Portuguese Thermal Building Legislation and Strategies for the Future

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ABSTRACT: Portugal must evaluate, according to the Energy Performance Building Directive, the national requirements for energy performance of new buildings until 2011, which can be an opportunity to devise a national strategy that tightens the minimum energy performance requirements. The present study intends to analyze the changes that should be introduced in the Portuguese Regulation to achieve highly energy efficient buildings. The objective consists on evaluating the relevant improvement of thermal envelope performance such as walls, roofs and floors thermal insulation (maximum U-values), air tightness (ventilation strategies) and windows (minimum shading requirements), heating and cooling systems, as well as wider use of integrated renewable energy. The study considers apartments with different shape factors located in different climatic zones. The optimizing methodology makes use of a genetic algorithm for the estimation of primary heating and cooling energy indexes through a simplified calculation methodology established by Portuguese Regulation.

1 INTRODUCTION

The reduction of greenhouse gases emissions, namely carbon dioxide (CO_2), and security have been identified by the European Commission as priority areas for action in order to comply with the Kyoto Protocol. And about 50% of the energy related to CO_2 emissions derive from energy use in buildings.

The studies carried out in the nineties concluded that if any action was taken in 2020, Europe would import about 80% of the energy consumed and the energy use in buildings represents 40% of the total energy consumption in Europe, furthermore, implementing a set of economically sustainable efficient measures, the potential of energy savings is more than 30%.

To overcome this situation, in 2000, the European Commission identified the need to introduce specific measures in the building sector, namely with the Energy Performance Building Directive (EPBD) - 2002/91/EC - was published on 16 December 2002. This Directive proposes the adoption of common methodologies for calculating energy consumption, quality requirements for new and existing buildings, periodic inspection of boilers and central systems air conditioning, as well as the buildings energy certification.

Portugal must evaluate, according to the EPBD, the national requirements for energy performance of new buildings until 2011, which can be an excellent opportunity to draw up a national strategy tightening the minimum energy performance requirements. Reviews of national building regulations should always be seen as an effective instrument for achieving highly energy efficient buildings.

The present study aims at analyzing the changes that should be introduced in the Portuguese Regulation, "RCCTE – Regulamento das Características de Comportamento Térmica dos Edifícios" for different scenarios in order to achieve very low energy demands in buildings.

This study is based on the RCCTE methodology where the energy performance sustains the building energy classification and, therefore, energy labeling. For an optimized analysis a genetic algorithm is used for a large number of parametric variations, in order to fix up the best solutions in terms of primary energy needs, heating and cooling energy indexes.

2 METHODOLOGY

2.1 *Optimization method*

Instead of calculating all possible combinations, which can easily reach thousands of possibilities (for the parameters of this work, all combinations would be more than 5,000,000 for each case study), a genetic algorithm is used. The methodology consists of generating a population with *n* individuals, which characteristics (‘genes’) are randomly generated within defined intervals. At each iteration, for all individuals, a fitness value – ζ – is calculated and the best solutions are saved.

Afterwards, genetic cross-over or mutation, according to the probability associated to each event, is applied for the ‘best’ individuals within the population. Genetic cross-over of each new individual (‘child’) consist of combining part of the genetic code between two individuals (‘parents’) randomly selected. Mutation is obtained by a randomly changing one of the ‘genes’.

The genetic code of an individual is a vector with parameters, such as, walls, roof and floor thermal insulation (U-value), walls and roof color (surface absorptance), windows glazing (single or double), type of shading devices (internal or external), building inertia, air tightness (infiltration), existence and type of solar panels for domestic hot water (DHW), type of heating and cooling systems and, finally, type of DHW system.

2.2 *Case studies*

It is noteworthy that the case studies presented in this paper, as well as the parameters, are used to exemplify the application of the optimization method. The same methodology could be applied for other cases whereas they are residential, under Portuguese climate conditions and following Portuguese thermal calculations for the energy index, even if generalizing the method for other countries is effortless.

