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ANALYSIS OF ENVELOPE THERMAL BEHAVIOUR THROUGH PARAMETRIC STUDIES

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ABSTRACT

A simulation methodology has been created for establishing the impact of increasing the insulation of the building envelope upon its global thermal performance and annual energy consumption (heating plus cooling). A particular emphasis is placed upon the consequences in terms of increased temperatures in summer leading to needs for installation of air-conditioning. This will provide an important input for the revision of the Portuguese thermal regulations for buildings. This paper presents this methodology, the models of buildings chosen for the first phase of simulation and the results that have been obtained. It also discusses future developments planned for these studies.

INTRODUCTION

The Portuguese thermal regulations for the building envelope have been in force since 1991 (Direcção-Geral de Energia, 1990). When they were drafted, the main intention was to improve the building envelope to allow comfortable conditions indoors without excessive energy consumption for both heating and cooling. They have been the first initiative in this field in Portugal, and they were therefore less demanding than other European thermal regulations at the time. Conversely, they have been one of the first European regulations that have taken aim at summer comfort by limiting the maximum nominal cooling needs that new buildings were required to satisfy, to prevent overheating and reduce the needs for air conditioning (Maldonado and Fernandes, 1993).

At present, these regulations are being revised to conform with the requirements set by the recent European Directive on the Energy Performance of Buildings (EU Official Journal, 2003). The Directive aims at setting requirements, as per earlier EU Commission documents, with a 8 year-payback or better, which will certainly result in the requirement for higher insulation thicknesses in Portuguese buildings. Therefore it is necessary to analyse the consequences of that increase for Portugal, because setting insulation thicknesses on the basis of heating needs alone would most probably result in increased needs for air conditioning that could completely undermine any savings from heating needs for the overall building energy balance.

The benefits of increasing the insulation thickness are evident in a typical winter situation, when a lower U-value directly reduces heating needs. This is the normal case in northern European countries, which have a long heating period and very short and mild summers.

The consequences during the summer period are not so evident, however, especially in non-air-conditioned spaces. A highly insulated envelope turns dissipation of internal and solar gains towards the exterior difficult contributing to increased internal temperatures, possibly above the comfort limits when solar and internal gains are not adequately controlled. This problem can be found in southern European countries, which have long summer periods with high outdoor temperatures and solar radiation exposure.

Beyond the discomfort problem, increased temperatures in summer can intensify the trend for installation of air-conditioning, increasing the energy consumption. The growth in European sales of air conditioning (Roaf, 2001) is already a sobering reality and it can only be worsened by more insulation in the building envelopes.

It thus seems wise to investigate the influence of increased insulation of the envelope, and to try to quantify the probability of the increase in the use of air conditioning. In other words, it is necessary to determine the limit until which it is possible to increase the insulation of the envelope without causing summer overheating, which would lead to more air conditioning, thereby eliminating any energy heating savings gained during winter.

To achieve this objective, it was decided to analyse the thermal behaviour of the envelope through sensitivity studies obtained via computational simulations, with distinct envelope insulation levels. Distinct building models, with distinct shape factors, area of windows, orientations, shadings, U-values, inertia and internal gains are to be studied. In this way, it will be possible to investigate the influence of other parameters that influence the thermal building behaviour, and make comparative analyses.

Before performing all these simulations, some initial sensitivity studies have been made to test the methodology and its applicability, as well as to analyse the initial results. This paper describes this initial phase. The models of chosen buildings, the methodology, and the results that have been obtained are presented. Future developments planned for these studies are also discussed.

In the following phases of the research, it is intended to define optimal levels of the envelope insulation for different types of buildings and climates, considering both heating and cooling demands. The objective is to minimize the use of air conditioning, considering all the costs involved on the basis of a detailed economic analysis.

METHODOLOGY

Program chosen for the simulation of the building thermal behaviour

TRNSYS (Solar Energy Laboratory, 2002) was the program chosen for the simulation of the building thermal behaviour. It is a well-known transient system simulation program with a modular structure. Before running this program, it is necessary to create two files. A main input file which contains part of the input data, and another file where geometric characteristics, walls composition, internal gains and set point temperatures for heating and cooling are defined, among others parameters.

Program created to perform the sensitivity studies

The proposed parametric studies consist of performing quite a few simulations for the same building, with distinct envelope insulation levels, patterns of use, internal gains, etc, both in free-float conditions and with heating and cooling systems.

