INSTITUTO SUPERIOR TÉCNICO
Universidade Técnica de Lisboa

Could the Portuguese Energy Certification of Buildings lead to sustainability?

Residential application case (RCCTE)

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Extended abstract

Jury

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October 2010

Could the Portuguese Energy Certification System of Buildings lead to sustainability? – Residential application case

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Abstract: This paper analyses if the actual Portuguese Energy Certification System of Buildings is adapted to the new principles of the recast of the EPBD Directive and if it is searching for passive house buildings, according to the *Passivhauss Norm*. Moreover, it points out some new measures that should be added in the regulation so it could be transformed into an effective tool for searching the sustainability in construction.

Key-words: Active measures, Passive measures, *Passivhauss Norm*, RCCTE, SCE, Sustainability

Introduction

During the last century, the world population increased from 1650 to nearly 6000 million and it is still increasing (PPDESA, 1999).

Joining this issue with the rapid growth of the Economy (with a five factor since 1950), based on a massive exploitation of the natural resources and the continuous emissions of GHG (Greenhouse Gases), it is simple to conclude, that Earth is not prepared to receive such pressing, without any consequences (Pinheiro, 2006).

Indeed, according to the *Ecological Footprint Atlas* (Ewing *et al.*, 2008), Earth would need 1.3 planets to restore all the resources consumed daily by Humankind. In Portugal, this problem is even bigger, since it would need more 180% of its area to achieve the environmental balance (Pinheiro, 2006; Wackernagel and Rees, 1996).

Therefore, in order to reduce this problem, it was signed the Kyoto Protocol in 1997, with specific reduction targets of the Greenhouse Gases.

In order to fulfil this protocol, the EU proposed itself an 8% reduction of the GHG between 2008 and 2012 (UN, 1997), so the Community has approved several efficient energetic policies, like the EPBD Directive - Energy Performance of Buildings Directive (Directive 2002/91/EC).

This Directive imposed the usage of an energy certification system for the buildings, in order to reduce their energy consumption, estimated as 40% of the global Community Energy Consumption (European Parliament, 2002).

Since Portugal is an EU member, the Decree Laws number 78, 79 and 80 of 2006 transposed this directive to the Portuguese Legislation, creating the Energy Certification System of Buildings and a new thermal regulation for service and residential buildings.

This paper will discuss if this new regulation applied to the residential sector (RCCTE) could be an important step to achieve the sustainability, so the new buildings are able to reduce significantly their consumptions and their emissions in an efficient way.

As the EPBD Directive has been recast in 2009, in order to increase the buildings energy performance, it will be transposed in the future to the Portuguese Legislation, so now it is the perfect time to point out some modifications that should be considered in this review.

Thus, the next chapters will discuss how the Portuguese Energetic Certification System of Buildings focuses this issue and what information it is giving to the construction market.

The Portuguese Energy Certification System of Buildings

The EPBD Directive was transposed to the Portuguese Legislation by the DL 78/2006, creating the Portuguese Energy Certification System of Buildings (hereafter SCE), supervised by the DGGE and managed by the ADENE. The calculation methodology and the regulations are sent to the DL 79/2006 and DL 80/2006 (Portuguese Legislation, 2006a).

The first one (RSECE) limits the energy consumption (imposing a maximum power of the HVAC systems) and requires minimum parameters for air quality in service buildings (Portuguese Legislation, 2006b).

The DL 80/2006 (RCCTE) is applied to the residential buildings with an area not higher than 1000 m^2, and the service buildings with an area lower than 1000 m^2 or 500 m^2 in case of supermarkets, swimming pools and shopping centers. Otherwise, they are subject of the RSECE (Portuguese Legislation, 2006c).

This last regulation (RCCTE) is the concerning point of this paper. In fact, the common residential buildings are subject of this regulation, that stipulates a maximum consumption of heating energy (winter), cooling energy (summer), energy for heating sanitary waters and primary energy, as a conversion of the last three parameters in *kgoe* (hereafter Ni, Nv, Na and Nt, respectively).

Known these maximums, the RCCTE points out a calculation methodology to estimate the consumption of the building, which shall be lower than them in case of new constructions (hereafter Niv, Nvc, Nac and Ntc respectively).

The Nt is the base level for the classification (class B-). When the Ntc is 25% lower, the building is B, 50% – A, 75% or more – A+. The existing buildings do not have to respect the Nt, so they can be C (until 50% more), D (50-100%), E (200-250%), F (250-300%) or G (>300%).

When analyzing the text of RCCTE it is possible to find out some new thermal impositions that can lead to a sustainable construction. Indeed, it divides the country in three winter climatic zones and other three summer climatic zones. In those zones, it imposes maximum U-values for current envelope elements and maximum solar factor for windows with an area higher than 5% of the serving room.

Moreover, it is written that plain thermal bridges shall be treated, so they cannot have a U-value higher than the double of the U-value of the envelope element, and they shall respect the legal maximum imposed. This is an important imposition, as it was estimated that the thermal bridges are the responsible for 20% of the final thermal energy consumption (Valério, 2007).

On the other hand, it is the first regulation that obligates the introduction of 1 m^2/person of solar thermal panels for heating sanitary waters, reducing the energy consumption.

Besides these obligations, the RCCTE points out some other recommendations (reference values), that can be interpreted as the regulation minimum quality values for a correct design (Rodrigues *et al*., 2009), such as more exigent U-values, more exigent solar heating gain coefficients of the glazing solutions, strong or medium thermal inertia, a light colored roof and a maximum glazing area of 15% of the floor area.

To conclude this review of the regulation, several authors concluded the fact that the calculation methodology is a good estimative, when compared with the results of the usage of simulation tools such as *Energyplus*, *equest* and *VisualDOE* (Silva *et al*., 2007; Silva, *et al*. 2009).

This paper will evaluate these parameters of the RCCTE. Therefore, it will conclude if they are adequate to the sustainability principles and for what solutions it is leading to.

Case-studies

The last chapter finished with the aim of the analyses developed in this paper – verify if the impositions of the RCCTE are well proposed to achieve a sustainable construction. To accomplish it, this study will be based on a building developed by LiderA – the HEXA Building.

