Energy and Buildings xxx (2011) xxx–xxx

Contents lists available at SciVerse ScienceDirect

Energy and Buildings

journal homepage: www.elsevier.com/locate/enbuild

Assessing the accuracy of a simplified building energy simulation model using BESTEST: The case study of Brazilian regulation

A.P. Melo[a,*], D. Cóstola[b], R. Lamberts[a], J.L.M. Hensen[b]

[a] *Energy Efficiency in Buildings Laboratory, Federal University of Santa Catarina, Brazil*
[b] *Building Physics and Systems, Eindhoven University of Technology, The Netherlands*

ARTICLE INFO

Article history:
Received 1 July 2011
Received in revised form 24 October 2011
Accepted 5 November 2011

Keywords:
Building energy simulation
Simplified model
Regulation
Building envelope
BESTEST

ABSTRACT

This paper reports the use of an internationally recognized validation and diagnostics procedure to test the fidelity of a simplified calculation method. The case study is the simplified model for calculation of energy performance of building envelopes, introduced by the Brazilian regulation for energy efficiency in commercial buildings. The first step of the assessment consisted on evaluating the simplified model results using the BESTEST. This paper presents a straightforward approach to apply the BESTEST in other climates than the original one (Denver, USA). The second step of the assessment consisted on applying the simplified model to evaluate four building typologies, and compare the results with those obtained using a state of the art building energy simulation (BES) program. For some BESTEST cases, the simplified model presented results inside of a confidence interval calculated by the authors. However, the simplified model was found to yield significant difference in the four building typologies analysed. Moreover, in all four building typologies analysed, the simplified model led to a lower energy efficiency label when compared to the label obtained using BES. The paper concludes that the simplified model may require improvements to properly indicate the actual energy performance of commercial building envelopes.

1. Introduction

Countries all over the world are discussing strategies to improve building energy efficiency and implementing energy regulations to reduce buildings energy consumption [1–9]. Most regulations are partially based on the thermal performance of the building envelope, usually informing through a label the impact of the envelope in the building energy performance [10–13]. The success of building energy regulation relies on three decisive points [14]: to achieve a label which produces expected results for the amount of resources invested; the accuracy of the labelling process (i.e. its capability to accurately quantify real energy savings); and the engagement to reduce the greenhouse gases in order to prevent impacts on global warning. From these three points, this paper addresses the accuracy of the prescriptive process.

In many countries, the labelling process relies in different levels on computational building performance simulation. Some energy regulations make extensive use of state of the art building energy simulation (BES) programs, such as EnergyPlus, EQuest, Vabi, IES-VE and ESP-r in their energy assessment. BES programs evaluate in detail the building thermal performance integrating a considerable number of input data and physical processes. Nowadays, different BES programs are available [15], increasing the possibility of carrying out detailed energy evaluation. However, BES demands considerable amounts of time and resources, particularly when compared to so-called simplified models [16–20]. These simplified models usually require few input data and are built using several assumptions regarding climate, patterns of use and construction techniques. Simplified models are a quick tool for energy assessment, and that is the main reason for many countries to adopt this approach in their building energy regulations. However, simplified models may also have a considerable uncertainty in their results, which may compromise the building energy labelling process. Quantify the uncertainty in simplified models is essential to assure that building energy labelling processes will achieve the desired results.

This paper present a methodology based on the use of an internationally recognized validation and diagnostics procedure to test the fidelity of a simplified calculation method. The assessment is based on BESTEST (Building Energy Simulation Test), combined with four different typologies. The case study is based on a new and important simplified model for calculation of energy performance

* Corresponding author at: Energy Efficiency in Buildings Laboratory, Federal University of Santa Catarina, P.O. Box 476, 88040-900 Florianópolis, Brazil.
Tel.: +55 483721 5184; fax: +55 483721 5191.
E-mail addresses: apaula_melo@labeee.ufsc.br, apaula_melo@hotmail.com (A.P. Melo).

0378-7788/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.enbuild.2011.11.007

Table 1
Predetermined values considered to the development of the SM_{RTQ-C}.

Parameters	
Building orientation (larger facades)	North and South
Air conditioning system	Window system
Air conditioning efficiency (COP)	3.19 W/W
Air conditioning set-point	18 °C for heating 24 °C for cooling
Internal Load Density (ILD)	25 W/m^2
Patterns of use	11 h
Infiltration	Office: 0.5 ACH Hotel: 0 8 ACH Store: 1.0 ACH

of building envelopes, introduced by the Brazilian regulation for energy efficiency in commercial buildings.

Brazil is the Latin America leader on the implementation of energy efficient policies [21]. In Brazil, 90% of the electric energy is produced by renewable energy [22], and this country has a main goal to lead governments and private companies to establish a more energy efficiency economic society [23]. In 2001, the first energy efficiency law in Brazil was approved [24,25]. One of the outcomes of this energy efficiency law is the Regulation for Energy Efficiency Labelling of Commercial Buildings in Brazil (RTQ-C) [13], published in February 2009 after years of studies and investments. The RTQ-C classifies buildings according to five levels: from “A” (most efficient) to “E” (least efficient). This classification can be based on two methods: (1) the simulation method, which uses hourly BES results or (2) the prescriptive method, which is based on a set of prescriptive rules combined with the results of the simplified model (SM_{RTQ-C}) for calculation of energy performance of building envelopes introduced by RTQ-C [13].

The primary intent of this study is to provide a preliminary assessment on the accuracy of the SM_{RTQ-C}, comparing its results with BESTEST. Moreover, four case studies with different characteristics were evaluated comparing the envelope label achieved using the SM_{RTQ-C} with the label achieved using a state of the art BES program. The paper is structured in 5 sections. Section 2 provides an overview of the SM_{RTQ-C}. Section 3 describes the methodology used in the simulations, also describing a straightforward approach to apply the BESTEST in other climates than the original one (Denver, USA). The results are presented in Section 4, followed by conclusions in Section 5.

2. Overview of the simplified model for calculation of energy performance of building envelopes in commercial buildings in Brazil (SM_{RTQ-C})

The SM_{RTQ-C} was developed based on the results of approximately a thousand simulations using EnergyPlus for each climatic zone in the country [26,27]. Multi-linear regression was applied to obtain simple equations which could reasonably describe the variety of cases simulated using EnergyPlus. Input parameters not related to the building envelope were kept fixed in all simulations (Table 1).

The SM_{RTQ-C} takes into account the building geometry (projection area, total floor area, envelope area and total volume area) and some parameters related to openings, such as WWR (window-to-wall ratio), FS (solar factor), AVS (horizontal shadings), and AHS (vertical shading). The acronyms of WWR, FS, AVS and AHS are the same as considered in the RTQ-C. Wall and roof thermal transmittance were not included in the SM_{RTQ-C}, in spite of its recognized importance in the thermal performance of the building envelope [28]. Thermal transmittance was not included because its effect on the building energy performance is not linear [29], and consequently the multi-linear regression did not provide satisfactory coefficient of determination when transmittance is taken into account.