This large amount of simulations cannot be made by individually running each case by hand. Therefore, a program, named PARAM and written in C++, was especially produced for such a task. This program both automatically executes TRNSYS for all the cases and treats the data (pre and post-processing).

Figure 1 shows a simplified scheme of the whole process. The first step consists of manually creating the two TRNSYS input files for the building that will be analysed. This building is called "base project". Geometrical characteristics, orientation, internal gains and infiltration behaviour in free-float conditions are defined in these files.

In the second step, the input file for the program PARAM has to be created. This file has to contain all needed data to perform the parametric studies: number of different cases that will be considered, envelope characteristics for each case, heating and cooling characteristics, climate, infiltration behaviour in non-free-float conditions and window shading.

To facilitate the process, a Visual Basic interface was also produced. This interface permits the input of the data described above and automatically creates the PARAM input file.

After the input file is completed, the third step simply consists of running PARAM. The program automatically creates the TRNSYS input files for each individual case to be simulated, run TRNSYS, considering both free-float conditions and when the building has heating and cooling systems with thermostatic control, and then performs the post data processing, which is described below.

Post data processing

The simulations performed by PARAM refer to distinct cases of the same building, where some characteristics, like envelope insulation levels, patterns of use, internal gains, etc, are changed.

The results of the simulations of each case include hourly values of the interior temperature and heating and cooling loads, all of them for each building zone. Post data processing treats these data in order to obtain summarized results and to show the differences between each case.

Figure 2 shows how these results are treated.

As the objective is to only consider the results related to the occupied period, values outside of this period are disregarded.

After that, in order to group the temperatures for the whole building, a weighted average from all zones is obtained. Some zones can be disregarded, like bathrooms and kitchens. For the cooling and heating loads, it is only necessary to sum the corresponding values of each zone.

The final results are calculated in relation to the occupied period: montly average interior temperature, annual cooling and heating load and the percentage of hours with temperatures lower or higher than previously selected setpoint temperatures (both for summer and for winter). These results are saved in a text file and presented in tables.

FIRST PHASE OF SIMULATIONS

The next sections describe the building models and the climate data selected for this first phase of simulations.

Selected buildings

Three residences were selected, a one-storey house (Figure 3) and two apartments (Figures 4 and 5), both of them located in intermediate floors of the building. The wall boundary conditions vary in each case. The house has four external walls and apartments A and B have three and two external walls, respectively.

Selected climate data

The Portuguese thermal regulations consider three climate zones for summer, and three for winter. As the main intention of this study is to concentrate on summer period, 3 cities were chosen, each one in a different climatic summer zone: Porto, Lisbon and Évora (Figure 6). Table 1 shows their average climate data for each city. Other regions will be considered at later phases.

As there is only one “official” TRY reference year available for Portugal (Lisbon), the hourly climate data for these three cities were generated by the Meteonorm program (Meteotest, 2000). The summer and winter periods correspond to the official periods set by the Portuguese building thermal regulations, as shown in Table 2.

SENSITIVITY STUDIES

The following sections describe all input data for the sensitivity studies that had to be described in the PARAM input file.

Selected solutions of external envelope

Typical solutions used in Portuguese houses were selected.

Double external wall. Considered for the residence and for both the apartments. External ceramic hollow bricks (15 cm) + intermediate air layer + insulation (0, 2, 4, 6 and 15 cm) + internal ceramic hollow bricks (11 cm).

Thick stone walls. Considered only for the residence. External insulation (0, 2, 4 and 6 cm) + stones (40 cm).

Ceramic hollow bricks slab. Insulation (0, 2, 4, 6,10 and 22 cm) + ceramic hollow bricks slab. Considered for the residence (external slab) and for both the apartments (internal slabs between them). For the apartments, the slab has no insulation.

The insulation material is assumed to be expanded polystyrene, but this is not so important - the dominating factor is the corresponding U-value.

Distinct solutions for window shading

Various possibilities of shading were considered and simulations performed with distinct solution of envelope for each of them.

- Without shading;
- External shading coefficient during summer: 20, 40, 50, 60, 70 and 80 %.
- External shading factor during winter: 10 and 20%.

The shading coefficient, as defined in TRNSYS, is the ratio of non-transparent area of the shading device to the whole glazing area.

Other parameters

Occupation. Two schedules were considered.