This building appeared from an architecture comparison study of several existing buildings in Lisbon, Oporto and Faro, so it could be similar to the common constructive and architecture practice (Pinheiro *et al.*, 2010).

In fact, it does not exist; it is a design from a building type, inserted in a block of houses, also developed by LiderA. This is not a problem because the HEXA aim is not to be constructed, but to test several sustainable measures that could be implemented to improve its environmental performance. The HEXA design drawing could be seen in the Figure 1, exposed as follows:

Fig 1 – Case-study flat (it was chosen the left one)

In order to test the most common construction types of buildings there were studied three different cases: the highest floor with no adjacent building (the worst situation among the common urban buildings), an intermediate floor with an adjacent building (the most common urban situation) and a villa (the most common rural situation).

The villa was created from the HEXA architecture by removing all the other zones (stairway enclosure, the adjacent flats and the adjacent building) and making the floor to contact directly with the soil.

Since the RCCTE divides the country in several climate zones, with corresponding different impositions, all of these three case-studies were located in three different regions: Lisbon (one of the Portuguese most housing density zone – INE, 2009), Bragança (the coldest winter zone) and Évora (the warmest summer zone).

What is an energy sustainable building?

As it was explained in the Introduction, the world has assisted to several Mankind environmental aggressions during the two last centuries. Thus, in 1987 it appears a new concept of development – the sustainable development – "to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland, 1987).

Since that date until now, several Authors discussed the means of achieving that objective, and nowadays there are two visions of sustainability, which describe two different ways of acting (Dietz & Neumayer, 2006):

- Weak Sustainability – tries to obtain the optimal usage of the income generated from the exploitation of the non-renewable resources, establishing the rules of consumption and the usage of the capital (including the natural capital).
- Strong Sustainability – divides the natural capital in four categories of functions and assumes that natural capital cannot be substituted by other forms of capital. This way, it should be afforded special protection.

Introducing these concepts in the EPBD Directive, it is possible to conclude that the 2002/91/EC focused a weak sustainability, as it wanted uniquely to reduce the buildings energy consumption.

However, there is an evolution on the EU objectives on the 2009 recast, when there is a firstly reference on nearly carbon and energy neutral buildings, seen as an imperative target to obtain until 2018 (European Parliament, 2002; European Commission, 2008; Regions Committee, 2009).

To reduce the environmental impact of the buildings, it is being discussed a new construction paradigm, named as sustainable construction. This philosophy was firstly debated in 1994 and defined by Kibert as "the responsible creation and management of a healthy built environmental, based on the ecological principles and the efficient utilization of the resources" (Pinheiro, 2006; Kibert, 2003).

In fact, when adopting this type of construction, people are thinking of all the life cycle of the building and its energy and resources consumptions. Moreover, it is characterized by (Tirone and Nunes, 2007):

- Less quantifiable parameters:
  - A healthy and a good environmental comfort;
  - A valorization of its natural resources, instead of wasting them;
  - Multifunctional areas nearby the living places;
  - Flexible buildings, that can be changed during its life cycle;
  - Functional architecture.
- Quantifiable parameters:
  - Thermal and acoustic comfort;
  - Less energy consumption (with a neutral tendency);
  - Less water demand;
  - Less carbon emissions (with a neutral tendency).

Like it was referred, the reduction of energy and carbon impact is a priority of the sustainable construction, which can be accomplished by two complementary ways, the passive and the active.

The first one deals with the bioclimatic and ecological principles, that, when well used together, can reduce significantly the thermal energy consumption. Actually, it is estimated that a passive house in Portugal can reduce nearly 90% of this kind of consumption, when using the maximum of the solar energy, a good solar orientation, solar protections during the summer, an efficient thermal insulation and natural ventilation, a rational use of the thermal inertia and a good usage of the glazing systems (Gonçalves and Brotas, 2007).

These conclusions are reported in the *Passivhauss Norm* applied to the Portuguese Climate, which refers six points that should be accomplished when designing passive buildings (Gonçalves and Brotas, 2007):

- Heating criterion – the maximum value for energy heating needs is 15 kWh/m^2.year;
- Cooling criterion – the maximum value for energy cooling needs is 15 kWh/m^2.year;
- Primary energy criterion – the global consumption of the building cannot be higher than 120 kWh/m^2.year;
- Ventilation criterion – When the air temperature is higher than 0^oC, the building should be ventilated with a maximum ratio of one air renovation per hour;
- Interior comfort temperature in winter – 20^oC;
- Interior comfort temperature in summer – according to the Norm EN 15251, if there is no active cooling system. Else, the design maximum temperature should be 26^oC.

After producing a correct passive design, it has to be complemented with efficient active measures, in order to reduce the energy consumption and to provide electric energy, produced by mechanical renewable systems.

With these two parts working together it is possible to reach neutral carbon and energy buildings. In other words, these are the steps that shall be given towards the buildings strong sustainability.

If it is possible to create (nearly) neutral constructions, the energy and carbon sustainable building can only be a (nearly) neutral one.

Strategic lines and solutions of the study

As the aim of this paper is to evaluate the impositions of the RCCTE, the methodology used starts with a solution respecting the maximum acceptable values for the envelope. Then, several sustainable passive measures are added and it is made a comparison with the terms of the *Pasivhauss Norm*.

The thermal calculation was made using the RCCTE methodology and, as it is not possible to consider exactly some measures (like the Trombe Wall) or the adaptive method, it was also used the software *Energyplus 4.0*, developed by the US Department of Energy.