The base case study is a small apartment with 53.5 m^2 of floor area, occupied by two people, located above a parking area. The apartment main façades are south and east orientated. The study covers also the same apartment but located in different positions inside the building, varying the shape factor (FF). The base case have a shape factor equal to 0.50; the other cases consist of an intermediate apartment between two residential apartments (FF = 0.34), in the last floor (FF = 0.74) and as a unique floor (FF = 1.14).

Walls are double brick, middle insulated with expanded polystyrene. In this study, thermal insulation thickness varies from 0.03 to 0.08 m (U-value from 0.57 to 0.34 $Wm^{-2}K^{-1}$). Floor slab is also thermally insulated by 0.03 to 0.10 m of expanded cork agglomerate (U-value from 0.88 to 0.40 $Wm^{-2}K^{-1}$); 0.03 to 0.08 m of expanded polystyrene is used for roof slab (U-value from 0.77 to 0.39 $Wm^{-2}K^{-1}$).

Windows are single or double glazed, externally shaded by roller blinds or internally shaded by semi-transparent curtains; sliding frames are in aluminium without thermal-breaking.

Variations are carried out on heating and cooling systems efficiency (or coefficient of performance for heat pumps) such as electric resistance, heat pump, gas or fuel boiler, absorption and compression chillers. For DHW, gas boiler, as well as electric and gas storage water heaters are considered; in some cases, standard solar panels (2 m^2) also contribute for DHW production.

2.3 *Parametric variations*

This study aims at searching for the optimum solutions among several possible combinations, enabling the variation of a large number of parameters, as synthesized in Table 1.

Table 1. Parametric variations.

Parameters	Possible solutions						
Wall thermal insulation, U-value ($Wm^{-2}K^{-1}$)	0.34	0.40	0.50	0.57			
Roof thermal insulation, U-value ($Wm^{-2}K^{-1}$)	0.39	0.45	0.53	0.66	0.77		
Floor thermal insulation, U-value ($Wm^{-2}K^{-1}$)	0.40	0.47	0.57	0.75	0.88		
Window U-value * ($Wm^{-2}K^{-1}$)	4.1/5.2 (single)	3.1/3.9 (double)					
Position and type of shading devices, $g_{\perp}$ †	0.10/0.07 (external)	0.47/0.46 (internal)					
Building inertia, coefficient a	1.8 (light)	2.6 (medium)	4.2 (heavy)				
Air tightness, infiltration (ACH)	1.00	1.05	1.10				
Wall color, absorptance	0.4 (light)	0.5 (medium)	0.8 (dark)				
Roof color, absorptance	0.4 (light)	0.5 (medium)	0.8 (dark)				
Heating system efficiency and energy source	1 (el.)	4 (el.)	0.87 (gas)	0.87 (liq.)	0.60 (sol.)		
Cooling system efficiency and energy source	3 (el.)	0.8 (el.)					
DHW system efficiency	0.87	0.82	0.80	0.75	0.70	0.65	0.50
Solar panels contribution to DHW (kWh/year)	0 (without)	794 (forced circulation)	944 (kit)				

*U-value depends also of the shading device (external roller blinds/internal curtains)

† $g_{\perp}$ is a function of the glazing type (single/double)

Furthermore, a sensitivity analysis to each one of these parameters is carried out in order to evaluate their influence in the primary energy index (Ntc/Nt), heating energy index (Nic/Ni) and cooling energy index (Nvc/Nv), given by the ratio of apartment energy needs (Nxc) and the standards established by Portuguese legislation (Nx), see Table 2. An eligible solution should verify legislation requirements for heating energy index ($Nic/Ni \leq 1$), cooling energy index ($Nvc/Nv \leq 1$), DHW energy index ($Nac/Na \leq 1$) and primary energy index ($Ntc/Nt \leq 1$).

In terms of climatic variability, Portuguese legislation defines three severity index values (from 1 to 3, where 3 is the most severe) for both winter (I) and summer (V) seasons. Therefore, three locations are chosen representing those climatic zones: Lisbon (I1,V2), Portalegre (I2, V3) and Montalegre (I3,V1).

