Assessment of the Portuguese building thermal code: newly revised requirements for cooling energy needs used to prevent the overheating of buildings in the summer

Marta J. N. Oliveira Panão, Susana M.L. Camelo and Helder J. P. Gonçalves,

National Laboratory of Energy and Geology (LNEG), Estrada do Paço Lumiar, 22, 1630-038 Lisbon, Portugal

Abstract

In this paper, cooling energy needs are calculated by the steady-state methodology of the Portuguese building thermal code. After the first period of building code implementation, re-evaluation according to EN ISO 13790 is recommended in order to compare results with the dynamic simulation results. From these analyses, a newly revised methodology arises including a few corrections in procedure. This iterative result is sufficiently accurate to calculate the building's cooling energy needs. Secondly, results show that the required conditions are insufficient to prevent overheating. The use of the gain utilization factor as an overheating risk index is suggested, according to an adaptive comfort protocol, and is integrated in the method used to calculate the maximum value for cooling energy needs. This proposed streamlined method depends on reference values: window-to-floor area ratio, window shading g-value, integrated solar radiation and gain utilization factor, which leads to threshold values significantly below the ones currently used. These revised requirements are more restrictive and, therefore, will act to improve a building's thermal performance during summer. As a rule of thumb applied for Portuguese climates, the reference gain utilization factor should assume a minimum value of 0.8 for a latitude angle range of 40-41°N, 0.6 for 38-39°N and 0.5 for 37°N.

Keywords: Portugal, thermal building code, EN ISO 13790, cooling, adaptive comfort, overheating index

1. Introduction

1.1. Background

In 2000, the European Commission identified the need to introduce specific measures for promoting energy efficiency in the building sector, namely with the Energy Performance of Building Directive (EPBD) published on 16 December 2002 [1] and its recast on 18 June 2010 [2]. This Directive proposes the adoption of common methodologies for calculating energy consumption, quality requirements for new and existing buildings, periodic inspection of boilers and air conditioning central systems, as well as energy certification for buildings.

Following the EPBD, Portugal is preparing the evaluation of national requirements for energy performance of new buildings until 2011, which is an excellent opportunity to devise a national strategy for paving way to very low energy buildings. Reviews of national building regulations should always be seen as an effective tool for highly achieving energy efficient buildings, but also to evaluate the accuracy and performance of thermal calculation methodologies, considering that very few studies have made this analysis according to the last Portuguese thermal building code - RCCTE [3] - which focus on residential and 'small' services buildings (floor area below 1000 m^2 and power HVAC systems lower than 25 kW).

The method for calculating cooling energy needs, incorporated into RCCTE, enacted in 2006, was developed by Dijk and Spiekman [4] and afterward gave rise to EN ISO 13790 [5]. It is noteworthy that preparatory studies for RCCTE conducted during the years 2003 and 2004 were only supported by draft versions of EN ISO 13790. Therefore, after the first period of building code implementation, it is desirable to evaluate the accuracy of RCCTE method according to EN ISO 13790 recommendations. Unlike heating energy demand calculations, which were found to be reliable for a great number of buildings [6, 7] with the exception of those with some ground connections, the method used to calculate the needs for cooling energy seems to have weaknesses [8], for example, the inability to properly reproduce the thermal behavior of buildings in Portugal. The aforementioned studies, however, mainly lack a systematic analysis in terms of energy balance breakdown.

No less important is the fact that summer Mediterranean climatic conditions cause a great thermal stress in buildings. Portuguese thermal building code limits cooling energy needs and the total solar energy transmittance for windows with active shading devices, established as maximum values that are a function of thermal inertia and climatic zones, which could not be adequately preventive to avoid indoor overheating conditions. Nevertheless, for Portuguese climate conditions, traditional and passive architecture shows reduced cooling energy demanding examples, so that HVAC systems are not required.

1.2. Aim of the paper

This paper intends to go further on the analysis of cooling energy needs and evaluate the performance of RCCTE calculations when compared with the results obtained by dynamic simulation tools, making use of an energy balance breakdown in order to explain the identified inaccuracies. Additionally, other mandatory requirements that could be implemented in the future revisions are also evaluated in order to prevent or minimize the risk of overheating inside the buildings during summer.

1.3. Relation to other publications in Energy

A review of previous published papers in the Energy journal shows that there are very few papers specifically about building energy codes. Despite of the small quantity, these codes have become effective techniques in achieving efficiency targets, which are key goals of any energy policy.

In respect to the EPBD implementation in Europe, an economic scenario-analysis highlighted some guidelines for building components of Flemish houses [9]. Other studies based on the EPBD and calculation procedures of EN ISO 13790 were not found.

It is noteworthy that, worldwide, the energy performance of the building envelopes is investigated in terms of the overall thermal transfer value (OTTV), a parameter commonly used in building energy codes [10]. Afterward, the envelope thermal transfer value (ETTV) proved to be more accurate for measuring thermal performance of building envelope. Correlations with both parameters are used to estimate the annual cooling energy consumption of residential buildings [12, 11]. Recently, a new assessment method for determining cooling demands of residential buildings was presented by Fouda and Melikyan [13] which provides more correct results, when compared to the aforementioned methods.

2. Cooling energy needs

2.1. EN ISO 13790

The method developed by Dijk et al. [14] is also described in detail in EN ISO 13790 and consists of a numerical estimation of the physical quantities of heat transfer ($Q_{C,ht}$) and heat sources ($Q_{C,gn}$) which differs from a mere comparison between gains and losses. The heat transferred by ventilation (including infiltration) and transmission (conduction, convection and longwave radiation) directly depends on the air temperature difference between inside and outside and, therefore, is part of the first term. The exchange of energy which does not fit in the first term constitutes the heat sources, e.g. shortwave radiative gains, sky longwave radiative exchange and internal gains.

Longwave radiation exchanges among surfaces are included in the heat transfer term because of their dependency from air temperature difference, considering a linearized approach of StefanBoltzmann law.

There are two formulations of the same numerical method to calculate cooling energy needs ($Q_{C,nd}$). One uses the loss utilization factor ($\eta_{C,ls}$) and the other uses the gain utilization factor ($\eta_{C,gn}$). The first is similar to heating energy needs calculation method, thus

$$Q_{C,nd} = Q_{C,gn} - \eta_{C,ls} Q_{C,ht} \tag{1}$$

where $\eta_{C,ls}$ is a function of the ratio between heat sources and heat transfer, $\gamma_C = Q_{C,gn}/Q_{C,ht}$, according to the expression valid for $\gamma_C > 0$ and $\gamma_C \neq 1$ given by

$$\eta_{C,ls} = \frac{1 - \gamma_C^{-a_C}}{1 - \gamma_C^{-(a_C+1)}} \tag{2}$$

with a_C the building thermal inertia constant.

In the gain utilization factor formulation, the one adopted in RCCTE, cooling energy needs is given by

$$Q_{C,nd} = (1 - \eta_{C,gn}) Q_{C,gn} \tag{3}$$

where $\eta_{C,gn}$ is also a function of γ_C by the expression valid for $\gamma_C \neq 1$ and given by

$$\eta_{C,gn} = \frac{1-\gamma_C^{a_C}}{1-\gamma_C^{a_C+1}} \tag{4}$$

Although such formulation has been adopted for RCCTE, according to Dijk et al. [14] the formulation with loss utilization factor has some advantages over the remaining because it can be used in climates with monthly or seasonally average temperatures above reference temperature. Therefore, the heat transfer term contributes to the increase of cooling energy demand. Furthermore, the passive cooling concept is better understood because the heat transfer term is explicitly a reduction for cooling energy demand.

2.2. RCCTE method specifications

The heat transfer term takes into account the contribution of transmission over the envelope (walls, floors, roofs and windows) and ventilation, expressed by their conductances, respectively, H_D and H_{ve},

$$Q_{C,ht} = L_C(H_D + H_{ve})(\theta_{int,st,C} - \theta_e) \tag{5}$$

with L_C as the cooling season length expressed in hours and $\theta_{int,st,C}$ as the reference temperature (25°C). The cooling season lasts from June to September and, therefore, θ_e corresponds to a time averaged external temperature for that period. It is noteworthy that the conductance term H_D does not account for heat transmission through linear thermal bridges, neither the heat transmission through the envelope which separates conditioned from unconditioned spaces (H_u) nor elements in contact with the soil (H_G). These three terms are neglected.