Therefore, the Table 1 summarizes the several solutions tested in this paper:

Table 1 – Common solutions studied

Solution	Description
Sol. A	Only respects the maximum regulation values for the envelope
Sol. B1	Respects the reference values of the RCCTE with exterior thermal insulation
Sol. B2	Respects the reference values of the RCCTE with interior thermal insulation
Sol. C	Solution B1 with a lower air renovation ratio
Sol. D	Solution C with light colored exterior walls
Sol. E1	Solution D with a common double glazing system, with a PVC frame and an exterior venetian blind
Sol. E2 Inv	Solution D with a double glazing system with reinforced thermal insulation, with a PVC frame and an exterior venetian blind
Sol. E2 Ver	Solution D with a double silvered glazing system, with a PVC frame and an exterior venetian blind
Sol. F-E1	Solution E1 with a south horizontal shading element
Sol. F-E2 Inv	Solution E2 Inv with a south horizontal shading element
Sol. G-E1	Solution E1 with the double of the thermal insulation
Sol. G-E2 Inv	Solution E2 Inv with the double of the thermal insulation
Sol. H-E1	Solution G-E1 with a large south orientated Trombe Wall (not ventilated)
Sol. H-E2 Inv	Solution G-E2 Inv with a big south orientated Trombe Wall (not ventilated)

In some cases it was interesting the study of some other solutions that could improve the performance of the respective dwelling. Thus, the Table 2 describes all the other solutions tested during the current paper:

Table 2 – Other solutions tested (1/2)

Solution	Description	Location and type of construction
H-E2i + P	Solution H-Ei with a South horizontal shading element	Lisbon – highest floor; villa Évora – highest floor
H-Ei SJ	Solution H-Ei without the double glazing of the Trombe Wall during the Summer	Lisbon – highest floor; villa Évora – highest floor
H-Ei II	Solution G-Ei with more 3 cm of thermal insulation in the walls and with a South orientated Trombe Wall with 50% of the area of the H-Ei Trombe Wall	Lisbon – highest floor; villa Évora – highest floor

Table 2 – Other solutions tested (2/2)

Solution	Description	Location and type of construction
G-Ei + P	Solution G-Ei with a south horizontal shading element	Lisbon – highest and intermediate floor
G-E2 Ver	Solution E2 Ver with the double thermal insulation	Lisbon – highest and intermediate floor
G-Ei II	Solution G-Ei with the same thermal insulation in the exterior and interior walls	Bragança – highest and intermediate floor
G-Ei III	30 cm of thermal insulation for all the envelope elements	Bragança – all solutions
G-Ei IV	Solution G-Ei III with a 0,6 h^{-1} air renovation ratio	Bragança – highest floor; villa
G-Ei IV SV	Solution G-Ei IV without the balcony	Bragança – highest and intermediate floor
G-Ei V	Solution G-Ei IV with dark walls	Bragança – all solutions
G-Ei VI	Solution G-Ei V with a dark roof	Bragança – highest floor
PR-E2 (pala)	Solution G-E2 Inv with a radiant floor with a maximum power of 10 W/m^2 and a south horizontal shading element	Bragança – highest and intermediate floor
G-Ei + isol	Solution G-Ei with more 3 cm of the walls thermal insulation	Évora – highest and intermediate floor
G-Ei + isol + P	Solution G-Ei + isol with a south horizontal shading element	Évora – highest and intermediate floor
H-Ei PR	Solution H-Ei with a radiant floor with a maximum power of 10 W/m^2	Bragança – villa
H-Ei PR SJ	Solution H-Ei PR without the double glazing system of the Trombe Wall during the summer	Bragança – villa
H-Ei CP SJ	Solution H-Ei with a dark roof and without the double glazing system of the Trombe Wall during the summer	Bragança – villa
H-Ei + isol	Solution H-Ei with more 3 cm of the walls thermal insulation	Évora – villa
H-Ei + isol SJ	Solution H-Ei + isol without the double glazing system of the Trombe Wall during the summer	Évora - villa

After this analysis, it was studied the impact of the usage of 1 m^2/person of solar collectors for hot sanitary waters production (minimum regulation area imposed). It was made with the regulation software *Solterm 5.1.3*, comparing three different patterns of consumption (I – regulation pattern, when all the consumption occurs from 17-18h; II – half consumption from 7-8h and the other half from 17-18h; III – al the consumption occurs form 7-8h) and five different areas of solar collectors (AQS 1 – no solar collectors; AQS 2 – 0.5 m^2/person; AQS 3 – 1.0m^2/person; AQS 4 – 1.5 m^2/person; AQS 5 – 2.0 m^2/person).

To evaluate the importance given to the Portuguese Certification System of Buildings for the passive measures and for the active measures in the energy class, there were tested four solutions of each case-study – the Solution A, the first regular solution after the solution A, an intermediate solution and, finally, the *Passivhauss* solution.

In all of the cases there were tested two kinds of active systems, efficient and inefficient, to evaluate the differences of the energy classes. Moreover, in the inefficient first solution –

Solution A (that could represent the construction before the thermal regulation) it was not introduced any solar collector.

Then, the other electric consumption was estimated according to the terms of the software *RETScreen*, and to a market empirical study, validated with the data of the Portuguese database available on equipamentos.p3e-portugal.com. In this part of the study, two solutions were studied: one with the most common power, and the second one with very efficient equipments.

Finally, it was estimated the real local energy production need, according to the energy mix of EDP for the year 2009, in order to produce the part of the electricity originated in non-renewable sources (59.8% of the total electric consumption).

This last study was made for the worst solution (Solution A – villa in Bragança) considering two scenarios (efficient and inefficient equipments) and for its corresponding *Passivhauss*. Furthermore, it was made according to the Roriz *et al.* (2010) recommendations and using the software *RETScreen*.

Results

After the brief explanation of the strategic lines adopted in this work, the results obtained are presented in the following tables (Tables 3-11 – thermal energy needs; Tables 12-17 – hot sanitary waters energy needs; Tables 18-26 – energy classes; Table 27 – other annual electric consumption).

Table 3 – Lisbon: Highest floor of the urban building

(kWh/m^2.year)	Nic		Nvc			Máx. RCCTE	
Solution	RCCTE	*Energyplus*	RCCTE	*Energyplus* (25°C)	ASHRAE 55	Ni	Nv
A	63,18	-	33,19	-	-	57,45	32,00
B1	45,01	43,67	16,27	15,01	1,46		
B2	51,20	-	16,06	-	-		
C1	40,86	38,56	17,06	16,10	1,87		
D1	40,86	43,87	14,45	11,05	0,48		
E1	37,12	38,22	13,31	10,05	0,30		
E2 Inv	32,58	32,56	11,15	11,15	0,54		
E2 Ver	39,41	37,73	12,09	10,07	0,17		
F-E1	40,38	39,18	12,81	8,75	0,17		
F-E2 Inv	36,93	33,54	13,27	9,78	0,33		
G-E1	26,36	25,2	11,73	10,76	0,60		
G-E2 Inv	23,18	19,81	12,14	12,23	1,16		
H-E1	25,66	6,77	12,05	26,45	8,48		
H-E2 Inv	22,48	3,54	12,46	29,27	11,34		
H-E2 Inv + P	-	4,14	-	28,35	10,64		
H-E2 Inv SJ	-	3,54	-	17,49	0,81		
H-E2 Inv II	-	8,44	-	19,44	5,17		
G-E2 Inv + P	-	20,53	-	10,70	0,73		
G-E2 Ver	-	24,51	-	8,86	0,37		