Table 2. Standard heating, cooling and DHW according to Portuguese legislation

kWh/(m^2.year)	Ni				Nv	Na
Climatic zone	FF 0.34	0.50	0.74	1.14		
Lisboa (I1, V2), South	51.5	51.6	62.1	77.4	32	44.2
Portalegre (I2,V3), North	73.2	73.4	88.7	111.1	26	44.2
Montalegre (I3, V1), North	115.9	116.2	141.0	177.4	16	44.2

3 RESULTS ANALYSIS

3.1 *The 'best' solutions*

The first goal of this paper is searching for the best solution in terms of primary energy needs for the base case study and respective shape factor variations. The fitness coefficient ζ corresponds to the minimization of the primary energy index, Ntc/Nt.

After some generations for different climatic zones, we conclude that the best solution in terms of construction options for all of them should be:

- high insulated walls, roof and floor (U-values of 0.34, 0.39 and 0.40, respectively),-
- walls and roof light color (absorptance of 0.40),
- double glazing windows with external roller blinds (U-value of 3.1 and g of 0.07),
- heavy inertia (coefficient a equal to 4.2) and
- minimum air infiltrations (ACH of 1.00).

In terms of systems for heating and cooling production, the best solution is a heat pump (COP equal to 4 for heating and 3 for cooling) or a compression chiller for cooling (COP of 3). For DHW energy production instead, solar panels of kit type system should be selected, as well as a heat gas boiler (η = 0.87) as backup.

It can also be observed that the primary energy index of the best solutions is almost invariable for the different geometries considered (apartment shape factor) and climate conditions; in fact, primary energy index lies between 0.24 and 0.31.

Analyzing the case of the apartment with FF equal to 0.50 (no external roof) at Lisbon; Ntc/Nt of the optimum solution is 0.24, i.e. a building that only consumes 24% when compared to a standard building (A^+ in terms of building labeling). However, some other possible combinations are also very close to that value, as shown in Figure 1. Building characteristics, such as walls color, inertia, walls insulation and air tightness are the less sensitive elements; primary energy index varies less than 3%. The glazing type and shading devices have a small influence of less than 8%.

On the other hand, the type and efficiency of the energy systems (heating, cooling and DHW) cause high variations. For example, the use of certified solar panels for DHW reduces the primary energy index by 48%, and the selection of a heat pump instead of an electric resistance for heating reduces primary energy index by 25%. Nevertheless, the most influential parameter is the DHW system where the worst solutions are the electric storage water heater with different level of thermal insulation.

Therefore, one of the first conclusions of this study is that systems efficiency and the existence of certified solar panels are determinant on the primary energy index, and all the other parameters have a minor influence.

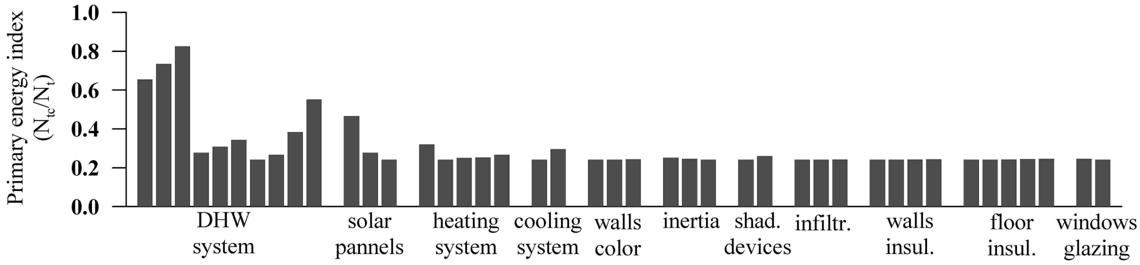

Figure 1. Primary energy index calculated to the best solution varying only one of the parameters for base case apartment (FF=0.50) at Lisbon.

3.2 *Heating energy index*

Systems efficiency, unlike construction characteristics, has a major impact on the primary energy index. However, construction characteristics are extremely important for heating and cooling energy index values. In this section, the same study is performed but establishing as fitness coefficient the heating energy index.