Heat sources account for internal, Q_{int}, and solar gains, Q_{sol}, by windows and opaque envelope (walls and roof) according to:

$$Q_{C,gn} = Q_{int} + Q_{sol} \tag{6}$$

Solar gains are generally calculated by the contribution of i elements for k orientations, including horizontal, by

$$Q_{sol} = \sum_k I_{sol,k} \sum_i F_{sh,ob,k,i} A_{sol,k,i} \tag{7}$$

where $F_{sh,ob,k,i}$ is the shading factor accounted for external obstacles excluding horizon, e.g. overhangs and fins, which is calculated only for windows, $A_{sol,k}$

is the collecting effective area of each element i and $I_{sol,k}$ is the integrated solar radiation during cooling season for each k orientation.

For windows, the collecting effective area is achieved by

$$A_{sol} = F_{sh,gl}(1 - F_F)A_w g_{gl} \tag{8}$$

where g_{gl} is the window's total solar energy transmittance (or g-value), A_w is the window area, F_F is the frame percentage from the total window area and $F_{sh,gl}$ is calculated by

$$F_{sh,gl} = \frac{(1 - f_{sh,with})g_{gl} + f_{sh,with}g_{gl,sh}}{g_{gl}} \tag{9}$$

with $g_{gl,sh}$ the total solar energy transmittance of the glazing with active shading and $f_{sh,with}$ the weighting day time fraction when shading devices are active. RCCTE assumes that, in summer, shading devices are activated 70% of the time, regardless of the orientation and without any further explanation, therefore $f_{sh,with}$ equals 0.7.

For non-scattering glazing, g_{gl} is obtained from that value at normal incidence - $g_{gl,n}$ - multiplied by a correction factor, F_w.

For opaque walls and roofs, the collecting effective area is calculated by

$$A_{sol} = \alpha_{S,c} R_{se} U_c A_c \tag{10}$$

where R_{se} is the external resistance and, for each i element, $\alpha_{S,c}$ is the absorption coefficient of the external surface, U_C is the heat transfer coefficient and A_c is the element area.

Additionally, EN ISO 13790 considers sky longwave radiative exchange included in Q_{sol} but RCCTE neglects this term.

3. Dynamic simulation tools

3.1. Modeling approach

Unlike steady-state methodologies, simulation tools, such as those used in this paper - EnergyPlus [15] - are able to dynamically calculate energy needs or free-float air temperatures on an hourly time-step (or even smaller) basis. In order to perform an accurate comparison between simulation and RCCTE models, simplifications were made to keep the same glazing area, elements' thermal transmittance (no thermal bridges), internal heat gains and air flow infiltrations.

The case studies are three flats different in their position and useful floor area: 89 m^2 (type A), 113 m^2 (type B) and 149 m^2 (type C). Flats A and B are repeated along five floors and flat C is located in the last floor. The first floor is elevated and externally connects with the outside environment. Common circulation areas (stairs and lifts), as well as the two attached buildings, are assumed to be unheated spaces, according to what RCCTE defines for those type of spaces.

Windows in flats A, B and C are positioned on the two opposite façades with a total approximate areas of 19%, 20% and 16% of floor areas respectively, and windows in the main façade correspond accordingly to 73%, 62% and 37% of the external surface, and windows in the back façade to 31%, 42% and 30%. No windows frame or obstructions were considered, despite the shading of windows caused by the building itself. The building is rotated in order to test two orientations for main/back façades: south/north and west/east. The initial case assumes that windows are clear and double glazed without any shading devices, even if that solution does not accomplish minimum g-value requirements, which is essential to studying the influence of external and internal shading devices.

Walls are double brick, middle insulated with expanded polystyrene. In this study, wall thermal insulation is 0.04 m thick (U-values stays within the range of 0.53 and 0.55 $Wm^{-2}K^{-1}$). Roof and floor slab are also thermally insulated with 0.06 m of expanded cork agglomerate (U-value of 0.49 $Wm^{-2}K^{-1}$) and 0.05 m of mineral stone wool (U-value of 0.42 $Wm^{-2}K^{-1}$), respectively. An air flow infiltration of 0.8 ACH is assumed and internal heat gains set to 4 Wm^{-2}, following default guidelines for Portuguese residential buildings according to RCCTE.

Hourly Portuguese climate databases for six cities - Bragança, Porto, Coimbra, Lisboa, Évora and Faro - were used and compared to the parameters used in RCCTE for cooling season (see Table 1). In order to set aside the climatic influence on the comparison of results, RCCTE was applied using averaged or integrated descriptive parameters obtained from hourly data (second line in the Table). In Table 1 the Climate Severity Index (CSI) and the maximum current values for cooling energy needs (N_v) are also indicated.

3.2. Assessment of heat transfer and heat sources terms

The seasonal steady-state method described above uses a heat transfer/heat sources approach. Therefore, instead of a gain/loss energy balance which is generally the output available in the software tools, heat transfer

Table 1: Climate conditions for cooling season: June to September.

Location Lat./Long.		CSI	θ_e (°C)	$I_{sol,k}$ ($kWh.m^{-2}$) N	E	W	S	H	N_v ($kWh.m^{-2}$)
Bragança	(1)	2-North	19.0	200	450	450	420	790	18
41.8°N, 6.7°W	(2)		19.5	199	381	483	425	788	
Porto	(1)	1-North	19.0	200	420	420	380	730	16
41.2°N, 8.7°W	(2)		18.6	189	329	464	391	737	
Coimbra	(1)	2-North	19.0	200	450	450	420	790	18
40.2°N, 8.4°W	(2)		20.4	196	327	462	387	739	
Lisboa	(1)	2-South	23.0	200	470	470	380	820	32
38.8°N,9.1°W	(2)		21.6	208	391	493	389	780	
Evora	(1)	3-South	23.0	210	460	460	400	820	32
38.6°N, 7.9°W	(2)		21.9	204	375	484	392	794	
Faro	(1)	2-South	23.0	200	470	470	380	820	32
37.0°N, 8.0°W	(2)		22.6	196	390	517	396	848	

(1) current RCCTE and (2) climate hourly data.

and heat sources are calculated separately using the methodology described in Corrado and Fabrizio [16]. The procedure consists of running three simulations for each model or parametric variation described by:

1. Canceling all heat sources - solar gains, sky longwave radiative exchanges and internal gains - and using both ideal heating and cooling systems with the setpoint temperatures at the reference temperature for summer ($\theta_{int,st,C}$) in order to calculate the heat transfer term from the heating ($Q^{(1)}_{H,st}$) and cooling energy needs ($Q^{(1)}_{C,st}$), by

$$Q_{C,ht} = Q^{(1)}_{H,st} - Q^{(1)}_{C,st} \tag{11}$$

2. Including all heat sources and repeating simulations at the conditions defined previously to get $Q^{(2)}_{H,st}$ and $Q^{(2)}_{C,st}$ and, afterwards, calculate the heat sources term by

$$Q_{C,gn} = Q_{C,ht} - (Q^{(2)}_{H,st} - Q^{(2)}_{C,st}) \tag{12}$$

3. Run a last simulation to obtain cooling energy needs,

$$Q_{C,nd} = Q^{(3)}_{C,st} \tag{13}$$

with an ideal system with the setpoint temperatures at the reference temperature ($\theta_{int,st,C}$).

The simulation condition, ensuring no solar gains, consists of using hourly climate data where solar radiation is nulled. In order to consider that building surfaces are totally enclosed, the sky longwave downward radiative exchange is assumed equal to the emitted by a surface at the external temperature and emissivity of 0.9 which is verified for most of the building materials. It is noteworthy that cooling energy needs in Eqs. 11 to 13 are always assumed positive.

4. RCCTE thermal calculations performance

4.1. Heat transfer

To evaluate the heat transfer term estimated by the steady-state approach (RCCTE), simulations are performed using hourly climate data for six different Portuguese cities where heat sources are null (shortwave solar radiation, sky longwave radiation and internal gains) and a constant value of $\theta_{int,st,C} = 25°\mathrm{C}$ is assumed for both heating and cooling energy needs. Building heat transfer only depends on inside to outside air temperature difference and can be theoretically approximated by the difference between absolute values of heating and cooling energy needs, which are calculated for the same setpoint temperature. Since façade orientation (no solar exposition) does not influence the heat transfer results, no model rotations are evaluated. Henceforth, energy terms of heat transfer, heat sources and cooling energy needs are always presented by unit of floor area. In the RCCTE, the cooling energy needs by unit of floor area are identified by N_{vc}, which is limited by the threshold values of N_v in Table 1.