Table 4 – Lisbon: Intermediate floor of the urban building

(kWh/m^2.year)	Nic		Nvc			Máx. RCCTE	
Solution	RCCTE	*Energyplus*	RCCTE	*Energyplus* (25°C)	ASHRAE 55	Ni	Nv
A	38,42	-	14,89	-	-	51,51	32,00
B1	28,98	28,32	11,31	18,78	3,50		
B2	32,99	-	11,27	-	-		
C1	23,52	21,96	12,40	21,23	5,36		
D1	23,52	24,73	11,38	19,93	2,96		
E1	18,82	19,89	10,25	15,64	2,57		
E2 Inv	15,03	15,17	10,68	17,64	4,17		
E2 Ver	18,21	17,10	9,04	13,63	2,02		
F-E1	21,08	20,67	9,75	12,05	3,41		
F-E2 Inv	15,88	20,38	10,24	15,39	2,78		
G-E1	15,11	15,41	10,31	15,61	3,24		
G-E2 Inv	11,46	10,91	10,74	17,87	5,27		
H-E1	14,45	4,41	10,57	34,87	17,29		
H-E2 Inv	10,84	4,24	11,01	38,83	22,12		
G-E2 Inv + P	-	11,35	-	15,65	3,77		
G-E2 Ver	-	12,65	-	13,44	2,60		

Table 5 – Bragança: Highest floor of the urban building

(kWh/m².year)	Nic		Nvc			Máx. RCCTE	
Solution	RCCTE	*Energyplus*	RCCTE	*Energyplus* (25°C)	ASHRAE 55	Ni	Nv
A	185,15	-	9,11	-	-	131,30	18,00
B1	115,90	82,93	2,44	7,52	1,34		
B2	131,67	-	2,41	-	-		
C1	105,71	74,56	2,99	8,03	1,61		
D1	105,71	79,11	2,31	6,03	0,76		
E1	101,17	78,16	2,00	5,74	0,61		
E2 Inv	91,11	67,69	2,40	6,42	0,92		
E2 Ver	99,18	74,06	1,74	5,03	0,45		
F-E1	107,24	79,50	1,82	4,97	0,37		
F-E2 Inv	96,88	69,07	2,22	5,55	0,60		
G-E1	78,90	56,49	1,98	6,15	0,87		
G-E1 II	77,33	53,98	2,02	6,01	0,84		
G-E1 III	63,56	38,83	2,03	6,74	1,43		
G-E1 IV	53,57	30,35	2,72	8,06	2,50		
G-E2 Inv	68,87	46,15	2,47	7,26	1,43		
G-E2 Inv II	67,31	43,65	2,47	7,16	1,44		
G-E2 Inv III	53,60	28,83	2,59	8,38	2,79		
G-E2 Inv IV	43,69	20,67	3,53	10,12	4,60		
H-E1	-	11,96	-	21,74	13,78		
H-E2 Inv	-	6,63	-	25,95	18,45		
G-E2 Inv IV SV	-	18,69	-	14,04	7,96		
G-E2 Inv V	-	19,69	-	11,27	5,56		
G-E2 Inv VI	-	17,84	-	14,37	8,21		
PR-E2 (pala)	-	12,20	-	8,36	3,16		

Table 6 – Bragança – Intermediate floor of the urban building

(kWh/m².year)	Nic		Nvc			Máx. RCCTE	
Solution	RCCTE	*Energyplus*	RCCTE	*Energyplus* (25°C)	ASHRAE 55	Ni	Nv
A	117,40	-	3,19	-	-	117,08	18,00
B1	80,67	53,25	2,16	12,45	4,37		
B2	90,94	-	2,16	-	-		
C1	67,01	41,36	3,13	14,73	6,61		
D1	67,01	44,10	2,75	12,09	4,54		
E1	61,92	43,26	2,36	11,92	4,42		
E2 Inv	50,92	34,00	3,12	13,95	6,56		
E2 Ver	56,31	36,77	2,10	10,36	3,70		
F-E1	66,80	44,40	2,10	9,86	2,98		
F-E2 Inv	55,60	35,12	2,83	11,78	4,78		
G-E1	53,07	34,36	2,52	12,43	5,50		
G-E1 II	49,25	31,80	2,52	12,47	5,79		
G-E1 III	43,05	24,79	2,67	12,15	6,20		
G-E2 Inv	42,14	25,33	3,36	14,78	8,09		
G-E2 Inv II	38,37	22,89	3,36	14,91	8,50		
G-E2 Inv III	32,29	16,31	3,58	12,42	7,19		
H-E1	-	15,35	-	23,79	16,12		
H-E2 Inv	-	7,57	-	28,50	21,35		
G-E2 Inv IV SV	-	15,64	-	13,68	8,33		
G-E2 Inv V	-	15,86	-	13,29	7,97		
PR-E2 (pala)	-	8,68	-	10,64	5,61		

