378: Relating Energy Indicators of Regulations to Passive Comfort in Residential Buildings

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Abstract

In most European regulations the thermal performance of the buildings is expressed mainly in terms of energy needs or energy consumption. This is the case of the Portuguese regulation. However, in the Mediterranean area and in temperate climates as in Portugal, given the mild climate and the tradition, it is not usual to control in a permanent way the indoor temperature (by heating or, even less, by cooling) of residential buildings. Even in colder climates the concept of passive house keeps gaining momentum and is often seen as the future standard. It is therefore necessary to develop alternative or complementary indicators to provide the end-user with an evaluation of the performance of the building in a more 'passive tonality', directly related to thermal comfort rather than to energy. This study tries to correlate the results of the energy needs assessed by the calculation method used by the Portuguese regulation RCCTE with the indoor temperatures in free-float mode assessed by dynamic simulation with the software ESP-r and draw conclusions.

Keywords: energy in buildings, thermal comfort, passive houses regulations

1. Introduction

The use of energy in buildings in Portugal has been increasing significantly for the past two decades, and the use of energy for climatization takes an important share in this process. The growth of energy use for climatization will continue if effective measures are not taken at all levels to control it. One of the tools with a potentially crucial contribution for the control of this is the new Energy Certification Scheme, induced by the EPBD, and its associated Portuguese regulations RSECE and RCCTE (decree-laws DL 78, DL 79 and DL80 / 2006 respectively) [1].

The regulation RCCTE is aimed essentially at residential and small commercial buildings, and it contains an underlying assumption that these buildings should be mainly passively climatized, although it may be admissible the existence of small mechanical auxiliary systems, especially for heating. The regulations are based upon the calculation of the energy needs for heating, cooling and energy domestic hot water. While this provides an effective tool for integrating the effects of the different energy-balance components, it also has some weak points for which it would be worth to explore solutions. On the one hand, the fact that one of the parameters of the energy performance is expressed as energy needs for cooling could be misinterpreted as supporting the current idea that the need for air-conditioning in housing buildings in Portugal is something unavoidable or, at least, very natural. On the other hand, the calculation is made with a simplified method for nominal conditions. It is assumed that the indoor temperature is kept always over 20ºC in winter and below 25ºC in summer, while in fact such a strict assumption cannot be adjusted to the reality of those buildings as they don't have an indoor climate controlled by systems. Moreover, it ignores the fact of the growing acknowledgment that temperatures below or above that band are often compatible with the highest comfort requirements according to the so called adaptive comfort model, which was formally included as the criteria of thermal comfort for naturally conditioned spaces in the ASHRAE standard 55-2004 [2].

2. Case-studies

The study relies upon the analysis of a comprehensive set of buildings. The set was chosen to include different building typologies, so it ranges from apartments to fully detached dwellings, including semi-detached dwellings as well. The buildings were chosen to represent different quality levels: some fulfil the regulation almost at the limit, while others have very low energy demand.

Sub-chapters 2.1 to 2.7 present a short description of each case-study, while table 1 shows a summary of their main characteristics.

2.1 Case Study 1: Detached dwelling

Single-family dwelling with 2 floors being built in Marco de Canaveses, North of Portugal. The dwelling has 3 sleeping rooms and a useful floor area of about 150 m^2. The most glazed façade faces Northwest.
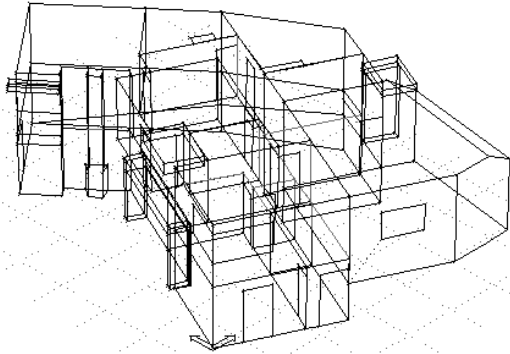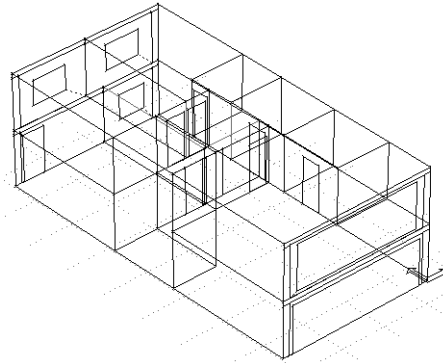
Fig 1.Case study 1: Detached dwelling.