- Schedule 1. Occupation on weekdays only between 19:00 and 08:00, and 24 hours on weekends.
- Schedule 2. Occupation 24 hours continuously every day of the week.

Internal gains. They are due to occupants, equipment and artificial lighting. Studies assumed a schedule for each room, during the corresponding period of occupation described above.

- *Internal gains due to occupants.* Residence and apartment A are occupied by 4 persons and apartment B, by 3 persons. Occupants mostly use the living room and the bedroom. The rates of heat gain were 120 Watts per person (activity: seated, very light writing) in the living room and 100 Watts per person in the bedroom (activity: seated at rest).
- *Internal gains due to artificial lighting and equipment.* They correspond to 10 Watts/m^2 for the living room and 5 Watts/m^2 for the corridor and other auxiliary spaces during occupied periods.

Heating and Cooling.

- There is heating and cooling only in the living room and in the bedrooms.
- Summer setpoint temperature: 25^0 C.
- Winter setpoint temperature: 20^0 C.
- Schedule. When it is necessary, heating or cooling begin automatically. This is considered for the correspondent occupation period, during the whole year.

Infiltration. Constant rate of 0.6 air changes per hour, no mechanical ventilation, as usual in the vast majority of residential buildings in Portugal.

Total number of simulations

Sensitivity studies consisted of combinations of all the input data previously described: three project typologies; distinct envelopes for each typology; winter and summer solutions of shading; two schedules of occupation; three climates. A total of 168 PARAM input files were created, therefore generating 798 .bui files and 2184 .dck files (TRNSYS input files). TRNSYS was executed 2184 times.

RESULTS

The results that have been obtained are presented and discussed below. The presented temperatures and heating and cooling demands are an average between the building zones, excluding the bathrooms, corridors and kitchen. They are related to the occupied period previously considered in each case. All the envelope characteristics, schedules and shading factors were already presented in the previous section.

Increase of the insulation x distinct shading factors

Figure 7 shows the percentage of warm hours (temperature above 25^{0} C) during summer, for the residence, in Porto. Distinct insulation thicknesses of the external envelope are represented in the "x" axis. The external envelope is made of ceramic hollow bricks. Each curve corresponds to a particular window shading factor. Fig. 7 corresponds to schedule 1 for occupation. Similar results are obtained for the other schedule.

Fig. 7 shows clearly different patterns of behaviour depending on the shading factor. Well insulated envelopes with low shading factors (high solar gains) have a tendency for more hours of discomfort in summer. This shows that the increase of the insulation of the envelope is favourable only when window solar gains are below certain limits. In this specific example, the cross-over point is between 50 and 60% of external shading.

This point can be better seen in Figure 8, which shows the differences between the percentage of warm hours for the envelope 5 (15 cm of insulation) and the envelope 1 (0 cm of insulation) for each shading factor.

The same types of graphics were made for the other cases studied, like the residence with thick stone walls, with the other pattern for occupation, and with other climate data. The same effect was always observed, changing only the critical shading point for each case (most of the time, between 50 and 70%).

Figure 9 shows same type of results of Figure 8, but for the apartments A and B, simulated under the same conditions.

It can be noticed that the optimal point of shading is higher for the apartment A than for the residence, and that apartment B has always more overheating hours for the higher insulated envelopes.

In winter, the increase of insulation obviously has a positive effect, reducing the heating load in all cases studied.

These results confirm the expectations of simple analytical models that can be made to represent the situation (Maldonado, 1993). The simulation results can now be used to fine-tune this model and allow for the prediction of optimum conditions in each case.

CONCLUSIONS

- The results show that, in order to obtain a positive effect of the increase of the envelope insulation in summer, it is necessary to closely control solar and internal heat gains. This seems simple to do for residential buildings, but it clearly indicates that office buildings, with much higher internal loads, should not be highly insulated.
- It is clear that, without Air conditioning, the limits for discomfort can be often exceeded, justifying why A/C use has been increasing in southern Europe, a tendency that is expected to continue.
- The studies will continue with different typologies, namely office buildings and variable shading.
- The analytical approach to identify the critical point for the shading level needs to be perfected on the basis of the insights obtained with these studies.