Table 7 – Évora: Highest floor of the urban building

(kWh/m².year)	Nic		Nvc			Máx. RCCTE	
Solution	RCCTE	*Energyplus*	RCCTE	*Energyplus* (25°C)	ASHRAE 55	Ni	Nv
A	76,81	-	33,03	-	-	66,34	32,00
B1	55,49	53,91	16,01	16,75	2,52		
B2	62,76	-	15,80	-	-		
C1	50,60	48,10	16,81	17,52	2,94		
D1	50,60	53,29	14,18	13,00	1,22		
E1	45,97	46,58	13,55	12,61	1,18		
E2 Inv	42,01	40,12	13,91	13,54	1,54		
E2 Ver	48,11	45,51	12,23	11,12	0,91		
F-E1	49,67	47,66	13,03	11,23	0,84		
F-E2 Inv	45,47	41,20	13,46	12,11	1,09		
G-E1	33,22	31,89	11,97	12,64	1,71		
G-E2 Inv	29,31	25,59	12,35	13,82	2,50		
H-E1	32,39	12,82	12,30	27,29	10,64		
H-E2 Inv	28,48	8,27	12,68	29,73	13,19		
H-E2 Inv + P	-	9,17	-	28,83	12,49		
H-E2 Inv SJ	-	8,27	-	12,37	2,09		
H-E2 Inv II	-	13,64	-	20,46	7,00		
G-E2 Inv + isol	-	22,39	-	13,89	2,85		
G-E2 Inv + isol + P	-	23,20	-	12,40	2,03		
G-E2 Ver + isol	-	27,99	-	10,75	1,37		

Table 8 – Évora: Intermediate floor of the urban building

(kWh/m².year)	Nic		Nvc			Máx. RCCTE	
Solution	RCCTE	*Energyplus*	RCCTE	*Energyplus* (25°C)	ASHRAE 55	Ni	Nv
A	47,19	-	14,81	-	-	59,41	32,00
B1	36,06	34,97	11,13	19,59	5,08		
B2	40,80	-	11,07	-	-		
C1	29,59	27,73	12,21	21,29	6,65		
D1	29,59	30,59	11,14	17,49	4,30		
E1	23,88	24,68	10,53	16,78	4,32		
E2 Inv	19,26	19,29	10,93	18,36	5,84		
E2 Ver	22,90	21,56	9,21	14,95	3,70		
F-E1	26,51	26,62	10,00	14,69	3,00		
F-E2 Inv	21,71	20,06	10,47	16,18	4,33		
G-E1	19,41	19,50	10,57	16,43	4,87		
G-E2 Inv	14,93	14,29	10,98	18,24	6,67		
H-E1	18,62	7,71	10,84	34,68	18,40		
H-E2 Inv	14,17	4,23	11,25	38,52	23,01		
G-E2 Inv + is	-	11,28	-	18,28	7,32		
G-E2 Inv + is + P	-	11,69	-	16,14	5,75		
G-E2 Ver + is	-	13,23	-	14,14	4,55		

Table 9 – Lisbon: Villa

(kWh/m².year)	Nic		Nvc			Máx. RCCTE	
Solution	RCCTE	*Energyplus*	RCCTE	*Energyplus* (25°C)	ASHRAE 55	Ni	Nv
A	95,35	-	39,37	-	-	61,37	32,00
B1	65,32	53,82	20,46	13,48	0,86		
B2	70,62	-	20,20	-	-		
C1	61,10	48,61	21,27	18,48	1,04		
D1	61,10	56,67	16,76	8,30	0,04		
E1	56,57	50,57	15,39	6,70	0,00		
E2 Inv	55,06	44,57	15,18	7,16	0,001		
E2 Ver	61,75	50,76	13,17	4,96	0,00		
F-E1	61,52	53,07	13,55	4,65	0,00		
F-E2 Inv	59,05	47,21	13,70	5,06	0,00		
G-E1	44,15	38,29	13,69	6,93	0,00		
G-E2 Inv	42,58	31,34	13,50	7,59	0,003		
H-E1	43,42	17,04	14,01	18,61	2,64		
H-E2 Inv	41,85	12,35	13,82	20,29	3,61		
H-E2 Inv + P	-	13,58	-	19,58	3,26		
H-E2 Inv SJ	-	12,35	-	7,27	0,0004		
H-E2 Inv II	-	20,11	-	12,57	0,77		

Table 10 – Bragança: Villa

(kWh/m².year)	Nic		Nvc			Máx. RCCTE	
Solution	RCCTE	*Energyplus*	RCCTE	*Energyplus* (25°C)	ASHRAE 55	Ni	Nv
A	266,44	-	11,57	-	-	140,71	18,00
B1	163,82	104,28	3,64	6,38	0,74		
B2	184,96	-	3,20	-	-		
C1	153,61	94,82	4,33	6,76	0,86		
D1	153,61	101,89	3,01	4,17	0,19		
E1	147,60	100,93	2,47	3,77	0,10		
E2 Inv	139,77	90,20	2,65	4,02	0,13		
E2 Ver	149,14	97,94	1,84	2,85	0,02		
E1 ESC	-	93,87	-	6,33	0,63		
F-E1	154,03	104,48	1,79	2,52	0,006		
F-E2 Inv	144,93	93,96	2,04	2,72	0,02		
G-E1	123,02	79,53	2,56	3,91	0,10		
G-E1 III	106,62	64,69	2,72	4,27	0,12		
G-E1 IV	96,46	55,67	3,54	4,94	0,29		
G-E1 V	-	53,81	-	5,98	0,64		
G-E2 Inv	115,19	68,78	2,98	4,29	0,14		
G-E2 Inv III	98,78	53,95	3,05	4,88	0,29		
G-E2 Inv IV	88,61	45,16	4,05	5,79	0,69		
G-E2 Inv V	-	43,46	-	6,99	1,25		
H-E2 Inv	-	22,37	-	19,05	9,77		
H-E2 Inv PR	-	14,71	-	19,05	9,77		
H-E2 Inv PR SJ	-	14,71	-	6,41	0,81		
H-E2 Inv CP SJ	-	20,99	-	8,34	1,75		

Table 11 – Évora: Villa

(kWh/m².year)	Nic		Nvc			Máx. RCCTE	
Solution	RCCTE	*Energyplus*	RCCTE	*Energyplus* (25°C)	ASHRAE 55	Ni	Nv
A	114,77	-	39,06	-	-	70,93	32,00
B1	79,60	66,36	20,05	16,85	2,24		
B2	85,82	-	19,8	-	-		
C1	74,66	60,39	20,86	17,42	2,46		
D1	74,66	68,88	16,38	11,12	0,73		
E1	69,17	61,60	15,68	10,18	0,58		
E2 Inv	67,08	54,64	15,42	10,57	0,61		
E2 Ver	74,39	61,32	13,30	8,31	0,35		
F-E1	74,55	64,71	13,75	7,75	0,31		
F-E2 Inv	71,41	57,80	13,85	8,12	0,32		
G-E1	54,57	46,37	13,99	9,87	0,55		
G-E2 Inv	52,43	39,57	13,74	10,41	0,64		
H-E1	53,71	25,72	14,32	21,62	5,31		
H-E2 Inv	51,57	20,16	14,07	22,95	6,32		
H-E2 + isol	-	14,11	-	24,17	7,75		
HE2 + isol SJ	-	14,11	-	10,34	0,71		

