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ENERGY PERFORMANCE EVALUATION AND COMPARISON OF SAMPLED BRAZILIAN BANK BUILDINGS WITH THE EXISTING AND PROPOSED ENERGY RATING SYSTEMS

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Abstract

The energy performance of 11 bank branches in the Brazilian city of Curitiba was analysed using bottom-up engineering energy benchmarking method. As part of a previous study to classify bank buildings, these bank branches were selected for a further study with their building parametric and energy-related data obtained from building drawings and specifications as well as on-site surveys. The energy assessment of these branches was conducted using the existing (RTQ-C) and proposed (INI-C) Brazilian energy efficient labelling regulations for non-domestic buildings. The ability of both systems to produce results which are compatible and could be used to reflect the actual building energy consumption was examined. The study shows improvement of the INI-C system with calculation of energy consumption values and conditions for different reference buildings. However, performance gap between the calculated and actual energy consumption was found due to various reasons including reference values for office buildings were inaccurate for bank buildings. Hence, a list of modified reference values was proposed for bank buildings to represent bank buildings more accurately. This paper highlights the strengths and limitations of both the existing and proposed regulations and presents a reality check against the calculations of energy ratings and actual energy consumption of the buildings. It was concluded that the existing and proposed regulations have to be improved significantly in terms of calculation methodology in order to meet the demand of future energy policy in Brazil.

Keywords: energy rating, bank building, energy consumption, building sample, benchmarking

1. Introduction

Buildings are major energy consumers, which contribute to the majority of greenhouse gas emissions in the world with up to one third of the carbon emissions in the United States (US) (DOE, 2012) and more than 38% in the European Union (EU) (Eurostat, 2015). Both domestic and commercial buildings contribute significantly

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to the emission of greenhouse gases, for up to an approximately 40% within developed countries (Perez-Lombard et al., 2008). In the United Kingdom (UK), buildings account for approximately half of the total carbon emissions (Power, 2010) and the nations' primary target is to reduce carbon emissions across the country by 80% in 2050, in comparison to 1990 levels (CCC, 2018). In Europe, early efforts to classify the energy performance of building sector under Directive 93/76/EEC (EC, 1993) were non-mandatory (Wong and Krüger, 2017). To increase the impact, Directive 2002/91/EC (EC, 2002) was introduced to make energy performance disclosure mandatory in all Member States through the introduction of comparable Energy Performance Certificates (EPCs) (Perez-Lombard et al., 2009). The Directive 2002/91/EC has been formally implemented in 2006 and the scope has been expanded through the recast, Directive 2010/31/EU in 2010 (EC, 2010). On the other hand, Brazil is facing the issue of growing building energy consumption, similar to other developing countries. Buildings accounted for 50% of the total electricity energy consumption in 2014, with electricity consumption in commercial and public buildings accounting for at least 90% of the total energy consumption (MME, 2015).

1.1. Energy performance certification in buildings

Since the Brazilian government launched the PROCEL Edifica Programme in 2003, a federal regulation was approved to provide voluntary energy efficiency labelling requirements for buildings in Brazil. In 2009, the Energy Efficiency Rating - Technical Quality Regulations for Commercial, Service and Public Buildings (RTQ-C) (MME, 2009) was implemented for all commercial buildings. During the initial stage of RTQ-C implementation, a number of weaknesses and improvement areas have been identified and reported when compared with more mature energy rating systems in other developed countries (Lopes et al., 2016; Wong and Krüger, 2017). A proposed improved version of energy rating regulation for commercial, service and public buildings (INI-C), which has been developed and is in the process of replacing the RTQ-C regulation was introduced in July 2018 (INMETRO, 2018). The INI-C regulation contains improvements with significant changes to the methodology adopted to calculate building energy ratings. According to Kottek et al (2006), southern European countries, such as Portugal and Spain have warm temperate climates with hot-summers and mild winters (Type C climate in Köppen-Geiger climate classification), which are similar to the climatic zones of southern Brazil. The energy performance requirement of Directive 2010/31/EU was transposed into national laws by decrees in these countries. The Spanish energy regulations classify their climates into 12 climatic zones (de la For et al., 2008); while in Brazil, the existing RTQ-C regulation adopts eight climatic zone classification by the Brazilian Association of Technical Standard (NBR 15.220-3) shown in Table 1 (ABNT, 2003). Roriz

(2014) published a more precise classification with 24 climatic zones in Brazil, which has been adopted by the proposed INI-C regulation.

Climatic zones	Key cities	Geographical zones	Average temperature (°C) (summer/ winter)
Zone 1	Curitiba	South	20.7/ 14.0
Zone 2	Piracicaba	South and southwest	22.9/ 19.0
Zone 3	Florianopolis	South	24.5/ 17.5
Zone 4	Brasilia	Centre west	22.5/ 20.8
Zone 5	Niteroi	Southeast and centre west	24.5/ 20.6
Zone 6	Campo Grande	Centre west	25.3/ 22.7
Zone 7	Picos	Arid region of northeast	27.9/ 28.1
Zone 8	Rio de Janeiro	North and most of coastal area	26.5/ 21.7

Table 1: Key characteristics of Brazilian bioclimatic zones (adapted from Barbosa and Ip, 2016)

Compared to Brazil (energy classes from A to E), both Portugal and Spain have seven or eight energy classes (A+ to F or A to G) in their energy certificates (Vaquero, 2020; Carpio et al., 2015). The energy performance of buildings in Portugal can be performed using PtnZEB (Vaquero, 2020) or a simulation tool that complies with ASHRAE 140-2004 standard (Nunes et al., 2013). In Spain, an approach similar with Brazil was used for certification (i.e. simplified methods using tables and simulation method using CALENER software) (Herrera, 2008; Andaloro et al., 2010; Carpio et al., 2015). Apart from mandatory EU requirement, EPCs in both countries serve as important tool either to enable access to funding schemes and tax benefits (Fragoso and Baptista, 2018) or improve building energy performance through PAREER-CRECE programme (Martin, 2018). Certification requirement in Brazil, however is premature and non-mandatory due to lack of professional capacity in the country (Lopes et al., 2016).

1.2. Performance gap between estimated and actual energy performance

The methodology developed to calculate the energy performance or certification of buildings however is not uncontroversial. Several studies undertaken in the past have demonstrated the discrepancies between the energy performance of the buildings calculated using certification tools/ simulation software and actual energy performance. Bordass et al (2001) concluded in earlier studies that actual energy consumption of most non-domestic buildings was higher than the calculated energy due to discrepancies between values assumed in the calculation tool and the actual values of the buildings. In the UK, the Standard Assessment Procedure (SAP) used for energy performance certification of domestic dwellings has been criticised as large variance between estimated and actual energy performance was found (Kelly et al., 2012). The energy performance gap between estimated and actual values was also confirmed for various non-domestic buildings in the UK, such as, schools, retail, offices, etc. (Pegg et al., 2007; Carbon Trust, 2011). In European countries, discrepancies of up to 30% were found in studies in Italy (Tronchin and Fabbri, 2010) and Denmark (Petersen and Hviid, 2012). In Spain, an average deviation of 30% was found between estimated and actual energy consumption of university buildings (Herrando et al., 2016). One of the main causes of such performance gap is inaccuracies and uncertainties in the input parameters (Menezes et al., 2012; Ahmad and Culp, 2006). These unrealistic input parameters are due to simplifications and inadequacies of the simulation tools/ software (Lomas, 1996), which consider standard operating conditions instead of the real values (Herrando et al., 2016). In addition, the overall quality of the finished buildings that may result in deficiencies during the construction process, such as gaps in the insulation and thermal bridges are also not considered in the calculation of energy performance (Dasgupta et al., 2012; Bordass, 2004). User behaviour is another important factor that significantly affects the building energy performance, which cannot be implemented accurately in simulation tools/ software and thus widen the performance gap (Barker et al., 2007).

This study aimed to assess energy performance of the Brazilian bank buildings using the existing (RTQ-C) and proposed (INI-C) Brazilian building energy efficiency labelling regulations and evaluate how effective the INI-C system could be used to predict energy performance of the buildings compared with actual energy consumption of the buildings. The calculated energy ratings of both RTQ-C and INI-C regulation were compared and any wider improvement the INI-C has on the Brazilian building energy rating regulations has been analysed and discussed critically.

2. Background and literature review

Bank buildings are among the main energy consumers among all office buildings. In the US, bank buildings consume approximately 301 kWh/m^{2}year of energy, but in warmer climatic regions such as Greece, bank buildings account for 48% of the final energy consumption (Spyropoulos and Balaras, 2011). In Brazil, bank buildings are commonly found in any typical urban area (Wong et al., 2019) with artificial lighting and HVAC consumption as high as 86% of the final electricity consumption (Paixão, 2013). Thus, it is important for us to fully understand the energy performance behaviour of bank buildings by conducting a detailed energy analysis.