Building geometry is an important aspect in the SM_{RTQ-C}. Two equations were developed to predict the energy performance of the building envelope for each climatic zone in Brazil, as a function of the building projection area. One equation is applicable for building with projection area equal or lower than 500 m^2 (R^2 = 0.9978) and another equation for building with projection area higher than 500 m^2 (R^2 = 0.9989) [27]. Another two input data are used to describe the building geometry: the FA (height factor) and FF (shape factor). The acronyms of FA and FF are the same as considered in the RTQ-C. FA is the ratio of roof area and total building floor area, while FF is the ratio of envelope area and total building volume. For each equation, limit values for FF are defined (minimum and a maximum), and these limit values should be adopted if the actual FF value is outside the limits.

Results of the SM_{RTQ-C} are represented by a Consumption Indicator (IC). In order to determine the label of a building, it is necessary to apply the SM_{RTQ-C} both for: (1) the proposed building design and (2) for the definition of IC values corresponding to each label. These IC values are not fixed, changing according to the building geometry. Firstly, the IC for the proposed building should be calculated using the proposed building characteristics. Secondly, IC_{max} and IC_{min} should be calculated using input parameters of the proposed building geometry (projection area, FF, FA) in combination with values prescribed by RTQ-C of other input parameters (WWR, FS, AVS and AHS). The subtraction of IC_{max} and IC_{min} should be divided by 4 resulting in an interval (i). Finally it is possible to fill Table 2 and analyse which label was achieved by the proposed building.

In the simulation method, the values of energy consumption required to obtain each label are also case dependent. BESs are also carried out using prescribed input parameters (WWR, FS, AVS, AHS, Uvalue, COP) correspond to the values necessary to reach each label (from A to D). All other input parameters are taken from the proposed building design (user pattern, building geometry, orientation, etc.). To achieve a planned label, the proposed building should consume the same or less energy consumption than the reference building.

It is important to keep in mind that the actual building energy consumption can be different from the energy consumption calculated using BES or SM_{RTQ-C}. ASHRAE Standard 90.1 states that these differences may happen due to variation in the behaviour of building occupants, as well as in the building control system [12].

3. Methodology to assess the accuracy of the SM_{RTQ-C}

3.1. Comparison with the BESTEST

The BESTEST (Building Energy Simulation Test) is a method for testing and diagnosing of building energy simulation programs, developed in the Annex 43 “Testing and Validation of Building Energy Simulation Tools” of the Energy Conservation in Buildings and Community Systems (ECBCS) Programme of the International Energy Agency (IEA) [30]. The BESTEST was later used in the development of the ASHRAE Standard 140 [31]. This method includes several test cases, evaluating the influence of different physical process in the simulation results.

In the present study, some BESTEST cases were used to evaluate the accuracy of the SM_{RTQ-C}. The selection of the cases was based on the relevant parameters that are also taken into account in the SM_{RTQ-C}. The cases selected are summarized in Table 3.

All of those cases explore different combinations of parameters and settings, adopting a weather characterized as cold clear winter/hot dry summers (Denver, USA). The simulations were

Table 2
Calculation to determine the limit results required by each building label.

Label	A	B	C	D	E
Min	–	$IC_{max} - 3i + 0.01$	$IC_{max} - 2i + 0.01$	$IC_{max} - i + 0.01$	$IC_{max} + 0.01$
Max	$IC_{max} - 3i$	$IC_{max} - 2i$	$IC_{max} - i$	IC_{max}	–

carried out using the EnergyPlus program, which complies with the BESTEST and encloses all the requirements established by RTQ-C.

The Cases 600 and 900 have the same typology and consider the same parameters, but the former has a low mass construction and the later a high mass construction. Most of the other cases adopt a low mass construction, equal to Case 600. The Case 610 has the same parameters of Case 600, except that Case 610 has an overhang of 1 m. The Case 620 consider one window in the west and east facade. The changes in the Cases 610 and 620 are the same as for Cases 910 and 920. The other cases have the same typology, but each one considers different settings of parameters such as: infiltration, set-point, shading, internal load, window orientation and solar absorptivity.

The BESTEST was originally designed to evaluate energy simulation programs that are capable to carry out simulation for any location and weather. However, the SM_{RTQ-C} is specifically designed to evaluate buildings in the climatic zones of Brazil. Therefore, it was necessary to develop a methodology to apply the BESTEST in other climates than the original one (Denver, USA). In this paper, the BESTEST simulations were carried out using the weather data of Porto Alegre—Brazil (bioclimatic zone number 3).

Table 3
Characteristics of BESTEST cases adopted to evaluate the SM_{RTQ-C}.

BESTEST	Characteristics
Case 600	8 m × 6 m × 2.7 m 2 south facing windows (6 m^2 each) Thermal mass: low Infiltration: 0.5 ACH Internal gains: 200 W continually Set-point: 20 °C for heating 27 °C for cooling
Case 610	Same as Case 600 Overhang of 1 m
Case 620	Same as Case 600 Windows orientation: west and east
Case 900	Same as Case 600 Thermal mass: high
Case 910	Same as Case 900 Windows orientation: west and east
Case 920	Same as Case 600 Overhang of 1 m
Case 220	Same as Case 600 No infiltration No internal gains Set-point: 20 °C for heating and cooling No windows: high conductance wall
Case 240	Same as Case 220 Internal gains: 200 W continually
Case 270	Same as Case 220 Windows as Case 600 Interior shortwave absorptivity: 0.9
Case 290	Same as Case 270 Overhang of 1 m
Case 320	Same as Case 270 Set-point: 20 °C for heating 27 °C for cooling
Case 400	Same as Case 600 No infiltration No internal gains External solar absorptivity: 0.1 No windows: high conductance wall

In order to evaluate the difference between Denver and Porto Alegre, degree-days of cooling and heating, with base temperatures of 10 °C and 18 °C, respectively, were determined for both weather data. The base temperature values are based on ASHRAE Standard 90.1 [12] to characterize the climate of a city. Results show that Porto Alegre and Denver have 583 and 3343 degree days for heating and 3653 and 1907 for cooling, respectively. It is shown that both weather data present a significant difference in the degree days. However, Porto Alegre is the one among the Brazilian places that present the lowest temperature during the winter season in Brazil and an average summer temperature close to the one in Denver.