Legend:

(red)	Indicates a no regular solution;
(white)	Indicates a solution that is explained in the table 1;
(dotted)	Indicates a solution that is explained in the table 2;

- Indicates that this result was not calculated;

Table 12 – Hot Sanitary Waters energy needs (Lisbon: Villa)

	Pattern of consumption (kWh/m².year)		
Solution	Pattern I	Pattern II	Pattern III
AQS-1	26,75	26,75	26,75
AQS-2	14,21	14,21	14,21
AQS-3	6,82	6,82	6,82
AQS-4	4,87	4,87	4,87
AQS-5	4,24	4,24	4,24

Table 13 – Hot Sanitary Waters energy needs (Lisbon: urban building)

	Pattern of consumption (kWh/m².year)		
Solution	Pattern I	Pattern II	Pattern III
AQS-1	26,75	26,75	26,75
AQS-2	16,02	16,80	16,64
AQS-3	11,14	12,42	11,84
AQS-4	8,97	10,20	9,54
AQS-5	7,82	8,96	8,33

Table 14 – Hot Sanitary Waters energy needs (Bragança: Villa)

	Pattern of consumption (kWh/m².year)		
Solution	Pattern I	Pattern II	Pattern III
AQS-1	26,75	26,75	26,75
AQS-2	15,49	15,49	15,49
AQS-3	8,48	8,48	8,48
AQS-4	6,57	6,57	6,57
AQS-5	5,73	5,73	5,73

Table 15 – Hot Sanitary Waters energy needs (Bragança: urban building)

	Pattern of consumption		
Solution	Pattern I	Pattern II	Pattern III
AQS-1	26,75	26,75	26,75
AQS-2	17,06	17,73	17,59
AQS-3	12,65	13,75	13,26
AQS-4	10,65	11,72	11,16
AQS-5	9,70	10,59	10,04

Table 16 – Hot Sanitary Waters energy needs (Évora: Villa)

	Pattern of consumption (kWh/m².year)		
Solution	Pattern I	Pattern II	Pattern III
AQS-1	26,75	26,75	26,75
AQS-2	13,68	13,68	13,68
AQS-3	6,33	6,33	6,33
AQS-4	4,59	4,59	4,59
AQS-5	3,88	3,88	3,88

Table 17 – Hot Sanitary Waters energy needs (Évora: urban building)

	Pattern of consumption (kWh/m².year)		
Solution	Pattern I	Pattern II	Pattern III
AQS-1	26,75	26,75	26,75
AQS-2	15,49	16,32	17,59
AQS-3	10,46	11,77	11,15
AQS-4	8,30	9,54	8,90
AQS-5	7,23	8,34	7,68

Table 18 – Energy Class (Lisbon: Villa)

	Energy Class	
Solution	Efficient	Inefficient
A	B	D
C1	A	B
GE2 Inv	A	B
HE2 Inv SJ	A	B

Table 19 – Energy Class (Lisbon: Highest floor of the urban building)

	Energy Class	
Solution	Efficient	Inefficient
A	B	D
B1	B	B-
GE2 Inv	B	B-
GE2 Inv + Pala	B	B-

Table 20 – Energy Class (Lisbon: Intermediate floor of the urban building)

	Energy Class	
Solution	Efficient	Inefficient
A	B	D
B1	B	B-
GE2 Inv	B	B-
GE2 Inv + Pala	B	B-

Table 21 – Energy Class (Bragança: Villa)

	Energy Class	
Solution	Efficient	Inefficient
A	B	D
E2 Inv	B	B
GE2 Inv IV	A	B
HE2 Inv PR SJ	A	B

Table 22 – Energy Class (Bragança: Highest floor of the urban building)

	Energy Class	
Solution	Efficient	Inefficient
A	B-	D
B1	B	B-
GE2 Inv IV	B	B-
PR E2 (pala)	B	B-

Table 23 – Energy Class (Bragança: Intermediate floor of the urban building)

	Energy Class	
Solution	Efficient	Inefficient
A	B	C
B1	B	B-
GE2 Inv III	B	B-
PR E2 (pala)	B	B-

Table 24 – Energy Class (Évora: Villa)

	Energy Class	
Solution	Efficient	Inefficient
A	B	D
E1	A	B
GE2 Inv	A	B
HE2 + isol SJ	A	B

Table 25 – Energy Class (Évora: Highest floor of the urban building)

	Energy Class	
Solution	Efficient	Inefficient
A	B	D
B1	B	B-
GE2 Inv	B	B-
GE2 + isol + P	B	B-

Table 26 – Energy Class (Évora: Intermediate floor of the urban building)

	Energy Class	
Solution	Efficient	Inefficient
A	B	D
B1	B	B-
GE2 Inv	B	B-
GE2 + isol + P	B	B-

Table 27 – Other annual electric consumption

	Annual consumption (kWh)	
Equipment	Usual equipments	Very efficient equipments
Aspirator	167	100
Computer	417	104
Clothes iron	225	150
Electric Cooker	2300	1779
Oven	313	240
Microwave	164	137
Dishwasher machine	383	329
Cloth washer machine	475	310
Dryer	420	-
DVD player	3	3
Radio	26	13
Hairdryer	104	83
Toaster	52	39
TV	164	99
Fridge	409	143
Freezer	526	284
Lamps	175	29
Others	63.23	38.42
Total	6386.23	3880.42

Discussion of results

Validating the thermal energy needs

When analyzing the Nic values obtained by the RCCTE and the *Energyplus*, it can be seen that they are very similar, excluding Bragança, where the deviations are notorious. This fact was expectable, according to Silva *et al.* (2009), who concluded that for the climate zone I_3 (Bragança zone) the regulation gives very conservative results.

