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EXTENDED ABSTRACT

EVALUATION OF COSTS ASSOCIATED WITH IMPROVING THE ENERGY CLASS OF SINGLE-FAMILY BUILTED HOUSES

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1 INTRODUCTION

In the current context in which any new or existing building for housing or services must have an energy certificate, with tax benefits being granted for owners of properties of energy class A and A +, it is important to identify the measures to improve the energy class of the property. In order to do that the improvement measures have to be characterised in terms of the required investment for their implantation, as well the return period associated to this investment. Another indicator of the efficiency of the improvement measures is the reduction in the energy bill.

The present work aims to analyse a number of improvement measures proposed by ADENE(1) and compare them with each other. Initially, a set of case studies was generated (buildings). A good quality envelope was considered for all cases in order to compliance with Portuguese Thermal Building Regulation, RCCTE(2). Improvement measures were applied individually for each case. Finally, a statistical analysis was performed on the energy class obtained, on the estimated cost of the investment, on the period of investment return and on the energy bill reduction achieved with each measure.

2 CHARACTERIZATION OF THE CASE STUDIES

The assessment of the costs associated with improving the energy class of single-family residential buildings will be conducted on a representative sample of 576 cases.

The buildings are located in the city of Guimarães, climatic zone I2 - V2 N, at an altitude below 600 m, with a distance to shore of more than 5 km.

In all cases studied, the same constructive solutions were assumed. It was considered a ceiling height of 2.60 m. To assess the effects of area and line thermal bridges, reinforced concrete structural elements (C25/30; A500NR) with an average span of 5 m were considered.

The RCCTE methodology was applied to all cases in order to obtain the energy rating for each case. The different cases were defined based on the variation of five parameters:

- Area of deployment;
- Number of floors;
- Configuration in plan;
- Solar orientation;
- Glazing area.

Given the current practice of architectural design and specialties, based on the application of traditional solutions in reinforced concrete building structures with masonry walls, were

(1) Energy Agency

(2) Regulation of the Characteristics of Thermal Performance of Buildings

advocated typified solutions for external walls, terrace roofing, flat thermal bridges, floors and glazing.

The linear thermal bridges were defined broadly based on the rules defined in RCCTE [1].
The maximum permissible values for the heat transfer coefficients are presented in Table 1 together with the reference values (more demanding) qualify for the automatic verification of the regulation in case of units with autonomous areas of floors with less than 50 m^2 [1].

Table 1 shows that the values of *U* adopted for the envelope are all significantly below the reference values which proves the excellent quality of the thermal envelope and indicates that high energy performance rating should be expected for the case studies.

The solar factor for glazing with more than 5% of the usable area of space for climate zone V2 and thermal mass of medium value is $g_{\perp} = 0.56$. The design value obtained is calculated as $g_{\perp} = 0.27$.

Table 1 - Maximum values and the reference of coefficient of thermal transmission and their comparison with values considered in the case studies (climate zone I2 [1])

Surrounding elements	Reference Values	Calculated values
External elements in the current zone:		
Opaque vertical zones	0.60	0.38
Opaque horizontal zones	0.45	0.32
Interior elements in the current zone:		
Opaque vertical zones	1.20	-
Opaque horizontal zones	0.90	-
Thermal bridges plane:		
Opaque vertical zones	0.76	0.65
Glazing ([3])	3.30	2.70

In case of favorable sunlight exposure and no significant obstruction, the use of solar collectors systems or other systems which make use of alternative renewable energy is a requirement of RCCTE [1].

Table 2 presents the values of solar energy to consider for each type of building according to the occupation by people.

[3] Average day-night (includes effect of protective device at night) for vertical or horizontal glazings always consider themselves as if installed in rooms unoccupied night.

Table 2 - Values of solar reference

Typology	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8
Nº of occupants $A_{colectores}$ (m^2)	2	3	4	5	6	7	8	9
E_{solar}^{ref} (kWh/ano)	724	1225	1702	2163	2619	3105	3578	4051

3 APPLICATION OF RCCTE TO THE CASE STUDIES

In this chapter the RCCTE is applied to the case studies considering the required parameters defined in section 2.

