ACCURACY OF SOME EPBD IMPLEMENTED THERMAL PERFORMANCE CALCULATION PROCEDURES

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Keywords: energy, simulations, regulations, EPBD

Summary

The driving force of the thermal regulations revision in the European Union (EU) was the European Directive for the Energy Performance of Buildings – EPBD (European Commission, 2003). The main objectives of the EPBD are the harmonization of all thermal regulations in the EU and the optimization of buildings energy performance, taking into account the climatic conditions, indoor comfort conditions and economic viability, for both new and existing buildings.

In order to be efficient and effective, the thermal regulations must lead to an accurate estimation of the energy performance of buildings allowing the energy certification to become a useful tool to compare results obtained in different countries. Having this fact in mind, the results obtained with the Portuguese calculation methodology, together with the results obtained with the methodologies used in two other countries (UK and Belgium), will be put side by side and also compared with the results obtained with a dynamic simulation tool for the energy performance estimation - VisualDOE.

This case study will be based on the heating and cooling needs estimation of some Test Cells built in the School of Engineering of the University of Minho. The simulated results obtained using the simplified calculation models established in the mentioned three countries thermal regulations and by VisualDOE.

1. Introduction

One of the main challenges that nowadays humankind has to face is the climatic changes and environmental depletion. It is known that these challenges are closely related to the energy consumption. In the EU 15, there are about 164 million buildings, responsible for 40% of the final energy demand and 1/3 of the greenhouse gas emissions. So, in order to promote the reduction of energy consumption, it is fundamental to apply sustainable development principles in the construction sector (Tzikopoulos et al, 2005; Eyckmans and Cornillie, 2002).

There are several measures that can be applied in order to reduce the buildings energy consumption, since the appeal of the consumers' consciousness to environmental problems, to the development of new construction solutions, more energy efficient.

One of the larger impact measures is the implementation of more restrictive thermal regulations. One of the new Portuguese thermal regulations, the RCCTE 2006, is applied to residential buildings and imposes a higher quality of the envelope, promotes the use of renewable energy and supports the use of certified materials.

The driving force of the thermal regulation revision was the European Energy Performance of Buildings Directive (European Commission, 2003). The main objectives of the EPBD are the harmonization of all thermal regulations in the European Union and the increase of buildings energy performance, taking into account the climatic conditions, indoor comfort and economic viability, for both new and existing buildings.

All the EU thermal regulations have methodologies that can, effectively, estimate the energy performance of standard buildings allowing a much more energy efficient design and thus an effective reduction of the energy consumption. The harmonization of methodologies and the subsequent building energy certification can allow comparing the European building stock in a more effective way.

The goal of this paper is to assess and compare different European thermal regulation methodologies, based on the EPBD. Three methodologies were applied to estimate the heating and cooling needs of a case study: the Portuguese (RCCTE, 2006), United Kingdom (SBEM, 2007) and Belgium – Walloon Region

(CWATUPE, 2007) thermal regulations. The heating and cooling needs were also determined by means of a dynamic simulation tool – VisualDOE – in each climate (Portugal, United Kingdom and Belgium). The case study used was the Test Cells built in the School of Engineering of the University of Minho, Portugal.

2. Building description

The Test Cells used in this study have three compartments: a Sustainable Test Cell (STC), a Conventional Test Cell (CTC) and a Passys Test Cell (PTC). However, this study focuses only the STC and the CTC, in order to guarantee that the Portuguese, the Belgium and the United Kingdom thermal regulations calculation methodologies can estimate with good accuracy the thermal behaviour of both conventional and non-conventional solutions.

2.1 Sustainable Test Cell

The Sustainable Test Cell (STC) contains two rooms (Figure1):

- Room 1 (simulates a bedroom) – It has a massive envelope with compacted earth walls (Goodhew & Griffiths, 2005) and an opening in the south façade. The high thermal inertia combined with an opening equipped with exterior horizontal and vertical shading devices - in order to avoid overheating in summer - is a passive solar technique. To improve the sustainability of the solution, the room' exterior walls were built with a locally available material - earth;
- Room 2 (simulates an office) – It is an insulated lightweight construction with a large opening in the north façade in order to promote the daylighting and thus reduce the energy consumption in lighting.

Between the two rooms of this Test Cell there is a movable partition that allows testing the performance of the whole Test Cell space or of the two distinct rooms (Silva, 2006).