Besides that, these two methodologies differently calculate the solar gains of the opaque envelope in winter: when RCCTE does not consider them, the *Energyplus* does. This can be the cause of the small deviations, more perceptible in the villa, where the exposed area is bigger.

In the Nvc values there are some considerable deviations, when comparing the RCCTE and the *Energyplus*. These differences can be explained with the own regulation, which refers that the methodology used has the main aim of comparing different buildings and not to precisely calculate the cooling energy needs (for what it is needed a dynamic simulation, as *Energyplus*).

On the other hand, the regulation fixes the summer duration (122 days), but the *Energyplus* analyses all the year. So, there are some days in May and in October that have cooling energy needs.

Moreover, in the detailed dynamic simulation, the calculations are made hourly, which is very different of using a global exterior mean temperature for all summer. One other difference of the methodologies is in the controlling of the windows blind – always 70% active in the RCCTE, when in *Energyplus* they are 100% active if the exterior temperature is equal or higher to 27^{o}C.

In the intermediate floor, the adjacent building was considered to have a balcony window with no blind, internal gains of 4 W/m^2 and no cooling machine (conservative measures), fact that in some occasions originates interior temperatures higher than the exterior air.

Even so, the differences are not so great is Lisbon and in Évora. However, in Bragança, the results are very distant, and, according to the National Meteorology Institute (2010), the values calculated by RCCTE are not conservative.

In the adaptive method it is was used the ASHRAE 55-2004 Standard instead of using the European Standard EN 15251, because the second one needed a daily calculation of the comfort temperature, instead of a monthly calculation in the first one, fact that needed much more simulations in the software, turning impossible to calculate all of the values pretended.

Conceptually, the results are not very different, because in the European Standard there are days with a comfort temperature higher than the ASHRAE 55-2004, but there are other days that have lower temperatures, so it is possible to assume that these deviations compensate themselves.

The results concerning the large Trombe Wall (not ventilated) can conclude that this passive measure has a very positive contribute in winter, but is very undesirable in summer, when the only way of solving this problem is to remove its window during the summer, fact very difficult in urban buildings. This way, it is needed a rigorous design of these passive devices.

Lisbon results

In Lisbon, the Ni and Nv values of the RCCTE are much higher than the *Passivhauss* purposes, and it is possible to accomplish the envelope impositions with no thermal insulation in the walls and with simple glazing solutions with Aluminum frame with no thermal cut. It is even possible to construct an intermediate floor with these not adequate measures.

When adopting the reference values, there is a significant reduction of the energy needs. However, in winter they are very distant from the 15 kWh/m^2.year, although in summer the energy needs are lower.

The usage of light colored walls manifested a substantial reduction of the cooling energy needs, especially in the villa, where the exposed area is bigger.

To have a *Passivhauss* it was needed the thermal insulation of the G solution (6 cm in walls and 12 cm in the roof). For the windows, when using this thermal insulation, it is possible to accomplish the purposes in the urban building with the E2 Ver or the E2 Inv glazing systems.

If it is used the E2 Inv glazing system, it is desirable to consider a south horizontal shading element, that can reduce significantly the cooling energy needs.

The large Trombe Wall (not ventilated) is needed in the villa, where it has to be predicted the removal of its glazing in summer. In the urban building it was possible to have a *Passivhauss* without this device.

Bragança results

In Bragança, the Ni and Nv values and the envelope impositions are also inadequate, in order to achieve the *Passivhauss* purposes.

The reference values reduce significantly the energy needs, but the solutions are very distant from the 15 kWh/m^2.year. Furthermore, in these recommendations, the U-value proposed for the glazing solutions obligates to introduce a double glazing solution.

To have a *Passivhauss*, it was needed to introduce 30 cm of thermal insulation (usual thickness in cold climates like in Germany – Castro, 2010), a 0.6 h^{-1} air renovation ratio, double glazing systems with reinforced thermal insulation and the usage of a radiant floor.

With the introduction of the radiant floor, it was possible to have a south horizontal shading element that reduced significantly the cooling energy needs in summer.

The introduction of dark colors in the roof could conclude that, despite their positive solar gains in winter, they not compensate the negative effects in summer. However, these colors applied to the exterior walls should be studied for each case isolated.

Évora results

The Évora results are very similar to the Lisbon ones, with some differences. First of all, the usage of light colors in the opaque envelope is indispensable, because of the warm summer.

On the other hand, since the winter is lightly colder, it is needed 9 cm of thermal insulation in the walls, instead of the 6 cm used in Lisbon, to construct a *Passivhauss*.

Hot Sanitary Waters results

Although there are some differences between the three climate regions, the results are very similar. Even so, as the solar radiation is higher in Évora, it is the region where the solar contribution is higher, after it is Lisbon, and, finally, Bragança.

The imposition area of $1m^2$/person in the regulation is adequate, because the gain of passing from 0.5 m^2/person to 1 m^2/person is very relevant, much more than passing from 1.0 to 1.5 m^2/person, which could not represent profitable economic investments.

The analysis of the three patterns of consumption, allied to a sensible analysis where it was studied the influence of the tank volume and its thermal insulation, could conclude that when the consumption is made in the morning it is needed a tank at least with the volume of consumption, very well thermo insulated. When the consumption is made in the afternoon, the thermal insulation looses importance.

This way it is needed a special design of the installation, according to the predictable patterns of consumption.

Energy Classes

The analysis of the energy classes of the solutions tested concludes that the energy class does not represent the passive performance of the building. In fact, there are several cases where the first solution (that does not satisfy the regulation in most cases) can have the same class of the *Passivhauss*.

This is the consequence of the importance given to the active equipments, where a simple variation of its efficiency modifies completely the energy class. Indeed, in the solution A, it is possible to pass from a D class to an A class, when using very efficient equipments.

Other electric consumption

The weight of all of the other electric equipments in the global electric consumption can vary from 50.31kWh/m^2.year to 30.57kWh/m^2.year. In other words, the simple usage of more efficient electric equipments corresponds to a 2506 kWh annual saving.

Referring the consumptions predicted in the SCE, it can be concluded that they can represent from 14% to 41% of the global electric consumption, when using usual equipments, and they can vary from 21% to 54% when using very efficient equipments.