2.2 Case Study 2: Apartment building

The case study nr.2 is the ground-floor of an apartment building, which comprises two one-bedroom apartments and two two-bedroom apartments. It is located in Lisbon. Apartments are oriented towards Northeast, and two others towards Southwest.
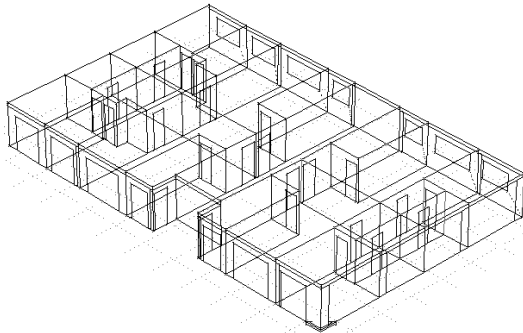

Fig 2. Case-study 2: Apartment building

2.3 Case study 3: Semi-detached dwelling

Semi-detached dwelling with 3-bedrooms and a useful area of 187 m^2. The external façades are the smaller ones and are oriented towards East and towards West.
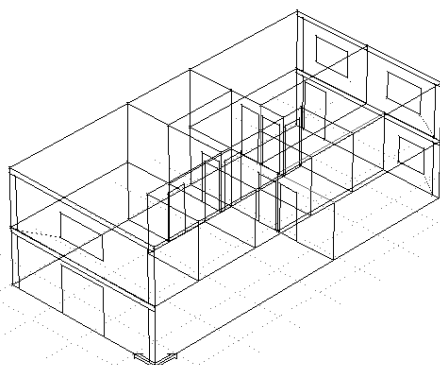

Fig 3.Case-study 3: Semi-detached dwelling

2.4 Case Study 4: Efficient variant of the semi-detached dwelling

This case-study is a variant of the case-study 3 some changes made in order to make it more efficient. The biggest changes were a rotation to put one of the external façades directly oriented

Fig 4. Case-sudy 4: Efficient variant of the semi-detached-dwelling

towards South, increase the glazed area in this façade, and better insulation in all the external envelope. The double glazing was replaced by triple glazing.

2.5 Case Study 5: Detached dwelling

Single-family detached dwelling with 5 bedrooms. The dwelling has 266 m^2 of heated floor area and is located in Trofa, North of Portugal.
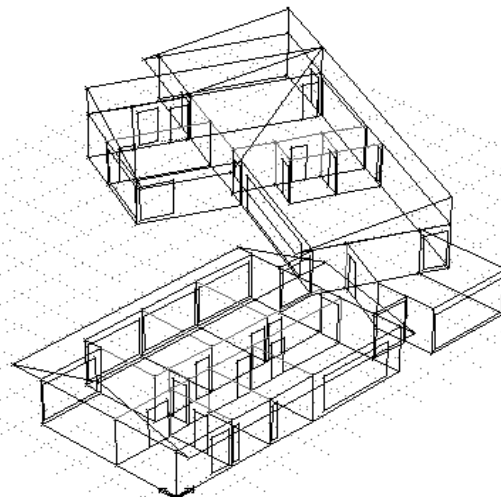

Fig 5: Case-study 5: Detached dwelling

2.6 Case Study 6: Passive House

This case-study was chosen after the results from the previous case-studies suggested the need to analyse more very-low energy houses. This house was built in the early 80's as a "Thermally Optimized House" and is still today used for educational visits. It is located in Porto and has three bedrooms and two floors. The main façade is oriented towards South, and is extensively glazed (including two trombe walls).

Although the good passive performance of the house was confirmed by monitoring [3], the calculation method used to account for thermal bridges (linear coefficient method,) ends up attributing a high loss though the ground and thus this case-study did not achieve the initial objective of representing a very low energy building.
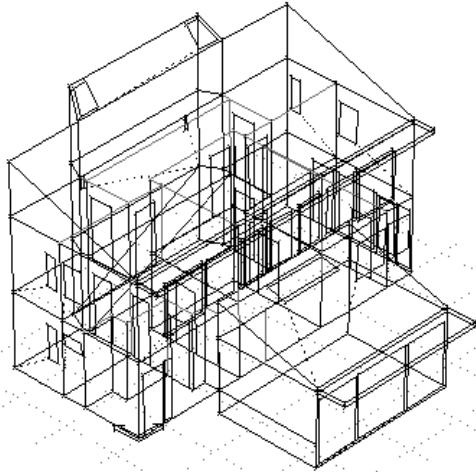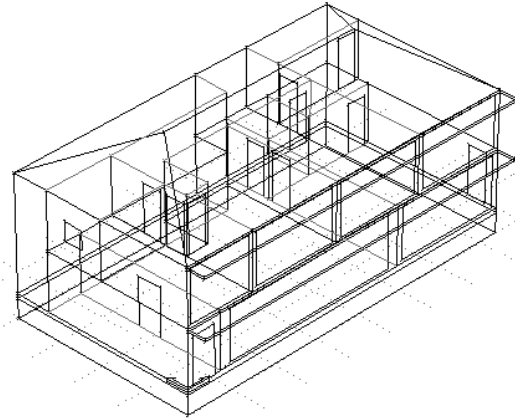
Fig 6. Case-study 6: Thermally optimized house