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Table 1
Average climate data

PORTO		*latitude: 41.08 º*
	WINTER	SUMMER
Temperature (ºC)	9.3	19.9
Humidity (%)	81	73
Global Horiz. Radiation (kWh/m2)	48	208
LISBON		*latitude: 38.43 º*
	WINTER	SUMMER
Temperature (ºC)	11.4	22.8
Humidity (%)	80	61
Global Horiz. Radiation (kWh/m2)	58	225
EVORA		*latitude: 38.34 º*
	WINTER	SUMMER
Temperature (ºC)	9.4	23.2
Humidity (%)	78	46
Global Horiz. Radiation (kWh/m2)	61	241

Temperature: maximum monthly average from summer months and minimum monthly average from winter months.

Humidity: minimum monthly average from summer months and maximum monthly average from winter months.

Global Horizontal Radiation: maximum monthly value from summer months and minimum monthly value from winter months.

Table 2
Summer and Winter periods

SUMMER												
months	J	F	M	A	M	J	J	A	S	O	N	D
Porto							X	X	X			
Lisbon						X	X	X	X	X		
Evora						X	X	X	X	X		
WINTER												
months	J	F	M	A	M	J	J	A	S	O	N	D
Porto	X	X	X	X							X	X
Lisbon	X	X										X
Evora	X	X	X								X	X

