Evaluation of the impact of some Portuguese thermal regulation parameters on the buildings energy performance

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ABSTRACT: Due to the high energy consumption associated to the building sector, several legal documents with the aim of promoting energy efficiency have emerged in recent years. Some of these documents led to deep changes in the way that buildings are designed. The Portuguese thermal regulation for residential buildings (RCCTE) is a good example of that.
The main objective of this paper is to analyze the RCCTE with the purpose of identifying the parameters that most influence the energy performance of buildings and in what way they interfere with the achievement of their final energy label.

1 INTRODUCTION

During recent years it has become clear that emissions produced by fossil fuels, used to satisfy the globally growing energy needs, are causing dangerous climate changes on our planet. The consequences of global warming are alarming and possibly will become catastrophic. The production and use of energy are responsible for 94% of CO_2 emissions (Isolani, 2008), so the use of energy in a rational way is one of the paths to follow in order to minimize these problems.

The building sector is responsible for consuming approximately 40% of final energy in Europe. However, more than 50% of this consumption can be reduced through energy efficient measures (ADENE, 2009).

Aware of this situation, the European Commission has been promoting relevant measures to improve the energy performance of buildings. The European Directive nº2002/91/CE, Energy Performance Building Directive (EPBD), recently updated by 2010/31/EU (EPBD Recast), is an example of that. The EPBD was transposed into the Portuguese legislation through the review and subsequent adaptation of the thermal regulation constituted by three decrees (Decree-law no. 78/2006, Decree-law no. 79/2006 and Decree-law no. 80/2006).

The purpose of this paper is to select the most relevant parameters that interfere in the energy labelling calculation of residential buildings and evaluate which of them have the strongest impact and in what way they are related to their final energy rating achieved.

2 METODOLOGY

For residential buildings, some parameters were chosen and a parametric analysis was carried out based on a case study building in order to assess their influence on the building thermal performance. This case study is a four room detached single family house with a heated area of 271.57 m^2. It is located in Ponte de Lima (Northwest of Portugal) at an altitude of 74m and about 25km way from the Atlantic Ocean coast. According to the Portuguese legislation, the climatic region of this building is I2, V2 North (between the most severe, I3 V3, and the mildest, I1V1, climatic regions) and its thermal inertia is classified as strong. The case study building, that will be referred as the reference solution, verifies all the legislative thermal requirements and its energy label is B- (low thermal quality – is the minimum allowed for new buildings).

The parameters analysed were the following: i) the heat transfer coefficient (U) of walls and slabs belonging to the exterior and interior envelope, thermal bridges and windows; ii) the number of indoor air changes per hour; iii) the windows solar factor; iv) the shading factor (Fs) of vertical and horizontal windows; v) the external walls absorption factor (α); vi) the efficiency of Domestic Hot Water (DHW) preparation systems (ηa); vii) the contribution of solar systems to DHW preparation (Esolar); viii) the heating system efficiency (ηi) and; ix) the cooling system efficiency (ηv).

For each of the abovementioned parameters, alternative solutions to the conventional reference solutions were investigated. The selected alternative solutions include at least one high-performance solution, one low performance solution and two other different solutions. In any case, all the selected solutions are used and marketed in Portugal.

After selecting all the solutions to be simulated, the energy calculations were performed according to the Portuguese residential buildings regulation methodology. The influence of each parameter on the building final energy label achieved will be discussed and shown bellow.

3 RESULTS

The detailed analysis performed to the exterior walls heat transfer coefficient will be explained as an example. The results obtained for the other studied parameters will be only presented and discussed.