Fig 7.Case-study 7: very-low energy dwelling.

2.7 Case Study nº7: Very low energy dwelling.
This case-study is a virtual building, designed to be thermally optimized and thus represent a very--low energy building. As case-study number 6, it has the main façade oriented towards South and extensively glazed, with proper external solar protection for summer. However, to avoid the high thermal loss by thermal-bridge effect through the ground, it is built over a small empty buffer-zone. This building was studied in three different locations of the country, in an attempt to achieve more data points in the very low energy zone. Given the relatively small size of the country, no constructive changes were considered between the three locations.

All the buildings are studied as built according to standards superior to the current Portuguese regulation RCCTE. The U-values of the walls range between 0.6 W/m^2.K (currently typical of new construction and about 0.2 W/m^2.K (extremely unusual in Portugal; used for very low energy buildings). The glazings are double (usual) or triple (very low energy buildings) and typically have external Venetian blinds.

3. Methodology
For each building, the following analysis steps were taken:
 i) Characterization of the house in term of heating and cooling needs, with the methodology of the RCCTE (Portuguese thermal regulation for residential buildings);
ii) Characterization of the heating and cooling needs through detailed simulation with the dynamic simulation software ESP-r [4];
iii) Characterization of the hourly indoor temperatures throughout the year in free-float mode through detailed simulation with ESP-r.

When analysing with ESP-r, linear thermal bridges were accounted for in the same way as in the Portuguese regulation RCCTE, through the linear coefficient method. Regarding the position of the solar shading devices, in the detailed simulation it was considered that they are usually not active (i.e., rolled up) but if the indoor temperature is higher than 24.5ºC then it becomes active (rolled down). It is also considered rolled down during the night, which is the usual pattern and offers additional protection against night thermal losses.

Table 1: Main characteristics of the case-study buildings

Case Study	Net floor area (m^2)	External wall area (m^2)	Wall U-value (W/m^2.K)	Roof area (m^2)	Roof U-value (W/m^2.K)	Window area (m^2)	Window U-value (W/m^2.K)	Shape factor*	Climate HDD**
CS_1	150.4	109.3	0.44	80.1	0.40	27.5	3.3	0.74	1770
CS_2: T1-A	53.5	21.1	0.57	0.0	-	10.8	3.1	0.76	1190
CS_2: T1-B	53.5	23.5	0.57	0.0	-	7.0	3.1	0.75	1190
CS_2: T2-C	68.1	12.6	0.57	0.0	-	9.0	3.1	0.66	1190
CS_2: T2-D	68.1	9.1	0.57	0.0	-	14.4	3.1	0.67	1190
CS_3	187.4	41.5	0.44	96.6	0.46	10.6	3.5	0.33	1610
CS_4	187.4	24.4	0.20	96.6	0.20	27.7	1.1	0.33	1610
CS_5	265.6	92.0	0.57	265.6	0.44	79.9	2.9	0.75	1670
CS_6	137.1	129.9	0.58	84.5	0.61	27.7	2.5	0.72	1610
CS_7- Lisbon	221.3	132.5	0.19	120.0	0.19	57.3	1.1	0.73	1190
CS_7 – Faro	221.3	132.5	0.19	120.0	0.19	57.3	1.1	0.73	1060
CS_7–Bragança	221.3	132.5	0.19	120.0	0.19	57.3	1.1	0.73	2850

* External surface area to volume ratio [1].   ** HDD- Heating Degree-Days

4. Results and analysis.

Table 2 shows the main results for each of the analysed case-studies, considering:

- The heating energy needs as computed by the national regulation method (N_{IC} RCCTE);
- The heating energy needs as computed by the dynamic simulation with ESP-r (N_{IC} ESPr);
- The percentage of time when the weighted temperature indoors is higher than the minimum comfort set-point (T_{min}) determined by the adaptive model according to the standard ASHRAE 55-2004.
- The cooling energy needs as computed by the national regulation method (N_{VC} RCCTE);
- The cooling energy needs as computed by the dynamic simulation with ESP-r (N_{VC} ESP-r);
- The percentage of time when the weighted temperature indoors is lower than the maximum comfort set-point (T_{max}) determined by the adaptive model according to the standard ASHRAE 55-2004.