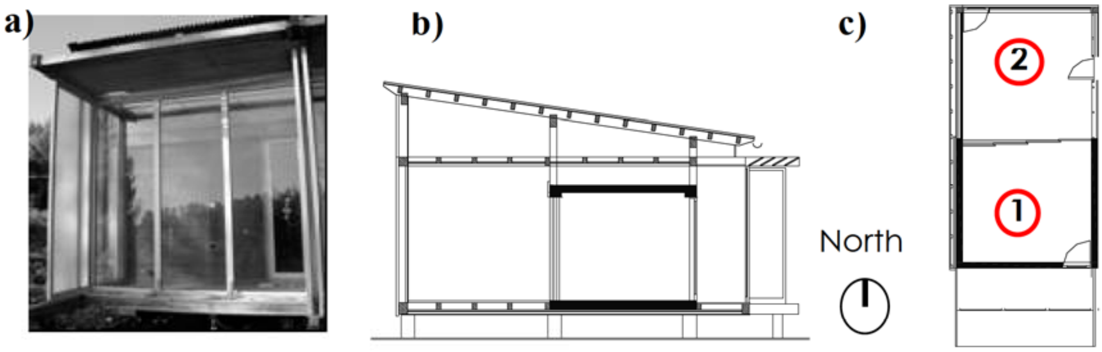

Figure 1 Sustainable Test Cell: a) Photo; b) lateral view; c) plan view

2.2 Conventional Test Cell

The Conventional Test Cell (CTC), shown in Figure 2, contains three rooms: the room 1 simulates a bedroom; room 2 simulates a bathroom; room 3 simulates a hall. The CTC was built with a double pane hollow brick wall with extruded expanded polystyrene in the air gap. This Test Cell is representative of the conventional Portuguese Construction (Mendonça, 2003).

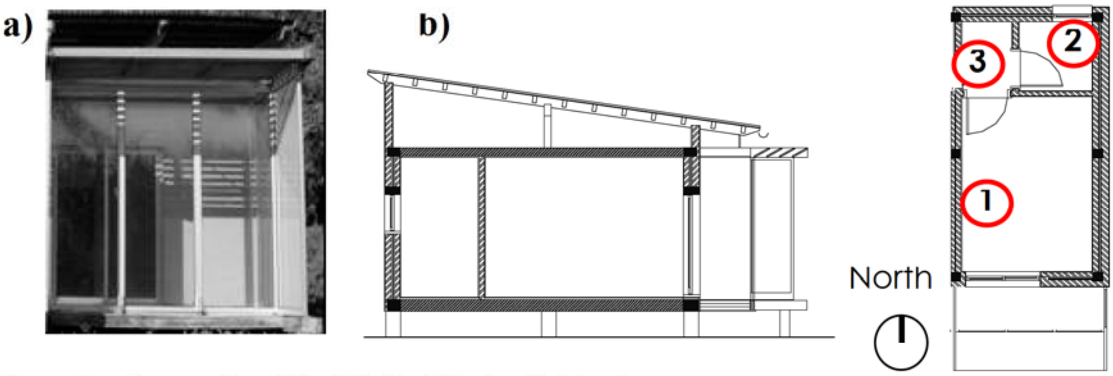

Figure 2 Conventional Test Cell: a) Photo; b) lateral view; c) plan view

3. Estimation methods

3.1 Portuguese thermal regulation - RCCTE

RCCTE is the Portuguese thermal regulation targeted to residential buildings and office buildings without HVAC systems. The objectives of this regulation are: guarantee that the heating and cooling requirements for thermal comfort, the ventilation requirements for indoor air quality and the hot water requirements are satisfied without an excessive energy consumption; Minimize the pathologies in the construction elements due to condensation.