2.1. Energy benchmarking

The process of determining how energy efficient a set of buildings are, is called energy benchmarking, which normally involves building classification with energy analysis. Energy benchmarking is crucial in improving energy efficiency of buildings and can be used as a process to determine if a particular building consumes energy more efficiently than similar types of buildings. Previous works have included and pooled relevant information on various benchmarking methods and analysed their associated benefits and limitations. In 1990s, The Energy Efficiency Best Practice Programme Energy Consumption Guide 19 (DETR, 2000) and the

Building Research Establishment Environmental Assessment Method (BREEAM) (BRE, 2018) developed in the UK are the earliest examples of energy benchmarking systems for buildings. Since then, many countries around the world have established their own systems or methodologies to develop benchmarks for building energy consumption. Most notably among all, Energy Star in the US and Canada (Energy Star, 2018), the EU-based energy rating system under Directive 2010/31/EU (EC, 2010), CIBSE TM46 (CIBSE, 2008) and Home Quality Mark (HQM) (BRE, 2015) in the UK, Energy Smart in Singapore, NABERS and NatHERS in Australia (Rajagopalan and Leung, 2012).

In general, a wide range of methods are available to develop energy benchmarking systems, which can be categorised depending on the reliability and quality of data available. For example, black box, gray box and white box methods (Li et al., 2014), or most commonly top-down and bottom-up approaches (Hong et al., 2013; McKenna et al., 2013). Top-down approaches are macroeconomic methods, starting in the macro scale or operating at an aggregated level, that can be used to investigate energy consumption data and their relation to a range of available variables (Alves et al., 2017). Bottom-up approaches on the other hand, are focused on the building's specific context and work at a disaggregated level by using data from representative buildings and extrapolating results to represent the large scale at regional, city or national levels (Burman et al., 2014; Alves et al., 2017). Bottom-up approaches can be further classified into: i) Statistical methods that rely on historical data to identify relationships between energy end-use and total energy demand; ii) Engineering methods that determine energy consumption of end-use energy demands based on physical and/or thermodynamic relationships (McKenna et al., 2013) or power ratings, characteristics and use of equipment and systems (Swan and Ugursal, 2009).

2.2 Statistical benchmarking methods on sampled buildings

Statistical methods are commonly used to analyse energy performance of sampled buildings due to the ability to establish a relationship between building energy consumption and end-uses, which can be divided into regression analysis, conditional demand analysis and artificial neural network. Regression analysis determines the coefficients of models that can regress the aggregate building energy consumption onto parameters or combinations of parameters which affect energy consumption (Swan and Ugursal, 2009). A range of regression analysis techniques discussed are linear (Borgstein and Lamberts, 2014), multiple (Lee, 2008; Jing et al., 2017; Ding et al, 2018; Wong et al., 2019), multivariate (Wang et al., 2014), stepwise linear (Wu et al., 2010) and quantile regression (Roth and Rajagopal, 2018). One of the weaknesses of regression analysis is the requirement of having sufficient data samples for the analysis to be reliable, especially without the risk of multi-collinearity among high dimensional dataset. To overcome this, Wang et al. (2014) developed Principal

Component Regression that could perform multivariate linear regression analysis, which was found to be more effective than traditional statistical methods. To increase the accuracy of multiple regression analysis, the analysis was often complemented by other methods, such as the back propagation network method (Jing et al., 2017) or data envelopment analysis (Lee, 2008). A non-parametric regression method (convex non-parametric least squares) with better model fit than ordinary least square benchmarking system has been used to develop benchmarking model for 84 office buildings in Hong Kong (Chung and Yeung, 2017). A new data-driven approach using Lorenz curve was employed during the planning stage using limited datasets without detailed information to analyse energy consumption of 195 samples of commercial buildings in China, which consisted of offices, malls and hotels (Chen et al., 2017; 2018).

Various works that employed statistical methods to develop energy consumption benchmarking for building samples have been reported. For examples, building information and energy consumption data of eight shopping centres in Gulf Coast countries were collected using statistical methods (Juaidi et al., 2016). Energy performance benchmark rating and object-oriented energy use intensity (EUI) quota determination model were developed using Shapiro-Wilk normality tests for office building in Chongqing, China (Li et al., 2015). Morgenstern et al. (2016) used descriptive statistics and multivariate approaches, which involved the use of a wide range of variables to predict EUI for improving industry guidance and providing evidence as basis for the development of meaningful national energy performance targets for hospital buildings. Multiple linear regression analyses and multi-factor ANOVA were used to develop electricity benchmarks for 13 complex university buildings in China (Ding et al., 2018).

2.3. Engineering benchmarking methods on sampled buildings

Energy benchmarking of actual building samples can be carried out to capture a wide range of buildings within building stock. Engineering methods can be employed at building stock-level using either simplified physical models or detailed simulation models with the functionality of the models based on the physics of the end-uses. Input parameters of these engineering methods models are building geometry, envelope fabric, equipment and appliance, climate properties, indoor temperatures, occupancy schedules and equipment use. The high level of detail of these parameters is the strength of the bottom-up approach as it has the capability of determining energy consumption of each end-use and modelling technological options. Engineering methods can be categorised into population distributions, archetypes and samples (Swan and Ugursal, 2009). Distributions technique can be used to calculate energy consumption of end-uses separately based on appliance ratings and then aggregated to obtain energy consumption at building stock level. Archetypes can be applied to a limited set of individual buildings to capture the interconnectivity of appliances and end-uses within a building based on size, type and other building characteristics, which is not possible using distribution technique. Previous works were undertaken to develop detailed simulation models to analyse energy performance of buildings, which had been divided into different archetypes. A range of criteria were used in generating these archetypes, such as occupancy, appliances and lights (MacGregor et al., 1993), age-use (Kohler et al., 1997), building heating and cooling loads (Huang and Broderick, 2000), floor area and age (Shipley et al., 2002), building fabric and parameters (Jones et al., 2001), roof area ratio, façade area ratio and internal load density (Carlo et al., 2003), wall thickness, window to wall ratio, glass thickness and wall absorptivity (Wan and Yik, 2004), etc. Sample technique however, uses actual building samples, which could realistically reflect the high degree of variety found in the actual building stock if the sample size is sufficiently large (Swan and Ugursal, 2009). One of the limitations of samples modelling technique is it involves high number of data as Farahbaksh et al. (1998) developed models of housing stock based on 16 archetypes using data from 8767 actual houses. Larsen and Nesbakken (2004) used data from 2013 dwellings in Norway to develop model and found the high number of numerical inputs as its fundamental weakness. Modified building simulation software also had been used to develop sample model for 2800 commercial buildings, when survey information from 2800 buildings was combined with energy (billing and metered) data and weather data (Ramirez et al., 2005). Griffith and Crawley (2006) also developed a similar model for 5430 commercial buildings, however focused on technical potential of the buildings by applying building code requirements to them.

Engineering methods have a strength of predicting energy performance and saving potential of different technological options employed in building stock (Mastrucci et al., 2014). Significant energy saving can only be achieved if tracking, monitoring and detecting abnormal energy consumption behaviour of a building through suitable energy benchmarking method are undertaken (Li et al., 2014). The majority of the works were undertaken to evaluate building energy performance of various types of commercial and non-domestic buildings at stock level and show the effectiveness of employing bottom-up approach on a large number of building stock. Two bottom-up studies based on building physics and aggregated end-use were employed to analyse energy performance of selected four samples of educational buildings in the UK, where their benefits and limitations were compared (Burman et al., 2014). Sheng et al. (2018) developed energy consumption model and energy benchmarks for 310 five-star hotels in China using a designer simulation tool, based on building information and energy-related data collected from a survey. Li and Li (2018) presented a multi-level benchmarking index system of energy consumption using simplified calculation formulas for air-conditioning systems to cool eight large shopping centre buildings. Wang et al. (2015) developed a bottom-up, physics-based Residential Heating Energy Model to estimate the residential heating energy consumption in China's hot summer and cold winter climatic region. With the addition of field measurement and questionnaire survey, the model can also be used to investigate the relationship between heating energy usage with occupant behaviours and building physics (Wang et al., 2015). A stochastic bottom-up model was developed to calculate hot water and space heating demands of 100 residential buildings based on the combination of physical and behavioural models, in which building heat load was calculated using a simplified physical model to allow for realistic energy demand profiles (Fischer et al., 2016). A multi-stage approach of engineering technique was also adopted to collect, analyse and classify bank buildings in Brazil into four typologies and determine critical design parameters in the absence of more complete building data set (Wong et al., 2019).

In other studies, the top-down approach was used to produce a new thermal energy benchmark for typical college buildings based on actual thermal consumption values on Display Energy Certificates (DEC) of 52 college buildings in Dublin, Ireland (Vaisi et al., 2018). Wiesmann et al. (2011) employed both top-down and bottom-up methods to investigate the influence of dwelling characteristics on residential electricity consumption in Portugal and an econometric study shows the direct effect of income on electricity consumption is low. Wang et al. (2017) developed a multi-criteria data-driven benchmarking method, which was a more rational option compared to traditional single-angle method to assess building performance with its embedded capability of simultaneously quantifying the effects of multiple factors. An iterative Clustering around Latent Variables (CLV) based TOPSIS method was established for multi-criteria building energy performance assessment and its robustness had been tested in a 324-dwelling case study. Table 2 shows a summary of various methods employed in previous studies to analyse energy consumption for a range of building samples. Among all reported methods, bottom-up approaches are most frequently used with the ability of calculating total energy consumption of buildings based on detailed descriptions of end-uses and energy data obtained. There is however, a lack of energy benchmarking studies in bank building samples, particularly in Brazil, which has become the main focus of the work presented in this paper.