The aim of this first application is to evaluate the energy performance class of each case study, in order to define a set of possible improvement measures to implement.

Figure 1 presents the distribution of results obtained for a full check of RCCTE [1], i.e., for the simultaneous compliance with the conditions: $N_{ic} \leq N_i$; $N_{vc} \leq N_v$; $N_{ac} \leq N_a$; and $N_{tc} \leq N_t$. In overall, the percentage of cases of study that meets the RCCTE [1] requirements is 53%, which is a very low value taking into account the thermal quality of construction solutions.

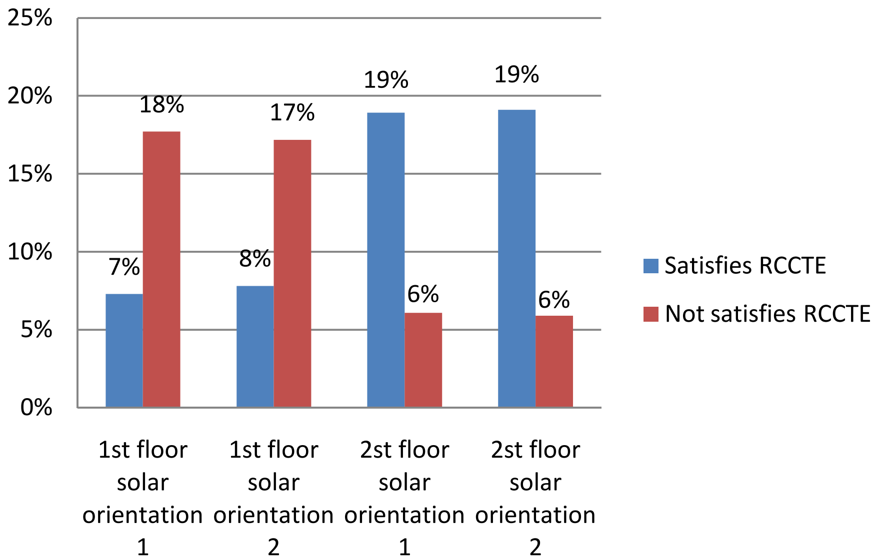

Figure 1 - Distribution of results for the full implementation of the RCCTE.

As this work aims to evaluate measures to improve energy performance to be applied to units that meet the requirements of the Building regulations, i.e., units that have an energy rating of at least B-, it is important to increase the sample size of satisfactory case studies.

Two measures to improve the envelope thermal quality were tested, combined in order to meet the limits of heating needs:

- To increase thickness of thermal insulation of facade walls in 4 cm for a total of 10 cm in order to reduce the heat transfer coefficient of the current zone to 0.27 W/m^{2}·ºC and flat thermal bridges for 0.38 W/m^{2}·ºC;

- To reduce heat transfer coefficient from glass to 1.70 W / m ^{2}· C, which can be achieved with double glazing 4+12+4 SGG CLIMAPLUS [2] with the negative consequence of reducing the solar factor of the glass , from 0.76 to 0.63 [2], i.e., the solar factor to consider on the glazing in the winter period is $g_{\perp} = 0.53$ and in the summer season is $g_{\perp} = 0.22$. The range of glass SGG CLIMAPLUS, more thermally efficient than the range SGG CLIMALIT initially considered, show a cost about 2 times higher (€ 42.93 /m^{2} compared to 22.50 € /m^{2}).

Figure 2Figure 2 presents the distribution of results on the overall satisfaction of RCCTE [1], i.e., for the simultaneous compliance with the conditions: $N_{ic} \leq N_i$, $N_{vc} \leq N_v$, $N_{ac} \leq N_a$, and $N_{tc} \leq N_t$. The percentage of satisfactory cases increased from 53 to 57%, which can be regarded as a marginal improvement.