4.1 Accuracy of the calculation method of RCCTE

Figure 8 shows a plot of the heating needs as computed with the simplified method of RCCTE vs those obtained through detailed simulation with ESP-r. The relationship clearly approaches a linear pattern, with an r^2 value of 0.96. The plot also shows that the results computed by the simplified method are about 20% above those computed by ESP-r (slope 1.197). A more detailed analysis has later shown that these differences occur mostly at the levels of the internal and solar gains. This might be because in the detailed simulation dynamic patterns were used for both, while in the simplified method of RCCTE the internal gains and the position of the solar protections are constant. Thermal bridges did not contribute to cause any difference since they were accounted by the linear coefficient method in both cases.

The same type of comparison between RCCTE and ESP-r results was done for the cooling needs, with the results shown in figure 9. The values of the cooling needs are much lower than those of the heating needs, and the linear pattern of the correlation is much less apparent than for the heating needs. The main reason for the differences observed is, again, the fact that in ESP-r the solar protection devices have dynamic patterns, while in the RCCTE they are constant. The fact that ESP-r makes a dynamic treatment of the storage also emerges as a source of differences.
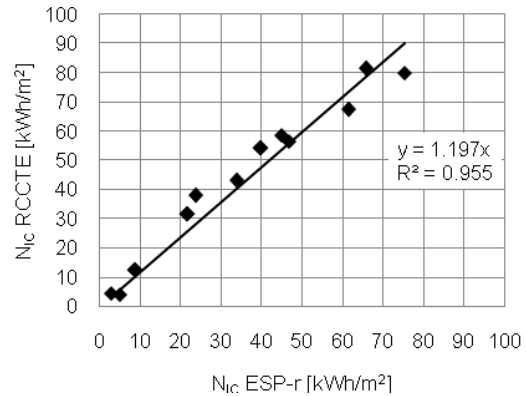
Fig 8. Heating needs calculated by RCCTE vs heating needs calculated with ESP-r
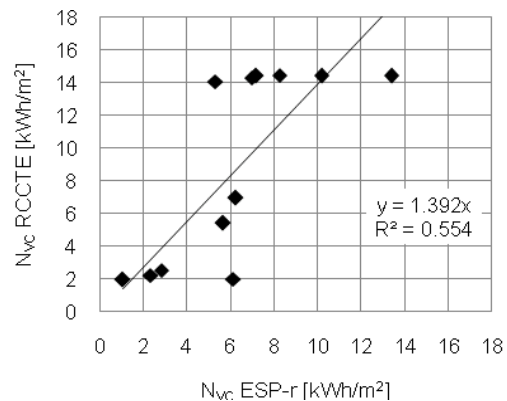
Fig 9. Cooling needs calculated by RCCTE vs cooling needs calculated with ESP-r

Table 2: Main results of the case-studies

Case Study	N_{IC} ESP-r	N_{IC} RCCTE	$T > T_{min}$ ESP-r ff*	N_{VC} ESP-r	N_{VC} RCCTE	$T < T_{max}$ ESP-r ff*
CS_1	75.3	79.9	28 %	2.3	2.3	99 %
CS_2: T1-A	44.9	58.6	27 %	8.3	14.5	97 %
CS_2: T1-B	33.7	43.1	38 %	5.3	14.1	99 %
CS_2: T2-C	39.7	54.2	26 %	7.2	14.5	98 %
CS_2: T2-D	23.6	38.0	51 %	7.0	14.3	99 %
CS_3	46.6	56.6	28 %	1.0	2.0	100 %
CS_4	8.7	12.3	83 %	6.2	7.0	99 %
CS_5	65.8	81.5	29 %	2.8	2.5	99 %
CS_6	61.4	67.4	37 %	6.1	2.0	99 %
CS_7 – Lisboa	4.9	4.0	96 %	10.2	14.4	98 %
CS_7 – Faro	2.7	4.5	96 %	13.4	14.4	96 %
CS_7 – Bragança	21.7	31.7	69 %	5.6	5.5	98 %

* ff stands for "free-float".