From the variables summarized in Table 1, only the first seven have a direct impact on this coefficient. Note that walls and roof absorptance are not considered for the heating index calculation.

Running the genetic algorithm for apartments with different shape factors in the three climatic zones, heating energy index increases with climate severity and varies with shape factor as shown in Figure 2. The sensitivity in one of the points (FF=0.50 and I1) is tested by making variations to each of the parameters (Fig. 3).

The most sensitive parameter is the building inertia; changing from light to heavy construction reduces the heating energy index (Nic/Ni) by 38%. Floor insulation is also an important element because an increase of the thermal insulation thickness (from 0.03 to 0.10 m) reduces Nic/Ni by 19%. Moreover, increasing the wall insulation thickness from 0.03 to 0.08 m reduces Nic/Ni by 9%. Infiltrations also play an important role on decreasing Nic/Ni, namely, the worst tested solution (1.1 ACH) has a Nic/Ni 8% higher than the best tested solution (1.0 ACH).

Selecting double glazing reduces the heating energy index by 11% compared with the single glazing solution. Adopting external shading devices reduces the heating energy index by 18% due to its additional thermal insulation for night time periods.

Some of these parameters can also be crucial for Regulation verification. For example, the same apartment (FF=0.50) located in Montalegre (I3) may have a floor insulation higher than 0.04 m, as well as external roller blinds that reduce the windows double glazing U-value from 3.9 to 3.1 W/(m^2.K).

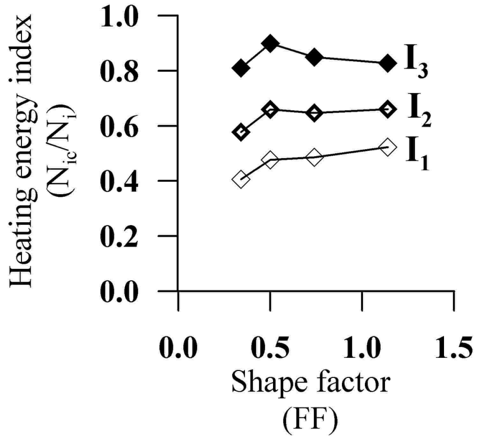

Figure 2. Heating energy index calculated to the best solution for different geometries and climates.

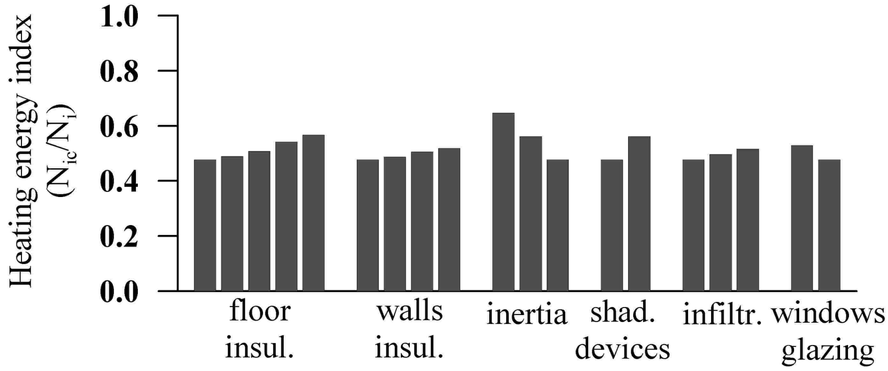

Figure 3. Heating energy index calculated to the best solution varying only one of the parameters for base case apartment (FF=0.50) and for Lisbon.

3.3 *Cooling energy index*

Some of the building characteristics are also important in terms of summer performance, which is here analyzed in terms of the cooling energy index (Nvc/Nv). The sensitivity analysis reveals the dominance of the shading devices position relatively to others parameters (Fig. 4). The cooling energy index for the single glazing solution is 10% higher than considering double glazing. Selecting lighter instead of darker colors for roof and walls decreases Nvc/Nv in 19% and 13%, respectively. Increasing roof thermal insulation is also decisive, as well as thermal inertia. Walls insulation and infiltrations has a minor influence on Nvc/Nv, which is less than 4%.