This regulation defines values for the heating needs (N_{ic}) and cooling needs (N_{vc}). The N_{ic} and N_{vc} are obtained using the following equations:

$$N_{ic} = \frac{0{,}024.GD.(U.A_e + U.A_i.\ \tau + \sum \Psi B_s + \sum \Psi B_j + (0{,}34 * Rph + Ap * Pd) - \eta_H(qi.M.Ap\,0{,}720 + G_{Sul}\sum_j [X_j \sum_n A_{snj}].M)}{A_p} \quad (1)$$

$$N_{vc} = \frac{(1-\eta_C).\left[\left[2{,}928\ U.A.(\theta_m - \theta_i) + U.A.(\frac{\alpha.Ir}{h_e})\right] + \sum_j \left[Ir_j \sum_n A_{snj}\right] + \left[2{,}928\,(0{,}34.Rph.Ap\,Pd)\right] + 2{,}928\,qi.Ap\right]}{A_p} \quad (2)$$

Where: A_p is the useful floor area; *GD* is the number of degree-day of heating for a 20ºC base; *U* is the thermal transmittance (U-value, *e* - for elements of the external envelope and *i* – for elements of the internal envelope); A_e is the area of the elements of the external envelope; A_i is the area of the elements of the internal envelope; τ is the coefficient of reduction of the thermal losses to non-heated spaces; Ψ_s is the linear thermal transmittance of the elements in contact with the soil; B_s is the length of the elements in contact with the soil; Ψ_j is the linear thermal transmittance of the linear thermal bridge; B_j is the length of linear thermal bridges; R_{ph} are the hourly air flow rate; P_d is the ceiling height; η_H is the dimensionless gain utilisation factor; η_C is the dimensionless utilisation factor for heat losses; *qi* are the internal heat gains (4 W/m^2 for residential buildings); *M* is the duration of heating period; G_{Sul} is the average mensal value of the solar energy hitting on a vertical surface south oriented of a unitary area during the heating season; X_j is the orientation factor; A_{snj} is the effective collecting area of the solar radiation (*n* – surface; *j* – orientation); θ_m is the average external air temperature for the cooling season; θ_i is the internal air temperature; α is the coefficient of absorption of solar radiation of the outside surface of the element; I_r is the average Intensity of the total solar energy hitting on the surfaces, per orientation, for all the cooling season; h_e is the external thermal superficial conductance of the envelope element (25 W/m^2.ºC).

3.2 United kingdom thermal regulation

In the United Kingdom the Energy Heating Needs are defined:

$$Q_{NH} = \sum\left[(\sum_i A_i U_i + \sum_k l_k \Psi_k).(\theta_i - \theta_{e,k})\right].t.\mathrm{f} + \rho_a.\mathrm{C_a}.\mathrm{U_{v\text{-}heat}}.A.(\theta_i - \theta_e).n.0.0864 - \eta_{\mathrm{G,H}}.\left[Q_i + \sum_j (q_{sun,j}.\mathrm{f}_{sh,j}.\mathrm{f}_{sun,j}.g_j.\mathrm{f_f}) + \sum_j (\mathrm{f}_{ab}.q_{sun,j}.U_{c,j}.A_{\mathrm{c,j}})\right] \quad (3)$$

And the Energy Cooling Needs are obtained:

$$Q_{NC} = \sum\left[(\sum_i A_i U_i + \sum_k l_k \Psi_k).(\theta_i - \theta_{e,k})\right].t.\mathrm{f} + \rho_a.\mathrm{C_a}.\mathrm{U_{V\text{-}Cool}}.A.(\theta_i - \theta_e').n.0.0864 - \eta_{\mathrm{L,C}}.\left[Q_i + \sum_j (q_{sun,j}.\mathrm{f}_{sh,j}.\mathrm{f}_{sun,j}.g_j.\mathrm{f_f}) + \sum_j (\mathrm{f}_{ab}.q_{sun,j}.U_{c,j}.A_{\mathrm{c,j}})\right] \quad (4)$$