The comparison between dynamic and steady-state calculations showed that the total heat transfer of each apartment is generally underestimated in the RCCTE steady-state approach by an average of 6.6 $kWhm^{-2}$ (see dashed line in Fig. 1A).

In subsequent simulations where the inner envelope separating conditioned from unconditioned spaces is considered adiabatic, that bias is corrected, as shown in Fig. 1B. For these new conditions, the seasonal steady-state approach estimates the heat transfer with an uncertainty of ± 1.6 $kWhm^{-2}$ ($\pm 8\%$), when compared to dynamic simulation results.

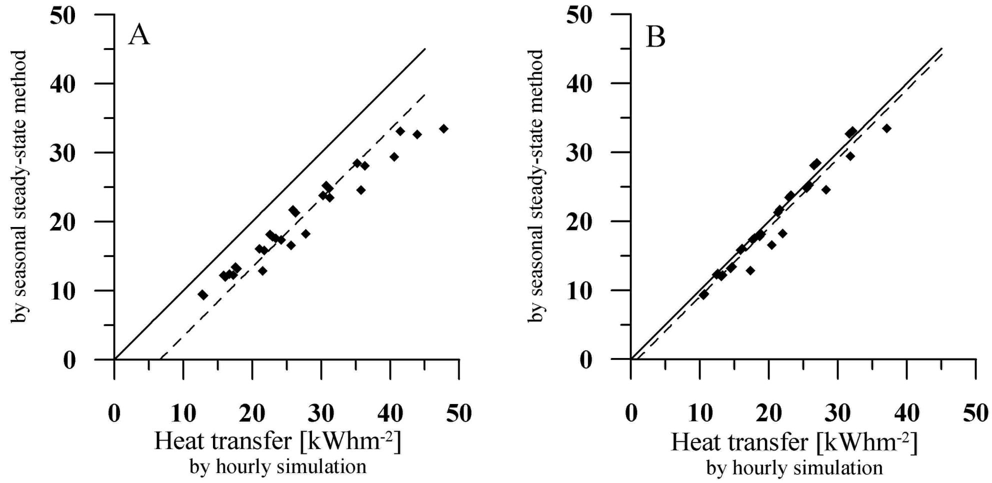

Figure 1: Heat transfer calculated by steady-state approach and dynamic simulations. A) current RCCTE method and B) model simulations with unconditioned spaces separated by adiabatic envelope.

Even if the heat transfer term does not have a direct influence over cooling energy needs (Eq. 3), the considerations above allows us to isolate the study on the heat sources term from its indirect influence.

4.2. Heat sources

4.2.1. No shading devices

The first studies were performed assuming that windows have clear float double glazed without any shading devices and the main façade is south or west oriented. Results show that RCCTE systematically overestimates heat sources term by an average of 2.4 $kWhm^{-2}$ (see dashed line in Fig. 2A).

Following EN ISO 13790, the sky longwave radiative exchange is included on Eq. 7, as

$$Q_{sol} = \sum_k I_{sol,k} \sum_i F_{sh,ob,k,i} A_{sol,k,i} - \sum_i F_{r,i} \Phi_{r,i} \tag{14}$$

where $F_{r,i}$ is the sky view factor of the building element and

$$\Phi_{r,i} = R_{se} U_c A_c h_r \Delta\theta_{er} \tag{15}$$

where h_r is the external radiative heat transfer coefficient assumed equal to five times the surface emissivity ε_c, and $\Delta\theta_{er}$ is the average difference between the external air temperature and the apparent sky temperature, assumed as 11 K for latitude intermediate zones [5].

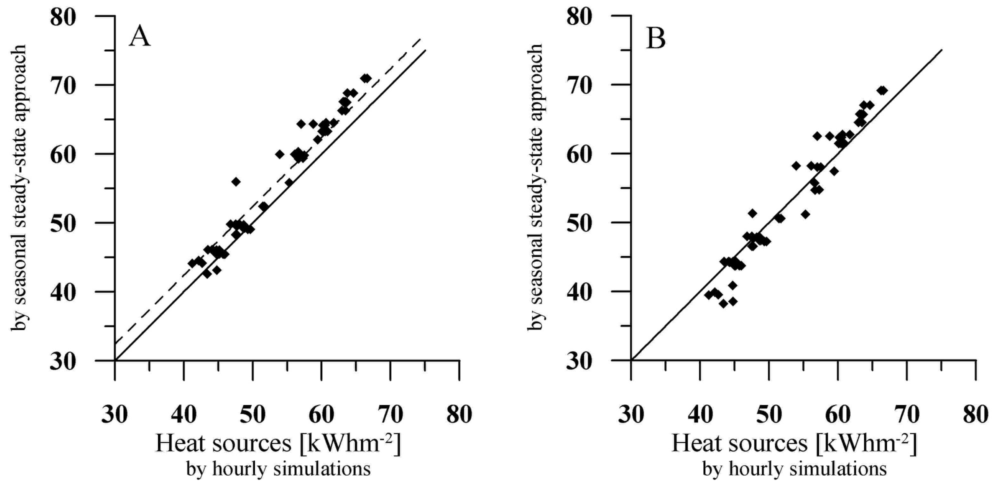

Figure 2: Heat sources calculated by steady-state approach and dynamic simulations. A) current RCCTE method and B) revised RCCTE method considering sky longwave radiative exchange.

When heat exchanged with the sky by longwave radiation is taken into account on heat sources calculations, the bias is annulled. However, the uncertainty of both estimations is similar: ± 2.0 $kWhm^{-2}$ and ± 2.3 $kWhm^{-2}$, respectively in Figs. 2A and 2B. Furthermore, when the sky longwave radiation term is considered on the heat sources term, the bias of RCCTE estimative for cooling energy needs is reduced from 3.0 $kWhm^{-2}$ to 1.1 $kWhm^{-2}$, as shown in Fig. 3.

The aforementioned modifications on heat transfer and heat sources terms influence directly the steady-state method in the calculation of cooling energy needs. In fact, if those parcels are accurately calculated, the expected result for cooling energy improves, as shown in Fig. 3B with an uncertainty of ± 1.5 $kWhm^{-2}$ ($\pm 5\%$). It is noteworthy that these values are very close to other tests performed by the method's authors [14], revealing that the approach is good enough to predict energy needs. It is also notable considering that is a seasonal steady-state approach and does not take into account

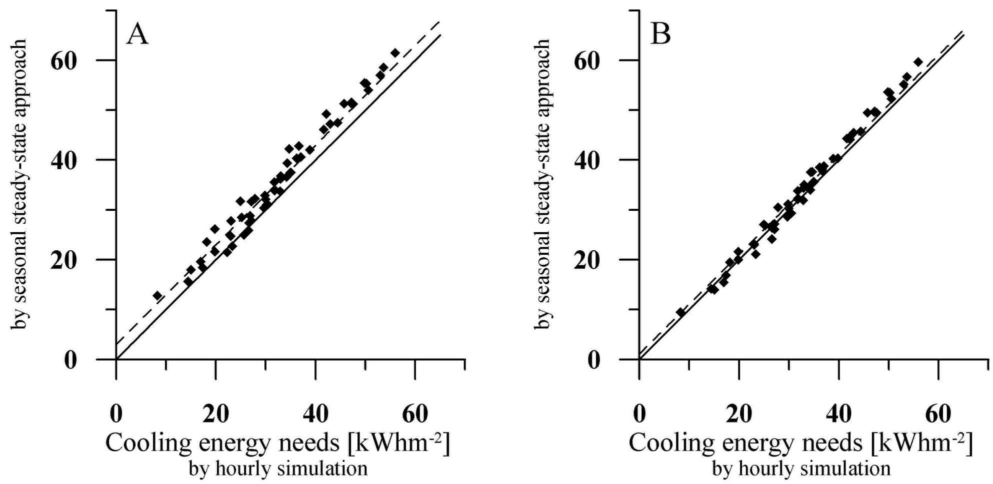

Figure 3: Cooling energy needs calculated by steady-state approach and dynamic simulations, considering unconditioned spaces separated by adiabatic envelope; A) current RCCTE method and B) revised RCCTE method considering sky longwave radiative exchange.

hourly and daily variations.