The following approach was applied to transpose the BESTEST results to the weather data of Porto Alegre. Initially, all the BESTEST cases were simulated taking into consideration the weather data of Denver, USA to assure that the energy demand results ($Q_{Eplus.Denver}$) are between the minimum and maximum values established by the BESTEST ($Qmin_{.Denver}$ and $Qmax_{.Denver}$). Based on the BESTEST range of acceptable results (maximum and minimum) and on the EnergyPlus results for Denver, confidence intervals were determined by the authors. These confidence intervals (CImax and CImin) are defined for each BESTEST case and performance indicator. CImax and CImin are calculated using Eqs. (1) and (2), as the relative difference (%) between the maximum/minimum limits described in the BESTEST and the EnergyPlus result (simulated by the authors) for Denver weather data:

$$\text{CImax} = \frac{Qmax_{.Denver} - Q_{Eplus.Denver}}{Q_{Eplus.Denver}} \quad (1)$$

$$\text{CImin} = \frac{Qmin_{.Denver} - Q_{Eplus.Denver}}{Q_{Eplus.Denver}} \quad (2)$$

Then, the same BESTEST cases were simulated using EnergyPlus for the weather data of Porto Alegre ($Q_{Eplus.PAlegre}$). Using EnergyPlus results for Porto Alegre and the confidence intervals previously determined, the new range of acceptable results (maximum and minimum) for Porto Alegre was calculated using Eqs. (3) and (4) for each BESTEST case ($Qmin_{.PAlegre}$ and $Qmax_{.PAlegre}$).

$$Qmax_{.PAlegre} = (1 + \text{CImax}) \cdot Q_{Eplus.PAlegre} \quad (3)$$

$$Qmin_{.PAlegre} = (1 + \text{CImin}) \cdot Q_{Eplus.PAlegre} \quad (4)$$

This approach is based on several assumptions. In an ideal scenario, the range of acceptable results for Porto Alegre should be constructed with results of all BES programs used in the BESTEST study. However, the use of all these programs would require considerable amounts of resources and expertise. The approach proposed in this paper provide means to construct ranges of acceptable results for the BESTEST cases for any location and weather, requiring minimum resources and knowledge.

3.2. Case studies: comparison between SM_{RTQ-C} and BES

These case studies consist of comparing the labels obtained using the two methods described in the RTQ-C: the simulation method, which uses hourly BES results and the prescriptive

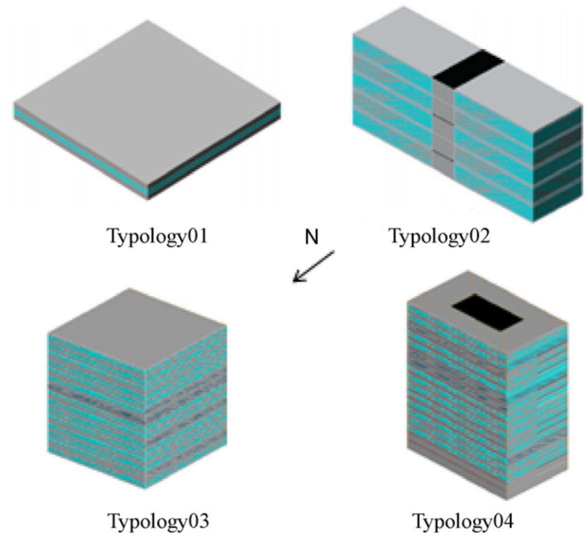

Fig. 1. A 3D view of Typologies 01, 02, 03 and 04.

method, which uses the $SM_{RTQ\text{-}C}$. It was also chosen to consider typologies with a building projection area higher than 500 m^2 to differ from BESTEST cases (building projection area lower than 500 m^2). Moreover, the buildings adopted have different combinations of FA, FF, WWR and FS to understand the influence of these inputs in the results.

Four commercial building typologies were evaluated, taking into consideration different total floor area and number of floors. The typologies are represented in Fig. 1 and their main characteristics are summarized in Table 4. All the typologies are acclimatized, except the central part of Typologies 02 and 04 (in black in Fig. 1). Input parameters not related to the building envelope are taken from Table 1. The parameters WWR (window-to-wall ratio), FS (solar factor) and AVS (horizontal shadings) were assumed to have different values (Table 4). All the case studies have the wall and roof thermal transmittance of 3.7 W/(m^2 K) and 1.0 W/(m^2 K), respectively. The simulation method (BES) and the prescriptive method ($SM_{RTQ\text{-}C}$) were applied on these typologies. The label achieved using each method was then compared.

Simulations were carried out using the BES program EnergyPlus, using the weather data of Florianópolis which belongs to the same bioclimatic zone number 3, as Porto Alegre. The weather data adopted is the same that was used in the development of the $SM_{RTQ\text{-}C}$ for the bioclimatic zone number 3, i.e. Florianópolis: TRY (Test Reference Year) from 1963, representing a typical year from a series of 10 years [32].

Table 4
Characteristics of the case studies.

Characteristic	Typologies			
	01	02	03	04
Length (m)	50	26.7	50	50
Width (m)	50	7.5	50	30
Height (m)	3.5	14.7	52.5	59.5
Total floor area (m^2)	2500	1001	37,500	25,500
Number of floors	1	5	15	17
WWR (%)	50	70	50	60
FS—solar factor	0.58	0.58	0.58	0.25
AVS (°)	0	12.5	0	0

4. Results

4.1. Comparison of the $SM_{RTQ\text{-}C}$ and the BESTEST

Before using the $SM_{RTQ\text{-}C}$ for bioclimatic zone number 3 (Porto Alegre), the shape factor of the building (FF) was calculated and compared to the limits defined by RTQ-C. The total projection area for the all BESTEST cases is 48 m^2, resulting in a FF value of 0.95. The maximum value of FF defined by RTQ-C for buildings with total projection area ≤500 m^2 and intended for bioclimatic zone 3 is 0.70. In these cases, RTQ-C states that the maximum value (0.7) should be considered in the simplified model calculation.

The comparison between the $SM_{RTQ\text{-}C}$ and BESTEST results are presented in Figs. 2–7. The first and the second columns are the maximum and minimum energy demand (MWh) values established by the BESTEST (combined heating and cooling energy demand). The third column is the energy demand result for Denver weather data calculated using EnergyPlus. The next column is the energy demand result for Porto Alegre weather data using the EnergyPlus, where the new BESTEST confidence interval for the Porto Alegre weather data is also represented. And the last column shows the result of the $SM_{RTQ\text{-}C}$. The $SM_{RTQ\text{-}C}$ provides results of energy consumption, based on a COP of 3.19. Based on this COP, energy consumption results of $SM_{RTQ\text{-}C}$ were converted to energy demand, which is presented in the figures.

Analysing the results for Case 600 (low thermal mass) and Case 900 (high thermal mass) in Fig. 2, it can be noticed that these buildings require less energy for cooling and heating in Porto Alegre than in Denver. For Case 600, the simplified model final result is practically inside of acceptable value calculated by the authors that is between −7% and +26% for Porto Alegre. Therefore, it was found for Case 900 significant difference when comparing the limit of acceptable values of this case for Porto Alegre weather data and the results of the $SM_{RTQ\text{-}C}$. For this case, the energy demand calculated using the $SM_{RTQ\text{-}C}$ exceeds the maximum acceptable value in 38%, i.e. 1.18 MWh. Results for the $SM_{RTQ\text{-}C}$ is the same for both Cases 600 and 900, as the simplified model does not take into account the building thermal mass. It can be noticed that Case 600 requires more energy demand than Case 900 for Porto Alegre to set the internal temperature according to the setpoint of 20 °C and 27 °C. The building thermal mass may help to reduce the energy consumption for heating and cooling systems. However, this parameter was not included as input parameter in the $SM_{RTQ\text{-}C}$.