3.1 *Heat transfer coefficient*

3.1.1 *Walls belonging to the exterior envelope*

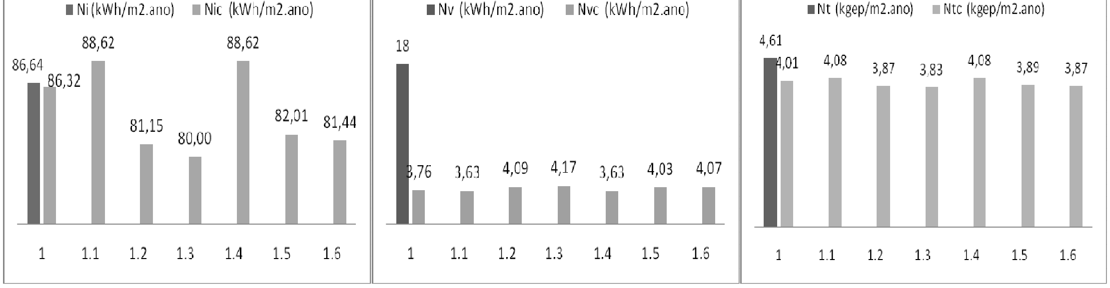
The solutions presented in Table 1 were used to carry out the analysis of the influence of the heat transfer coefficient of walls belonging to the exterior envelope. Two types of construction solutions, double walls and External Thermal Insulation Composite Systems (ETICS), were studied. These two construction systems were chosen because they are the most current solutions used in Portugal nowadays.

Table 1. Solutions under study to analyze the exterior walls heat transfer coefficient influence.

Solution	U ($W/m^2 \cdot ºC$)
1 – Reference Solution: Double masonry wall 15+11(cm) with 4cm of extruded polystyrene (XPS)	0,50
1.1 - Double masonry wall 15+11(cm) with 3cm of XPS	0,58
1.2 - Double masonry wall 15+11 (cm) with 8cm of XPS	0,32
1.3 - Double masonry wall 22+22 (cm) with 8cm of XPS	0,28
1.4 – ETICS (15 cm) with 4cm XPS	0,58
1.5 - ETICS (15 cm) with 8cm XPS	0,35
1.6 - ETICS (22 cm) with 8cm XPS	0,33

The results obtained for the different exterior walls solutions are presented in Figure 1.

In this figure, the dark grey bar represents the maximum regulatory values for heating needs (Ni), cooling needs (Nv) and primary energy needs (Nt). The light grey bars represent the heating needs (Nic), cooling needs (Nvc) and primary energy needs (Ntc) of each solution.



a) b) c)

Figure 1. Obtained results for the analysed exterior walls solutions for exterior walls. a) Buildind heating needs (Nic). b) Building cooling needs (Nvc). c) Annual primary energy needs (Ntc).

Through the overall results obtained it was possible to verify that the solutions that have better performance in the heating season are those which have the worst performance in the cooling season.

It was also verified that with an increase in the insulation thickness, the influence on the element's U value decreases. At a certain point the increase in the insulation thickness has very limited influence on the element's U value and on the corresponding contribution to the overall heating needs (Nic value).

For the two construction solutions types studied (double masonry walls and ETICS), it was observed that both have similar performance although the double masonry walls have a slightly higher performance. The ETICS system can, however, be considered a viable alternative system to the double walls regarding the building thermal behaviour.

In Table 2 are presented the obtained results of the solutions with high and low heat transfer coefficients and the differences between both.

The Nac index represents the DHW energy needs for the building. However, this index isn't influenced by this parameter.

Table 2. Differences between solutions with high and low heat transfer coefficients (external walls analysis)

	Nic	Nvc (kWh/m²·year)	Nac	Ntc (kgep/m²·year)
Umin=0,28W/m²ºC (Solution 1.3)	80,00	4,17	17,12	3,83
Umax=0,58W/m²ºC (Solution 1.1)	88.62	3,63	17,12	4,08
Variation on energy needs	8.62	0,73	0,00	0,25

It can be observed that the exterior walls heat transfer coefficient has a relevant influence on the Nic value. The solutions with the higher and the lower values of U lead to a significant variation of the Nic value.

It was also verified that the influence of this parameters regarding summer comfort conditions is not negligible. The final energy label of the building is achieved from an index directly proportional to primary energy needs. Thus, as this parameter has a small influence as regards to primary energy needs, it has also a small influence on the final rating of the building.

3.1.2 *Walls belonging to the interior envelope*

The walls belonging to the interior envelope don´t have, in the reference solution, any influence regarding to energy indexes, since they all are in contact with a non-heated space where the coefficient τ is zero, which means that this non-heated space is at the same temperature as the building (20ºC). However, any modification on their constitution will have impact on the thermal inertia of the building. Because of this, four solutions were studied corresponding to different thicknesses of the brick used. Nevertheless, it was verified that the thermal inertia class did not change and so these elements have no influence on the final energy label of the studied building.