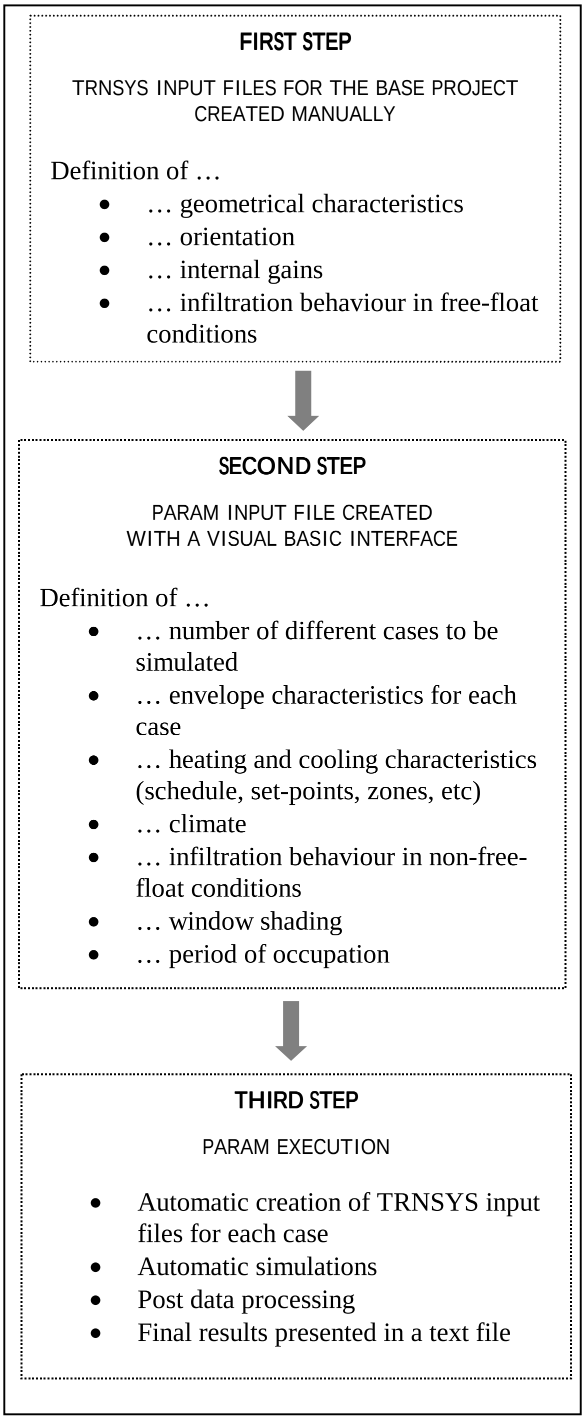

Figure 1 Sensitivity studies scheme

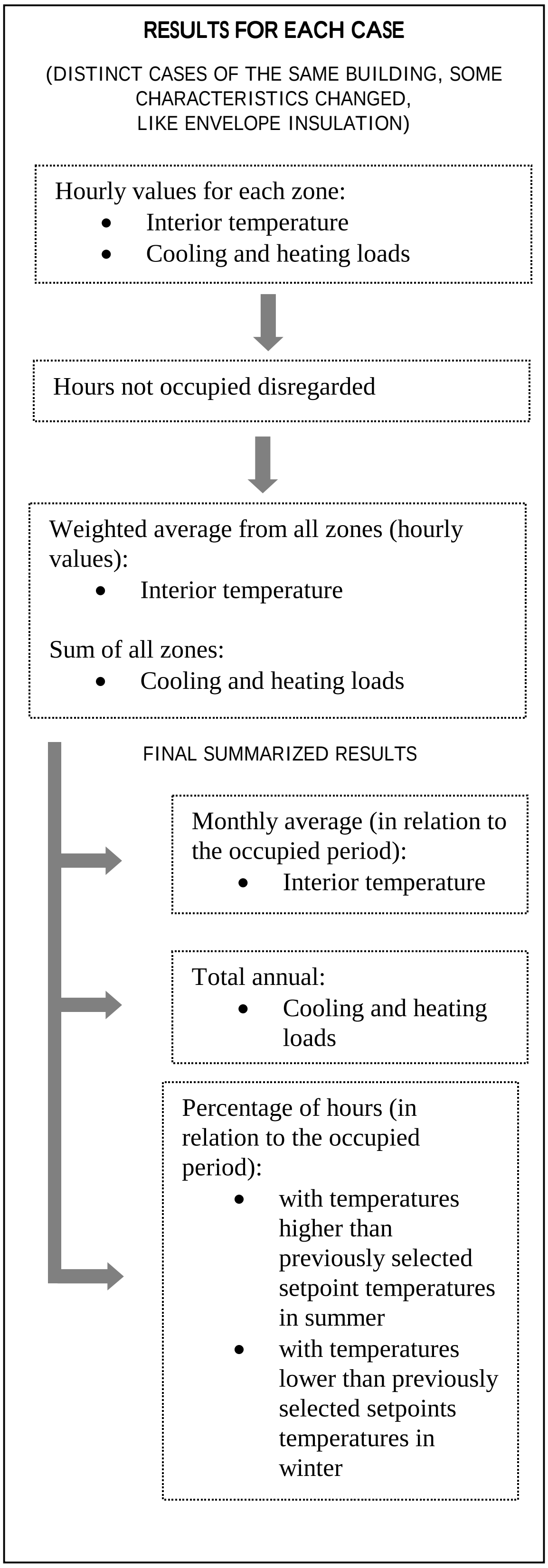

Figure 2 Post data processing

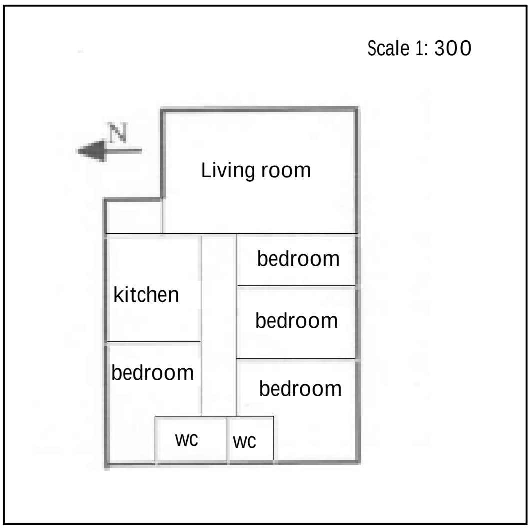