4.2 Passive comfort vs. energy in Winter

4.2.1 ESP-r free-float vs ESP-r climatized.

Figure 10 compares an indicator of passive comfort with an indicator of energy demand. The x-axis represents the heating energy needs computed with ESP-r to maintain the buildings at 20ºC. The y-axis represents the % of hours in the winter season when the temperature indoors is higher than the minimum comfort temperature computed by the adaptive model (ASHRAE 55 standard).

The first conclusion is that to achieve high percentage of time with comfort in fully passive mode it is necessary to bring the heating energy needs in climatized more down to values lower than 20 or even 10 kWh/m^2.year.

It is possible to see that the relation does not seem to be linear, and in fact the linear fitting yielded a low correlation coefficient of r^2=0.76. It was thus decided to try a relation of the type:

$$y = a^{-bx} \qquad (1)$$

Such an equation respects the expected physical limits of the problem. The adjustment though the minimum-square differences revealed the best fitting with a= 1.04 and b=0.56, thus yielding

$$y = 1.04^{-0.56x} \qquad (2)$$
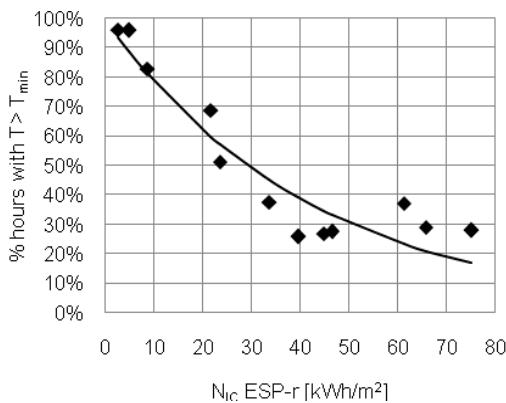
With a correlation coefficient r^2=0.92.

Fig 10. % hours with T> T_{min} (from ESP-r) vs heating needs in the heating season (ESP-r)

4.2.2 ESP-r free-float vs. RCCTE.

Even if a good correlation for the comparison of the ESP-r free-float vs. ESP-r climatized mode was achieved, in practice the indicator that exists for most buildings is the heating needs calculated by the RCCTE method and not a detailed simulation. It is therefore necessary to correlate the results of detailed simulation in free-float mode with the analysis of RCCTE to see if a relationship may still be established. This exercise is done in figure 11. Using the same procedure described above for the ESP-r vs. ESP-r comparison, the best-fit parameters found are a=1.05 and b=0.37, thus leading to the correlation equation:

$$y = 1.05^{-0.37x} \qquad (3)$$
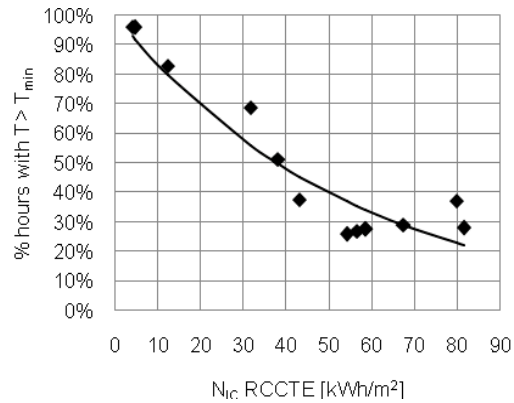
The corresponding correlation coefficient is r^2=0.84.

Fig 11. % hours with T> T_{min} (from ESP-r) vs heating needs in the heating season (RCCTE)

4.3 Passive comfort vs. energy in Summer

4.3.1 Importance of natural ventilation in Summer

The calculation of the cooling energy in the RCCTE is made considering a constant air change rate, which for natural ventilation, although depending on the building specific location and characteristics, is usually close to 1.0 ach^{-1}. The same constant air change rate was used in the calculation of the energy needs with ESP-r. However, when analysing the building in the perspective of fully passive comfort, it is important to consider the effects of free-cooling through increased ventilation due to open windows, e.g. at night. Thus in the free-float mode in summer it was considered that when the indoor temperature is higher than 25ºC and the outdoor temperature is lower, some windows open to allow natural free-cooling. This effect was modelled in ESP-r through an air flow network [5,6]. Figure 12 shows the effect of window opening the average air change rate in a zone of case-study 3.
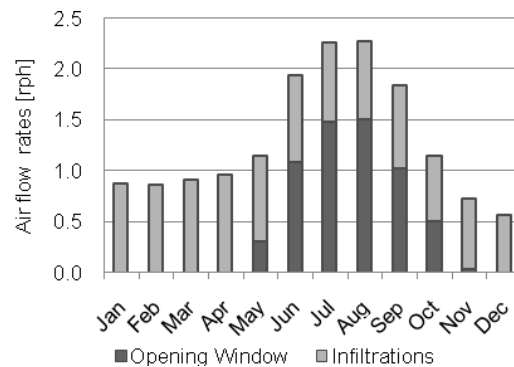

Fig 12. Average air change rate for case- study one in the free-float analysis.