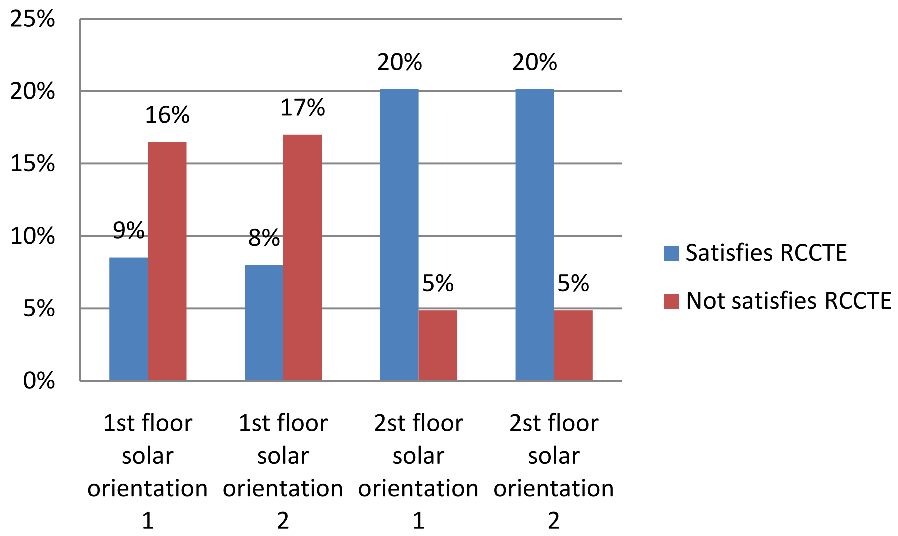

Figure 2 - Distribution of results for the simultaneous satisfaction of the conditions: $N_{ic} \leq N_i$, $N_{vc} \leq N_v$, $N_{ac} \leq N_a$, and $N_{tc} \leq N_t$.

Figure 3 shows the energy ratings distribution obtained for the case studies. It is observed that despite the high quality thermal envelope, it was difficult to verify RCCTE in its entirety, yielding a B- rating only for the satisfactory case studies.

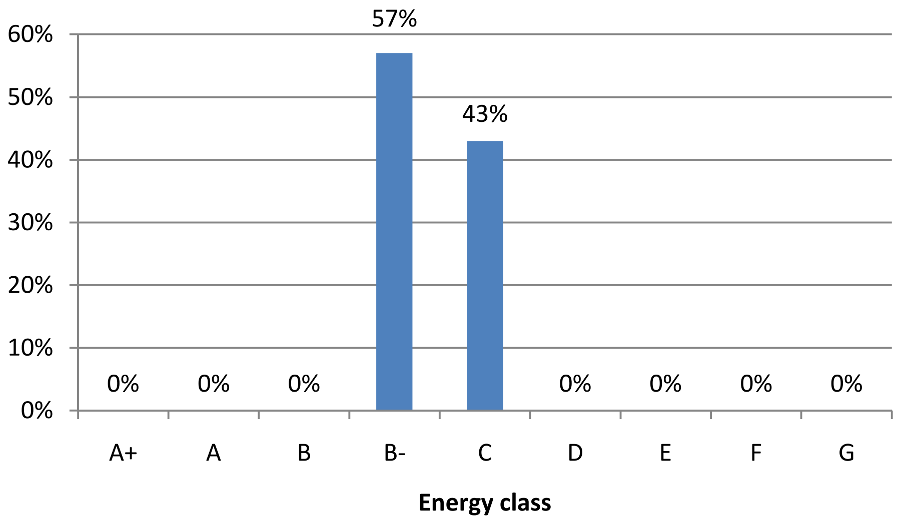

Figure 3 - Distribution of results for the energy rating.

Taking into account these difficulties, it was chosen to perform the analysis of the improvement measures, presented in Chapter 4, only for the satisfactory case studies, i.e., the sample size was reduced from of 576 the initial cases to only 331 case studies.

4 PRESENTATION AND ANALYSIS OF PROPOSALS FOR IMPROVING THE ENERGY PERFORMANCE OF BUILDINGS

In the scope of energetic certification of buildings, ADENE provides a list to qualified experts of standard measures to improve the energy class of buildings. From this list, which is very extensive, was selected a set of improvements to implement to the basic solution. As construction solutions used in the envelope of the case studies exhibit high thermal quality, improvement measures considered in this section focuses mainly on heating and cooling systems for cooling and to produce hot water.