For Cases 610 and 910 (Fig. 3), it can be observed that the $SM_{RTQ\text{-}C}$ results are out of the range of acceptable values, when comparing to EnergyPlus results. The $SM_{RTQ\text{-}C}$ result for Cases 610 and 910 exceed in 2% and 47% the maximum acceptable value, respectively. Both cases have the same characteristics as the Cases 600 and 900, except that Cases 610 and 910 have an overhang of 1 m. The overhang significantly reduces the energy demand in the EnergyPlus simulations. $SM_{RTQ\text{-}C}$ results are also reduced due to the overhang, but this reduction is smaller than in EnergyPlus.

The change in the window position, for west and east orientation (Cases 620 and 920 in Fig. 4), increases the energy demand for Porto Alegre. For Case 620, it was found significant difference when comparing the limit of acceptable values of this case for Porto Alegre weather data and the results of the $SM_{RTQ\text{-}C}$. For this case, the energy demand calculated using the $SM_{RTQ\text{-}C}$ is 17% lower than the minimum acceptable value, i.e. 0.90 MWh. However, the Case 920 presents results inside of the range of acceptable values that are between −15% and +27% for Porto Alegre. Also, it can be noticed that for this case the EnergyPlus result for Porto Alegre and $SM_{RTQ\text{-}C}$ final results have almost the same value. For both cases, the $SM_{RTQ\text{-}C}$ final result is the same. Therefore, as the Case 920 requires less energy demand to set the internal temperature between the setpoint values of 20 °C and 27 °C and based on a combination of different

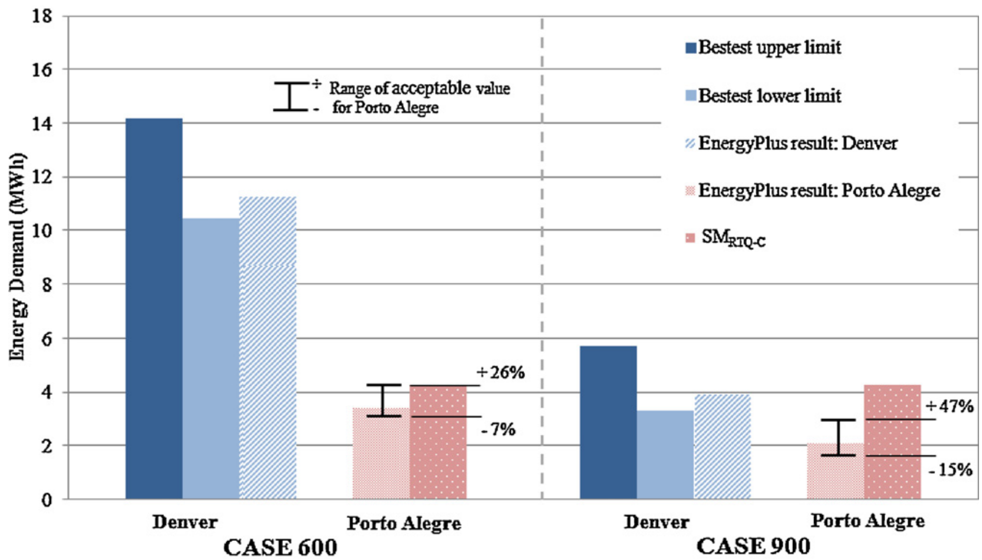

Fig. 2. Comparison between $SM_{RTQ\text{-}C}$ and EnergyPlus—Cases 600 and 900 results.

factors, this case could present its $SM_{RTQ\text{-}C}$ final result between the confidence intervals calculated by the authors.

In Case 220 the windows were replaced by a high conductance wall, i.e. there is no direct solar radiation entering the building. Case 220 has a set-point with no deadband (20 °C for heating and 20 °C for cooling) and also it does not consider any internal gain. Although much simpler than the previous cases, results in Fig. 5 for Case 220 show difference between EnergyPlus and $SM_{RTQ\text{-}C}$. The $SM_{RTQ\text{-}C}$ result exceeds the maximum acceptable value in 6%. Adding an internal load of 200 W (Case 240) reduces the heating energy demand, as shown in EnergyPlus results in Fig. 5. But, the $SM_{RTQ\text{-}C}$ final result also exceeds the maximum acceptable value in 14%, i.e. 0.5 MWh. The $SM_{RTQ\text{-}C}$ results are the same for Cases 220 and 240 as the internal gains are not taken into account by $SM_{RTQ\text{-}C}$. Those values were set as fixed during the development of the simplified model as was mentioned in the second part of this paper. $SM_{RTQ\text{-}C}$ results for Cases 220 and 240 are outside of the range of acceptable values. These differences could be attributed as both cases do not consider any windows and the $SM_{RTQ\text{-}C}$ presents strongly importance to the parameters related to openings.

Fig. 6 shows the results for Cases 270 and 290. For Case 270, which is the same as Case 600, except that it does not take into account any internal gains, infiltration and the setpoint is without deadband (20 °C for heating and 20 °C for cooling), the $SM_{RTQ\text{-}C}$ final result is really close of acceptable value that is between −4% and +29% for Porto Alegre. Therefore, adding an overhang (Case 290) it can be noticed that the $SM_{RTQ\text{-}C}$ results are clearly inside of the range of acceptable values. Considering an overhang, the $SM_{RTQ\text{-}C}$ and EnergyPlus final result is reduced when compared to Case 270.

For both Cases 320 and 400 (Fig. 7), the $SM_{RTQ\text{-}C}$ results are clearly outside of the range of acceptable values. The $SM_{RTQ\text{-}C}$ result for Cases 320 and 400 exceed in 52% and 60% the maximum acceptable value, respectively. The Case 320 is the same as Case 270, but it has the same setpoint as Case 600. Although the change of the setpoint values reduces the EnergyPlus energy demand for both cases, the $SM_{RTQ\text{-}C}$ results does not decrease as the setpoint values were set as fixed during the development of the simplified model as was mentioned in the second part of this paper. The Case 400 has the same characteristics as Case 600, but it does not consider

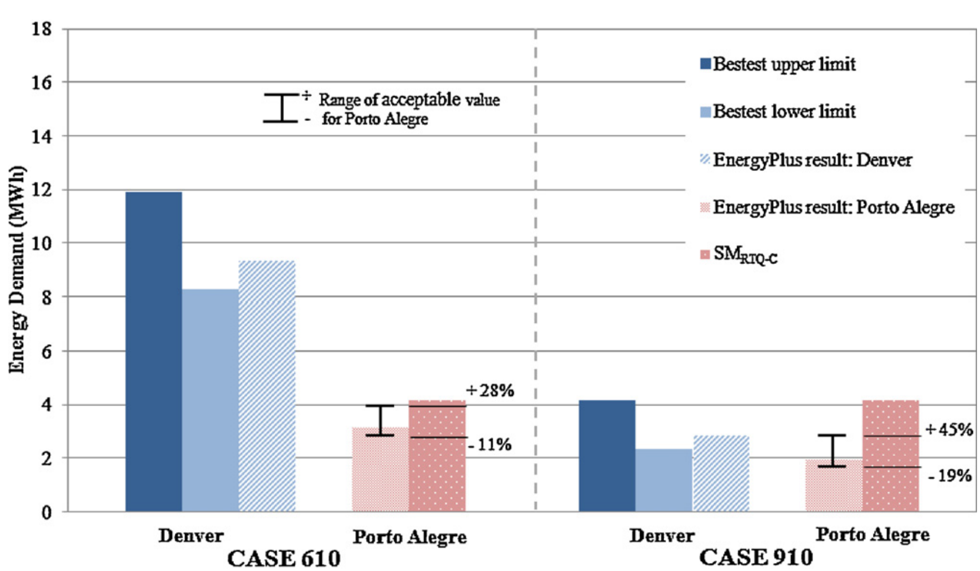

Fig. 3. Comparison between $SM_{RTQ\text{-}C}$ and EnergyPlus—Cases 610 and 910 results.