3.1.3 *Slabs*

The influence of the slabs heat transfer coefficient was studied taking into consideration the existing construction solution on the reference building. Four solutions were considered, three with different insulation thicknesses and one where the position of insulation was changed.

The results obtained with the different heat transfer coefficients considered are presented in Table 3. This table shows three different situations. Two correspond to floor slabs with different types of coating ($U_{(LI1)}$ e $U_{(LI2)}$) and one corresponds to a ceiling slab ($U_{(LS)}$).

Table 3. Differences between solutions with high and low heat transfer coefficients (slabs analysis)

	Nic	Nvc (kWh/m²·year)	Nac	Ntc (kgep/m²·year)
$U_{(LI1min)}$=0,20; $U_{(LI2min)}$=0,32 e $U_{(LSmin)}$=0,34 (Slab with 8cm of XPS)	76,37	3,76	17,12	3,72
$U_{(LI1max)}$=0.60; $U_{(LI2max)}$=0,58; $U_{(LSmax)}$=0,67 (Slab with 3cm of XPS)	92,25	3,76	17,12	4,18
Variation on energy needs	15,88	0,00	0,00	0,46

The results presented in Table 3 show how this parameter has a significant influence on heating demands and comfort conditions in the heating season.
However, these results may not be so expressive in other building types because these results are due to the large contact area of the ceiling slab with a non–heated space, which leads to substantial heat losses. This situation is not characteristic of many Portuguese buildings.

3.1.4 *Thermal bridges*

The heat transfer coefficient of the thermal bridges was analysed considering different thermal insulation thicknesses. Table 4 shows the solutions studied.

Table 4. Differences between solutions with high and low heat transfer coefficients (thermal bridges analysis)

	Nic	Nvc (kWh/m²·year)	Nac	Ntc (kgep/m²·year)
Umin=0,32W/m²ºC (Plane thermal bridges with 8cm of XPS)	86,16	3,77	17,12	4,01
Umax=2,00W/m²ºC (Plane thermal bridges without insulation)	86,86	3,73	17,12	4,03
Variation on energy needs	0,70	0,04	0,00	0,02

The values shown in the table show that the building energy needs are not significantly influenced by the thermal bridges heat transfer coefficients. This is because in the reference solution the thermal bridge area is small. Therefore, if other buildings have larger thermal bridge areas, these elements might have a bigger influence on their comfort conditions, especially when they are not treated.

3.1.5 *Glazing*

In this case different types of glass and window frames were analysed taking into account some windows solutions described on the official publication ITE50. Table 5 shows the solutions studied.

Table 5. Differences between solutions with high and low heat transfer coefficients (glazing)

	Nic	Nvc (kWh/m²·year)	Nac	Ntc (kgep/m²·year)
Umin=2 W/m²ºC (Double glass, plastic window frames without thermal break)	81,91	4,32	17,12	3,89
Umax=4,1 W/m²ºC (Simple glass, Metal window frames without thermal break)	90,33	3,31	17,12	4,12
Variation on energy needs	8,42	1,01	0,00	0,23

The building comfort conditions in both heating and cooling seasons are influenced by this parameter, as shown in Table 5.

3.2 *Number of indoor air changes per hour*

The study of the influence of the indoor air changes rate (Rph) was performed taking into consideration the existence, or not, of three items: window frames labelled by EN12207, air admission devices on the facade and mechanical ventilation.

Table 6. Diferences between solutions with high an low number of indoor air changes per hour

	Nic	Nvc (kWh/m²·year)	Nac	Ntc (kgep/m²·year)
Rph min=0,66 (mechanical ventilation)	74,35	6,52	17,12	3,69
Rph max=0,95 (Window frame without classification and without air admission devices on the facade)	86,32	3,76	17,12	4,01
Variation on energy needs	11,97	2,76	0,00	0,32

Observing the results in Table 6 it is possible to verify the significant influence this parameter has in both heating and cooling seasons. However, when regarding the energy labelling this influence is not so significant.

3.3 *Windows Solar factor*

The thermal regulation calculations include different solar factors both for cooling and heating seasons. The study for the summer solar factor consisted on the analysis of different kinds of glass and external solar protections. The winter solar factor was studied through the analysis of different types of internal solar protections.