The above studies were performed without shading devices on windows and g_{gl} were calculated by correcting $g_{gl,n}$ with the factor for non-scattering glazing, F_w, assuming the value of 0.75 (south), 0.80 (north) and 0.85 (east and west) according to window orientation. However, the use of shading devices on clear glazing is a mandatory requirement of RCCTE legislation. Therefore, the second step consists of testing the influence of different shading devices for the following conditions: i) always active and ii) controlled by solar radiation. The results are analyzed in the following two sections.

4.2.2. Shading devices always active

Four types of diffusing roller shading devices were selected: light opaque (transmittance τ = 5%, reflectance ρ = 50%), medium opaque (τ = 5%, ρ = 35%), medium translucent (τ = 30%, ρ = 25%) and light translucent (τ = 40%, ρ = 45%), positioned internally or externally, relatively to the glazed element. As shading devices are always assumed to be active, $F_{sh,with}$ equals 1 in Eq. 9. The parameter $g_{gl,sh}$ assumes the values given in Fig. 4 as a function of angle incidence, for each set constituted by glazing with shading devices.

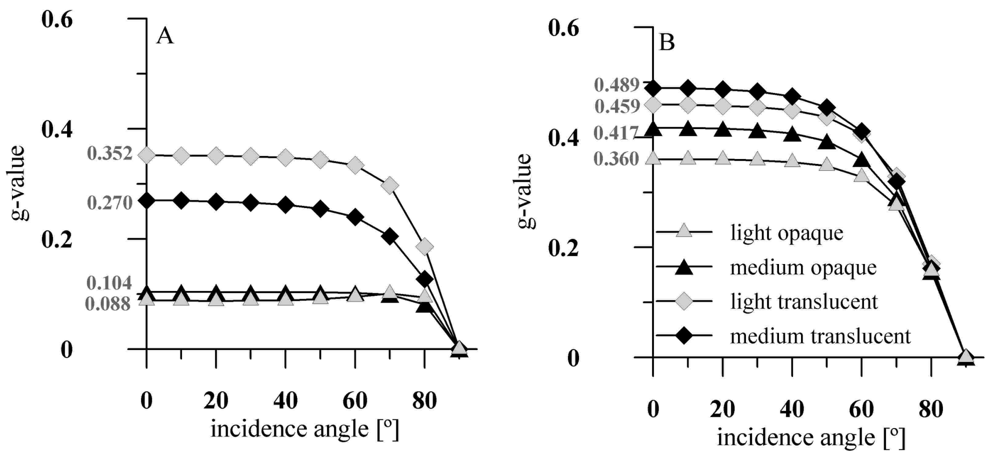

Figure 4: Window g-value as a function of the incidence angle for double glazed with: A) external and B) internal roller diffusing shading devices: light opaque, medium opaque, light translucent and medium translucent.

As a first test, considering for opaque shading devices only, calculations were performed for Lisbon's climate considering $g_{gl,sh} = g_{gl,n}$. Results showed small differences between cooling energy needs regardless of calculation method used with an uncertainty of $\pm 1.4\ kWhm^{-2}$ ($\pm 16\%$), as shown in Fig. 5B. However, for windows with shading devices, RCCTE methodology considers the same correction (F_w) as in clear glazing which, from our point of view, is a misleading interpretation of EN ISO 13790. Comparing the first results with those obtained with $g_{gl,n}$ and corrected by F_w, we can verify that RCCTE largely underestimates the heat sources term by an average of 4.9 $kWhm^{-2}$ and, therefore, also underestimates the cooling energy needs by an average of 3.6 $kWhm^{-2}$ (see dashed line in Fig. 5).

For translucent shading devices, windows g-value estimative follows the EN ISO 13790 [5],

$$g_{gl,sh} = a_{gl} g_{gl,alt} + (1 - a_{gl}) g_{gl,dif} \tag{16}$$

with a_{gl} a weighting factor representative of the window position, climate and season, $g_{gl,alt}$ the solar energy transmittance at an incidence angle (alt) representative of the window, climate and season and, finally, $g_{gl,dif}$ the solar energy transmittance for isotropic diffuse solar radiation. For Portuguese climates a_{gl} and alt assume the values indicated in Table 2, since it was verified that both a_{gl} and alt parameters do not vary significantly with the six Portuguese climates. It is noteworthy that in the current RCCTE, window g-value with shading devices is always affected by the correction factor, F_w, besides windows opacity. This fact motivated the comparison of both procedures, and results suggest that RCCTE methodology, when assuming a correction factor equivalent to the considered for clear glazing, leads to a systematic underestimation of the heat sources term by an average of 3.6 $kWhm^{-2}$ and cooling energy needs of 2.0 $kWhm^{-2}$ (see dashed line in Fig. 6).

Table 2: Weighting factor and incidence angle representative of the window orientation for Portuguese climates, from June to September period; solar heat transmittance for clear double glazed with external (LT_{ext}) and internal light translucent (LT_{int}) shading devices.

	N	E	W	S
a_{gl}	0.10	0.35	0.55	0.45
alt (°)	75	50	40	70
$g_{gl,sh}$ LT_{ext}	0.318	0.333	0.339	0.314
$g_{gl,sh}$ LT_{int}	0.392	0.418	0.431	0.372

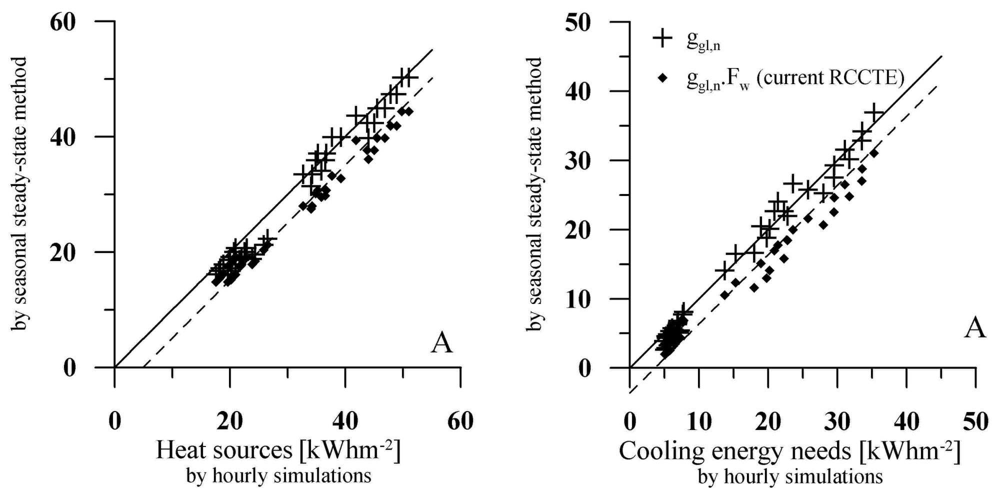

Figure 5: For Lisbon climate and opaque shading devices always active A) heat sources and B) cooling energy needs calculated by steady-state approach and dynamic simulations, when windows shading g-value is calculated according to the current RCCTE method and the revised methodology which follows EN ISO 13790.

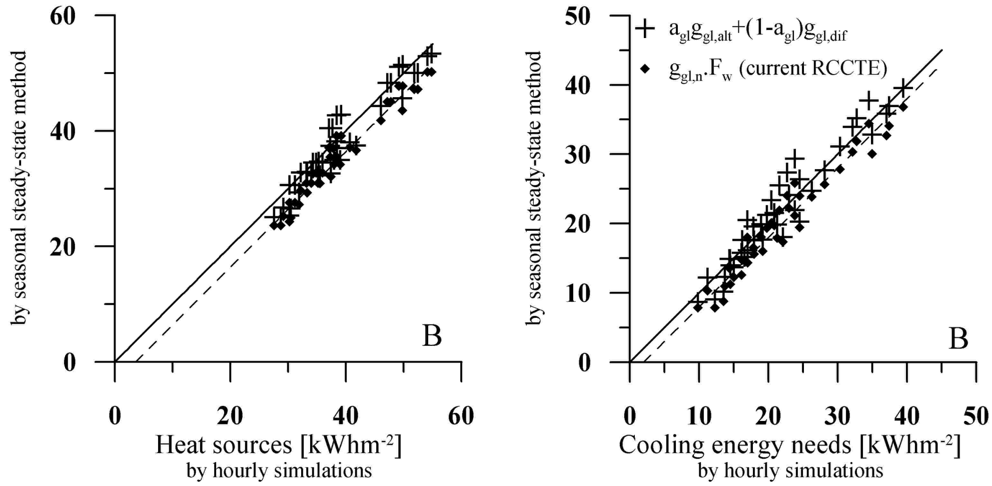

Figure 6: For Lisbon climate and translucent shading devices always active A) heat sources and B) cooling energy needs calculated by steady-state approach and dynamic simulations, when windows shading g-value is calculated according to the current RCCTE method and the revised methodology which follows EN ISO 13790.