Improvement proposals related to renewable energy are not included because the basic solution considers the use of solar collectors to capture energy as required by RCCTE [1], for new buildings.

In the following, the selected proposals for improving the energy performance, which will be subsequently applied to each case study are presented:

1. Proposal 1 - Installation of a false ceiling.
2. Proposal 2 - Replacement of existing equipment and / or installation of condensing boiler for environment heating.
3. Proposal 3 - Replacement of existing equipment and / or installation of individual air conditioning unit SPLIT reversible (heat pump) type *inverter* with energy class A for air conditioning.

4. Proposal 4 - Replacement of existing equipment and / or installation of individual air conditioning unit Multisplit reversible (heat pump) type *inverter* with energy class A for air conditioning.
5. Proposal 5 - Replacement of existing equipment and / or installing high-efficiency gas heater for preparation of sanitary hot water (SHW).
6. Proposal 6 - Replacement of existing equipment and / or installation of condensing boiler for SHW preparation.
7. Proposal 7 - Replacement of existing equipment and / or installation of mural gas boiler for SHW preparation.
8. Proposition 8 - Replacement of existing equipment and / or installation of diesel mural boiler for SHW preparation.
9. Proposal 9 - Replacing the existing equipment and / or installation of heat pump with high COP for SHW preparation.
10. Proposal 10 - Installation, on the facades, of permanent openings self-regulated.

5 ANALYSIS OF PROPOSALS FOR IMPROVING THE ENERGY CLASS

The analysis of the proposals for improving energy performance defined in section 4 shall be made according to separate vectors. Will be considerate the effective improvement of energy class but also the efficiency of the proposal in terms of gains made against the cost of investment. Since the current format of the Statement of Compliance and Energy Certificate considers the cost of investment and reducing the energy bill as a parameter for evaluating the measures to improve the energy class, the same option will be taken in this work. The reduction of the energy bill can be given by

$$\Delta C = C_{d,base} - C_{d,proposal} \ (€/year), \tag{5.1}$$

where $C_{d,base}$ e $C_{d,proposal}$ the deferred costs associated with the operation of the building (energy bill) during the reference year.

The deferred costs are calculated based on the cost of energy as a function of the energy source considered [3, 4], as shown in Table 3.

Table 3 – Cost of energy

Energy source	Cost (€/kWh)
Natural gas	0.064
Diesel	0.121
Electricity	0.130

Since the energy performance of the basic solution was evaluated based on standard systems for heating (electrical resistance) and cooling (heat pump) indoor air, the deferred costs associated with annual operating of the base solution are given by

$$C_{d,base} = \frac{N_{ic}}{\eta_i} \times A_p \times C_{u,i} + \frac{N_{vc}}{\eta_v} \times A_p \times C_{u,v} \ \ (€/year), \tag{5.2}$$

where the efficiency of the electrical resistance is unity and that of the heat pump is 3.0; and the unit cost of electricity consumed by both systems, $C_{u,i}$ and $C_{u,v}$ is 0.13 € / kWh (Table 3).
To evaluate the period of investment return it will be considered, in all cases studied, as actualisation rate of 5%.

6 DISCUSSION OF RESULTS

Table 4 is presented a summary of the results obtained with the application of each of the 10 measures considered to improve energy class.
For readability, results for the initial investment cost, reduced annual energy costs and the period of investment return are presented on the basis of the classification used in the model of Energy Certificate provided by Adene [4].

The analysis of Table 4 shows that the proposed 5 and 7, which lead to A + ratings with lower return periods of the initial investment are the most efficient. However, it is difficult to assess and compare the remaining measures. It can be noted that the proposal 1 is the one that leads to longer periods of investment return and that proposals 3, 5 and 10 are leading to lower return periods. Higher values of investment cost can be observed with proposals 1 and 4. The proposals 5, 7 and 10 are the cheapest to implement. Proposals 2 and 3 are those that lead to major reductions in annual energy bill and proposals 1 and 10 produce greater savings.