Benchmarking methods	Characteristics	Data and variables	Sampled buildings	References
Building physics	Establish baseline for building energy performance Calculate using mathematical equations Divide building into thermal zones Commonly used with dynamic building simulation	building physical properties, building services characteristics, control attributes	Educational buildings	Burman et al (2014)
	No dependency on historical datasets	Physical parameters of buildings	Commercial buildings	Chen et al (2018)
Physics-based Residential Heating Energy Model	Estimate heating energy consumption and occupant heating behaviours	Field measurement, questionnaires, building physical parameters	Residential buildings	Wang et al (2015)
Simplified formulas	Establish multi-level benchmarking index system	Metering and building operational data	Commercial buildings	Li and Li (2018)
Aggregated end-use	Calculate total energy use based on energy use of all end-uses Identify and estimate contributing factors of each end-use			
Regression	Strong dependency on available data	Multi-dimensional parameters of sufficient buildings samples	Commercial buildings	Chen et al (2018)
Statistical percentile	Slight dependency on available data	Partial physical parameters of enough samples	Commercial buildings	Chen et al (2018)
Multiple linear regression	Determine electricity benchmarks	Building information, real time electricity consumption, factors affecting electricity consumption	Complex campus buildings	Ding et al (2018)
	Predict energy consumption and verified with backpropagation neural network algorithm	Building information, energy consumption, building services specifications	Office buildings	Jing et al (2017)
	Examine effectiveness of energy management with data envelopment analysis	Environmental factors, building information, occupancy data	Government buildings	Lee (2008)
Statistical analysis	Classify buildings in terms of energy efficiency	Building information and energy consumption data	Shopping centres	Juaidi et al (2016)
Statistical analysis using Shapiro-Wilk normality tests	Develop energy performance benchmark rating and object-oriented EUI quota determination model	Building information and energy consumption data	Office buildings	Li et al (2018)
Stochastic frontier analysis	Determine benchmark values for various activities and disciplines	Energy data, occupancy patterns, building characteristics	Education buildings	Khoshbakht et al (2018)

DUE-B	Benchmarking building energy consumption at the urban scale that integrates recursive partitioning and stochastic frontier analysis	Building characteristics, energy use data	General building stock	Yang et al (2018)
Multi-variate linear regression	Perform energy efficiency evaluation of existing building envelopes	Multi correlated variables related to building envelopes	Residential buildings	Wang et al (2014)
Quantile regression	Model the distribution of electricity consumption of buildings and create efficiency ranking scores	Electricity consumption data, building characteristics	Commercial buildings	Roth and Rajagopal (2018)
Simple linear regression	Provide end-use energy breakdown with validation using thermal simulation	Building information, energy consumption data, building services information	Bank buildings	Borgstein and Lamberts (2014)
Stepwise linear regression	Establish benchmark model for energy use and greenhouse gas emissions	Building information, energy consumption data, operational characteristics	Hotel buildings	Wu et al (2010)
Monte Carlo modelling	Estimate aggregate mean hourly electricity consumption	EPC databases, knowledge of user behaviour	Residential buildings	Oliveira Panao and Brito (2018)
Bottom-up method with one-minute resolution	Model daily energy consumption profile and compared with the measured profile	Occupant number and their behaviour data/ pattern of using different equipment	Residential buildings	Sepehr et al (2018)
Monthly Thermal Energy Models	Develop new energy benchmark and check against CIBSE TM46 benchmark	Building information, heating degree days, typical heating operation hours	College buildings	Vaisi et al (2018)
Designer simulation tool	Establish energy consumption model and energy benchmarks	Building information and energy-related data	Hotels	Sheng et al (2018)

Table 2: Summary of different benchmarking methods used for energy analysis of building samples

3. Methodology

The work presented in this paper is a follow-up study from the bank building classification and energy analysis in Curitiba (bioclimatic zone 1 as shown in Table 1), Brazil reported by Wong et al. (2019). From the 72 bank branches analysed in the engineering bottom-up studies, 11 bank branches were selected for a more detailed study, where the energy ratings of these selected bank buildings were calculated using the existing RTQ-C regulation. Subsequently, the calculations were repeated using the newly proposed INI-C regulation and the results from both sets of rating systems were compared. The ability of both RTQ-C and INI-C regulations to produce results which are compatible and could be used to reflect the actual building energy consumption data was then examined.

3.1. Bank building sample selection

Figure 1 shows images of some of the 11 selected bank branch buildings, captured using Google Street View. The bank samples were selected based on the common physical characteristics which could be found in these buildings, such as sizes, shapes, storey number, design characteristics and building materials used. Bank buildings have been selected for this study because they can be commonly found in any typical Brazilian city. Energy consumption data and design parameters of bank branches could be easily available from the facilities management and engineering team within the commercial bank organisation due to their centralised management structure. Complete annual electricity consumption data for each bank branch was obtained based on three-year (2014 to 2016) electricity bills provided by the bank facilities management and engineering teams. Only electricity consumption was obtained for the bank branches surveyed and their use of non-electric energy is likely to be negligible as suggested in previous research (Borgstein and Lamberts, 2014) because bank branches in Brazil typically do not use gas or liquefied petroleum gas as central cooking facilities or hot water systems are seldom available. In Brazil, space heating system is also not a feature in these buildings (de Oliveira Veloso et al., 2020).

Figure 1: Images of selected bank branch samples taken from Google Street View

3.2. Building design data

In all of the 11 bank branches, the standard working schedule was from 8am to 6pm, Monday to Friday, except cash machine facilities, which are available from 6am to 10pm every day. To retain anonymity of individual bank branches, each bank branch was given a unique identifier. Building information and energy-related data, such as types and capacity of building services equipment, details of artificial lighting, building parameters, and building material specifications were collected for the bank branches, based on:

a) Specification and parametric data gathered from bank building plans and design drawings kindly provided by the bank engineering and management team, such as parametric details, internal floor areas, sizes and parameters of window openings, internal floor heights, and building services installation, such as air conditioning and lighting systems.

b) Site visits conducted to the selected bank branches to record specifications or details, which were not available on the design drawings and building plans, such as types and capacity of air-conditioning and lighting systems, types of window glazing and external building façade, availability and positions of solar shading devices, and other relevant building material specifications.

Table 3 shows general specifications and parametric details of the sampled bank branches. Input data to the calculation considered are building properties, such as geometry, envelope fabric, equipment and appliances, occupancy schedules and equipment use. The U-values of the building fabric for the bank branches were estimated based on their construction details and material specifications provided. Their thicknesses were verified during site visits but field measurement was not permitted due to potential disruptions to the bank operation. Other building and services data such as building and glazing parameters, occupancy, air conditioning and lighting details were obtained from drawings and design specifications as well as verified during site visits. Lighting density was calculated using total area of building space with lighting installation only.

Bank	Orientation (main entrance)	Area (m^2)	Wall		U-values (W/m^2K)			Air-conditioning		Luminaire (Lamp x Power)
			Materials	Thickness (cm)	Wall	Roof	Window	Type	Power (kW)	
3	East	669.64	Cement board and drywall	15	1.26	0.51	5.58	Split/ central	20.41	Fluorescent (4x14W/ 2x16W)
5	East	1188.39	Conventional masonry	20	1.82	0.51	5.61	Split/ central	24.57	Fluorescent (4x16W)
6	West	960.30	Conventional masonry	23	1.74	0.51	5.55	Split/ central	73.71	Fluorescent (4x16W)
10	South	1043.07	Conventional masonry	21	1.79	0.51	5.58	Split/ VRF	22.98	Fluorescent (4x14W/ 2x16W)
11	North	1176.85	Conventional masonry	19	1.85	1.14	5.55	Split/ Chiller	56.56	Fluorescent (2x32W/ 2x16W)
16	West	1050.86	Conventional masonry	20	1.82	0.51	5.55	Split/ central	54.55	Fluorescent (4x14W/ 2x16W)
28	Southwest	800	Conventional masonry	22	1.76	0.51	5.55	Split/ VRF	36.82	Fluorescent (4x14W/ 2x16W)
31	East	499.80	Conventional masonry	23	1.74	0.51	5.55	Split/ central	35.36	Fluorescent (4x14W/ 2x16W)
33	East	1606.64	Conventional masonry	21.5	1.78	0.51	5.55	Split/ central	76.98	Fluorescent (4x16W)
36	Southeast	751	Conventional masonry	16.5	2.36	0.51	5.55	Split/ central	41.21	Fluorescent (4x14W/ 2x16W)
46	North	774.90	Conventional masonry	31	1.50	0.51	5.55	Split/ central	47.05	Fluorescent (4x14W/ 2x16W)

Bank	No. of luminaire	Lighting density (W/m^2)	Glazing			% of glazing		No. of occupants	Occupant density (m^2/ person)	Floor area/ volume	Thermal load* (kWh/year)
			Types	Thickness (mm)	Solar factor	Total	main entrance				
3	134	11.14	Temperate colourless	10	0.72	11.29	25.85	12	55.80	0.32	41,487.49
5	236	13.79	Temperate colourless	10	0.75	21.48	30.50	17	69.91	0.30	70,629.25
6	248	17.93	Temperate colourless	10	0.71	15.05	62.82	20	48.02	0.46	17,651.66
10	157	10.62	Temperate colourless	10	0.72	16.21	50.48	27	38.63	0.17	52,961.17
11	214	12.23	Temperate colourless	10	0.70	23.52	53	31	37.96	0.17	26,307.95
16	201	11.09	Temperate colourless	10	0.70	18.38	53.9	21	50.04	0.31	56,806.35