3.3.1 *Summer Solar Factor (g_{Summer})*

Table 7. Diferences between solutions with high an low solar factor (glass type analysis)

	Nic	Nvc (kWh/m²·year)	Nac	Ntc (kgep/m²·year)
g_{Summer} min=0,43(Double glass – reflective, coloured in mass + clear glass (4mm+8mm)	86,32	2,69	17,12	4,00
g_{Summer} max=0,59 (Simple Glass - clear glass 4mm)	89,53	4,16	17,12	4,11
Variation on energy needs	3,21	1,47	0,00	0,11

The variation in the glass type has significantly influenced the cooling needs. As in the previous studies, the Ntc variation is low, meaning that the influence of the glass type on this index is small.

Table 8. Diferences between solutions with high an low solar factor (external protection analysis)

	Nic	Nvc (kWh/m²·year)	Nac	Ntc (kgep/m²·year)
g_{Summer} min=0,25 (External light wooden shutters and double clear glass)	86,39	1,43	17,12	3,99
g_{Summer} max=0,55 (Internal dark wooden shutters and double clear glass)	86,39	3,76	17,12	4,01
Variation on energy needs	0,00	2,33	0,00	0,02

The influence of external solar protection on Nvc value is even greater than the glass type influence. However, regarding to primary energy needs and to building energy label this influence is small.

3.3.2 *Winter solar factor (g_{Winter})*

As shown in Table 9, the interior solar protection has a little influence over the comfort conditions of heating season. However, as in many previous parameters the Ntc index is slightly influenced by these elements.

Table 9. Diferences between solutions with high an low winter solar factor

	Nic	Nvc (kWh/m²·year)	Nac	Ntc (kgep/m²·year)
g_{Winter} min= 0,30 (Light wooden shutters (opaque) with simple clear glass)	91,67	3,76	17,12	4,17
g_{Winter} max=0,70 (Very transparent light curtains and simple clear glass)	85,19	3,76	17,12	4,01
Variation on energy needs	6,48	0,00	0,00	0,16

3.4 *Shading factor*

The study of the influence of the shading factor was carried out by evaluating the effects of horizontal and vertical shading elements. To do so, several shading elements with different sizes were evaluated in the main building's orientations.

3.4.1 *Horizontal Shading (Fo)*

Table 10 shows that the horizontal shading devices influence on both Nic and Nvc indexes. However, this influence is greater when regarding to cooling needs. It was verified that the shading solutions which decrease the Nic index increase the Nvc index.

Table 10. Diferences between solutions with high an low α value (horizontal shading analysis)

	Nic	Nvc	Nac	Ntc
	(kWh/m²·year)			(kgep/m²·year)
Fo min (Without shading α=0º)	85,72	4,32	17,12	4,00
Fo max (All windows shaded with α=60º)	89,32	2,07	17,12	4,08
Variation on energy needs	3,60	2,25	0,00	0,08

Note: α is the angle between the plane of the glass and the line joining the glass midpoint to the edge of the horizontal shading device.

3.4.2 *Vertical shading (Ff)*

The vertical shading devices have little influence on both cooling and heating needs. When regarding to cooling needs, horizontal shading devices have higher influence than vertical shading devices (Table 10 and Table 11).

Table 11. Diferences between solutions with high and low α value (vertical shading analysis)

	Nic	Nvc	Nac	Ntc
	(kWh/m²·year)			(kgep/m²·year)
Ff min (Without shading, β=0º)	85,15	3,78	17,12	4,01
Ff max (All vain shadows with β=60º)	88,47	3,30	17,12	4,07
Variation on energy needs	2,32	0,48	0,00	0,06

Note: β is the angle between the plane of the glass and the line joining the glass midpoint to the edge of the vertical shading device.

3.5 *External walls absorption coefficient*

The influence of the external walls absorption coefficient (α) was evaluated through the analysis of three kinds of paint colours – light, medium and dark – as described in the regulation.

Table 12. Diferences between solutions with high an low α value

	Nic	Nvc	Nac	Ntc
	(kWh/m²·year)			(kgep/m²·year)
α min=0,4 (External walls with light colour finishing)	86,39	3,76	17,12	4,01
α max=0,8 (External walls with dark colour finishing)	86,39	5,05	17,12	4,02
Variation on energy needs	0,00	1,29	0,00	0,01

The comfort conditions in cooling season are considerably influenced by this parameter as shown in Table 12. Moreover, the Ntc index is once again slightly influenced by the variation of a parameter.