Where: A_i is the area of the element *i* of the building envelope; U_i is the thermal transmittance (U-value) of the element *i* of the building envelope; l_k is the length of the linear thermal bridge *k*; Ψ_k is the linear thermal transmittance of the linear thermal bridge *k*; θ_i is the internal temperature of the building zone (heating set point); $\theta_{e,k}$ is the external temperature (the monthly average temperature) of element *k*; *t* is the duration of the calculation period; *f* is a factor for conversion from Wh to MJ; ρ_a . C_a is the specific air heat capacity (1.2 kJ/m^3); $U_{v\text{-}heat}$ is the air flow rate through the conditioned space, for heating; $U_{v\text{-}cool}$ is the air flow rate through the conditioned space, for cooling; *A* is the zone floor area; θ_i is the internal temperature of the building zone (heating set point); θ_e is the external temperature (the monthly average temperature); θ'_e is the modified external air temperature; *n* is the number of days within a month; $\eta_{G,H}$ is the dimensionless gain utilisation factor; $\eta_{L,C}$ is the dimensionless utilisation factor for heat losses; Q_i is the sum of internal heat sources (occupants, appliances and lighting) over a given period; $q_{sun,j}$ is the quantity of solar radiation per month on the plane, for weather location an orientation of window j; $f_{sh,j}$ is the shading correction factor of the window *j*; $f_{sun,j}$ is the reduction factor for moveable solar protection for window *j*; g_j is the total solar energy transmittance, for window *j*; $A_{r,j}$ is the area of window *j*, including the frame; $\mathrm{f_f}$ is the computation value for the frame factor (taken as 0.75); $\mathrm{f_{ab}}$ is the dimensionless absorption coefficient for solar radiation of the opaque construction multiplied by the external surface heat resistance (0.9X0.05= 0.045); $q_{sun,j}$ is the quantity of solar radiation per month on the plane, for weather location and orientation of construction part *j*; $U_{c,j}$ is the thermal transmittance of construction part *j*; $A_{c,j}$ is the area of construction part *j*.

3.3 Belgium, Walloon thermal regulation

The Belgium Walloon region regulation also defines the heating and cooling needs, as presented in the following expressions:

$$Q_{\text{heat, final, m}} = \frac{Q_{\text{heat, gross, m}}}{\eta_{\text{ger, heat}}} \tag{5}$$

$$Q_{\text{heat, gross, m}} = \frac{A_T \cdot K_S \cdot (18-\theta_{e,m}) \cdot t_m + H_{\text{V, heati}} \cdot (18-\theta_{e,m}) \cdot t_m + \eta_{util,heat,m} \cdot (Qi + 0.95 . g_j . A_{g,j} . I_{s,m,j,shad})}{\eta_{\text{sys, heat, m}}} \tag{6}$$

The cooling needs are obtained:

$$Q_{\text{cool, final, m}} = \frac{\max\left\{0, \min\left(\frac{I2-I1}{I3-I1}, 1\right)\right\} \cdot Q_{excess,cool,m}}{8.1} \tag{7}$$

Where: $\eta_{ger,heat}$ is the efficiency of the mensal energy production for heating; $\eta_{sys,heat,m}$ is the efficiency of the heating system; A_T is the total envelope area; K_S is the average thermal transmittance (average U-value); $\theta_{e,m}$ is the mensal external average temperature; t_m- is the duration of the heating period; $H_{v,heat}$ are the thermal losses due to ventilation and infiltration; Q_i is the sum of internal heat sources (occupants, appliances and lighting); g is the solar factor; Window area; $I_{s,m,j,shad}$ is the incident solar radiation having in account the effect of the fixed obstacles; $\eta_{util,heat,m}$ is the thermal gains utilization factor; I_1, I_2 and I_3 can be obtained from Figure 3; $Q_{excess.cool.m}$ are the excessive heat gains comparatively to the comfort temperature (23ºC).

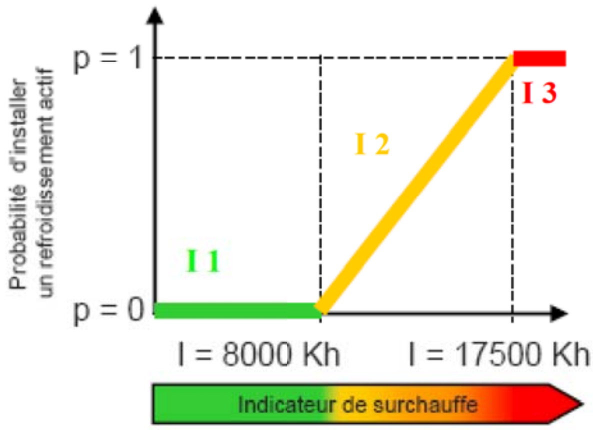

Figure 3 Probability of installing an active, conventional cooling system

3.4 VisualDOE

VisualDOE is a WindowsTM application that can estimate the buildings energy performance. The calculation engine used in this tool is the very well known and tested DOE2.1E. However, only the 3rd version of this tool (VisualDOE 3.1) can be considered as a Graphical User Interface of the DOE engine, as it allows a good control of the introduction of geometrical elements, in real-time, through the pictures of the model produced by the tool and it has the possibility of editing the model simply by clicking with the mouse in an element. This tool can be used without any knowledge of the source engine (Green Design Tools, 2001).