Extending this study for other climates with light translucent shading devices always active, internally or externally positioned, the uncertainties in the estimation of cooling energy needs are similar to those obtained for Lisbon. In other words, the use of a correction factor equivalent to the clear glazing leads to an underestimation of the cooling energy needs by an average of 1.7 $kWhm^{-2}$ (see dashed line in Fig. 7). The assumption of a $g_{gl,sh}$ calculated by Eq. 16, taking into account the window position, climate and season, reduces the bias between methods to 0.7 $kWhm^{-2}$, with an error of ± 2.1 $kWhm^{-2}$ ($\pm 13\%$).

Therefore, this study underlines the importance of defining specific correction parameters according to window position, season, climate and shading devices optical properties, different from the adopted guideline for clear glazing.

On the other hand, the total solar energy transmittance at normal incidence, calculated for windows with opaque shading devices (transmission below 5%) is sufficiently accurate to estimate solar gains and, therefore, no correction factor should be applied. Since this study nevertheless focuses only on roller diffusing shading, it should be extended in the future to include other types of shading devices.

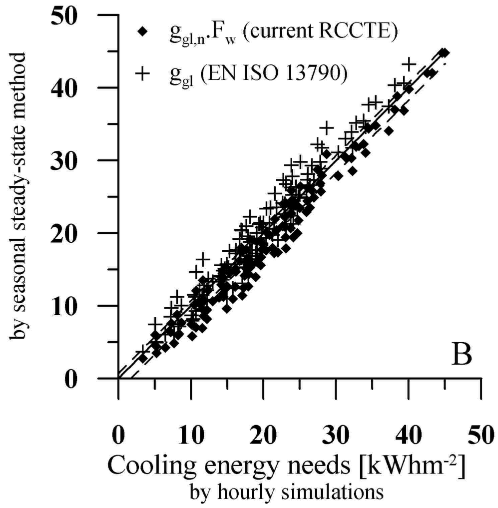

Figure 7: For light translucent shading devices always active, cooling energy needs calculated by steady-state approach and dynamic simulations, when windows shading g-value is calculated according to the current RCCTE method and the revised methodology which follows EN ISO 13790.

4.2.3. Shading devices controlled by solar radiation

At this stage, it is noteworthy that the previous two sections do not comply with RCCTE requirements because shading devices are always required for clear double glazed (not north oriented). For cooling energy needs calculations, a weighting day time fraction of 30% without any windows solar protection (1-$f_{sh,with}$) should be considered.

Therefore, simulations are run considering that light opaque shading devices are activated by solar radiation incidence above 300 $kWhm^{-2}$ in order to compare with RCCTE's assumption, i.e. $f_{sh,with}$=0.70 regardless the orientation. For Lisbon, for example, from June to September, the coefficient $f_{sh,with}$ is 0.61 for east orientation, 0.66 for south and 0.74 for west (Table 3). Due to the fact that north oriented windows are not influenced by this condition - incidence radiation is always below that level of solar radiation - higher differences are expected in final results.

In fact, differences between the two options - considering the calculated $f_{sh,with}$ in Table 3 or $f_{sh,with}$ fixed at 0.70, as assumed by current RCCTE - are verified only for heat gains of a north-south oriented model as shown in Fig. 8. Also the current RCCTE procedure underestimates cooling en-

Table 3: Hourly calculated weighting day time fraction when shading devices are active (above 300 Wm^{-2}), $f_{sh,with}$, as a function of climate and orientation.

Location	$f_{sh,with}$			
	N	E	W	S
Bragança	0	0.61	0.72	0.73
Porto	0	0.54	0.73	0.70
Coimbra	0	0.52	0.72	0.67
Lisboa	0	0.61	0.74	0.66
Évora	0	0.60	0.74	0.68
Faro	0	0.66	0.77	0.68

ergy needs by an average of 1.1 $kWhm^{-2}$ (see dashed line in Fig. 8). On the other hand, calculated values for $f_{sh,with}$ lead to a null bias. Considering both orientations east-west and north-south models, cooling energy needs are accurately estimated by the steady-state approach with an error of ± 1.6 $kWhm^{-2}$ ($\pm 16\%$), as shown in Fig. 9.

From the results in this section, it can be concluded that the new revised methodology, based on a seasonal steady-state approach, is sufficiently accurate to calculate cooling energy needs. But the method is very sensitive to solar gains, therefore, special care should be taken on the solar gains calculations, namely on total solar energy transmittance of windows and their shading devices. Movable operation plays also an important role on the cooling energy needs.

However, the current RCCTE method should be improved in order to better estimate cooling energy needs. This will be discussed in the following section.

4.3. RCCTE revised

The performance evaluation of the RCCTE methodology to calculate cooling energy needs was divided into heat transfer and heat sources terms. For the first term, the main conclusion is that RCCTE neglects the heat transmitted by transmission between conditioned and unconditioned spaces, although this influence could be significant only for unconditioned spaces with average air temperatures significantly below reference temperature.

According to EN ISO 13790, unconditioned spaces are included on energy needs calculations and are expressed by a b coefficient which 'corrects' the average external air temperature. In fact, RCCTE follows that methodology,

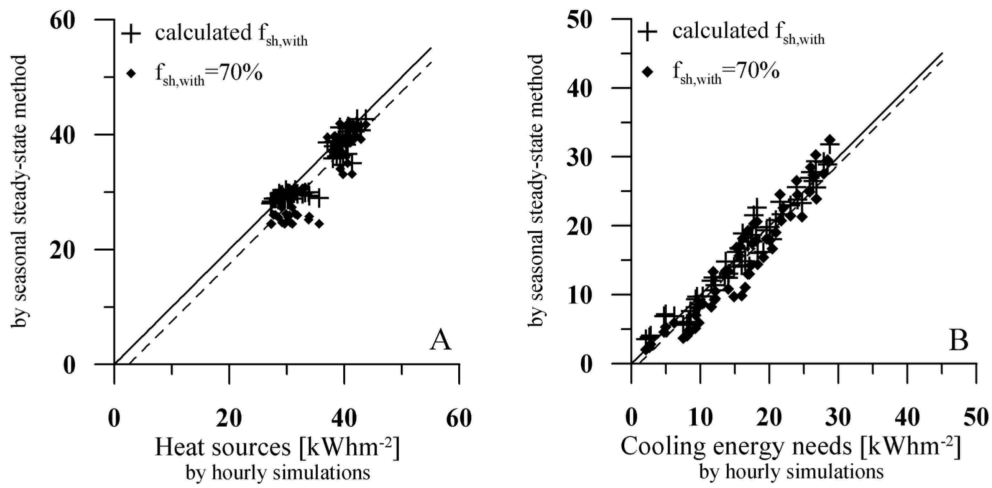

Figure 8: For light opaque shading devices controlled by solar radiation and for north-south model A) heat sources and B) cooling energy needs calculated by steady-state approach and dynamic simulations, when the weighting day time fraction with active shading devices assumes the values defined by the current RCCTE method and the revised methodology which follows EN ISO 13790.

