1. Calibration (geometrical models) Simplified Models with Detailed Models (Phase 1) – submit simplified models (1 and 2) to different conditions presented in the detailed models

The difference between the temperatures obtained through the detailed models and those obtained through simplified models (during the seven days selected to represent the summer and winter season) did not exceed  $\pm 0.5$  °C for most of the housing units observed.

Therefore it appears that both simplified Models are responding very similarly to the selected detailed models (phase 1).

#### Model 1



#### Model 2

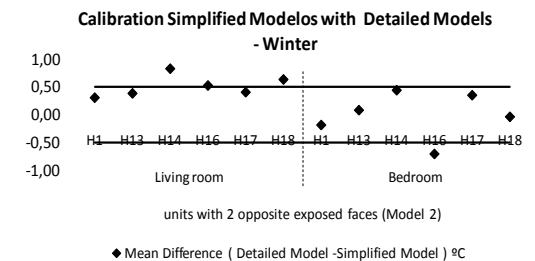
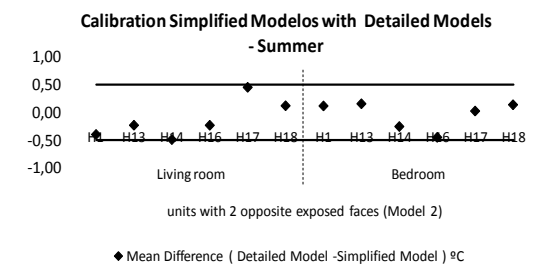


Figure 7: Calibration Simplified Models (1 and 2) with Detailed Models (Phase 1) – summer and winter.

## 6.2. Calibration (geometrical models) Simplified Models with Detailed Models (Phase 2) and Analysis of the influence of different parameters

Calibration phase two is the implementation of several parametric variations in both simplified and detailed geometrical models, in order to verify the behavior of both in the hot season (summer) and cold season (winter), or whether they respond similarly to different parametric variations, which involve different degrees of ventilation, different types of protection on glazing, glass types and degrees of insulation, and different types of exterior walls (see graphic captions below to check the parametric variations performed).

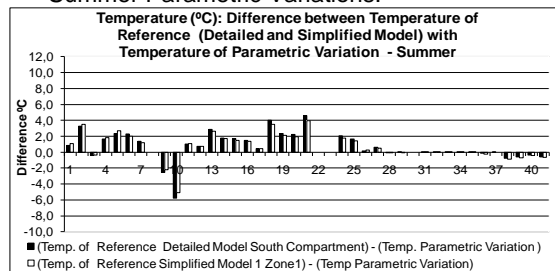
The different variations are compared with the reference solution (represented in the charts below always with the value zero). The reference solution corresponds to solutions that characterize the detailed and simplified models under the conditions for which the real model was monitored.

Below are the parametric variations performed (summer and winter) for Model1 with a single face exposed to the South (Detail and Simplified geometrical models) and Model 2 with one face exposed to the south and one to the north (Detailed and Simplified geometrical models). These variations permitted the verification of the parameters of major and minor influence on thermal behaviour of the models in question.

### Model 1

Reference solution corresponds (80% of the south façade is glazing): horizontal shading with 0,85m; without interior and exterior glazing protection, double clear glass.

### Summer Parametric Variations:



1-5 Infiltration	6-10 Horizontal Shading	11-14 Interior Blind	15-22 Exterior Blind	23-27 Double Glass	28-35 Insulation Thickness	36-41 Exterior Wall Type
Rph=1 2m	activated 50%	with activated (13h-19h)	clear	0.0001m	Granite 40-60cm	
Rph=3 1.5m	20mm insulation	activated (15h-19h and 24h-9h)	Colored in the mass	0.02m	Concrete 1 - 20cm	
Rph=0.5 1.1m	activated 50%			0.04m	Concrete 2 - 20cm	
Rph=Night 0,6m	without insulation	activated (24h-9h)	Reflectant	0.06m	Ceramic Brick - 20cm	
Ventilation 0,05m	activated 100%	activated (9h-19h)	Incolor	0.08m	Concrete block 1 - 20cm	
Rph=Day	with 20mm	activated (24h-12h)	LOW-E 1	0.1m	Concrete block 1 - 20cm	
Ventilation	activated 100%	activated (9h-13h)	LOW-E 2	0.12m	Concrete block 2 - 20cm	
	without insulation	always activated		0.2m	Concrete block 2 - 20cm	
		always desactivated				

Figure 8: Calibration Simplified Model 1 (Phase 2) – summer.