To estimate the buildings energy performance with VisualDOE it is necessary to follow 3 steps:

- Project data introduction;
- Execution of the simulation;
- Results analysis.

The project data introduction begins with the definition of all the VisualDOE databases containing the elements applied into the building – Glazing, Openings, Materials, Constructions, Occupancy, Schedules and Utility rates – and afterwards with the introduction of the model and project data that is formed by 6 folders – Project, Blocks, Rooms, Façade, Systems, Zones. As VisualDOE was created for the WindowsTM platform, the databases are easily updated with new materials and constructions through a graphical interface, as shown in Figure 4.

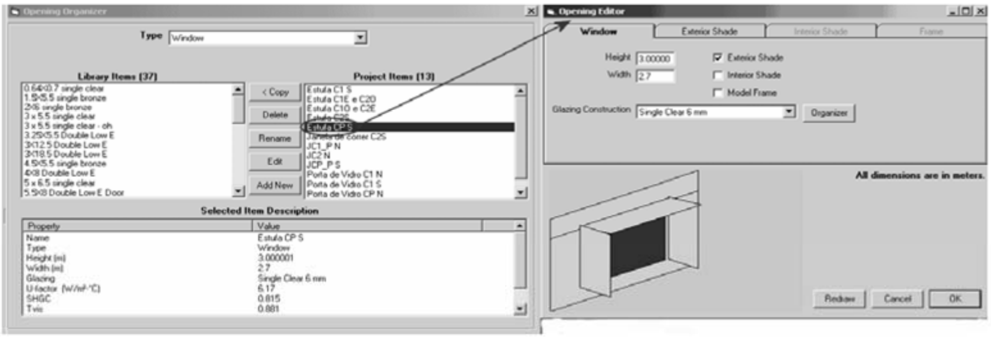

Figure 4 Openings definition in VisualDOE databases

In the 2nd step there will be present three folders – Simulation, Standard DOE-2 Reports and Hourly Reports – where we can define the base case, the alternatives (if necessary) and all the reports needed (hourly, daily, monthly or yearly results) for each specific study.

For the results analysis there are two main groups of data – the VisualDOE graphs and reports and the DOE-2 reports. The main difference between these sets of result is that the ones obtained with VisualDOE follow the WindowsTM platform (allows exporting results to other tools) while the DOE-2 reports follow a DOS platform.

The Test Cells were modelled and calibrated following the procedure shown in Silva *et al* (2006) in order to apply the model to VisualDOE. The final model is shown in Figure 5.

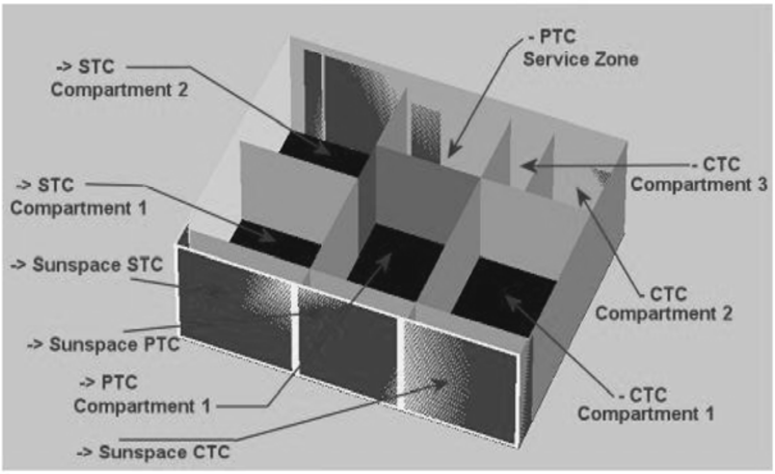

Figure 5 Model of the Test Cells

4. Simulations

This study was executed following three building energy performance calculation methodologies, all based on the EPBD (Energy Performance of Buildings Directive):

- The Portuguese methodology – RCCTE – Regulation of the Thermal Behaviour of Buildings;
- The Belgium methodology (Walloon region) – CWATUPE – Walloon Code of the Territory Development, Urban Planning, Heritage and Energy;
- The UK methodology – NCM – National Calculation Methodology;

Since the different methodologies enclose different input data, like the climatic data, heating and cooling set points and others, they can not be compared directly. Then, it was applied a dynamic simulation tool – VisualDOE – in order to put side by side with all the methodologies, in each case with the same input data.