Finally, the proposals 5 to 9 allow an upgrade of energy classification of most cases or, in some cases, of all cases of B- to A +. Proposal 1 is the only one that does not allow any improvement of the energy rating. So, it is clear that proposal 1 is the one that produces the worst results, as expected for a measure intervening on the building envelope.

In order to compare the proposals for improving of energy performance more objectively a detailed summary of the results obtained with the application of each proposal is presented in Table 6.

Table 4 - Summary of results obtained with the implementation of improvement measures

Suggestions for improvement measures	Energy Class Rating	Estimated investment cost	Annual reduction of energy bill	Period of return on investment
1 Installation of a false ceiling	B-	●●●●	●	●
2 Replacement of existing equipment and / or installation of condensing boiler for environment heating	B	●●●	●●●●	●●●●
3 Replacement of existing equipment and / or installation of individual air conditioning unit SPLIT reversible (heat pump) type *inverter* with energy class A for air conditioning.	A	●●●	●●●●	●●●●
4 Replacement of existing equipment and / or installation of individual air conditioning unit Multisplit reversible (heat pump) type *inverter* with energy class A for air conditioning.	A ou B	●●●●	●●●●	●●●●
5. Replacement of existing equipment and / or installing high-efficiency gas heater for SHW preparation	A+	●●	●●	●●●●
6 Replacement of existing equipment and / or installation of condensing boiler for SHW preparation	A+	●●●	●●	●●●
7 Replacement of existing equipment and / or installation of mural gas boiler for SHW preparation	A+	●●	●●	●●●
8 Replacement of existing equipment and / or installation of diesel mural boiler for SHW preparation	A+	●●●	●●	●●
9 Replacing the existing equipment and / or installation of heat pump with high COP for SHW preparation	A+	●●●	●●	●●●
10 Installation, on the facades, of permanent openings self-regulated.	B	●●	●	●●●●

Table 5 - Classification used by ADENE [4]

Annual reduction of energy bill	Estimated investment cost	Period of return on investment
●●●● more than 999 €	●●●● more than € 4999	●●●● less than 5 years
●●● between 499 and 999 €	●●● between 999 and 4999 €	●●● 5 to 10 years
●● 100 to 499 €	●● between 200 and 999 €	●● 10 to 15 years
● Less than 100 €	● less than 200 €	● more than 15 years

Now, applying the classifications listed in Table 7 to the distribution percentages given inTable 6, we obtain Table 8, where each of the parameters of Table 4 is sorted numerically.

Assigning now a weight to each of the evaluation parameters considered in Table 8 it is possible to order the proposals of energy class in an objective way. Since the choice of weights can significantly conditionate the final ranking of proposals, the two distributions indicated in Table 9 are considered, which favor the energy rating achieved and the period of investement return of initial investment. The first distribution gives the same weight (50%) for energy rating and the parameters related costs. In the second distribution, a weight of only 40% is assigned to the energy rating in order to evaluate the sensitivity of the weighting method.

Table 6 – Detailed summary of results from the implementation of improvement measures

Distribution of profit (%)	Class				Investment cost (€)				Reduced annual energy costs (€/year)				Return Period (years)			
Proposal	A+	A	B	B-	< 200	200 a 999	1000 a 4999	≥ 5000	< 100	100 a 499	500 a 999	≥ 1000	< 5	5 a 10	10 a 15	≥ 15
1	-	-	-	100	-	-	39	61	100	-	-	-	-	-	-	1
2	-	-	100	-	-	-	100	-	-	-	26	74	100	-	-	-
3	-	73	27	-	-	-	62	38	-	-	1	99	100	-	-	-
4	-	55	45	-	-	-	45	55	-	-	2	98	100	-	-	-
5	94	6	-	-	-	100	-	-	-	100	-	-	100	-	-	-
6	100	-	-	-	-	-	100	-	-	100	-	-	17	83	-	-
7	100	-	-	-	-	100	-	-	-	100	-	-	71	29	-	-
8	100	-	-	-	-	-	100	-	29	71	-	-	-	43	55	2
9	100	-	-	-	-	-	100	-	-	100	-	-	-	71	29	-
10	-	-	100	-	29	71	-	-	56	44	-	-	99	1	-	-