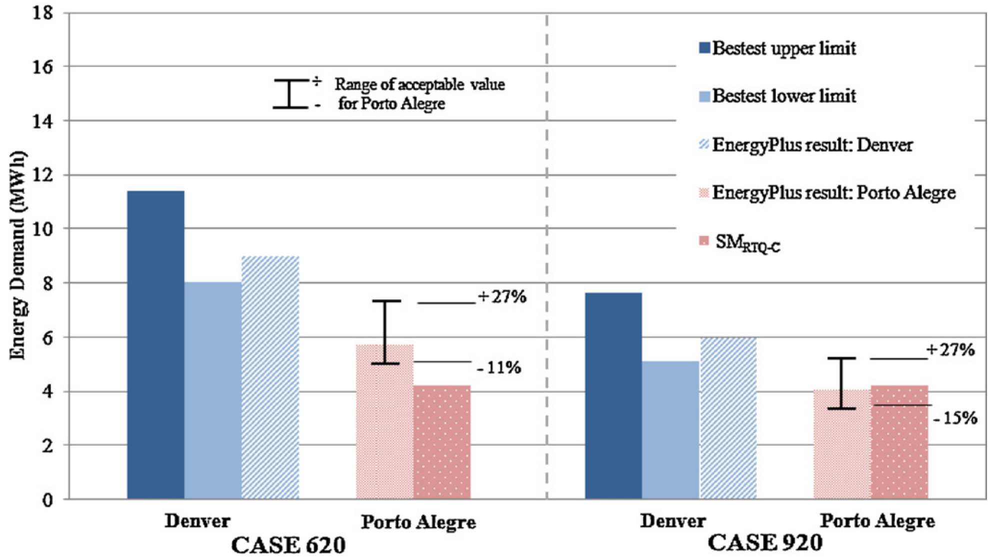

Fig. 4. Comparison between SM_{RTQ-C} and EnergyPlus—Cases 620 and 920 results.

infiltration, internal gains and windows. As it was previously observed in Fig. 5 (Cases 220 and 240), the SM_{RTQ-C} presents strong importance to the parameters related to openings.

In some of the BESTEST cases, SM_{RTQ-C} results are inside the range of acceptable values (Cases 600, 920, 270, and 290). However, in most other cases (220, 240, 320, 400, 610, 900 and 910), SM_{RTQ-C} results exceed the maximum acceptable value in up to 60%. In one case the SM_{RTQ-C} result is 17% lower than the minimum acceptable value (Case 620). These differences could be attributed to, among other factors, the small floor area of BESTEST cases, because the SM_{RTQ-C} was generally applicable to calculate the performance of more complex buildings. The next section presents results of comparisons between BES (EnergyPlus) and SM_{RTQ-C} for four realistic case studies.

4.2. Comparison of the SM_{RTQ-C} and the BES

The height factor (FA) and shape factor (FF) were calculated for the four buildings analysed. According to RTQ-C, buildings with a total projection area higher than 500 m^2 for bioclimatic zone number 3 should consider a minimum FF value of 0.15. Table 5 shows the values of FA and FF for each building. The Typology 01, Typology 03 and Typology 04 should have a minimum FF value of 0.15 and for Typology 02 a maximum FF value of 0.70. The Typologies 01 and 02 present FF value of 0.37 and 0.41, respectively. Both values are acceptable by RTQ-C. The Typology 03 and Typology 04 have a FF value lower than the minimum value. For these cases, the recommended minimum value of 0.15 was set during the simplified model calculation.

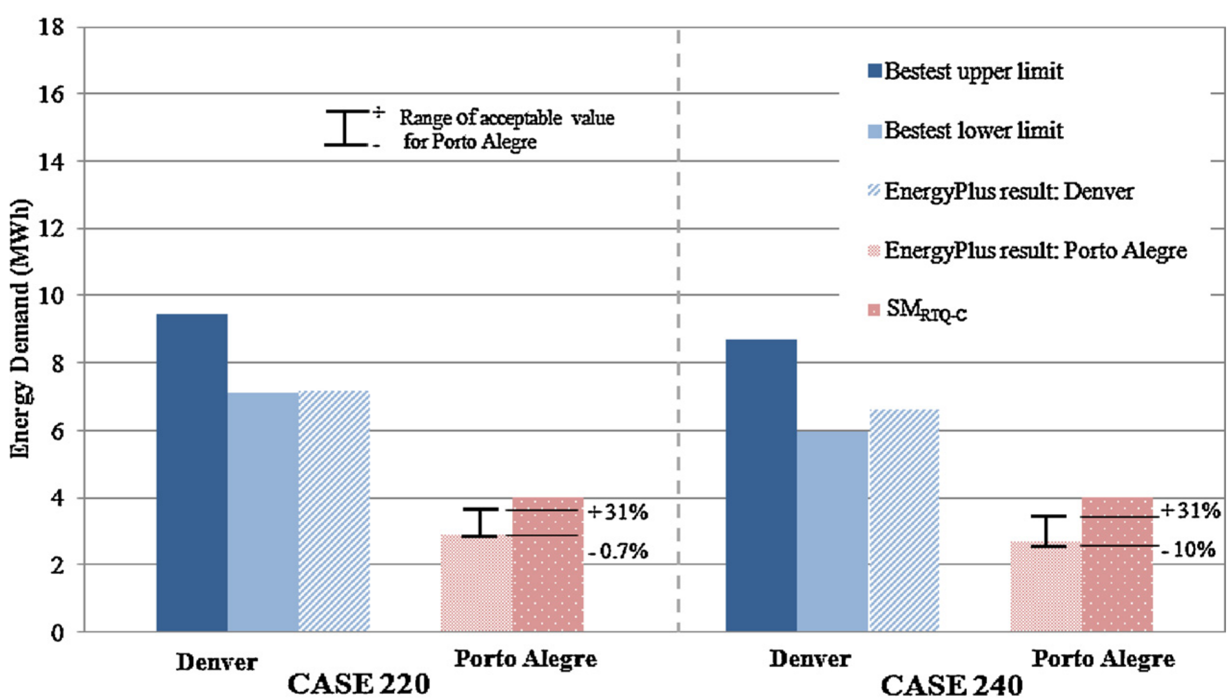

Fig. 5. Comparison between SM_{RTQ-C} and EnergyPlus—Cases 220 and 240 results.