4.1 Portuguese thermal regulation - RCCTE

The Portuguese regulation was assessed using the calculation model of the RCCTE to obtain the energy needs of the case study, with the following input data:

- City: Guimarães (41º27'N, 8º17'W));
- Heating set point: 20ºC;
- Cooling set point: 25ºC.

The results obtained with RCCTE and VisualDOE are expressed in Table 1.

Table 1 Heating and Cooling needs from RCCTE and VisualDOE

Test Cells		Heating Needs (kwh/m^2.year)		Cooling Needs (kwh/m^2.year)		Total Needs (kwh/m^2.year)	
		RCCTE	VisualDOE	RCCTE	VisualDOE	RCCTE	VisualDOE
With Sunspace	STC	127.7	124.7	49.5	41.9	177.2	166.6
	CTC	100.9	120.5	13.8	13.6	114.7	134.1
Without Sunspace	STC	139.8	135.2	51.3	42.5	191.1	177.7
	CTC	129.4	149.8	30.3	32.3	159.7	182.1

4.2 United Kingdom thermal regulation - NCM

In the case of the UK regulation, it was applied the basic user interface iSBEM Version 3.0 (Simplified Building Energy Model) in order to obtain the case study energy needs, with the following input data:

- City: London (51º30'N, 0º7'W);
- Heating set point: 18ºC;
- Cooling set point: 25ºC.

The results obtained with NCM and VisualDOE are expressed in Table 2.

Table 2 Heating and Cooling needs from NCM and VisualDOE

Test Cells		Heating Needs (kwh/m^2.year)		Cooling Needs (kwh/m^2.year)		Total Needs (kwh/m^2.year)	
		SBEM	VisualDOE	SBEM	VisualDOE	SBEM	VisualDOE
With Sunspace	STC	346.41	366.2	17.6	6.4	364.0	372.6
	CTC	355.2	359.1	10.0	1.2	365.2	360.3
Without Sunspace	STC	384.12	383.2	27.2	5.4	411.3	388.6
	CTC	403.04	383.5	37.5	4.8	440.6	388.3

4.3 Belgium, Walloon region thermal regulation - CWATUPE

For the Belgian regulation (Walloon region) it was applied the tool CALE Version 1.3 (Built with the Energy – Construire Avec L'Energie) in order to obtain the case study energy needs, with the following input data:

- City: Saint Hubert (50º1'N, 5º22'E);
- Heating set point: 18ºC;
- Cooling set point: 23ºC.

The results obtained with CWATUPE and VisualDOE are expressed in Table 3.

Table 3 Heating and Cooling needs from CWATUPE and VisualDOE

Test Cells		Heating Needs (kwh/m^2.year)		Cooling Needs (kwh/m^2.year)		Total Needs (kwh/m^2.year)	
		CWATUPE	VisualDOE	CWATUPE	VisualDOE	CWATUPE	VisualDOE
With Sunspace	STC	402.8	405.7	10.7	1.5	413.5	407.2
	CTC	379.4	379.4	10.8	0.0	390.2	379.4
Without Sunspace	STC	402.8	426.7	10.7	1.6	413.5	428.3
	CTC	435.0	479.0	10.0	1.1	445.0	480.1

5 Results

With the energy needs estimated following each of the Energy Performance Regulations presented before, and with the simulations performed with VisualDOE using, in each case, a similar input data, it is now possible to compare the performance of the different regulations. However, it is necessary to have in mind that the Portuguese model should have a more efficient calibration, as the climatic input data used for the

RCCTE calculation was retrieved from the "*in-situ*" Climatic File, obtained as shown in Silva *et al* (2006), applied in VisualDOE. Although, the rest of the model calibration, like the U values, is similar in all the models.

5.1 RCCTE Vs VisualDOE

The results of the RCCTE calculation methodology were compared with the ones obtained with VisualDOE. The variation between the two estimation methods is presented in Table 4.