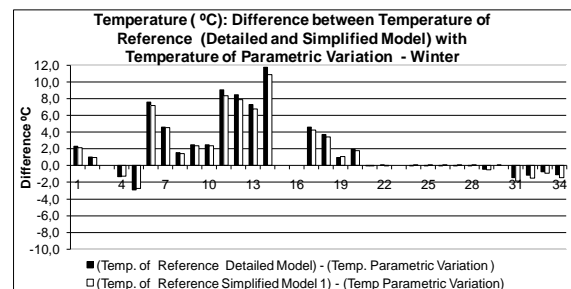
In the above graph we can see that both the detailed model and the simplified model responded similarly to each parametric variation (variations 1-41). Between the two models there is a difference in most of the parametric variations of +0.1 °C on

average. The differences between the two models (along the different variations made) were up to +0.54 °C and -0.65 °C.

The variations in the air change per hour (ACH), showed a great potential to reduce the indoor temperature, up to 3°C. The changes made relative to the size of the horizontal shading (width) showed the possibility to reduce temperatures by up to 8°C on average. This possibility with the interior wood shutters was between 1°C and 3°C, and with the exterior blinds was between 1.5 °C and 4.5°C. The variations on the degree of insulation on the outside elements (in this case the exterior walls, because it is an intermediate floor fraction), as well as on the type of cloth wall (single wall) had little influence on results.

### Winter Parametric Variations:

In the next graph we can see that both the detailed model and the simplified model responded similarly to each parametric variation (variations 1-34). Between the two models there is a difference in most of the parametric variations of +0.2 °C on average. The differences between the two models (along the different variations made) were up to +0.9 °C and -0.2 °C.



1-5 Horizontal Shading	6-7 Interior Blind	8-15 Exterior Blind	16-20 Double Glass	21-28 Insulation Thickness	29-34 Exterior Wall Type
2m	activated 100%	activated (13h-19h)	clear	0.0001m	Granite 40-60cm
1,5m	with 20mm	activated (15h-19h and 24h-9h)	Colored in the mass	0.02m	Concrete 1 - 20cm
1,1m	activated 100%			0.04m	Concrete 2 - 20cm
0,6m	without insulation	activated (24h-9h)	Reflectant	0.06m	Ceramic Brick - 20cm
0,05m		activated (9h-19h)	Incolor	0.08m	Concrete block 1 - 20cm
		activated (24h-12h)	LOW-E 1	0.1m	Concrete block 1 - 20cm
		activated (9h-13h)	LOW-E 2	0.12m	Concrete block 2 - 20cm
		always activated		0.2m	Concrete block 2 - 20cm
		always desactivated			

Figure 9: Calibration Simplified Model 1 (Phase 2) – winter.

Through the charts we can see the infiltration influence, because the difference between the two situations (with 0.5ACH and 1ACH) in terms of temperature can be of 4.5 °C on average. The solutions between 0.6 ACH and 1.2 ACH are recommended in DL/80 2006 as winter conditions for all glazing (closed), and the ACH rate varies consonant with the wind exposure and the type of frames.

Regarding the types of protection, the solution that showed the best results for this season was the solution that considers the exterior blind closed between the 24h-9h (Night). The solution with blind closed 24 hours showed temperatures below the reference (Tsimulation) at 10°C on average.

The best glass type solution for this season was the clear double glass. This solution presented

temperatures above the solution with coloured double glass (difference of 4°C on average).

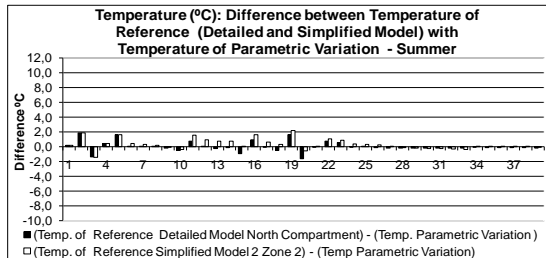
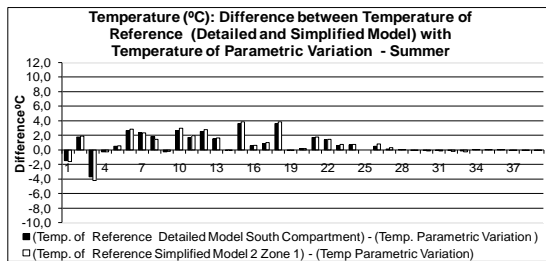
As with the summer parametric variations, the degree of insulation and the type of cloth wall had little influence on the result.