28	149	10.22	Temperate colourless	10	0.47	25.5	66.39/ 34.04	14	57.14	0.33	47,698.91
31	91	10.24	Temperate colourless	10	0.73	6.16	20.88	14	35.70	0.40	28,963.53
33	301	13.03	Temperate colourless	8	0.62	13.01	32.21	39	41.20	0.22	86,636.01
36	134	10.23	Temperate colourless	8	0.70	12.89	13.45/ 45.69	14	53.64	0.36	24,993.26
46	133	9.6	Temperate colourless	10	0.70	17.02	50.52	16	48.43	0.36	56,574.11

Note: * Thermal load (CGT) was calculated from the INI-C regulation

Table 3: Design parameters and specifications of selected bank branch buildings in Curitiba, Brazil

3.3. Energy rating calculations

This study aims to evaluate the performance of the existing and the newly proposed INMETRO energy rating regulation for Commercial, Service and Public buildings in Brazil, RTQ-C (MME, 2009) and INI-C (INMETRO, 2018). Some difference in calculation or policy improvement on the new INI-C regulation when compared with the existing RTQ-C was highlighted and reported. The energy ratings of the sampled bank branches calculated using both RTQ-C and INI-C based on the collected building data were compared and also with the actual energy consumption data of the buildings. The effectiveness and reliability of RTQ-C and INI-C to generate energy performance predictions which can truly reflect the actual energy consumption of the sampled buildings were assessed. Table 4 distinguishes the difference in scope and calculation between the RTQ-C and INI-C rating regulations. Energy ratings for the 11 bank branches were calculated using the prescriptive method of RTQ-C, which covers three components: lighting system, air conditioning system and building envelope. The INI-C calculations were conducted based on a simplified method, which included energy consumption for electrical equipment and water heating energy consumption in addition to the three categories covered in RTQ-C calculation. The INI-C system also provides reference conditions for various types of non-domestic buildings, making calculations much consistent compared to RTQ-C. However, as discussed in the previous section, water heating energy consumption was not considered in this study since this is not applicable for bank buildings in Brazil. One significant improvement of the INI-C was the use of calculated energy consumption (kWh/year) for energy rating classification, instead of the point system used by the RTQ-C.

Descriptions	RTQ-C	INI-C
Status	Implemented	Proposed
Assessment methods	Prescriptive and simulation	Simplified and simulation
Assessment scope	Building envelope (30%), HVAC system (30%), Lighting system (40%)	Building envelope, HVAC system, Lighting system, Electrical equipment, Water heating system
How are these measured?	Defined weighting	Energy consumption
Pre-requisites	Yes	No
Partial certification	Yes	Yes
Bioclimatic zones	8	24
Reference conditions for various building types	Not specified	8
Grading system	A-E	A-E
Indicator	Point (PT)	Consumption (kWh/year)
Adjacent building consideration	Solar access angle	Adjacent condition of building façade
Parameters	Shape factor Façade opening Shading angle Solar heat gain coefficient Consumption indicator Lighting power density Ambient index	Thermal load for cooling Form factor Building volume Internal load density, DCI (W/m^2) Lighting power density, DPI (W/m^2) Equipment power density, DPE (W/m^2) Primary energy consumption (kWh/year)

	Lighting system efficiency level	
Classification	Set and defined for all buildings	Calculated using coefficient of reduction, varies for different types of buildings
Reference building	No	Yes
Renewables consideration	Yes (bonus only)	Yes

Table 4: Comparison of scope for calculation between RTQ-C and INI-C rating regulations

In the RTQ-C calculation, geometric attributes of the buildings as well as characteristics and properties of wall and roof materials were taken into consideration. RTQ-C calculations can be divided into two stages: a) pre-requisite determination and b) calculations for envelope, lighting and air conditioning categories. In order to achieve 'A' rating, certain mandatory requirements or pre-requisites must be complied (Wong and Krüger, 2017). For envelope calculation, the Consumption Indicator was calculated for each building. The assessment of the air conditioning system largely depends on the efficiency level of the equipment and for the lighting system, the Lighting Power Density expressed as W/m^2 is determined. To produce the energy efficiency rating for buildings, numerical equivalents (EqNum) for each category were calculated and totalled up to obtain the final point (PT) for rating classification using Equation 1 (MME, 2009).

$$PT = 0.30\left\langle\left(EqNumEnv.\frac{AC}{AU}\right) + \left(\frac{APT}{AU}.5 + \frac{ANC}{AU}.EqNumV\right)\right\rangle + 0.30(EqNumDPI) + 0.40\left\langle\left(EqNumCA.\frac{AC}{AU}\right) + \left(\frac{APT}{AU}.5 + \frac{ANC}{AU}.EqNumV\right)\right\rangle + b\,_0^1 \quad \text{(Eq. 1)}$$

AC, AU, ANC, and APT represent air-conditioned floor area, usable area, unconditioned area and circulation area (such as toilet, corridor, and etc. where occupants only spend a short time in them), respectively. *b*(0 to 1) refers to the additional score obtained from bonuses which could come from energy efficient facilities, such as renewables and water recycling facilities. EqNum represents envelope, lighting and air conditioning systems calculated separately, which are used in the equation to generate PT.

The INI-C regulation (INMETRO, 2018), on the other hand, requires the division of internal air-conditioned building spaces into different zones, measured on a distance of 4.5m from the external wall façade, regardless of the availability of window opening. For each zone, parametric data, such as areas of internal floor space, window opening and external wall façade, wall-to-window ratio (WWR), availability of external shading devices and specifications of façade materials were collected. To evaluate air conditioning system, the estimated energy consumption of the air conditioning system (CCA) (kWh/year) can be calculated using Equation 2, where CGT (kWh/year) is the annual thermal load of the building and SPLV is the energy efficiency of the air conditioning system.

$$CCA = \frac{CGT}{SPLV} \quad \text{(Eq.2)}$$

The total energy consumption of the lighting system (CIL) (kWh/year) can be calculated using Equation 3, where *PI* is the potential installed electricity load of the lighting system (kW/year), *h* is the operational hours of the lighting system per day (hour), and N_{year} is the number of operational days of the building per year.

$$CIL = PI\left(h. N_{year}\right) \quad \text{(Eq.3)}$$

The energy consumption of other electrical equipment in the bank, in addition to air-conditioning and lighting systems was calculated as well, such as computers, cash machines, photocopiers, printers, etc. In INI-C, the energy consumption of all these electrical equipment (CEQ) (kWh/year) can be expressed in Equation 4, where P_i is the potential installed electrical capacity of the equipment (Watt), *h* is the operational hours of the building per day (hour), and N_{year} is the number of operational days of the building per year.

$$CEQ = P_i\left(h. N_{year}\right) \quad \text{(Eq.4)}$$

Equation 5 shows the calculation of electric (CTE_E) energy consumption (kWh/year) using CIL, CCA, and CEQ calculated using Equations 2 to 4, minus any renewable energy generated from a local source (GE).

$$CTE_E = CIL + CCA + CEQ - GE \quad \text{(Eq. 5)}$$

With the available parameters and dataset, annual cooling energy loads (kWh/year) for the entire building can be calculated using an interface website published by PBE Edifica (2018) for both actual and reference buildings. The final energy rating of the building can be determined based on the primary energy consumption (CEP) calculated from both electric (CTE_E) and thermal (CTE_T) (if applicable) energy consumption with their respective conversion factors (f_cE *or* f_cT) as determined by Equation 6.

$$CEP_{real\ or\ ref} = \left(CTE_E. f_cE\right) + \left(CTE_T. f_cT\right) \quad \text{(Eq. 6)}$$

The INI-C regulation produces five energy ratings, from A (best) to E (worst), of which D rating represents the performance required for reference building (Figure 2). The energy rating classification of the calculated building can be determined according to the percentage of improvement on energy performance (shown as percentage or X%) compared to the energy efficiency level of the reference building. The INI-C regulation also allows either partial or full certification to the building, as some systems may not be suitable for a particular type of building. For example, as mentioned before, water heating system may not be applicable to some commercial buildings. The following building parameters and material specifications were determined for the INI-C energy rating calculation.

a) Building geometrical parameters, such as floor, roof and external façade areas, internal volume of the building space, length, width and floor to ceiling height within building space.

b) Specifications of building façade materials (wall, window and roof), such as U-values, solar absorptance and thermal capacities.

c) Building services specifications, such as artificial lighting (total quantity and wattage per lamp) and air conditioning system (types, models and capacity).