Please cite this article in press as: A.P. Melo, et al., Assessing the accuracy of a simplified building energy simulation model using BESTEST: The case study of Brazilian regulation, Energy Buildings (2011), doi:10.1016/j.enbuild.2011.11.007

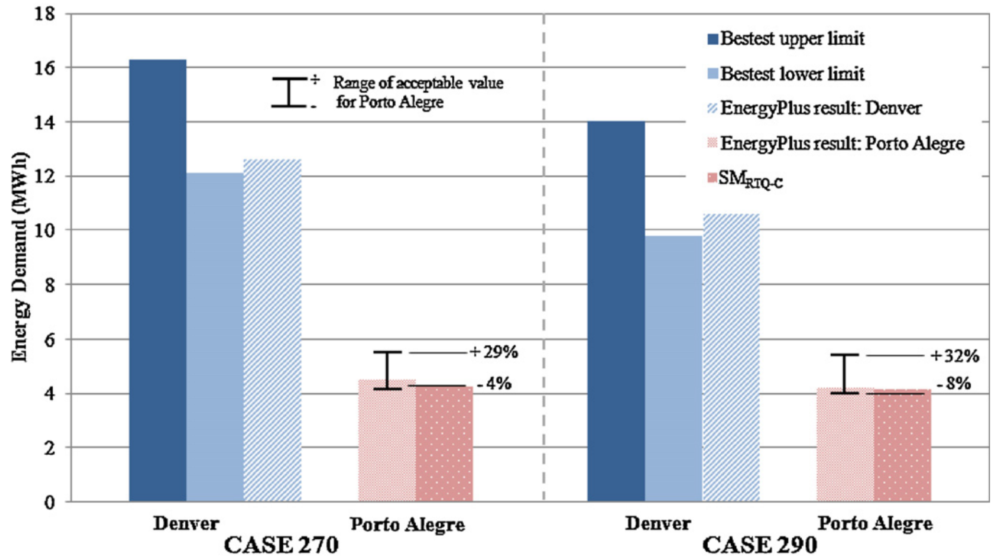

Fig. 6. Comparison between SM_{RTQ-C} and EnergyPlus—Cases 270 and 290 results.

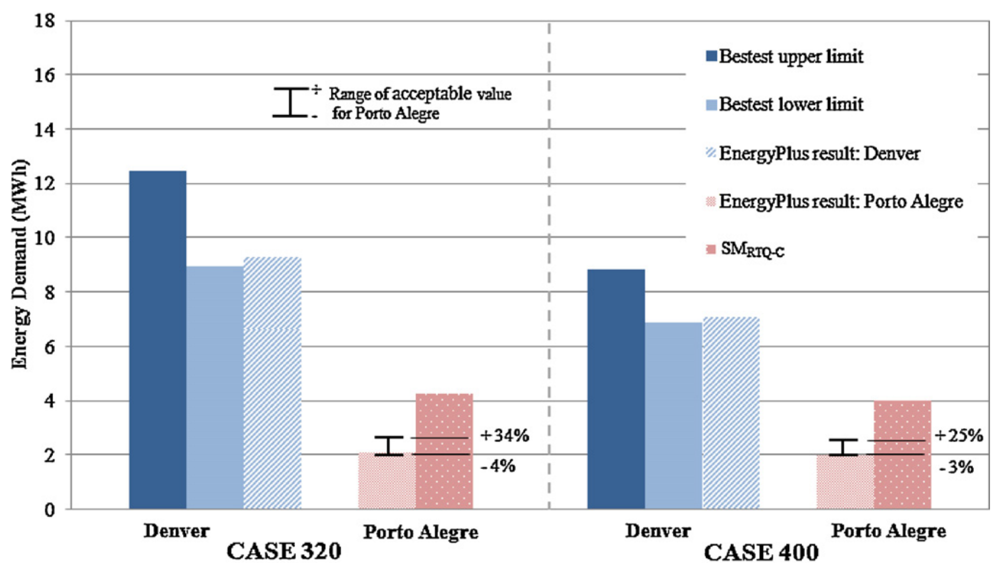

Fig. 7. Comparison between SM_{RTQ-C} and EnergyPlus—Cases 320 and 400 results.

The range of results corresponding to labels A–E for Typology 01 is presented in Table 6. The result of the SM_{RTQ-C} is presented in IC and the BES result is presented in kWh/m^2. The IC result for Typology 01 is 152.65, corresponding to label D (in bold in Table 6). Adopting the simulation method, the energy consumption result is 98.1 kWh/m^2, corresponding to label C. For this building, the use of SM_{RTQ-C} and BES lead to different labels, which is not desirable in the labelling process.

As mentioned in Section 3, the minimum results required to obtain a certain label are not fixed in the RTQ-C, being calculated for every particular building as a function of some of its own characteristics. One would expect that the SM_{RTQ-C} and BES would provide similar minimum values required to obtain a certain label, however Table 6 shows that these values are significantly different. Although the IC does not indicate the actual energy consumption of the building, IC is based on extensive simulations using BES (EnergyPlus).

Table 5
FA (height factor) and FF (shape factor) of the typologies simulated in the case studies.

	Typology			
	01	02	03	04
FA	1.00	0.20	0.07	0.06
FF	0.37	0.41	0.10	0.12
FFfinal	0.37	0.41	0.15	0.15

Table 6
Label for Typology 01 according to two different methods.

Prescriptive method (SM_{RTQ-C})					
Label	A	B	C	D	E
Min (IC)	–	137.87	144.54	**151.21**	157.88
Max (IC)	137.86	144.53	151.20	**157.87**	–

Simulation method (BES)				
Label	A	B	C	D
Max (kWh/m^2)	94.8	97.5	**100.4**	108.3

Table 7
Label for Typology 02 according to two different methods.

Prescriptive method (SM_{RTQ-C})					
Label	A	B	C	D	E
Min (IC)	–	211.18	213.82	**216.46**	219.11
Max (IC)	211.17	213.81	216.45	**219.10**	–

Simulation method (BES)				
Label	A	B	C	D
Max (kWh/m^2)	73.7	76.5	**78.7**	80.1

Therefore, large differences between minimum results on the prescriptive method and in the simulation method might indicate that important information about the building performance was lost in the development of the multi-linear regression.

It is also noticeable that the relative difference between the minimum values required to obtain labels A and B is smaller in the simulation method than in the prescriptive method for Typology 01. In the simulation method, the difference between these labels is 2.8%, while in the predictive method the difference is 4.8%. Moreover, the interval between two consecutive labels is not similarly distributed in the two methods. The difference between labels C and D in the simulation method (7.8%) is much larger than between labels A and B (2.8%). However, in the prescriptive method the difference between labels C and D (3.9%) is smaller than between labels A and B (4.8%). These inconsistencies might also indicate important discrepancies between the methods. These discrepancies might be related to the definition of minimum results required to obtain a certain label, as well as potential problems in the multi-linear regression used to develop the SM_{RTQ-C}.

Table 7 presents the results for Typology 02. The SM_{RTQ-C} gives a result of IC = 218.54 representing a label D (in bold), while BES indicates an energy consumption of 78.2 kWh/m^2 and the label achieved is C. As in Typology 01, the two methods indicate different labels, and the simulation method indicates a better label than the one obtained using SM_{RTQ-C}.