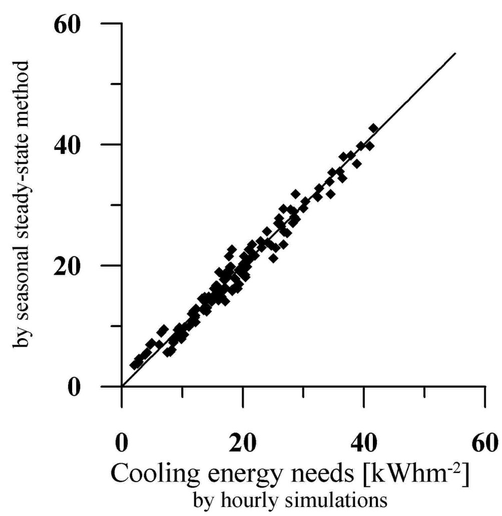

Figure 9: For light opaque shading devices controlled by solar radiation, cooling energy needs calculated by steady-state approach and dynamic simulations, when the weighting day time fraction with active shading devices assumes the values defined by the revised methodology which follows EN ISO 13790.

but only for heating energy needs calculation, attributing b coefficients (τ in RCCTE) for each type of space and ventilation levels.

For summer season, the inclusion of unconditioned spaces could reduce cooling energy needs, specially for those where air temperature is always below reference temperature, such as, basement, parking lot and other spaces with low internal gains and no solar gains. Unconditioned spaces with high internal or solar gains (e.g. sunspaces, atrium, roofspaces) could also be taken into account, as long as gains are included in the calculation of the b coefficient calculation, which could result in negative values.

However, despite some specific cases, it is expected that neglecting heat transfer between conditioned and unconditioned spaces has a minor influence on cooling energy needs. Therefore, since the heat sources term plays an important role on cooling energy needs, our suggestion is that a revised RCCTE methodology should be considered in order to correct the following aspects:

- The non-scattering glazing correction factor, F_w, is improperly associated to $g_{gl,sh}$ and, therefore, is affecting also windows shading g-value;
- The day time fraction when shading devices are active, $f_{sh,with}$, is always 0.7 regardless the orientation, which for north oriented windows does not reflect the solar radiation control at 300 Wm^{-2};
- Sky longwave radiative heat transfer is not included either in Q1 heat source or heat transfer terms.

The results suggest that increasing the complexity of the aforementioned items is justified by improved accuracy. Regarding the day time fraction when shading devices are active, we suggest that this parameter should be tabled as a function of climate and windows orientation based on an integrated solar radiation analysis from June to September, see for example the calculated values in Table 3 for the studied Portuguese climates. As a first approximation, the current value could be kept for all windows, besides north oriented where $f_{sh,with}$ should be null.

Additionally, window g-value at normal incidence is sufficiently accurate to estimate solar heat gains for opaque shading devices, and, therefore, no correction is needed. For translucent shading devices, however, g-value should take into account the window position, season and climate and its variability with the angle of incidence, following the methodology suggested in EN ISO 13790 [5], see for example the calculated values of Table 2.

5. Comfort and cooling energy needs

5.1. Assessment of comfort

The Portuguese building code mainly establishes two conditions for preventing overheating during summer season: 1) control cooling energy needs by imposing limits according to climatic severity index, CSI, ranging from 16 (CSI 1, North) to 32 $kWhm^{-2}$ (CSI 3, South); 2) limiting all non-north oriented windows g-value with active shading devices - $g_{gl,sh}$ - where maximum values range from 0.10 (light inertia and CSI 3) to 0.56 (heavy inertia and CSI 1).

In order to test if the aforementioned requirements are preventive enough to control overheating in buildings during summer season, simulations are performed on free-float mode. Hourly operative temperatures are obtained for the case studies described in Sec. 3, adopting shading rolls light opaque, medium opaque, medium translucent and light translucent, externally positioned, so that RCCTE requirements in terms of $g_{gl,sh}$ are always accomplished.

Since there is no established 'overheating index' specific for residential buildings, under mid latitude climates, the analysis uses different parameters correlated with cooling energy needs ($Q_{C,nd}$) and the gain utilization factor ($\eta_{C,gn}$). $Q_{C,nd}$ is calculated by the RCCTE revised methodology (Sec. 4.3), where $f_{sh,with}$ assumes the values defined in Table 3, e.g. shading devices are controlled by solar radiation. However, since we are trying to identify if $\eta_{C,gn}$ is a good indicator of overheating risk, the former parameter considers that shading devices are always activated in order to reproduce users' behavior for very warm periods, e.g. shading devices are always active.

The first criterion to evaluate overheating is the percentage of hours where operative temperature is above 28°C, $P_{\theta_{op}>28}$, which should not exceed 1% of the occupied hours according to CIBSE [17] (see dashed line in Fig. 10A). This analysis is complemented by the distribution of hourly temperature differences between operative and reference temperature ($\theta_{op} - \theta_{int,st,C}$). To be in compatible with the aforementioned condition, the 99^{th} percentile should not exceed 3°C (see dashed line in Fig. 10C).

The studies developed on adaptive comfort [18] have shown, however, that people could demonstrate satisfaction even above 28°C, especially when daily average external air temperature exceeds 20°C.

One of the conclusions of the EU Project Smart Controls and Thermal Comfort (SCAT) [19], conducted in a large number of European buildings, was that comfort temperature is empirically correlated with the running mean outdoor temperature, θ_{rm}, by a linear function expressed by $\theta_c = 0.33\theta_{rm} + 18.8$ (in Celsius degrees), where θ_{rm} is calculated on a daily basis that takes into account the outdoor temperature of the past 3.5 days, approximately half a week, which corresponds to weighted coefficients of 0.2 for the average air temperature of the previous day and 0.8 for the running mean air temperature obtained for the same previous day [20].

According to Nicol and Humphreys [20], the overheating risk, which is evaluated here by the percentage of votes 'warm' and 'hot' on the ASHRAE comfort scale, increases to 25% when operative temperature exceeds the comfort temperature in more than 3°C. For new buildings and renovations, a 'normal expectation' corresponds to an operative temperature within range of $\theta_c\pm$ 3°C (see dashed line in Fig. 10B). Nevertheless, the operative temperatures should not fall outside that range for more than 3-5% of occupied hours [20]. Considering the worst scenario, Fig. 10D shows the 97^{th} percentile of the hourly difference between operative and comfort temperatures which should not exceed 3°C.

This analysis leads to the conclusion that the criterion of the percentage of hours above 28°C is a much more demanding requirement than the adaptive comfort approach. For Lisbon, only a few case studies verify the first criterion, while significantly more case studies verify the adaptive comfort criterion (Fig. 10). It can also be concluded, as a rule of thumb, that adaptive comfort requirements are ensured whenever the gain utilization factor is above 0.5 for Faro (latitude of 37°N), 0.6 for Lisboa and Évora (38-39°N) and 0.8 for Porto, Bragança and Coimbra (40-41°N), which is designated as the reference gain utilization factor, $\eta_{gn,ref}$ (see Fig. 11). If a standard comfort approach is used, this parameter is much higher for all climates and, therefore, more restrictive.

5.2. Revised threshold for cooling energy needs

Cooling energy needs by unit of floor area - N_{vc} - are inversely proportional to the gain utilization factor - $\eta_{C,gn}$ - used in the comfort analysis and can be approximated by logarithmic functions (see Fig. 12). These needs are calculated assuming that the shading devices are controlled by solar radiation. The threshold value now required by RCCTE - N_v on Table 1 - is a function of climatic zones defined by CSI and North/South regions and is represented in Fig. 12 by a solid black line; the dashed black line is the new proposed threshold value considering adaptive comfort requirements.