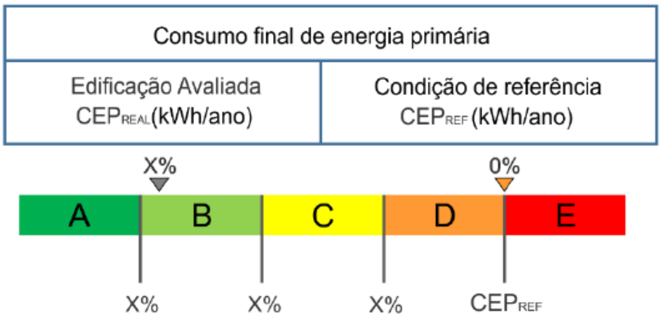

Figure 2: Energy efficiency rating classification based on final primary energy consumption for actual and reference buildings according to INI-C regulation (INMETRO, 2018)

4. Results and Discussion

4.1. Energy efficiency rating of sampled bank buildings

The energy ratings of the 11 selected bank branches were calculated using the RTQ-C and INI-C rating regulations described in previous section. Table 5 shows that the calculated energy ratings for the sampled bank branches can be divided into three major categories: building envelope, lighting and air conditioning as well as the final rating. For the Brazilian energy rating system, different energy ratings can be calculated separately for these major categories, prior to the calculation of the final rating for the entire building. The existing RTQ-C regulation has a list of pre-requisite criteria, which is essential to be met if a building needs to achieve higher rating. In this study, the energy ratings of several bank branches shown in Table 4 (such as banks 3, 10, 28, and so on) have their rating 'downgraded' due to this reason (see ratings with and without pre-requisites), which would also affect the final ratings of the bank branches. The INI-C regulation of the branches on the other hand, were calculated based on energy consumption values within each category, without the need to satisfy specific pre-requisite criteria, which makes the INI-C regulation a better and improved energy rating version. Comparing with the RTQ-C ratings, the majority of the bank buildings have energy ratings of either equal or worse compared to those calculated using INI-C regulation with the exception of bank branch 10. Despite similar or worse final ratings, most bank branches received better INI-C ratings in the sub-category calculations.

Banks	RTQ-C ratings	INI-C ratings

	Envelope (a/b)	Lighting (a/b)	Air Cond (a/b)	Final	Envelope	Lighting	Air Cond	Final
3	A/ B	B/ D	C/ C	C	A	C	A	C
5	B/ B	D/ D	A/ B	C	B	D	B	D
6	D/ D	E/ E	A/ B	C	B	E	A	E
10	A/ B	B/ D	A/ B	C	A	C	A	B
11	B/ C	C/ C	A /A	C	B	D	B	C
16	D/ D	B/ D	A/ B	C	A	C	A	C
28	A/ B	B/ D	A/ A	B	A	B	A	C
31	A/ B	B/ D	C/ C	B	A	B	A	C
33	A/ B	D/ D	A/ B	C	A	D	B	D
36	A/ C	B/ D	C/ C	C	A	B	A	C
46	B/ B	A/ D	D/ D	B	A	B	A	B

Note: a – without pre-requisite; b – with pre-requisite

Table 5: Comparison of energy ratings of 11 sampled bank buildings calculated using both RTQ-C and INI-C regulations

4.2. Comparison between the calculated INI-C and actual energy consumption

The existing RTQ-C regulation produces energy efficiency rating based on point-scoring system, which does not calculate energy consumption of the building. This has been one of the main limitations and criticisms of the RTQ-C regulation reported in the past (Wong and Krüger, 2017). Hence, with the improvement of the proposed INI-C regulation, energy consumption of the building assessed can be calculated. In this study, the potential energy consumption of the bank branches was calculated and divided into three main categories (see Table 6). As it can be seen, the calculated air-conditioning energy consumption in all bank branches were lower than the other categories because Curitiba has the lowest average winter and summer temperatures in Brazil (Table 1). Previous studies show that bank buildings in Curitiba consume less energy for cooling than lighting (Borgstein and Lamberts, 2014) due to the fact that the average monthly dry and wet bulb temperatures in Curitiba are consistently below comfort zone temperature (20°C) (INMET, 2016). The total calculated energy consumption (kWh/m^{2}year) of the bank branches was compared with the actual energy consumption, obtained as average values from the monthly utility bills from 2014 to 2016. The actual energy consumption breakdown for each category was not possible due to unavailability of such dataset from the bank. As reported by de Oliveira Veloso et al (2020), this is because electric energy consumption in Brazil is considered private data, hence it is not possible to breakdown the electricity consumption into different end-users in a building.

Banks	INI-C calculation (kWh/m^{2}year)				Actual (2014 to 2016) (kWh/m^{2}year)	Deviation (%)
	Equipment	Lighting	Air Cond	Total		
3	27.20	38.18	10.09	75.47	167.30	-122
5	27.61	45.88	12.55	86.04	107.91	-25
6	27.59	52.62	3.48	83.69	167.53	-100
10	22.52	27.77	6.34	56.62	96.73	-71
11	27.74	37.04	3.96	68.74	140.41	-104
16	27.81	31.88	9.94	69.63	124.42	-79
28	28.20	36.71	6.99	71.89	124.50	-73

31	27.99	29.79	6.12	63.90	183.50	-187
33	27.20	36.39	10.17	73.76	129.38	-75
36	28.07	29.50	4.60	62.17	153.19	-146
46	28.59	27.36	10.31	66.26	152.38	-130

Table 6: Comparison of calculated INI-C and actual energy consumption values for sampled bank buildings

The INI-C calculation results show that all the 11 bank branches have predicted total energy consumption of between 56 and 86 kWh/m^{2}year, while the actual energy consumption of these bank buildings was averaged between 96 and 183 kWh/m^{2}year. The typical range of energy consumption for bank buildings in Brazil is from 137 to 175 kWh/m^{2}year, according to the Brazilian energy benchmarking indicators published by CBCS (2014), where bank buildings with energy consumption of less than 137 kWh/m^{2}year can be regarded as energy efficient. Based on the actual energy consumption, most of these bank buildings are either within the typical range or more energy efficient. The INI-C calculation however, shows an average negative deviation of 100% compared to actual energy consumption for all bank branches. One of the main reasons attributed to these discrepancies was the reference conditions used for bank buildings in this study obtained from Table A.1 in the INI-C regulation, which was designated for office buildings rather than bank buildings. There are currently no reference values for bank buildings in the proposed INI-C regulation despite they are one of the main non-domestic building type and the office buildings were however the closest type of buildings. In addition, the temperature set point (i.e. 24°C) used to calculate the energy consumption for air conditioning systems in the INI-C system is not comparable with the real temperature set points of 21°C and 22°C used in the bank branches. As discussed in previous literature, these reference values are mostly standard operating conditions, which may vary to real or actual values. Energy consumption of IT data centre and electrical equipment for bank buildings also varies significantly compared to standard office buildings. Bank buildings have variable operating pattern for cash (ATM) machines, which operation ranges from 6am to 10pm every day; while standard office space (reception, cashier, individual office space) follows standard working hours from 8am to 6pm Monday to Friday. Such variations make the operational pattern of bank buildings significantly different compared to standard office buildings and difficult to predict. Another factor which increases the energy performance gap is user behaviour, which has been discussed in previous studies. It is extremely difficult to model/ calculate the influence of user behaviour in buildings in general. Occupancy rate of the bank buildings in this study applied only to bank worker in the branches, excluding customers visiting the branches. Therefore, bank institution which operates their business to receiving customers more frequent than standard offices, are more prone to variation in user behaviour. Consequently, the actual energy consumption of bank buildings is significantly higher than expected. The user behaviour is very difficult to be implemented in a calculation or modelling tool due to their unpredictable nature. Thus, the implementation of a more realistic operation schedules would reduce the performance gap in the future.

4.3. Correlation analysis between the RTQ-C and INI-C calculated variables

In order to assess a causal relationship between input variables in both RTQ-C and INI-C regulations, a correlation analysis was undertaken using IBM SPSS Statistics 18 software, for identifying the Kendall's tau correlation coefficient. This is a non-parametric analysis which can be employed in the case of a small data set with little variation in the ranks (Field, 2009). Variables such as levels of energy efficiency, the EUI and total areas of the 11 bank branches were considered in the analysis. Based on the analysis, the correlation can be categorised into light (values from 0.01 to 0.09), low (0.10 to 0.39), moderate (0.40 to 0.69) and high (0.70 to 0.99). Table 7 shows the correlation analysis between variables calculated using the RTQ-C and INI-C regulations. A stronger or higher correlation (closer to 1) means that output variables calculated by both RTQ-C and INI-C regulations have higher degree of similarity and hence fewer changes to the INI-C calculation methods. On the other hand, a lower correlation means significant improvement or changes to the INI-C calculation methods, compared to its earlier RTQ-C version.