Comparison between the requirement for Typologies 01 and 02 shows differences in IC and kWh/m^2 results. Differences between requirement for Typologies 01 and 02 are only due to the building geometry, because the buildings are identical in all other aspects. These differences indicate that the building external area plays a significant role in the definitions of requirements to achieve each label.

Table 8 presents the results for Typology 03. The SM_{RTQ-C} gives a result of IC = 49.84 representing a label D (in bold), while BES indicates an energy consumption of 26.9 kWh/m^2 and the label achieved is B. As in Typologies 01 and 02, the two methods indicate different labels, but in this case the difference between the labels is bigger (B–D). Requirements for Typology 03 are much more restrictive than for Typologies 01 and 02. A building with the geometry of Typology 03 and an envelope characteristics of label E according to RTQ-C (i.e. roof thermal transmittance higher than 2.0 W/(m^2 K)), consuming, for example, 32 kWh/m^2. As previously mentioned in the last paragraph, it can be seen that the building external area plays a significant role in the definitions of requirements to achieve each label.

Table 8
Label for Typology 03 according to two different methods.

Prescriptive method (SM_{RTQ-C})					
Label	A	B	C	D	E
Min (IC)	–	35.06	41.74	**48.41**	55.08
Max (IC)	35.05	41.73	48.40	**55.07**	–

Simulation method (BES)				
Label	A	B	C	D
Max (kWh/m^2)	25.2	**27.1**	28.8	31.5

Table 9
Label for Typology 04 according to two different methods.

Prescriptive method (SM_{RTQ-C})					
Label	A	B	C	D	E
Min (IC)	–	35.17	41.85	**48.52**	55.19
Max (IC)	35.16	41.84	48.51	**55.18**	–

Simulation method (BES)				
Label	A	B	C	D
Max (kWh/m^2)	121.9	**123.5**	126.4	132.6

The results for Typology 04 (Table 9) present the same scenario of previous typologies. The IC of this building is 53.43 representing a label D (in bold) in the prescriptive method, while the energy consumption for the simulation method is 122.4 kWh/m^2 representing a label B.

In all 4 cases studied, the use of the prescriptive method (SM_{RTQ-C}) led to a lower energy efficiency label when compared to the label obtained using the simulation method (BES). Analysing Typology 03 and Typology 04, the simulation method presents labels two levels more efficient than the prescriptive method (B–D).

Considering that BES can better describe the physical phenomena involved in the calculation of energy consumption, it can be concluded that those results for SM_{RTQ-C} may suggest that the simplified model is performing as a conservative method. The differences found in the case studies might indicate that the multi-linear regression adopted to develop the SM_{RTQ-C} was unable to describe the relation between inputs parameter and energy consumption in the case of commercial buildings in Brazil.

It is clear that the main strength of the SM_{RTQ-C} is its simplicity, which makes energy performance evaluation very straightforward and inexpensive. However, its main deficiency is the bias in the predictions (usually overestimation of energy demand) that can be observed in several buildings analysed in this paper, disregarding the floor area, building geometry, thermal mass, etc. The use of BES is therefore recommended in all cases where the energy label is important for the building stakeholders and when the costs of this sort of simulation can be afforded.

5. Conclusions and future work

In this study, the use of an internationally recognized validation and diagnostics procedure to test the fidelity of the Brazilian regulation simplified model for calculation of energy performance of building envelopes was applied. The methodology was based on a comparison between the RTQ-C simplified model and BESTEST results. In addition, the energy labels of four commercial building typologies were evaluated using two approaches: the RTQ-C simplified model and a state of the art building energy simulation program (EnergyPlus). Based on the results the following conclusions can be made:

1. The paper presents and applies a straightforward method to use the BESTEST in other climates than the original one (Denver, USA);
2. The methodology presented can be applied in different countries to verify the accuracy of their simplified model used in the context of building energy performance labelling;

Please cite this article in press as: A.P. Melo, et al., Assessing the accuracy of a simplified building energy simulation model using BESTEST: The case study of Brazilian regulation, Energy Buildings (2011), doi:10.1016/j.enbuild.2011.11.007

3. For some BESTEST cases the SM_{RTQ-C} results are inside of acceptable values (Cases 600, 920 270, and 290). However, for most other cases (610, 900, 910, 220, 240, 320 and 400) the SM_{RTQ-C} results exceed the maximum acceptable value in up to 60%. These differences can be explained as BESTEST geometry is not among the typologies considered during the simplified model development. However, the comparison between simplified model and BESTEST let to understand the influence of different physical processes;
4. The RTQ-C simplified model led to a lower energy efficiency label than the one obtained using a state of the art building energy simulation program (EnergyPlus) for all four commercial buildings that have been analysed;
5. The results related to the RTQ-C simplified model may suggest that the simplified model is performing as a conservative method. The use of BES is therefore recommended in all cases where the energy label is important for the building stakeholders and when the costs of this sort of simulation can be afforded.

The development of the Regulation for Energy Efficiency Labelling of Commercial Buildings in Brazil is an important instrument to guarantee the energy efficient of future buildings in the country. However, this study emphasizes the need for a more accurate and efficient simplified model for the calculation of energy consumption used in labelling process. The outcomes of this paper may be relevant for all policy makers and stake holders involved in the development of energy regulation for the built environment.

Many possibilities are available when considering the future work in the improvement of the SM_{RTQ-C}. A few of the possibilities are briefly presented below.

One of the clearest limitations of the SM_{RTQ-C} is the range of building typologies used for its development, for example regarding building area, building geometry (namely the height factor (FA) and shape factor (FF)) and building orientation. One possibility of future work is to extend the number of typologies and also the input parameters used in the development of an improved SM_{RTQ-C}, better representing the variety found in the existing commercial buildings in Brazil.

The development of the SM_{RTQ-C} used extensive BESs, where most input parameters were kept fixed in each simulation and only one parameter was modified at a time. This method might mask combined effects of several input parameters varying simultaneously, which might compromise the SM_{RTQ-C} development. It would be advisable to analyse these combined effects, by applying for example, the Hypercube Latin sampling method to define the set of cases to be simulated.

The use of linear multi-linear regression involves large simplifications in the statistical modeling of the relation between building design and energy consumption. Future work should evaluate the feasibility and relevance of more complex statistical modeling techniques, such as the artificial neural network (ANN). ANN can describe correlation between input and output that are non-linear, possibly leading to more accurate models. In spite of its complexity, computer programs using ANN can provide fast calculation results.

Future work should pay attention on the correlation between energy consumption and the label obtained. As described in Section 4.2, there is a large variation between the energy consumption per m^2 of buildings obtaining similar labels. This variation is mainly related to the building geometry, which is strongly dependent on the plot aspect ratio and on the legislation regulating the maximum amount of floors. Further studies of the potential for energy saving in relation to the building geometry can lead to policies supporting a more energy efficient configuration of urban plots, which is especially relevant in countries facing large growth rates of urban areas, as is the Brazilian case.