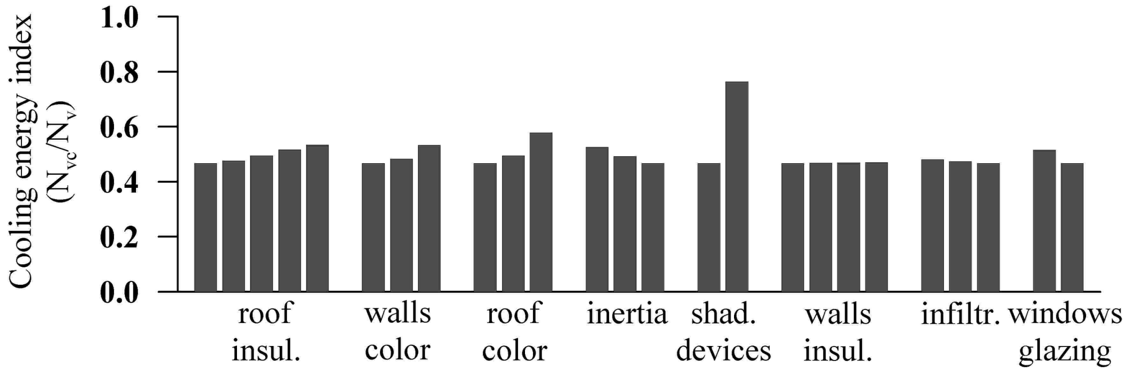

Figure 4. Cooling energy index calculated to the best solution varying only one of the parameters for the last floor apartment (FF=0.74) at Lisbon.

3.4 *Defining a target value*

For a given case study, another common problem consists of knowing what characteristics an apartment should have in order to be in classified by a certain label, i.e. Ntc/Nt should be less than a target value.

Taking the base case apartment (FF=0.50) with the following building characteristics: heavy inertia, walls medium color, 1.0 ACH of infiltrations, the method is applied to define the systems type or how much insulated should be building walls, so that Ntc/Nt ≤ 0.5 (A or A+ label in building certification).

In this section the standard solution for systems is a gas boiler for DHW with efficiency of 0.87 and a heat pump of COP 4 and 3 for heating and cooling, respectively.

3.4.1 *Standard systems and no solar panels*

After running the genetic algorithm in search of solutions with Ntc/Nt of less and close to 0.5, it is possible to know the minimum of wall and floor insulation for different cases:

A - double glazing (DG) and external shading devices (ESD);
B - double glazing and internal shading devices (ISD);
C - single glazing (SG) and external shading devices and;
D - single glazing and internal shading devices.

These results are presented in Table 3 which shows that 0.30 m of thermal insulation (expanded polystyrene in walls and expanded cork agglomerate in floors) is enough for I1 climate, except for D case (SG/ISD) where 0.40 m of thermal insulation should be used inside walls. For I2 climate, 0.30 m of thermal insulation is enough when double glazing is used, otherwise, walls should be insulated with 0.60 m and floors with 0.80 m. For D case of I2 and I3 climate, there are no solutions performing as required.

Table 3. Maximum allowed wall and floor U-value for a **A** building (Ntc/Nt ≤ 0.50) with standard systems and no solar panels.

	I1 (Lisbon)		I2 (Portalegre)		I3 (Montalegre)	
Case study	wall	floor	wall	floor	wall	floor
A – DG/ESD	0.57	0.88	0.57	0.88	*	
B – DG/ISD	0.57	0.88	0.57	0.88	*	
C – SG/ESD	0.57	0.88	0.40	0.47	*	
D – SG/ISD	0.50	0.88	*		*	

* there is no solutions for the defined condition.

3.4.2 *Double glazing, external shading devices and 0.30 m of thermal insulation*

Another possibility is to evaluate different systems solutions keeping the same level of thermal insulation on walls and floor (0.30 m). In this study it is assumed that an electric or gas/fuel system can be used for heating . For cooling, an electric system with COP equal to 3 is always selected and for DHW a gas system is always used. Table 4 shows the minimum of system efficiency to assure that Ntc/Nt is less than 0.50 for two climatic zones, I1 and I2.