	RTQ-C ENV#	**RTQ-C ENV**	**INI-C ENV**	**RTQ-C ILL#**	**RTQ-C ILL**	**INI-C ILL**	**RTQ-C AC#**	**RTQ-C AC**	**INI-C AC**	**RTQ-C FINAL**	**INI-C FINAL**	**AREA**	**CONSUMP ($kWh/m^2/year$)**
RTQ-C ENV#	1,000	,619*	,578	,267	,327	,432	-,239	-,130	,102	,204	,243	-,270	,045
RTQ-C ENV	,619*	1,000	,361	,255	,104	,297	-,254	-,193	-,108	,433	,258	-,095	-,143
INI-C ENV	,578	,361	1,000	,686*	,560	,685*	-,440	-,414	,542	,375	,530	-,385	,000
RTQ-C ILL#	,267	,255	,686*	1,000	,816**	,830**	-,633*	-,450	,588*	,523	,857**	-,497*	,022
RTQ-C ILL	,327	,104	,560	,816**	1,000	,718*	-,423	-,184	,440	,360	,827**	-,423	,000
INI-C ILL	,432	,297	,685*	,830**	,718*	1,000	-,603*	-,429	,560	,654*	,618*	-,555*	,103
RTQ-C AC#	-,239	-,254	-,440	-,633*	-,423	-,603*	1,000	,870**	-,440	-,440	-,437	,605*	-,460
RTQ-C AC	-,130	-,193	-,414	-,450	-,184	-,429	,870**	1,000	-,414	-,223	-,279	,442	-,316
INI-C AC	,102	-,108	,542	,588*	,440	,560	-,440	-,414	1,000	,375	,430	-,661*	,275
RTQ-C FINAL	,204	,433	,375	,523	,360	,654*	-,440	-,223	,375	1,000	,364	-,440	,220
INI-C FINAL	,243	,258	,530	,857**	,827**	,618*	-,437	-,279	,430	,364	1,000	-,306	-,131
AREA	-,270	-,095	-,385	-,497*	-,423	-,555*	,605*	,442	-,661*	-,440	-,306	1,000	-,527*
CONSUMP ($kWh/m^2/year$)	,045	-,143	,000	,022	,000	,103	-,460	-,316	,275	,220	-,131	-,527*	1,000

with pre-requisite; * 95% significance; ** 99% significance

Table 7: Correlation analysis between parametric variables calculated using RTQ-C and INI-C regulations

As it is evident by the correlations between the RTQ-C and INI-C calculations for building envelope (INI-C ENV versus RTQ-C ENV), lighting (INI-C ILL versus RTQ-C ILL) and air-conditioning system (INI-C AC versus RTQ-C AC), the changes to INI-C calculation methods used for both building envelope (0.361) and air-conditioning system (-0.414) were quite significant. In contrast, the lighting calculation methods used in both RTQ-C and INI-C regulations have greater similarity (0.718*) compared to the other categories. There was a low correlation (0.364) between the final energy ratings calculated using both RTQ-C and INI-C regulations (RTQ-C FINAL versus INI-C FINAL), which shows the significant changes to the INI-C calculation method compared to the existing RTQ-C regulation. It was also observed that the correlations between the final and lighting ratings for existing RTQ-C regulation were lower (0.360) than the INI-C regulation (0.618*). This shows that in RTQ-C regulation, the lighting energy performance is likely to have greater influence on the final rating, compared to INI-C regulation.

4.4. Recommendation of reference values for bank buildings

A number of weaknesses or limitations can also be reported from the proposed INI-C regulation. Not all types of non-domestic/ commercial buildings have been considered in the INI-C calculation. For example, despite bank buildings are recognised for their large stock in the urban areas in Brazil, the existing reference conditions are not suitable to be used for bank buildings. For bank branches calculation in this study, we used the reference conditions for office buildings specified in Table A.1 in the INI-C regulation. Studies show that operational hours, temperature set point, occupancy and equipment loads in bank buildings would be different from standard office buildings. Therefore, these nominal profiles of office buildings could be replaced by bank building profiles which are more realistic. At its current state, neither RTQ-C nor INI-C regulations are able to produce energy consumption that is reflective of or close to actual energy consumption of the studied buildings. Similar to previous studies, the actual energy consumption of the bank buildings studied is higher than what it is estimated in the Brazilian certification system. The large deviation reported in this study was due to the use of standard operating conditions or values in the certification system was designated for office buildings instead of bank buildings. Thus, we recommend to improve building energy rating system for Brazilian bank building stock, by proposing reference values shown in Table 8.

References in Table A.1 of INI-C regulation	Units	Existing values	Recommended values
Power density of equipment (DPE)	W/m^2	9.7	approximately 44.73 kWh/m^{2}year
Occupancy rate (for bank staff only)	m^2/ person	10	average 48.77 (from 35 to 70)
Operation (hours)	Hour	10	10 (general bank office) 18 (ATM space)
Operation (days)	Day	260	260 (general bank office) 365 (ATM space)
Temperature set point	°C	24	21 to 22

Table 8: Recommended reference values for bank buildings used to replace existing values for offices in Table A.1 in the INI-C regulation

Table 8 shows the existing reference values obtained from Table A.1 of the INI-C regulation, which are originally used for energy calculation for offices, but have been used for bank buildings. A list of reference values which are more realistic and suitable for bank buildings have been recommended based on the findings from either previous or this study. The existing Power Density of equipment (DPE) of 9.7 W/m^2 on Table A.1 is unrealistic for bank buildings because bank buildings normally have higher DPE with more electrical equipment, such as IT servers and ATM. An energy benchmarking study undertaken shows an average energy consumption for servers and electrical equipment of 44.73 kWh/m^2year for Brazilian bank buildings (Borgstein and Lamberts, 2014). The reference value for occupancy rate are average values obtained from the 11 bank buildings and is significantly higher than office buildings. Bank operational hours are significantly different to standard office buildings as it is recommended that operation hours for ATM space within the bank branches should be calculated separately in addition to the standard office hours for bank staff. On-site survey also found that the temperature set points for air-conditioning system in the bank branches are between 21°C and 22°C. These reference values are critical to improve the method employed to calculate the energy performance of bank buildings using the INI-C regulation as they can be used to better represent actual conditions of the bank buildings.

5. Conclusions

Brazil is committed to continuing to improve the energy efficiency of its building stock. As with other Latin American developing countries, their energy efficiency regulation and policy are slowly taking shape and continuing to be improved. The existing RTQ-C is the first ever regulation in Brazil to target on reducing energy consumption in Brazilian buildings. It is however, developed based on point-scoring system with its own limitation. The proposed INI-C regulation aims to address some of the existing limitations in RTQ-C calculation methods and develop an improved energy rating system that could quantify the actual energy performance of the assessed buildings. This paper aims to conduct a first-hand investigation into the effectiveness and efficiency of the proposed energy efficiency regulation, by comparing energy ratings calculated using INI-C regulation with the existing RTQ-C regulation. Such comparison enables us to identify any strengths or limitations of the INI-C regulation. When comparing the RTQ-C and INI-C regulations, a number of significant improvements to the INI-C regulation can be observed:

a) Inclusion of reference conditions or values for different types of non-domestic buildings, which makes it easier to calculate the energy performance ratings for different ranges of buildings in Brazil, compared to the existing RTQ-C regulation which has no consideration for building variants.

b) Removal of point-scoring system from the existing RTQ-C regulation, which are unrealistic and setting conditions that heavily influence building energy ratings, such as bonus points and pre-requisition. Such pre-requisite conditions can affect the energy ratings of each category and final rating of the building.

c) Inclusion of energy consumption calculations (in kWh/m^{2}year) in the INI-C regulation makes the proposed certification system easier to recognise and quantify the energy performance of a building as well as for the purpose of comparison with similar types of building, instead of influenced by existing weighting distribution across the three main categories.

d) The final energy ratings calculated using the INI-C regulation reflect a more stringent standard as most bank branches have equal or worse final energy ratings compared to the those certified using existing RTQ-C regulation.

This study is a follow-up to previous work reported by Wong et al (2019), where the energy consumption of 72 bank buildings was collectively analysed. It further investigates energy ratings for selective bank building samples based on detailed design specifications and building parameters available. However, due to constraints on time and resources, only 11 samples were selected in this study, which pose as limitation to the size of the samples. For future studies, we recommend that larger building samples to be obtained and more rigorous investigations could be undertaken which involve field measurement of u-values for building envelopes as well as possibility of obtaining energy consumption breakdown for different end-uses in buildings. To accurately calculate energy ratings of the proposed and existing Brazilian energy efficient regulations, reference values should be defined specifically not only for bank buildings, but each major type of building, drawing from large pool of building samples across Brazil.

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References

ABNT. (2003). Thermal performance in buildings – Brazilian Bioclimatic Zones and Building Guidelines for Low-Cost Houses. Brazilian National Standards Organization (NBR 15.220-3) (In Portuguese).

Ahmad, M., & Culp, C.H. (2006). Uncalibrated Building Energy Simulation Modeling Results. HVAC&R Research 12, 1141-1155.

Alves, T., Machado, L., Gonçalves de Souza, R., & de Wilde, P. (2017). A methodology for estimating office building energy use baselines by means of land use legislation and reference buildings. Energy and Buildings 143, 100-113.

Andaloro, A.P.F., Salomone, R., Ioppolo, G., & Andaloro, L. (2010). Energy certification of buildings: A comparative analysis of progress towards implementation in European countries. Energy Policy 38, 5840-5866.

Barbosa, S., & Ip, K. (2016). Predicted thermal acceptance in naturally ventilated office buildings with double skin facades under Brazilian climates. Journal of Building Engineering 7, 92-102.

Barker, T., Ekins, P., & Foxon, T. (2007). The macro-economic rebound effect and the UK economy. Energy Policy 35, 4935-4946.