Figure 3 Residence

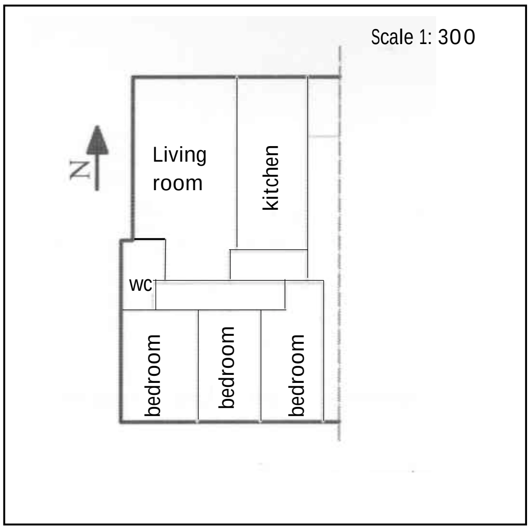

Figure 4 Apartment A

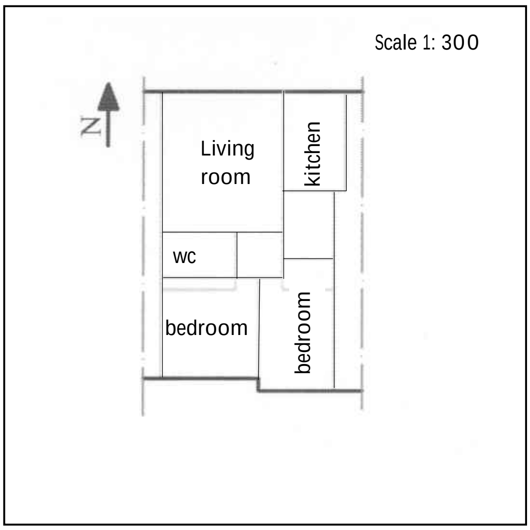

Figure 5 Apartment B

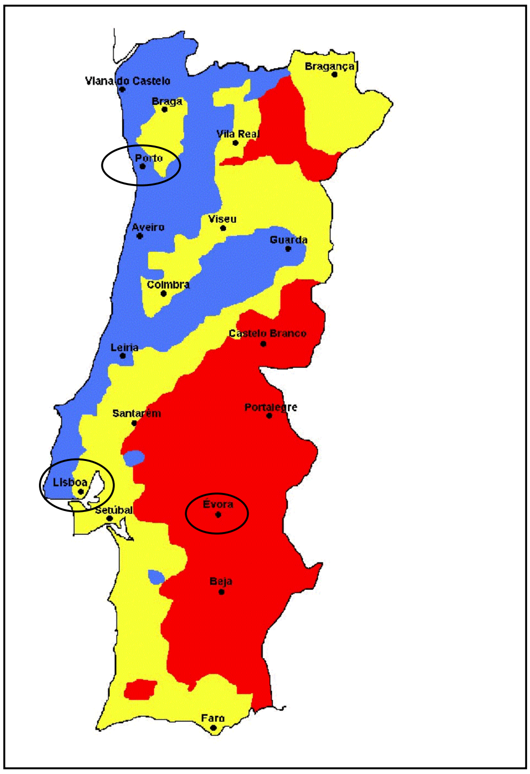