4.3.2 Passive comfort vs cooling needs

Figures 13 shows the relationship obtained between the free-float assessment (% of hours below threshold of adaptive comfort) and the cooling energy computed by detailed dynamic simulation (ESP-r) in climatized mode for the summer season. Figure 14 shows similar results but comparing with the cooling needs computed by the RCCTE method instead of comparing with the dynamic simulation.

The results show in the first place that, in the residential sector, adopting the criteria of the adaptive comfort and considering good solar protection devices and the usual procedure of free/night cooling, the fraction of time when the comfort is not assured is very low (less than 4% of the time). This is a clear indicator that the massification of air-conditioning in the residential sector in Portugal can only be justified based on severe design mistakes or on market moods.

In terms of correlation passive vs energy, a reasonable relationship is found when comparing ESP-r free float vs. ESP-r climatized, but the correlation ESP-r free-float vs RCCTE is very poor. The effects of free-cooling ventilation discussed in section 4.3.1 play a fundamental role in explaining these discrepancies.
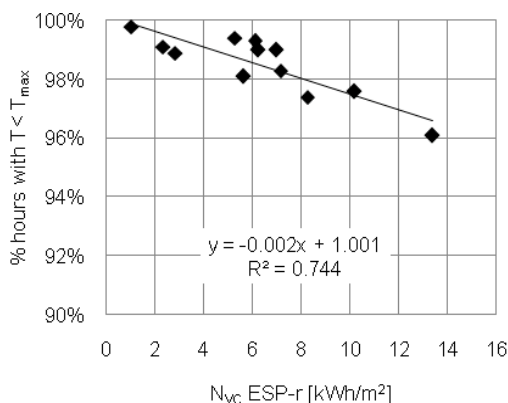

$$y = -0.002x + 1.001$$
$$R^2 = 0.744$$

Fig 13. % hours with T> T_{max} (from ESP-r) vs cooling needs in the cooling season (ESP-r)
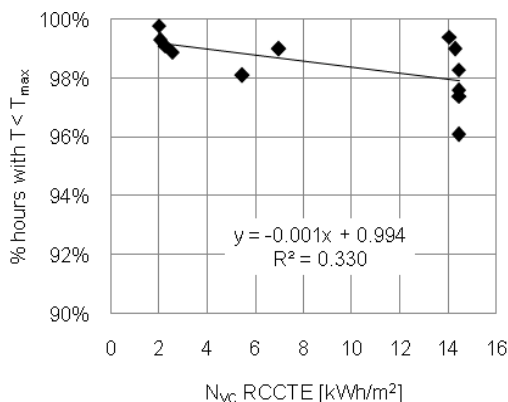

$$y = -0.001x + 0.994$$
$$R^2 = 0.330$$

Fig 14..% hours with T> T_{max} (from ESP-r) vs cooling needs in the cooling season (RCCTE)

5. Conclusions

The results of this work showed in the first place that the heating needs obtained by the simplified method used in the Portuguese national regulation RCCTE correlate well to those obtained by detailed dynamic simulation with ESP-r. The same was not observed for the cooling needs, where significant discrepancies and non-linearity were found. The values of the cooling needs are however typically much lower than those of the heating needs.

Regarding the possibility to develop passive comfort indicators based on the current method of RCCTE, it seems that such approach may be possible for the winter season. A relationship of the type $y=a^{-bx}$ (eq. 1) seems to yield good results, although more case-studies are need to build strong statistical relevance. It was also interesting to note that apparently the percentage of time when comfort is assumed in free-float mode only goes above 80% when the heating needs in climatized mode are lower than 10 $W/m^2.K$.

Regarding the summer season, the results are not encouraging in terms of the possibility to establish a relationship between comfort in fully passive mode and the cooling needs in climatized mode. However, it seems that if the regulations are strong enough to avoid severe design mistakes, the problem of cooling can be cut by the root, ensuring more than 96% (or even 98%) of time with indoor comfort.

6. Acknowledgements

7. References

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