Bordass, B. (2004). Energy performance of non-domestic buildings: closing the credibility gap. In: Proceedings of the 2004 Improving Energy Efficiency of Commercial Buildings Conference, Frankfurt, Germany.

Bordass, B., Cohen, R., Standeven, M., & Leaman, A. (2001). Assessing building performance in use 3: energy performance of the probe buildings. Building Research Information 29, 114–128.

Borgstein, E.H., & Lamberts, R. (2014). Developing energy consumption benchmarks for buildings: bank branches in Brazil. Energy and Building 82, 82–91.

Burman, E., Hong, S.M., Paterson, G., Kimpian, J., & Mumovic, D. (2014). A comparative study of benchmarking approaches for non-domestic buildings: Part 2 – Bottom-up approach. International Journal of Sustainable Built Environment 3, 247-261.

BRE. (2018). BRE Environmental Assessment Methods. (Available at) (https://www.breeam.com/).

BRE. (2015). Home Quality Mark. (Available at) (http://www.homequalitymark.com/).

Carbon Trust. (2011). Closing the gap – lessons learned on realising the potential of low carbon building design.

Carlo, J., Ghisi, E., & Lamberts, R. (2003). The use of computer simulation to establish energy efficiency parameters for a building code of a city in Brazil. In: IBPSA, eighth international conference, Eindhoven, Netherlands.

Carpio, M., Martin-Morales, M., & Zamorano, M. (2015). Comparative study by an expert panel of documents recognised for energy efficiency certification of buildings in Spain. Energy and Buildings 99, 98-103.

Chen, Y.B., Tan, H.W., Wu, J.Z., & Song, X.D. (2017). Resilient regional energy benchmarking of classified public buildings. Energy Procedia 142, 2365-2370.

Chen, Y.B., Tan, H.W., & Berardi, W. (2018). A data-driven approach for building energy benchmarking using the Lorenz curve. Energy and Buildings 169, 319-331.

Chung, W., & Yeung, I.M.H. (2017). Benchmarking by convex non-parametric least squares with application on the energy performance of office buildings. Applied Energy 203, 454-462.

CIBSE. (2008). TM46: Energy Benchmarks. The Chartered Institution of Building Services Engineers, ISBN: 9781903287958.

Committee on Climate Change. (2018). How the UK is progressing. (Available at) (https://www.theccc.org.uk/tackling-climate-change/reducing-carbon-emissions/how-the-uk-is-progressing/).

Conselho Brasileiro da Construção Sustentável (CBSC). (2014). Plataforma de Cálculo Benchmarking (in Portuguese). ⟨http://www.cbcs.org.br/website/benchmarkingplataforma/⟩.

Dasgupta, A., Prodromou, A., Mumovic, D. (2012). Operational versus designed performance of low carbon schools in England: bridging a credibility gap. HVAC&R Research 18, 37-50.

de la Flor, F.J.S., Dominguez, S.A., Felix, J.L.M., & Falcon, R.G. (2008). Climatic zoning and its application to Spanish building energy performance regulations. Energy and Buildings 40, 1984-1990.

de Oliveira Veloso, A.C., Goncalves de Souza, R.V., & dos Santos, F.N. (2020). Energy benchmarking for office building towers in mild temperate climate. Energy and Buildings 222, 110059.

Department for Business, Energy & Industrial Strategy. (2018). Final UK greenhouse gas emissions national statistics: 1990-2016. (Available at) (https://www.gov.uk/government/statistics/final-uk-greenhouse-gas-emissions-national-statistics-1990-2016).

Department of Energy (U.S). (2012). Building Energy Data Book, Table 1.1.3, 2012. (Available at) (http://buildingsdatabook.eren.doe.gov/docs/xls_pdf/1.1.3.pdf).

DETR. (2000). Energy use in Offices. Energy Efficiency Best Practice Programme Energy Consumption Guide 19, January 2000, London: Department of the Environment, Transport and the Regions.

Directorate-General for Energy and Ecology & Portuguese Energy Agency. (2018). Calculation of cost-optimal levels of the minimum energy performance requirements of buildings and building elements: Hotel buildings. (https://ec.europa.eu/energy/sites/ener/files/documents/pt_2018_cost-optimal_en_version_hotels.pdf).

Ding, Y., Zhang, Z.Q., Zhang, Q., Lv, W.H., Yang, Z.C., & Zhu, N. (2018). Benchmark analysis of electricity consumption for complex campus buildings in China. Applied Thermal Engineering 131, 428-436.

ENERGY STAR. (2018). Benchmark Energy Use: Learn about Benchmarking. https://www.energystar.gov/buildings/about-us/how-can-we-help-you/benchmark-energyuse/benchmarking.

European Council. (1993). Directive 93/76/EEC to Limit Carbon Dioxide Emissions by Improving Energy Efficiency (SAVE).

European Council. (2002). Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings (EPBD).

European Council. (2010). Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast) (EPBD recast).

Farahbakhsh, H., Ugursal, V.I., & Fung, A. (1998). A residential end-use energy consumption model for Canada. International Journal of Energy Research 22(13), 1133–1143.

Field, A. (2009). Descobrindo a estatística usando o SPSS. 2° edicion. Porto Alegre: Artmed (in Portuguese).

Final energy consumption, EU-28. (2015) (% of total, based on tonnes of oil equivalent), Eurostat Statistics Explained. (Available at) (http://ec.europa.eu/eurostat/statistics-explained/images/7/72/Final_energy_consumption%2C_EU-28%2C_2015_%28%25_of_total%2C_based_on_tonnes_of_oil_equivalent%29_YB17.png).

Fragoso, R., & Baptista, N. (2018). Energy implementation in Portugal: December 2016. Concerted Action Country Reports. (https://epbd-ca.eu/wp-content/uploads/2018/08/CA-EPBD-IV-Portugal-2018.pdf)

Griffith, B., & Crawley, D. (2006). Methodology for analyzing the technical potential for energy performance in the U.S. commercial buildings sector with detailed energy modeling. In: IBPSA-USA, SimBuild conference, Cambridge, Massachusetts, USA.

Herrando, M., Cambra, D., Navarro, M., de la Cruz, L., Millan, G., & Zabalza, I. (2016). Energy Performance Certification of Faculty Buildings in Spain: The gap between estimated and real energy consumption. Energy Conversion and Management 125, 141-153.

Hong, S.M., Paterson, G., Burman, E., Steadman, P., & Mumovic, D. (2013). A comparative study of benchmarking approaches for non-domestic buildings: Part 1 – Top-down approach. International Journal of Sustainable Built Environment 2, 119-130.

Huang, Y., & Broderick, J. (2000). A bottom-up engineering estimate of the aggregate heating and cooling loads of the entire US building stock. Lawrence Berkeley National Laboratory, Report LBNL-46303.

INMET. (2016). Average monthly temperature graph for Curitiba. (Available at) (http://projeteee.mma.gov.br/dados-climaticos/?cidade=PR+-+Curitiba&id_cidade=bra_pr_curitiba-pena.intl.ap.838400_try.1969) (In Portuguese).

INMETRO. (2018). INSTRUÇÃO NORMATIVA INMETRO PARA A CLASSE DE EFICIÊNCIA ENERGÉTICA DE EDIFICAÇÕES COMERCIAIS, DE SERVIÇOS E PÚBLICAS, SERVIÇO PÚBLICO FEDERAL, MINISTÉRIO DA INDÚSTRIA, COMÉRCIO EXTERIOR E SERVIÇOS, (Available at) (http://www.inmetro.gov.br/legislacao/rtac/pdf/RTAC002520.pdf) (In Portuguese).

Jing, R., Wang, M., & Zhang, R.X. (2017). A study on energy performance of 30 commercial office buildings in Hong Kong. Energy and Building 144, 117-128.

Jones, P.J., Lannon, S., & Williams, J. (2001). Modelling building energy use at urban scale. In: IBPSA, seventh international conference, Rio de Janeiro, Brazil.

Juaidi, A., AlFaris, F., Montoya, F.G., & Manzano-Agugliaro, F. (2016). Energy benchmarking for shopping centers in Gulf Coast region. Energy Policy 91, 247-255.

Kelly, S., Crawford-Brown, D., & Pollitt, M.G. (2012). Building performance evaluation and certification in the UK: Is SAP fit for purpose? Renewable and Sustainable Energy Reviews 16, 6861-6878.

Khoshbakht, M., Gou, Z.H., & Dupre, K. (2018). Energy use characteristics and benchmarking for higher education buildings. Energy and Buildings 164, 61-76.

Kohler, N., Schwaiger, B., Barth, B., & Koch, M. (1997). Mass flow, energy flow and costs of the German building stock. In: CIB, 2nd International Conference on Buildings and the Environment. Paris, France.

Kottek, M., Grieser, J., Beck, C., Rudolf, B. & Rubel, F. (2006). World Map of the Köppen-Geiger climate classification updated. Meteorologische Zeitschrif 15(3), 259-263.

Larsen, B.M., & Nesbakken, R. (2004). Household electricity end-use consumption: results from econometric and engineering models. Energy Economics 26(2), 179-200.

Lee, W. (2008). Benchmarking the energy efficiency of government buildings with data envelopment analysis. Energy and Building 40, 891–895.