### Model 2

Reference solution corresponds (80% of the south façade and 35% of north façade is glazing): horizontal shading with 0,6m; without interior and exterior glazing protection (living room), interior blind (bedroom), double clear glass.

### Summer Parametric Variations:

In the next graph we can see that both the detailed model and the simplified model responded similarly to each parametric variation (variations 1-39). Between the two models there is a difference in most of the parametric variations of -0.05 °C (living room – south orientation) and of -0.3 °C (bedroom – north orientation) on average. The differences between the two models (along the different variations made) were up to +0.5 °C and -0.36 °C (living room) and up to +0.16 °C and -1.09 °C (bedroom).



1-5 Infiltration	6-9 Horizontal Shading	10-11 Interior Blind	12-19 Exterior Blind	20-25 Double Glass	26-33 Insulation Thickness	34-39 Exterior Wall Type
Rph=1	2m	activated 100% with	activated (13h-19h)	clear	0.0001m	Granite 40-60cm
Rph=3	1,5m	20mm insulation	activated (15h-19h and 24h-9h)	Colored in the mass	0.02m	Concrete 1 - 20cm
Rph=0.5	1,1m	activated 100%	activated (24h-9h)	Reflectant	0.06m	Ceramic Brick - 20cm
Rph=Night	0,6m	without insulation	activated (9h-19h)	Incolor	0.08m	Concrete block 1 - 20cm
Ventilation			activated (24h-12h)	LOW-E 1	0.1m	Concrete block 1 - 20cm
Rph=Day			activated (9h-13h)	LOW-E 2	0.12m	Concrete block 2 - 20cm
Ventilation			always activated	Incolor + always desactivated Film	0.2m	Concrete block 2 - 20cm

Figure 10: Calibration Simplified Model 2 (Phase 2) – summer.

In the figure 10 graphs: when the displayed value is greater than zero the solution in question has temperatures below the reference solution (that matters in this season). The reference solution is always represented at zero.

Most of the variations made have provided better results compared with the reference solution, most obviously in the south compartment. However, regardless of the reference solution adopted which

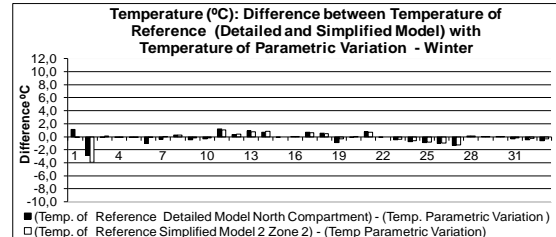
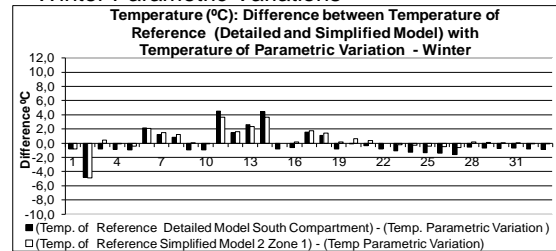
parameters have greater and lesser influence can also be verified in these graphs.

The different variations implemented for the ACH (variations 1-5), showed a difference, on average, of the inside temperature between the various solutions, being up to 6°C (living room) and up to 4°C (bedroom).

Within the parametric variations related to the size of the horizontal shading (variations 6-9) was observed a difference in temperature of up to 3.5 °C (living room); between the variations of interior blinds there is a difference of up to 3°C (living room) and 2°C (bedroom); relative to the variations made to exterior blinds this difference was up to 5°C (living room) and 2.5°C (bedroom). Among the variations made with double glass types there was a difference of up to 2 °C (living room) and 1 °C (bedroom).

The variations on the degree of insulation on the outside elements (in this case the exterior walls, because it is an intermediate floor fraction), as well as on the type of cloth wall had little influence on results of both compartments.