Table 7 - Assignment of ratings to results

Classifications	Energy class	Investment cost (€)	Reduced annual energy costs (€ / year)	Return Period (years)
100	A+	< 200	≥ 1000	< 5
60	A	200 - 999	500 - 999	5 - 10
40	B	1000 - 4999	100 - 499	10 - 15
20	B-	≥ 5000	< 100	≥ 15

Table 8 - Summary of ratings

Proposals	Energy Class	Investment cost (€)	Reduced annual energy costs (€ / year)	Return period (years)
1	20.0	27.8	20.0	20.0
2	40.0	40.0	89.6	100.0
3	54.6	32.4	99.6	100.0
4	51.0	29.0	99.2	100.0
5	97.6	60.0	40.0	100.0
6	100.0	40.0	40.0	66.8
7	100.0	60.0	40.0	88.4
8	100.0	40.0	34.2	48.2
9	100.0	40.0	40.0	54.2
10	40.0	71.6	28.8	99.6

Table 9 - Distribution of weights for each evaluation criteria

Weights (%)	Energy Class	Investment cost (€)	Reduced annual energy costs (€ / year)	Return period (years)
1 st distribution	50	10	10	30
2 nd distribution	40	15	15	30

Finally, Table 10 shows the final sorting of the proposals for improvement of the energy class obtained with both weighting methods.

It is observed that the final ranking shows some sensitivity to the weighting method (some proposals exhibit a difference in ordering of two positions). However, one might conclude that proposals 5 and 7 are always the most efficient and that proposals 2, 10 and 1 are always, respectively, in 8th, 9th and 10th place in the standings. The proposal 6 is always the 3rd most efficient and the proposals 3 and 9 are equivalent, being ranked in 4th place. Finally, proposals 4 and 8 are equivalent and are also ranked in 6th place in terms of efficiency.

Table 10 - Final ordering of proposals of improving the energy class

Proposals	Classification		Position		
	1st distribution	2nd distribution	1st distribution	2nd distribution	Average
1	20.78	21.17	10th	10th	10th
2	62.96	65.44	8th	8th	8th
3	70.50	71.64	6th	4th	4th
4	68.32	69.63	7th	5th	6th
5	88.80	84.04	2nd	1st	1st
6	78.04	72.04	3th	3th	3th
7	86.52	81.52	1st	2nd	1st
8	71.88	65.59	5th	7th	6th
9	74.26	68.26	4th	6th	4th
10	59.92	60.94	9th	9th	9th

7 CONCLUSIONS

The study conducted was aimed at the characterisation and comparison of measures to improve the energy performance of buildings.

A sample of 576 case studies corresponding to single-family houses for 2 a 9 people was considered. The statutory method of assessment of indicators of energy performance was applied and proved that despite the building envelope exhibit a high thermal quality, 47% of the case studies did not meet regulatory requirements, particularly due to excessive heat loss in the cold season. With the aim of improving the rate of compliance with RCCTE [1], some measures to improve the envelope were tested, particularly in terms of roofing and the glazing. Since, as noted earlier, the thermal quality of the original solution was high, the rate of compliance with

RCCTE [1] improved from 53 to 57%, which is still a very low value. These results illustrate a problem that often arises and that relates to the difficulty of complying with RCCTE [1] in single-family houses, especially when they have a single floor, due to the influence of heat losses by elements in contact with the ground. Since this problem was not in the scope of the present work, a set of 10 measures to improve energy class was tested only in satisfactory cases, which presented energy class B- (or higher). Therefore, 3310 tests were performed improvement measures based: on the quality of the thermal envelope (Proposition 1); on the production of SHW (Proposal 5 to 9); and on the control of natural ventilation (Proposal 10).

The results show that intervention in the production systems of SHW is far more efficient in terms of producing an excellent energy rating (A +) with a rapid return of investment.

The measures associated with the envelope or ventilation are less efficient.

8 REFERENCES

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