Related to the other electric consumption, it can be concluded that the cooker is the principal electrical consumer. Furthermore, it is possible to save 420kWh/year when substituting the dryer for an adequate place for drying clothes. The substitution of the low consumption lamps with LED can reduce 83.4% of the lamps electric consumption (from 175 to 29kWh/year).

Micro generation

According to the Portuguese energetic mix, it is needed to locally produce 59.8% of the electricity consumed in order to have a carbon neutral solution. The worst case studied was the Solution A of the Bragança villa, equipped with usual equipments, which has a total consumption of 10893kWh/year.

Its corresponding *Passivhauss* with very efficient equipments has a consumption of 5676kWh/year. Thus, it is needed a local production of 6514 kWh/year in the first case and 3394kWh/year in the second one.

According to the software *RETScreen* and to the Roriz *et al*. (2010) recommendations, it is needed 14 photovoltaic units for the first case and 7 units for the second. These units have efficiency equal to 14.4%, 1.94 m^2 area, and they should be inclined with 35^o, with a south orientation.

This difference in the needed areas reinforces the importance to have lower consumption buildings.

Conclusions

The first conclusion to refer is that it is needed a review of the RCCTE methodology in Bragança zone, like Silva *et al.* (2009) concluded, so that the energy needs can be more precisely estimated.

Then, the solar gains of the opaque surfaces have some benefic effects during the winter and should be considered in RCCTE, especially when dark colors are used.

To finalize the methodology conclusions, the simplification adopted for the Trombe Walls does not faithfully represent the reality. Moreover, it is needed the study of a correct and simple calculation methodology to simple consider these devices in the design.

Referring the maximum regulation limits, they are simply accomplished, so they should be substantially reduced. In fact, as the solution G-E1 is very simple to achieve with common construction solutions, the corresponding values of Nic should be the maximum ones (Table 28).

In summer, the Bragança limit is easily satisfied in the three climates and produces *Passivhauss* solutions, so it should be adopted as the maximum Nv value – 18 kWh/m^2.year.

To achieve the solutions G-E1, it is needed to have the U-values used in this study, so they should be the maximum acceptable values (Table 29).

Table 28 – New Ni proposed

Solution	Ni (kWh/m^2.year)		
	Lisbon	Bragança	Evora
Villa (FF*=0.72)	44.15	79.53	54.57
Highest floor (FF*=0.63)	26.36	56.49	33.22
Intermediate floor (FF*=0.25)	15.11	34.36	19.41

* Form factor

Table 29 – New maximum U-values proposed

(U-W/m^2°C)

Envelope element	Climate zone		
	Lisbon (I_1)	Bragança (I_3)	Evora (I_1)
Exterior elements:			
Vertical opaque elements.........	0,45	0,27	0,45
Horizontal opaque elements.....	0,28	0,21	0,28
Interior elements			
Vertical opaque elements.........	0,52	0,52	0,52
Horizontal opaque elements.....	-(1)	-(1)	-(1)

(1) - they were not tested in this study

For the glazing solutions, as the reference values for the solar heating gain coefficient when the shading is 100% active for windows with an area bigger than 5% of the room that they are serving represent a great improvement comparing with the actual maximums, they should be the new maximum ones (V_2: Lisbon and Bragança – 0.20; V_3: Évora – 0.15).

Furthermore, the introduction of double glazing solutions represents a substantial reduction of the energy needs. As a maximum U-value of 3.30 W/m^2°C obligates to introduce this solution, it should be considered as a new maximum U-value for glazing solutions (a maximum that does not exist in the actual regulation).

The actual reference values are more adaptable to the summer situation than the winter situation. Thus, since they can be considered as the minimum quality a building should have, they should be maintained with the following substitutions (Table 30), in order to achieve *Passivhauss* buildings.

Table 30 – Substitutions proposed for the reference values

	Envelope element	Climate Zone Lisbon (I_1)	Evora (I_1)	Bragança (I_3)
U (W/m²ºC)	Exterior elements:			
	Vertical opaque elements.........	0.45	0.34	0.12
	Horizontal opaque elements.....	0.28	0.28	0.12
	Interior elements:			
	Vertical opaque elements..........	0.52	0.37	0.13
	Horizontal opaque elements.....	-(1)	-(1)	-(1)
	Glazing elements..........................	1.80	1.80	1.60
Air renovation ratio (h^{-1})	-	1.0	1.0	0.6
SHGC(1)	For windows with more than 5% of the room they are serving	0.10	0.10	0.10

(1) – Solar Heating Gain Coefficient with the shading 100% active

Although it is possible to build houses with low energy needs without using active systems, in Bragança it is recommended to introduce a radiant floor working with solar energy, so it should be referred in the regulation.

The part of the RCCTE concerning the hot sanitary waters is perfectly adapted to the Portuguese Climate, so it is not necessary any alteration.

On the other hand, the SCE is the energy classification of the buildings, but there is no reference to the other electric consumption, or indeed, to the micro generation (only possible when it is serving directly the sources of consumption predicted in the regulation).

Therefore, they should be considered, or introducing a "in service" certificate, where it could precisely calculate the total energy needs, or using a benefit factor for the micro generation.

Concerning about the energy class, it is possible to have a higher class with no adequate construction, so it does not well represent the passive design.

According to the exposed results, the actual SCE is transmitting to the market the idea of using efficient active systems, besides using an adequate construction, so, responding to the title question, the SCE (in the residential application) is not leading to the sustainability.

Besides all of these modifications in the RCCTE, it is needed a new way of calculation the energy class, giving much more weight to the passive performance. One possibility is to transform the ratio R=Nt/Ntc in a weighted average, like the exposed in the equation (1).

$$R = \frac{\frac{Ntc}{Nt} + \frac{Nic}{Ni} + \frac{Nvc}{Nv}}{3} \qquad (1)$$

Resuming the conclusions of this work, although the RCCTE and the SCE are not adapted to the recast of the Directive 2002/91/EC, they can be transformed into effective tools in the sustainable construction search, if they become more exigent.

In fact, this work illustrated some passive impositions that could be adopted in order to transform the actual regulation into a "guideline" for achieving passive design buildings.

Thus, these are some examples of steps that could be given in order to seek Strong Sustainable buildings, instead of the Weak Sustainable ones, focused in the actual EPBD Directive.

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