### Winter Parametric Variations



1-2 Infiltration	3-5 Horizontal Shading	6-7 Interior Blind	8-15 Exterior Blind	16-20 Double Glass	21-27 Insulation Thickness	28-33 Exterior Wall Type
Rph=1	1,1m	activated 100% with	activated (13h-19h)	clear	0.0001m	Granite 40-60cm
Rph=0.5	0,6m	20mm insulation	activated (15h-19h and 24h-9h)	Colored in the mass	0.04m	Concrete 1 - 20cm
	0,05m	activated 100% without insulation	activated (24h-9h)	Reflectant	0.06m	Ceramic Brick - 20cm
			activated (9h-19h)	Incolor	0.08m	Concrete block 1 - 20cm
			activated (24h-12h)	LOW-E 1	0.1m	Concrete block 1 - 20cm
			activated (9h-13h)	LOW-E 2	0.12m	Concrete block 2 - 20cm
			always activated	always desactivated	0.2m	Concrete block 2 - 20cm

Figure 11: Calibration Simplified Model 2 (Phase 2) – winter.

In the graph above we can see that both the detailed model and simplified model responded similarly to each parametric variation (variations 1-33). Between the two models there is a difference in most of the parametric variations of -0.53 °C (living room – south orientation) and of -0.1°C (bedroom – north orientation) on average. The differences between the two models (along the different variations made) were up to +0.8 °C and -1.2 °C (living room) and up to +0.15 °C and -0,94 °C (bedroom).

In the figure 11 graphs: when the displayed value is greater than zero the solution in question has temperatures below the reference solution (no matter

the season). The reference solution is always represented at zero.

Through the different variations carried out for the ACH (variations 1-2), we can see a difference, on average, of inside temperature between the various solutions (ACH=0.5 and ACH=1), being up to 5°C (living room) and up to 3.5°C (bedroom), demonstrating the influence of infiltration during period of the year.

Within the parametric variations related to the interior blinds was observed a difference in temperature up to 2 °C (living room); relative to the variations made to exterior blinds this difference was up to 4°C (living room) and 1°C (bedroom). Among the variations made with double glass types there was a difference of up to 3°C (living room) and 1 °C (bedroom).

Regarding the variations made on the degree of insulation, there is a difference between the solutions of up to 1.5°C (living room and bedroom) in order to observe any influence of this parameter in the models in question.

The variations on the type of cloth wall and on the size of the horizontal shading had little influence on results of both compartments.

## 7. CONCLUSION

The calibration process in this study showed that the simplified models (Model 1 and Model 2) had results similar to those of the detailed models selected (phase1) as well as the parametric variations conducted during the hot and cold seasons (phase 2), being that the mean difference between the detailed and simplified model in the various tests did not exceed  $\pm 0.5^\circ\text{C}$ .

During the summer: the study demonstrate the importance of natural ventilation and the presence of sun protection devices near the windows to achieve a better thermal performance in housing units with characteristics similar to that adopted for this study.

During the winter: the study verified the importance of the level of control of infiltration since significant interior temperature differences were observed among the solutions studied (ACH=0.5 e ACH=1).

Future work will continue with the aim of building a Matrix of constructive solutions of interest to the area professionals. This will allow the investigation of the influence of certain parameters; not only over the interior temperature conditions but also over energy issues. In the future the interested professional will be able to access the information needed by using a tool that will show the solutions within a Matrix of his area of interest. Following are graphic examples of information that will be available in such a tool.

Therefore this study aims to assist and alert professionals in their decision making at an early stage of the project and taking into account the findings obtained from models, especially as regards residential buildings with glazing areas of this proportion.

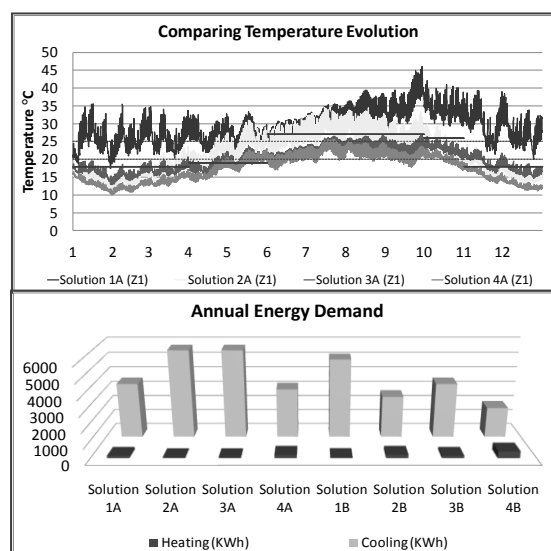


Figure 12: Example of graphs to be obtained through the tool (solutions matrix) data on temperature and energy demand.

## 8. ACKNOWLEDGEMENTS

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Technical University of Lisbon - FA-UTL, Lisbon, Portugal. Technology Architecture Department.

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