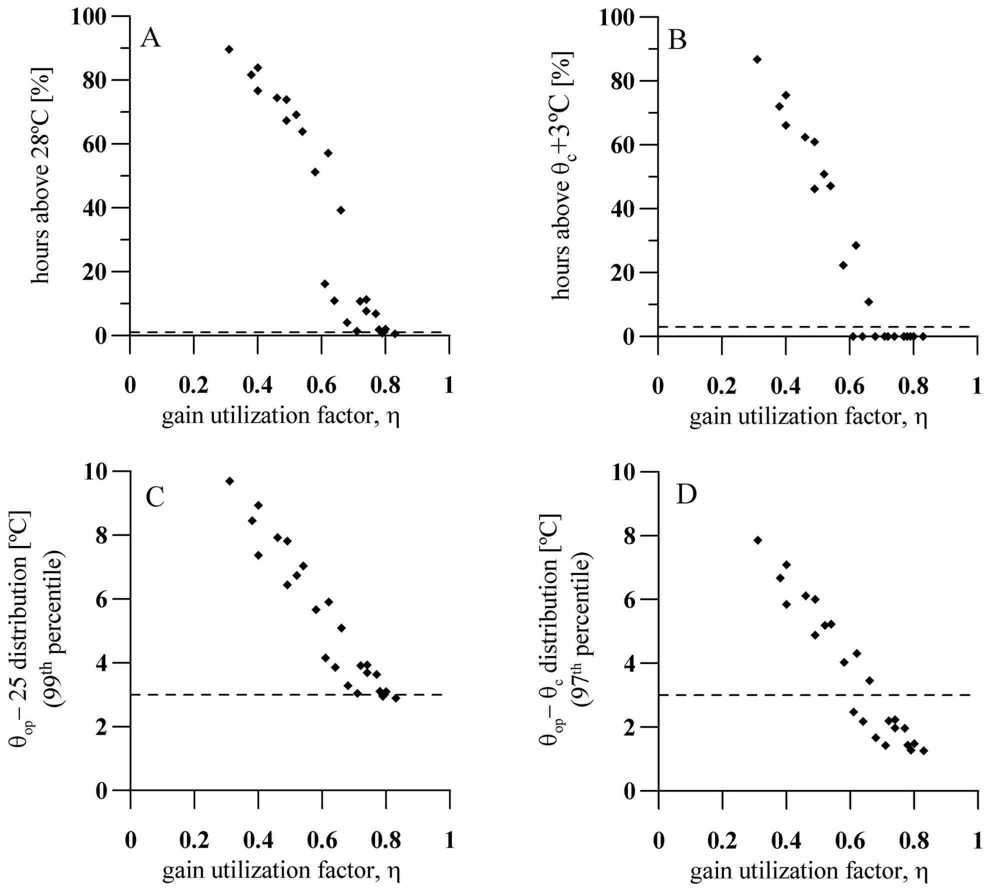

Figure 10: Gain utilization factor correlated with overheating index for Lisbon climate: A) percentage of hours above 28°C, B) percentage of hours that exceed comfort range, θ_c+3°C, C) 99th percentile of difference distribution between operative temperature and 25°C and D) 97th percentile of difference distribution for operative to comfort temperature. Dashed lines represent the overheating criterion defined by each approach.

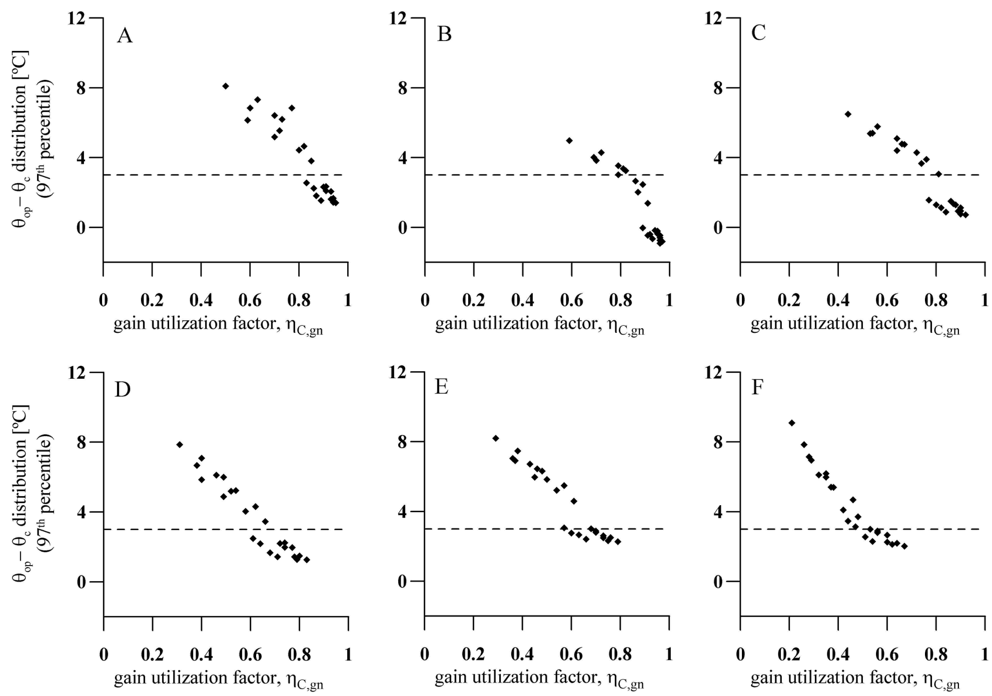

Figure 11: Gain utilization factor correlated with 97^{th} percentile of operative to comfort temperature difference distribution for: A) Bragança, B) Porto, C) Coimbra, D) Lisboa, E) Évora and F) Faro.

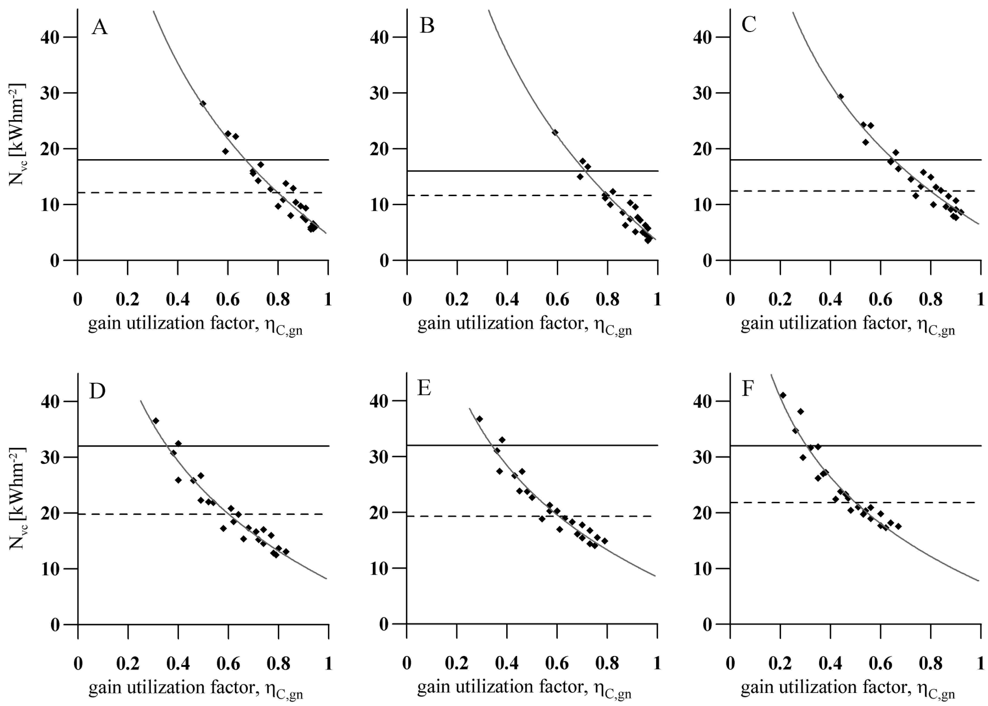

Figure 12: Gain utilization factor correlated with cooling energy needs calculated by revised methodology for: A) Bragança, B) Porto, C) Coimbra, D) Lisboa, E) Évora and F) Faro. Current threshold values for cooling energy needs (solid black line) and new revised values with adaptive comfort requirements (dashed black line)

The new threshold values found for each climate depend on logarithmic functions, which are specific for each city. Therefore, a simplified methodology to find these values is required.

The formulation we propose to calculate the maximum cooling energy needs, N_v, is derived from Eq. 3 and is expressed by

$$N_v = (1 - \eta_{gn,ref}) \frac{Q_{gn,ref}}{A_f} \tag{17}$$

where $\eta_{gn,ref}$ is defined in the Sec. 5.1 and $Q_{gn,ref}/A_f$ is calculated by

$$\frac{Q_{gn,ref}}{A_f} = q_i L_C + \frac{A_w}{A_f} g_{ref} I_{ref} \tag{18}$$

with q_i as the internal heat gain flux, expressed in kWm^{-2}, and L_C as the temporal length cooling season in hours. The other parameters could assume standard values to be defined at a national level: window to floor area ratio, A_w/A_f; reference g-value g_{ref}; and integrated solar radiation I_{ref}.