Figure 6 Climatic zones for summer, in Portugal

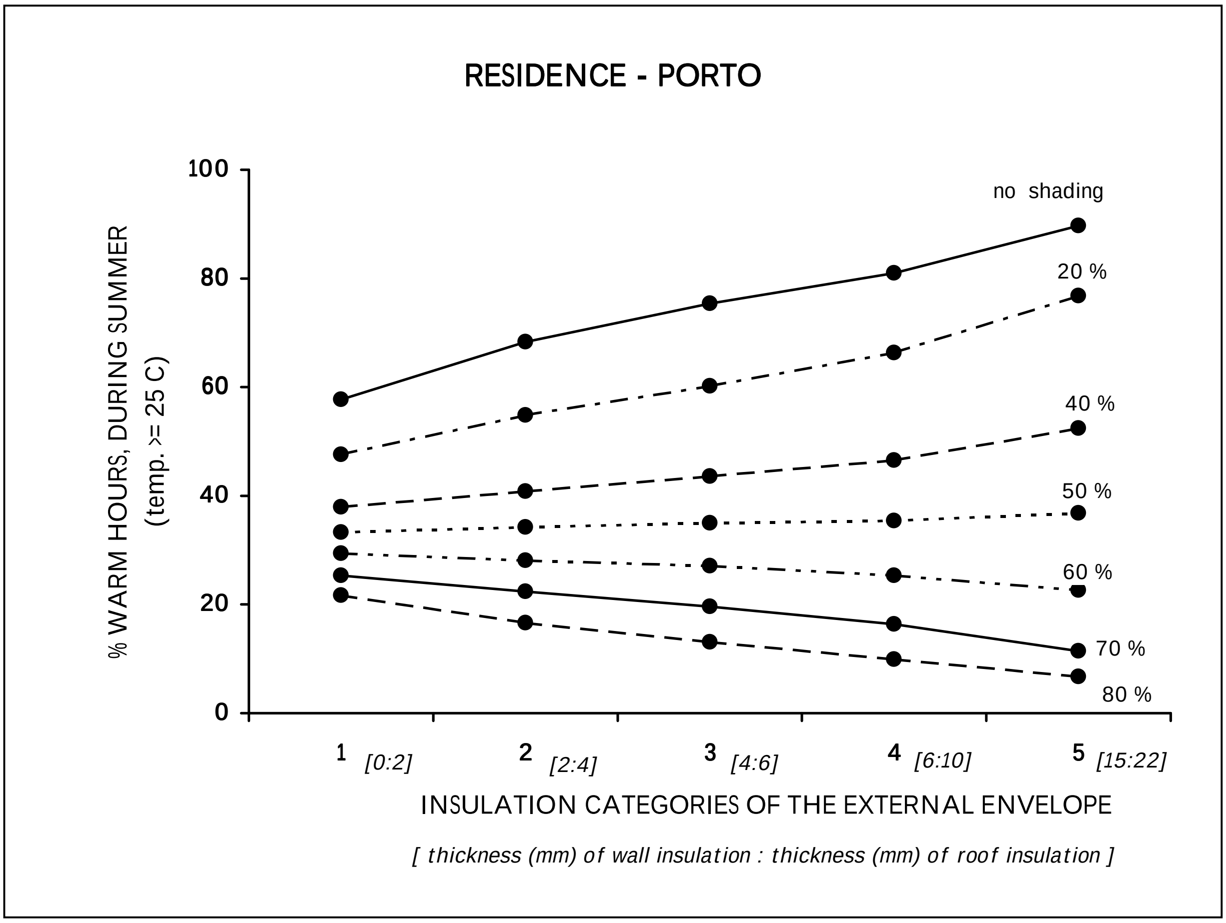

Figure 7 Percentage of warm hours (temperature above 25^0 C) during Summer, for the residence in Porto.