Table 4 Differences between RCCTE and VisualDOE estimation

Test Cells		Heating Needs	Cooling Needs (kwh/m^2.year) (%)	Total Needs
Guimarães, Portugal				
With Sunspace	STC	3.0 (2.3%)	7.6 (15.4%)	10.6 (6.0%)
	CTC	19.6 (16.3%)	0.2 (1.4%)	19.4 (14.5%)
Without Sunspace	STC	4.6 (3.3%)	8.8 (17.2%)	13.4 (7.0%)
	CTC	20.4 (13.6%)	2.0 (6.2%)	22.4 (12.3%)
Total error in the average energy needs estimation of all models				**13.1 (2.7%)**

From Table 4 it can be concluded that there is a good approximation between the STC total needs estimated with RCCTE and with VisualDOE, with only an average errpr of 6.5% in the total needs (average between STC with and without sunspace). This fact should be due to a good calculation methodology from the RCCTE associated to a good calibration of the models. The higher variation in the estimation of CTC total needs, 13.4% (average between CTC with and without sunspace), is due to the heating needs contribution. This fact can be explained by a higher south oriented glazing area in this Test Cell that can lead to very high solar gains. This could have led to an overestimation of the thermal gains in the RCCTE methodology.

4.7 NCM Vs VisualDOE

The results of the NCM methodology were compared with the ones obtained with VisualDOE. The variation between the two estimation methods is presented in Table 5.

Table 5 Differences between NCM and VisualDOE estimation

Test Cells		Heating Needs	Cooling Needs (kwh/m^2.year) (%)	Total Needs
London, United Kingdom				
With Sunspace	STC	19.8 (5.4%)	11.2 (63.6%)	8.5 (6.0%)
	CTC	3.9 (1.1%)	8.8 (88.0%)	4.9 (1.3%)
Without Sunspace	STC	1.0 (0.2%)	21.8 (80.1%)	22.8 (5.5%)
	CTC	19.5 (4.8%)	32.7 (87.2%)	52.2 (11.9%)
Total error in the average energy needs estimation of all models				**22.1 (4.5%)**

As Table 5 shows there is a high approximation between the CTC with sunspace and STC without sunspace heating needs estimated with NCM and with VisualDOE. It can be observed that the heating needs have a very good approximation between both the estimation methods, however the cooling needs appears to be overestimated by the NCM methodology.

5.3 CWATUPE Vs VisualDOE

The results of the CWATUPE methodology were compared with the ones obtained with VisualDOE. The variation between the two estimation methods is presented in Table 6.

Table 6 Differences between CWATUPE and VisualDOE estimation

Test Cells		Heating Needs	Cooling Needs (kwh/m^2.year) (%)	Total Needs
Saint Hubert, Belgium				
With Sunspace	STC	2.9 (0.7%)	9.2 (86.0%)	6.2 (1.5%)
	CTC	0.01 (0.0%)	10.8 (100%)	10.8 (2.8%)
Without Sunspace	STC	23.9 (5.6%)	9.1 (85.0%)	14.8 (3.5%)
	CTC	44.0 (9.2%)	9.1 (89.0%)	35.1 (7.3%)
Total error in the average energy needs estimation of all models				**16.7 (1.9%)**

From Table 6 it can be concluded that there is a very high approximation between the CTC, with sunspace, heating needs estimated with CALE and with VisualDOE. It can be observed that the heating needs have a very good approximation between both the estimation methods, however the cooling needs appears also to be overestimated by the NCM methodology.

6. Conclusions

The objective of this study was to evaluate and compare the precision of the Portuguese thermal regulation calculation methodology and some other countries calculation models. Therefore, the RCCTE, CWATUPE and NCM heating and cooling needs estimation methodologies were put side by side with the ones calculated with the dynamic simulation tool VisualDOE.

From this evaluation it can be said that all the calculation methodologies have a good precision, better than one could expect, as they are simple steady state methods. All the methods just appear to have a higher difficulty in estimating accurately the heating needs of buildings with large openings. Also, the Belgium and UK methodology have problems in the cooling needs estimation, overestimating them.

The three methodologies show similar errors, being the Belgium one the most accurate and the UK methodology the least accurate.

Then, it can be said that all the studied thermal codes can produce good results in what concerns energy needs. Thus, as they correctly foresee the energy performance of buildings, the buildings energy certification will allow that the comparisons of the certified building stock of each country can be more meaningful.

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