In the above formulation, solar gains by opaque envelope as well as sky longwave radiative heat transfer can be neglected when compared to solar gains by windows and internal gains. Considering, for example, the reference values of 20% for window to floor ratio (A_w/A_f), 0.4 for window g-value (g_{ref}) and the west orientation integrated solar radiation (the worst case for Portugal), the calculated threshold values for N_v are in agreement with those obtained by the logarithm function approach, as shown in Table 4.

It is necessary to clarify that the reference g-value is weight average between double glazing with shading devices (0.25) and without (0.75) and weighting coefficients of 0.7 and 0.3, respectively, which result from an approximation of $f_{sh,with}$.

Depending on climatic zone, from 2 to 10% of the current new buildings will have cooling energy requirements above the new revised limits. In a short term perspective, energy savings are not expected because cooling demands are not directly related to cooling energy consumptions. This is due to the fact that most of residential buildings, new and old, still do not have cooling systems. Therefore this scenario is preventive, in a medium term perspective, in terms of further energy consumptions.

Table 4: Current and new revised limits for cooling energy needs to prevent buildings overheating.

Location	N_v $(kWh.m^{-2})$		
method	simplified	logarithmic	current RCCTE
Bragança	10.1	12.1	18
Porto	9.8	11.6	16
Coimbra	9.7	12.4	18
Lisboa	20.5	19.8	32
Évora	20.2	19.3	32
Faro	26.5	21.8	32

6. Conclusions

This study stresses that simplified methodologies for evaluating heating or cooling energy needs should be tested and compared with detailed simulation results, in order to determine whether these validated methods are being properly applied. For example, a mistyping error was found in EN ISO 13790 for the Trombe walls simplified method when results were compared to detailed simulations [21]. In this paper, cooling energy needs were calculated by the steady-state methodology of the Portuguese building thermal code, RCCTE, and compared with hourly simulations performed by EnergyPlus. The analysis suggests that the heat gains term should include the influence of:

- the non-scattering glazing correction factor applied only to the glazing g-value (without shading devices) as stated in EN ISO 13790; therefore, no correction factor should be used for the weighting day time fraction when shading devices are in operation;
- the windows shading g-value at normal incidence is used for opaque shading devices;
- the windows shading g-value is calculated considering windows orientation, season and climate for translucent shading devices;
- the weighting day time fraction of active shading devices, controlled by the solar radiation threshold 300 Wm^{-2}, should be zero for north oriented windows while the current constant value, 0.7, could be kept

as a first approximation or replaced by other tabled orientation values according to climate;

- sky longwave radiative heat transfer should be included, following the simplifications defined in EN ISO 13790.

A comfort analysis was performed with the main goals of (1) identifying the building thermal code requirements and (2) preventing or minimizing overheating in buildings. This study shows that currently established parameters are insufficient to prevent overheating. Following an adaptive comfort approach, we propose that the gain utilization factor, $\eta_{C,gn}$, could be used as an overheating risk index. As a rule of thumb applied for Portuguese climates, the reference gain utilization factor should assume a minimum value as a function of latitude, 0.8 for 40-41°N, 0.6 for 38-39°N and 0.5 for 37°N. In order to minimize the number of mandatory requirements, this paper suggests that the aforementioned overheating risk index be integrated into the protocol to calculate the maximum value for cooling energy needs (N_v in RCCTE). The proposed simplified method depends on a few reference values, established at the national level for each climatic zone. These reference values are: window-to-floor area ratio, window g-value and integrated solar radiation. The threshold values calculated by the simplified method are close to those obtained by the logarithmically correlated functions of cooling energy needs, N_{vc}, and gain utilization factors, $\eta_{C,gn}$.

From to the results obtained, new threshold values are proposed that are significantly lower than the current ones is use, resulting in more restrictive rules that will improve buildings thermal performance during the summer. New threshold values would also reduce the number of building units requiring air conditioning systems. Additionally, since N_v is dynamically calculated, internal gains are taken into account so non residential buildings have specific maximum values. This marks a departure from current RCCTE definition.

Another avenue for investigation - the examination of passive cooling strategies in the simplified method - should be undertaken since EN ISO 13790 pertains only to heating parameters.

7. Acknowledgments

The authors wish to thank the two anonymous reviewers for providing useful comments and suggestions on this paper, which led to a substantial

improvement of the original manuscript. Further, the authors are extremely grateful to Joan and Mark for their English writing support.

References

[1] CEC. Energy Performance of Building Directive, Directive 2002/91/EC. Official Journal of the European Communities; 2003:65-71.

[2] CEC. Energy Performance of Building Directive, Directive 2010/31/EU. Official Journal of the European Communities; 2010:13-35.

[3] Decreto-Lei nr. 80/2006. Regulamento das Características do Comportamento Térmico dos Edifícios, RCCTE. Portugal; 2006 (in portuguese).

[4] van Dijk D, Spiekman M. Energy performance of buildings; outline for harmonised EP procedures. Final report of EU SAVE ENPER project, Task B6. Delft (NL): TNO Building and Construction Research; June 29, 2004.

[5] EN ISO 13790 Energy performance of buildings, calculation of energy use for space heating and cooling; 2007.

[6] Silva P, Bragança L, Almeida M. The calculation model of the new portuguese thermal regulation put side by side with dynamic simulation. In Proceedings of SB07: Sustainable Construction, Materials and Practices. Lisboa, Portugal: IOS Press; 2007: 90-97.

[7] Silva P, Silva S, Almeida M, Braganç L. Accuracy of the portuguese EPBD implemented thermal performance calculation procedures - RCCTE. In Proceedings of the Eleventh International IBPSA Conference, Building Simulation 2009. Glasgow, Scotland; 2009:2106-2113.

[8] Leal V, Ferreira H, Oliveira Fernandes E. Relating energy indicators of regulations to passive confort in residential buildings. In Proceedings of the 25th conference on Passive and Low Energy Architecture, PLEA 2008. Dublin, Ireland; 2008.

[9] Audenaert A, De Boeck L, Roelants K. Economic analysis of the profitability of energy-saving architectural measures for the achievement of the EPB-standard. Energy, 35; 2010: 2965-2971.

[10] Lam JC, Tsang CL, Li DHW, Cheung SO. Residential building envelope heat gain and cooling energy requirements. Energy, 30; 2005: 933-951.

[11] Chua KJ, Chou SK. Energy performance of residential buildings in Singapore Energy, 35; 2010: 667-678.

[12] Yik FWH, Wan KSY. An evaluation of the appropriateness of using overall thermal transfer value (OTTV) to regulate envelope energy performance of air-conditioned buildings. Energy, 30; 2005: 41-71.

[13] Fouda A, Melikyan Z. Assessment of a modified method for determining the cooling load of residential buildings. Energy, 35; 2010: 4726-4730.

[14] van Dijk D, Spiekman M, de Wilde P. A monthly method for calculating energy performance in the context of european building regulations. In Proceedings of the Ninth International IBPSA Conference, Building Simulation 2005. Montreal, Canada; 2005.

[15] Crawley DB, Lawrie LK, Pedersen CO, Winkelmann FC, Witte MJ, Strand RK et al. EnergyPlus: an update. In Proceedings of the SimBuild 2004 Conference, IBPSA. Boulder, CO, USA; 2004.

[16] Corrado V, Fabrizio E. Assessment of building cooling energy need through a quasi-steady state model: simplified correlation for gain-loss mismatch. Energy and Buildings; 2007: 569-579.

[17] Chartered Institution of Building Services Engineers, CIBSE Guide A, 7th edn, CIBSE, London; 2006.

[18] Humphreys MA, Nicol JF. Understanding the adaptive approach to thermal comfort. ASHRAE Transactions 206 (2); 1998: 991-1004.

[19] McCartney KJ, Nicol JF. Developing an adaptive control algorithm for Europe: results of the SCATs project. Energy and Buildings, 34 (6); 2002: 623-635.

[20] Nicol JF, Humphreys MA. Derivation of the adaptive equations for thermal comfort in free-running buildings in European standard EN 15251. Building and Environment, 45; 2010: 11-17.

[21] Ruiz-Pardo A, Dominguez SA, Fernandez JAS. Revision of the Trombe wall calculation method proposed by UNE-EN ISO 13790. Energy and Buildings, 42; 2010: 763-773.