Finally, the global cost (economic, social and environmental) of solutions for energy conservation supported by the labelling system should be evaluated in a police making level. Building labels have the potential to induce large modifications in the building industry, and in some cases, the global cost of such solutions might be higher than the energy potentially saving. Evaluating the global cost may support police makers when choosing among solutions with similar energy saving potential, but with different global costs for the society and for the environment (embedded energy, production residual, life-cycle, etc.).

Acknowledgements

This research is supported by The Brazilian Federal Agency for Support and Evaluation of Graduate Indication – CAPES, Proc. no 2335/10-7, and has partly been carried out at Eindhoven University of Technology, The Netherlands.

References

[1] O. Guerra Santin, L. Itard, H. Visscher, The effect of occupancy and building characteristics on energy use for space and water heating in Dutch residential stock, Energy and Buildings 41 (2009) 1223–1232.
[2] K.M.S. Chvatal, E.A.B. Maldonado, M.H.P. Corvacho, Study of the impact of the increase of the thermal insulation of the building envelope upon its thermal performance, in: PALENC—Passive and Low Energy Cooling for the Built Environment, Greece, 2005.
[3] P. Silva, M. Almeida, L. Bragança, V. Mesquita, Methodology to enhance the Portuguese thermal regulation accuracy for existing buildings, in: Proceedings of the Building Simulation 2009, Glasgow, 2009.
[4] F. Asdrubali, M. Bonaut, M. Battisti, M. Venegas, Comparative study of energy regulations for buildings in Italy and Spain, Energy and Buildings 40 (2008) 1805–1815.
[5] M. Beerepoot, N. Beerepoot, Government regulation as an impetus for innovation: evidence from energy performance regulation in the Dutch residential building sector, Energy Policy 35 (2007) 4812–4825.
[6] X.G. Casals, Analysis of building energy regulation and certification in Europe: their role, limitations and differences, Energy and Buildings 38 (2006) 381–392.
[7] P. Pezzini, O. Gomis-Bellmunt, J. Frau-Valentí, A. Sudrià-Andreu, Energy efficiency optimization in distribution transformers considering Spanish distribution regulation policy, Energy 35 (2010) 4685–4690.
[8] H. Radhi, A. Eltrapolis, S. Sharples, Will energy regulations in the Gulf States make buildings more comfortable—a scoping study of residential buildings, Applied Energy 86 (2009) 2531–2539.
[9] N. Wang, Y.-C. Chang, V. Dauber, Carbon print studies for the energy conservation regulations of the UK and China, Energy and Buildings 42 (2010) 695–698.
[10] Portugal, RCCTE—Regulation of the Buildings Thermal Behaviour Characteristics (in Portuguese), Ministry of Public Works, Transportation and Communications, Decree-Law n° 80/2006 of April 4, 2006.
[11] NEN, NEN 2916 – Energy Performance of Non-residential Buildings – Determination Method, NNI, Delft, The Netherlands, 1994 (in Dutch).
[12] ASHRAE, ANSI/ASHRAE Standard 90.1-2004: Energy Standard for Building Except Low-rise Residential Buildings, ASHRAE, Atlanta, 2004.
[13] Brasil, Portaria 185, de 22 de junho de 2009, Regulamento de Avaliação da Conformidade do Nível de Eficiência Energética de Edifícios Comerciais, de Serviços e Públicos, Instituto Nacional de Metrologia, Normalização e Qualidade Industrial (INMETRO), Rio de Janeiro, 2009 (in Portuguese).
[14] L. Pérez-Lombard, J. Ortiz, R. González, I.R. Maestre, A review of benchmarking, rating and labelling concepts within the framework of building energy certification schemes, Energy and Buildings 41 (2009) 272–278.
[15] D.B Crawley, J.W. Hand, M. Kummert, B.T. Griffith, Contrasting the capabilities of building energy performance simulation programs, Building and Environment 43 (2008) 661–673.
[16] T.M. Lawrence, J.E. Braun, Evaluation of simplified models for predicting CO_2 concentrations in small commercial buildings, Building and Environment 41 (2006) 184–194.
[17] G. Liu, M. Liu, A rapid calibration procedure and case study for simplified simulation models of commonly used HVAC systems, Building and Environment 46 (2011) 409–420.
[18] Y. Pan, Y. Li, Z. Huang, G. Wu, Study on simulation methods of atrium building cooling load in hot and humid regions, Energy and Buildings 42 (2010) 1654–1660.
[19] X. Xu, S. Wang, Optimal simplified thermal models of building envelope based on frequency domain regression using genetic algorithm, Energy and Buildings 39 (2007) 525–536.
[20] Y.G. Yohanis, B. Norton, Utilization factor for building solar-heat gain for use in a simplified energy model, Applied Energy 63 (1999) 227–239.
[21] CIB, Task Group 66 Web Event: The Implementation of Energy Efficient Buildings Policies in South America, CIB: International Council Building, 2010.

[22] Brasil, Balanço Energético Nacional (in Portuguese), MME—Ministério de Minas e Energia, 2009. Available at http://www.mme.gov.br.
[23] Brasil, Plano Nacional de Energia 2030 (in Portuguese), MME—Ministério de Minas e Energia, 2006. Available at http://www.mme.gov.br.
[24] Brasil, Decreto No. 4.059, de 19 de dezembro de, 2001, Regulamenta a Lei No. 10.295e dá outras providências, Diário Oficial da República Federativa do Brasil, Brasília, 2001 (in Portuguese).
[25] Brasil, Lei No. 10.295, de 17 de outubro de 2001, Dispõe sobre a Política Nacional de Conservação e Uso Racional de Energia e dá outras providências, Diário Oficial da República Federativa do Brasil, Brasília, 2001 (in Portuguese).
[26] J. Carlo, Development of a methodology for evaluating the energy efficiency of non-residential buildings envelope (in Portuguese), Ph.D. Thesis, Federal University of Santa Catarina, Florianópolis, 2008.
[27] J. Carlo, R. Lamberts, Parameters and methods adopted in the energy efficiency labelling regulation for buildings—part 1: prescriptive method, Revista Ambiente Construído 10 (2010) 7–26 (in Portuguese).
[28] K.M.S. Chvatal, H. Corvacho, The impact of increasing the building envelope insulation upon the risk of overheating in summer and an increased energy consumption, Journal of Building Performance Simulation 2 (2009) 267–282.
[29] A.P. Melo, R. Lamberts, Opaque envelope parameters versus energy consumption in commercial buildings in Brazil, Journal of Building Performance Simulation 1 (2008) 237–244.
[30] R. Judkoff, J. Neymark, International Energy Agency building energy simulation test (BESTEST) and diagnostic method. Report NREL/TP-472-6231, NREL, Golden, 1995.
[31] ASHRAE, ANSI/ASHRAE Standard 140-2004: Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs, ASHRAE, Atlanta, 2004.
[32] S.V. Goulart, Climate files to evaluate the building performance in Florianopolis (in Portuguese), Master Thesis, Federal University of Santa Catarina, Florianópolis, 1993.

Please cite this article in press as: A.P. Melo, et al., Assessing the accuracy of a simplified building energy simulation model using BESTEST: The case study of Brazilian regulation, Energy Buildings (2011), doi:10.1016/j.enbuild.2011.11.007