Lomas, K.J. (1996). The U.K. applicability study: an evaluation of thermal simulation programs for passive solar house design. Building and Environment 31, 197-206.

Lopes, Ad.C.P., Filho, D.O., Altoe, L., Carlo, J.C., & Lima, B.B. (2016). Energy efficiency labelling program for buildings in Brazil compared to the United States' and Portugal's. Renewable & Sustainable Energy Reviews 66, 207–219.

Li, Z.W., Han, Y.M., & Xu, P. (2014). Methods for benchmarking building energy consumption against its past or intended performance: An overview. Applied Energy 124, 325-334.

Li, H.R., & Li, X.F. (2018). Benchmarking energy performance for cooling in large commercial buildings. Energy and Buildings 176, 179-193.

Li, X.Y., Yao, R.M., Li, Q., Ding, Y., & Li, B.Z. (2018). An object-oriented energy benchmark for the evaluation of the office building stock. Utilities Policy 51, 1-11.

MacGregor, W.A., Hamdullahpur, F., & Ugursal, V.I. (1993). Space heating using small-scale fluidized beds: a technoeconomic evaluation. International Journal of Energy Research 17(6), 445-466.

Martin, A.D. (2018). Implementation of the EPBD in Spain: December 2016. Concerted Action Country Reports (https://epbd-ca.eu/wp-content/uploads/2018/08/CA-EPBD-IV-Spain-2018.pdf).

Mastrucci, A., Baume, O., Stazi, F., & Leopold, U. (2014). Estimating energy savings for the residential building stock of an entire city: A GIS-based statistical downscaling approach applied to Rotterdam. Energy and Buildings 75, 358-367.

McKenna, R., Merkel, E., Fehrenbach, D., Mehne, S., & Fichtner, W. (2013). Energy efficiency in the German residential sector: A bottom-up building-stock-model-based analysis in the context of energy-political targets. Building and Environment 62, 77-88.

Menezes, A.C., Cripps, A., Bouchlaghem, D., & Buswell, R. (2012). Predicted vs. actual energy performance of non-domestic buildings: using post-occupancy evaluation data to reduce the performance gap. Applied Energy 97, 355–364.

Ministry of Mines and Energy (MME). (2009). 2 - Regulamento Técnico da Qualidade do Nível de Eficiência Energética de Edifícios Comerciais, de Servicos e Públicos (in Portuguese).

Ministry of Mines and Energy (MME). (2015). Brazilian Energy Balance 2015: Year 2014 Empresa de Pesquisa Energética. Rio de Janeiro, Brasil.

Morgenstern, P., Li, M., Raslan, R., Ruyssevelt, P., & Wright, A. (2016). Benchmarking acute hospitals: Composite electricity targets based on departmental consumption intensities? Energy and Buildings 118, 277-290.

Nunes, P., Lerer, M.M., & da Graca, G.C. (2013). Energy certification of existing office buildings: Analysis of two case studies and qualitative reflection. Sustainable Cities and Society 9, 81-95.

Oliveira Panao, M.J.N., & Brito, M.C. (2018). Modelling aggregate hourly electricity consumption based on bottom-up building stock. Energy and Buildings 170, 170-182.

Paixão, A.C.C. (2013). Caracterização tipológica de agências bancárias e seu potencial de economia de energia elétrica e etiquetagem com a implantação de sistemas fotovoltaicos (Typological Characterization of Bank Branches, Their Potential Electrical Energy Savings and Labelling with the Installation of Photovoltaic Systems) (Masters dissertation in Architecture and Urbanism), Federal University of Viçosa (in Portuguese).

PBE Edifica. (2018). (Available at) (http://pbeedifica.com.br/redes/comercial/index_with_angular.html#).

Pegg, I.M., Cripps, A., & Kolokotroni, M. (2007). Post-occupancy performance of five low energy schools in the UK. ASHRAE Transactions 113.

Perez-Lombard L., Ortiz J., & Pout C. (2008). A review on building energy consumption information. Energy and Buildings 40(3), 394-398.

Perez-Lombard, L., Ortiz, J., Gonzalez, R., & Maestre, I.R. (2009). A review of benchmarking, rating and labelling concepts within the framework of building energy certification schemes. Energy and Buildings 41, 272–278.

Petersen, S., & Hviid, C.A. (2012). The European energy performance of buildings directive: comparison of calculated and actual energy use in a Danish office building. In: Building Simulation and Optimisation (BSO 2012), Loughborough, United Kingdom.

Power, A. (2010). Housing and sustainability: demolition or refurbishment? Proceedings of the Institution of Civil Engineers: Urban Design and Planning 163 (4), 205-216.

Rajagopalan, P., & Leung, T.C.Y. (2012). Progress on building energy labelling techniques. Adv. Build. Energy Res. 6 (1), 61–80.

Ramirez, R., Sebold, F., Mayer, T., Ciminelli, M., & Abrishami, M. (2005). A building simulation palooza: the California CEUS project and DrCEUS. In: IBPSA, Ninth international conference, Montreal, Canada.

Roriz, M. (2014). Classificação de climas do Brasil – versão 3.0. ANTAC: Associação Nacional de Tecnologia do Ambiente Construído. Grupo de Trabalho sobre Conforto Ambiental e Eficiência Energética de Edificações. São Carlos, SP. (Available at) (http://cb3e.ufsc.br/sites/default/files/Roriz_2014.pdf) (In Portuguese).

Roth, J., & Rajagopal, R. (2018). Benchmarking building energy efficiency using quantile regression. Energy 152, 866-876.

Sepehr, M., Egtedaei, R., Toolabimoghadam, A., Noorollahi, Y., & Mohammadi, M. (2018). Modeling the electrical energy consumption profile for residential buildings in Iran. Sustainable Cities and Society 41, 481-489.

Sheng, Y., Miao, Z.Z., Zhang, J.Y., Lin, X.Y., & Ma, H.T. (2018). Energy consumption model and energy benchmarks of five-star hotels in China. Energy and Buildings 165, 286-292.

Shipley, D., Todesco, G. & Adelaar, M. (2002). Modelling a nation of buildings: estimating energy efficiency potential for large building samples. In: IBPSA Canada, eSim Conference, Montreal, Canada.

Spain's Ministry of Public Works. (2018). Report on the calculation of the cost-optimal levels of the minimum energy performance requirements for buildings in the new Spanish regulations and their comparison with the current requirements. Madrid (https://ec.europa.eu/energy/sites/ener/files/documents/es_2018_cost-optimal_en_version.pdf).

Spyropoulos, G.N., & Balaras, C.A. (2011). Energy consumption and the potential of energy savings in Hellenic office buildings used as bank branches – A case study. Energy and Buildings 43, 770-778.

Swan, L.G., & Ugursal, V.I. (2009). Modeling of end-use energy consumption in the residential sector: a review of modelling techniques. Renewable and Sustainable Energy Reviews 13(8), 1819-1835.

Tronchin, L., & Fabbri, K. (2010). A Round Robin Test for buildings energy performance in Italy. Energy and Building 42, 1862–1877.

Vaisi, S., Pilla, F., & McCormack, S.J. (2018). Recommending a thermal energy benchmark based on CIBSE TM46 for typical college buildings and creating monthly energy models. Energy and Buildings 176, 296-309.

Vaquero, P. (2020). Buildings Energy Certification System in Portugal: Ten years later. Energy Reports 6, 541-547.

Wan, K.S.Y., & Yik, F.H.W. (2004). Representative building design and internal load patterns for modelling energy use in the residential buildings in Hong Kong. Applied Energy 77, 69-85.

Wang, E., Shen, Z., & Grosskopf, L. (2014). Benchmarking energy performance of building envelopes through a selective residual-clustering approach using high dimensional dataset. Energy and Building 75, 10–22.

Wang, E.D., Alp, N., Shi, J., Wang, C., Zhang, X.D., & Chen, H. (2017). Multi-criteria building energy performance benchmarking through variable clustering based compromise TOPSIS with objective entropy weighting. Energy 125, 197-210.

Wang, Z., Zhao, Z., Lin, B.R., Zhu, Y.X., & Ouyang, Q. (2015). Residential heating energy consumption modeling through a bottom-up approach for China's Hot Summer – Cold Winter climatic region. Energy and Buildings 109, 65-74.

Wiesmann, D., Azevedo, I.L., Ferrao, P., & Fernandez, J.E. (2011). Residential electricity consumption in Portugal: Findings from top-down and bottom-up models. Energy Policy 39, 2772-2779.

Wong, I.L., & Krüger, E. (2017). Comparing energy efficiency labelling systems in the EU and Brazil: Implications, challenges, barriers and opportunities. Energy Policy 109, 310-323.

Wong, I.L., Krüger, E., Loper, A.C.M., & Mori, F.K. (2019). Classification and energy analysis of bank building stock: A case study in Curitiba, Brazil. Journal of Building Engineering 23, 259-269.

Wu, X., Rajagopalan, P., & Lee, S.E. (2010). Benchmarking energy use and greenhouse gas emissions in Singapore's hotel industry. Energy Policy 38, 4520–4527.

Yang, Z., Roth, J., & Jain, R.K. (2018). DUE-B: Data-driven urban energy benchmarking of buildings using recursive partitioning and stochastic frontier analysis. Energy and Buildings 163, 58-69.