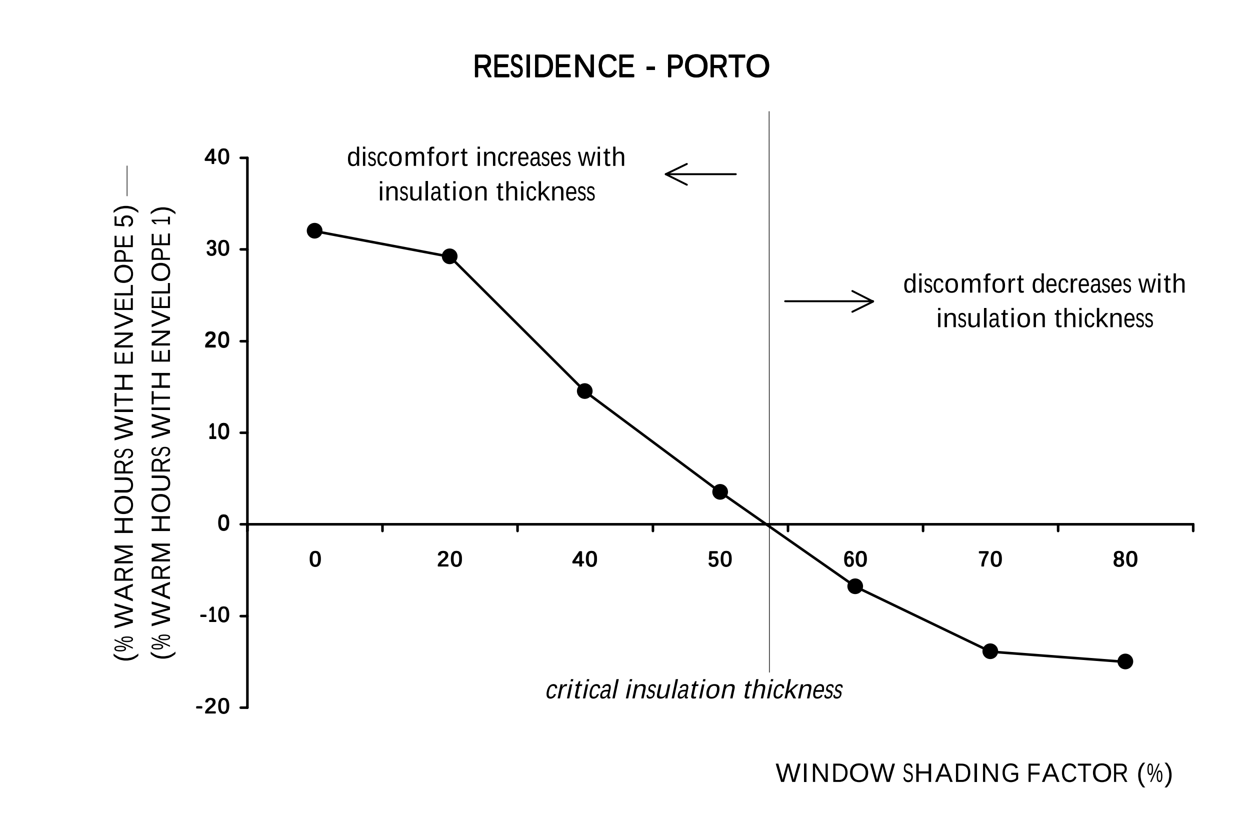

Figure 8 Difference between the percentages of warm hours (temperature above 25^0 C) during Summer, for the residence with the envelope 5 (15 cm of insulation) and with the envelope 1 (0 cm of insulation), in Porto.

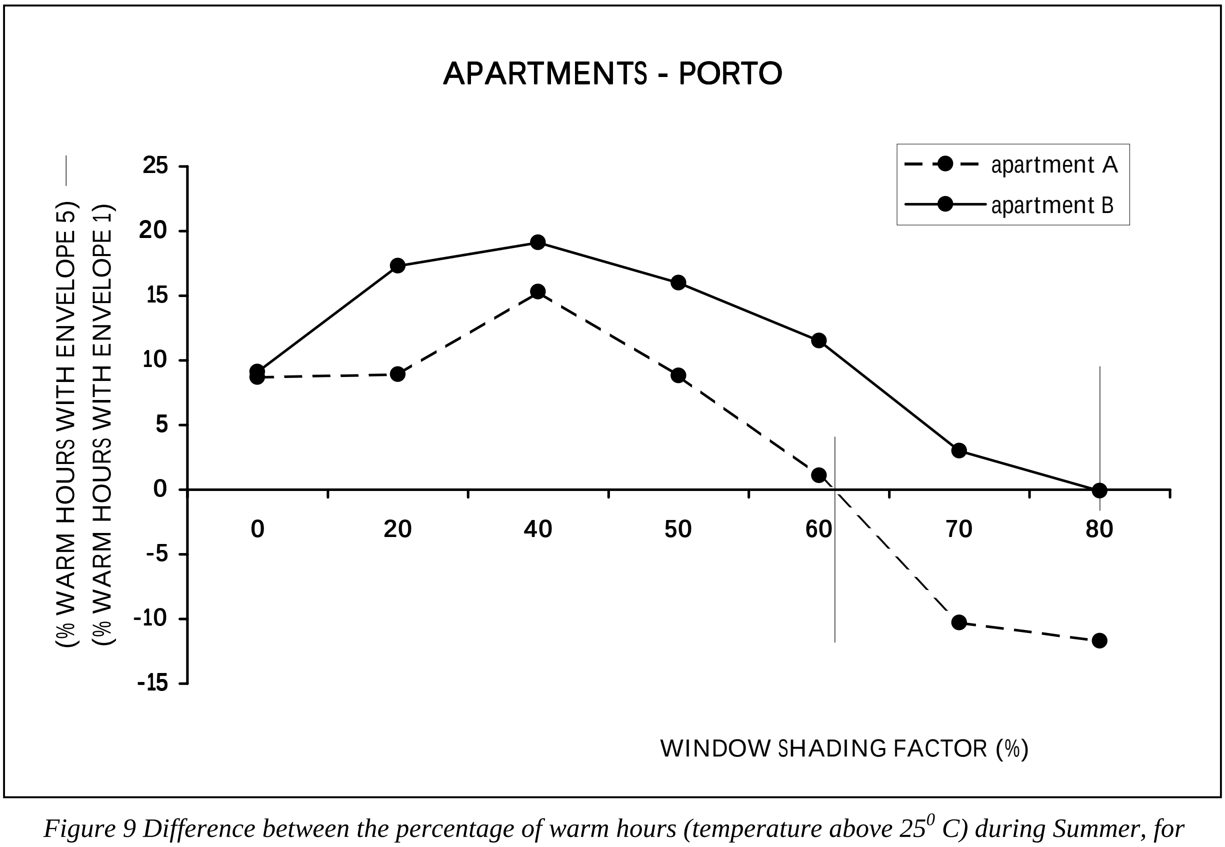

Figure 9 Difference between the percentage of warm hours (temperature above 25^0 C) during Summer, for apartments A and B, with the envelope 5 (15 cm of insulation) and with the envelope 1 (0 cm of insulation), in Porto.