3.6 *DHW preparation systems efficiency*

To evaluate the influence of the DHW preparation systems efficiency (ηa), several equipments, with different efficiencies and fed by different fuels, were studied.
The study enabled to observe that the equipment with worse efficiency is the one that leads to the greater Nac index but it is not the one that leads to the higher primary energy needs. This fact is the reason why the results of the parametric study performed for this parameter are presented in two tables instead of one.

Table 13. Diferences between solutions with high an low ηa

	Nic	Nvc	Nac
		(kWh/m²·year)	
ηa_{min}=0,65 (Gas boiler)	86,32	3,76	17,2
ηa_{max}=1,09 (Gas boiler)	86,32	3,76	6,21
Variation on energy needs	0,00	0,00	10,91

Table 14. Differences between solutions that lead to a high and a low Ntc

	Ntc (kgep/m²·year)
Ntc_{max} (Electric heater η=1)	4,76
Ntc_{min} (Gas boiler, η=1,09)	3,07
Variation on primary energy needs	1,69

Through the results recorded in Table 13 and Table 14 the big influence of this parameter is clear both in Nac index and in primary energy needs.

3.7 *Contribution of solar systems to DHW preparation*

The contribution of solar systems to DHW preparation (Esolar) was assessed through different solar collectors' analysis. The analysed collectors were selected from the database of the official SOLTERM 5.0 software, being the ones with the best and the worst circulation systems and thermosiphon systems.

Table 15. Diferences between solutions with higher an lower Esolar

	Nic	Nvc	Nac	Ntc
		(kWh/m²·year)		(kgep/m²·year)
$Esolar_{min}$ = 0 (Without solar collectors)	86,39	3,75	27,02	4,86
$Esolar_{max}$ = 2153kWh (Collector "CPC Ao Sol" – forced circulation)	86,39	3,75	17,12	4,01
Variation on energy needs	0,00	0,00	9,90	0,85

The results in Table 15 proof the high influence of the solar collectors both on Nac index and on primary energy needs.

3.8 *Heating system efficiency*

The heating system efficiency (ηi) study was preformed through the analysis of several equipments with different efficiencies and fed by different fuels.

Table 16 – Diferences between solutions with high an low ηi

	Nic	Nvc	Nac	Ntc
		(kWh/m²·year)		(kgep/m²·year)
ηi max = 4,46 (Heat pump)	86,39	3,75	17,12	2,07
ηi min =1(Electrical resistance)	86,39	3,75	17,12	4,01
Variation on energy needs	0,00	0,00	0,00	1,94

The values recorded in Table 16 show that the heating system is one of the elements that most influences the primary energy needs and the final energy rating of the building.

3.9 *Cooling system efficiency*

To evaluate the cooling system efficiency (ηv) different air conditioning systems were considered.

Table 17. Diferences between solutions with high an low ηv

	Nic	Nvc (kWh/m^2·year)	Nac	Ntc (kgep/m^2·year)
ηv Max (air conditioning systems with η=5.15)	86,32	3,76	17,12	4,01
ηv min (air conditioning systems with η=3)	86,32	3,76	17,12	4,00
Variation on energy needs	0,00	0,00	0,00	0,01

The results presented in Table 17 enable to confirm that cooling system efficiency has a small influence on Ntc index. This fact is due to the small value of the cooling needs and to the high efficiency of all studied systems. However, there were only studied the most common equipments in Portugal.

4 CONCLUSIONS

The carried out study allowed verifying that the parameters which have a greater influence on heating energy needs were: the external walls, the slabs and glazing heat transfer coefficients and the indoor air changes rate. However, the windows solar factor had also a relevant influence on these needs.

In what concerns cooling needs, the most influent parameters were: the windows solar factor, the indoor air changes rate and the shading factor (especially horizontal shading devices).

Only two of the studied parameters interfered in the DHW energy needs: the contribution of solar systems to DHW preparation and the DHW preparation systems efficiency.

When regarding to the primary energy needs, the most influent parameters were: the heating systems efficiency, the contribution of solar systems to DHW preparation and the DHW preparation systems efficiency. Due mainly to political reasons, translated in the regulation calculations, the parameters related with DHW preparation have a huge influence on the primary energy needs, in opposition to the cooling and heating needs provoked by the envelope. For this reason, the importance of parameters related with the envelope performance is low.

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