Table 4. Minimum system efficiency (COP for heat pump) for heating and DHW systems for an **A** building (Ntc/Nt ≤ 0.50) with double glazing, external shading devices and 0.30 m of thermal insulation. Cooling COP is always 3.

	I1 (Lisbon)		I2 (Portalegre)	
Solar panels	Heat	DHW	Heat	DHW
A – no	0.80 (not elec.)	0.87	* (not elec.)	
	4 (electric)	0.87	4 (electric)	0.87
B – forced circulation	0.60 (not elec.)	0.65	0.80 (not elec.)	0.65
	1 (electric)	0.70	1 (electric)	0.87
C – kit	0.60 (not elec.)	0.65	0.60 (not elec.)	0.65
	1 (electric)	0.65	1 (electric)	0.82

* there is no solutions for the defined condition.

The results evidence different possible combinations. When certified solar panels are not installed, it is necessary to choose systems with a higher efficiency, such as, for heating, a fuel heat boiler (η = 0.80) or an electric heat pump (COP = 4) and, for DHW, a gas heat boiler (η = 0.87). In terms of climate severity, higher efficiency is generally required when the apartment is located in I2.

4 FINAL REMARKS AND CONCLUSIONS

In this study, a genetic algorithm is used to calculate the energy indexes of a large number of parametric variations, with the goal of searching for the best solution according to different criteria, namely the lowest primary, heating or cooling energy index. This optimization method is useful for the identification of the parameters which exert most influence on those indexes.

The main conclusion is that the primary energy index (the index used for certification labeling) is mainly established by the systems efficiency, as well as the use of certified solar panels (or other renewable energy sources, not here considered). Passive strategies, like adequate thermal insulation or windows dimensioning, have a small influence on building labeling.

This influence is, however, disguised on heating and cooling energy indexes, which are quite restrictive in terms of the quality of the building envelope. For the apartment studied at the more severe winter climatic zone (I3), solutions according to Portuguese legislation are hardly found. In fact, the heating energy index is close to 1 for the best solution and any small variation in one of the parameters makes the solution impracticable. For winter thermal performance, thermal inertia, thermal insulation, infiltrations and windows characteristics are elements that play an important role on the heating energy index. It is noteworthy, however, that this study does not cover all the possible parametric variations in a building, such as air tightness window frames and mechanical ventilation.

Instead, for summer season, windows shading devices position are crucial for cooling energy index. But roof thermal insulation, surfaces color, thermal inertia and windows glazing are no less important. Due to the monthly dependence on the average temperature in the methodology to calculate cooling energy needs, heat transfer by ventilation, conduction and convection always contribute for building losses. However, thermal gains trough the envelope are considered by the sol-air temperature concept, which is not true for infiltration gains. In fact, the 'best' solution for minimizing cooling energy needs corresponds to infiltrations increasing. So, summer methodology should be rethinking, besides minimum shading requirements, in order to prevent overheating periods.

The optimization method applied in this paper is a good contribution for common case studies analysis. However, this study intends to go further and raise questions for the Energy Performance Building Directive revision at national level. According to ours point of view, building characteristics differentiation should have a greater impact on building labeling. As shown is the paper, it is possible to have an A^+ apartment with windows single glazed, since it has solar panels for DHW and efficient systems. Is that a real contribution to energy consumption reduction?

Another issue is that related to the climatic zones where buildings are located, for the more severity winter climatic zone (I3) it was not possible to achieve, for the solution adopted of no solar panels and standard systems, any combination where $Ntc/Nt \leq 0.50$, however this was possible for I1 and I2, trough the increase of thermal insulation. The parity of criteria should not be the same?

These raised questions direct the problem to the definition of standards indexes and the possibility of their reduction, which for certain cases could lead to impracticable solutions. Other important issue would be minimum requirements for A and A^+ building in terms of envelope thermal quality, such as double glazing, as well as the use of renewable energy production (certified solar panels, for example), in order to standardize buildings labeling throughout climatic zones.