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VARIABLES OF INFLUENCE ON THERMAL PERFORMANCE OF BUILDINGS UNDER TRANSIENT CONDITIONS

VARIÁVEIS DE INFLUÊNCIA NO DESEMPENHO TÉRMICO DE EDIFICAÇÕES EM REGIME TRANSIENTE

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Abstract

Residential buildings significantly increase electricity demand, especially in developing countries. In this case, the requirements addressed by the standards can ensure the climatic adequacy of the envelope, enhance thermal performance, and promote thermal comfort conditions while reducing energy consumption. However, the criteria for evaluating the thermal performance of a building's envelope that is commonly adopted in energy performance standards and codes have proved to be inefficient in hot climates. The heat exchanges within buildings are dependent on solar radiation and ventilation. The purpose of this article is to establish the variables with the greatest influence on the thermal performance of naturally ventilated dwellings in hot climates (equatorial, tropical and subtropical). For this investigation, a factorial design was adopted for sensitivity analysis. The structure of the factorial experiment defined the simulations of four patterns of single-family and multifamily residential buildings. We varied the thermophysical properties of the external walls and roofs, the heat gain coefficient of the openings, and natural ventilation. Brazil was adopted as a basis for climate analysis, including equatorial, tropical and subtropical climates. The analyses were based on comfort hours in an adaptive model and statistically evaluated using Analysis of Variance (ANOVA) tests. In general, the absorption of the walls and cover, the thermal transmittance of the cover and the natural ventilation were the variables of greatest influence on thermal comfort in a hot climate.

Keywords: Thermal performance. Naturally ventilated buildings. Standards. Factorial design.

Resumo

Os edifícios residenciais aumentam significativamente a demanda de eletricidade, especialmente nos países em desenvolvimento. Neste caso, os requisitos contemplados pelas normas podem garantir a adequação climática da envolvente e o melhor desempenho térmico, bem como promover condições de conforto térmico, ao mesmo tempo que reduz o consumo de energia. No entanto, os critérios para avaliar o desempenho térmico do envelope de um edifício comumente adotados em padrões e códigos de desempenho energético provaram ser ineficientes em climas quentes, nos quais as trocas de calor dentro dos edifícios dependem da radiação solar e ventilação. O objetivo deste artigo é estabelecer as variáveis com maior influência no desempenho térmico de residências ventiladas naturalmente em climas quentes (equatorial, tropical e subtropical). Para tal, o planejamento fatorial foi adotado para análise de sensibilidade. A estrutura do experimento fatorial definiu as simulações de quatro modelos de edifícios residenciais unifamiliares e multifamiliares, variando as propriedades termofísicas das paredes externas e coberturas, o fator solar das aberturas e o uso de ventilação natural. O Brasil foi adotado como base para as análises climáticas, incluindo climas equatorial, tropical e subtropical. As análises foram baseadas em horas de conforto em modelo adaptativo e avaliadas estatisticamente por meio de testes de Análise de Variância (ANOVA). Em geral, a absorção das paredes e cobertura, a transmitância térmica da cobertura e a ventilação natural foram as variáveis de maior influência para o conforto térmico em um clima quente.

Palavras-chave: *Desempenho térmico. Edificações condicionadas naturalmente. Normas. Experimento fatorial.*

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Introduction

The energy consumption of residential buildings currently represents 22% of the world's total energy use. To mitigate the growth of energy consumption in buildings, energy policies in buildings intend to reduce the energy consumption of the existing buildings without compromising the comfort levels of users (IEA, 2019).

Building Energy Efficiency Codes have a wider adoption in cold climate regions than in hot climate regions. As a result, most codes evaluate the energy efficiency of buildings with a focus on reducing heat demand, analyzing the behaviour of the building envelope strictly by the thermal transmittance of external walls, roofs, and glazed surfaces. This choice is justified under conditions close to a state of a permanent regime. There is a great difference between the external and internal air temperature, where the latter is kept practically constant through artificial conditioning systems. Thus, in this case, the heat flow depends mainly on the thermal transmittance of the building envelope. In hot climates, buildings mainly require energy for cooling or do not have HVAC systems. In many developing countries, such as Brazil and Mexico, it is possible to obtain thermal comfort with natural ventilation and bioclimatic designs (LIU; MEYER; HOGAN, 2010). Usually, this is the only viable strategy for a significant portion of the population due to economic conditions. Therefore, passive strategies that ensure thermal comfort should be encouraged, as they represent the lowest level of energy consumption and affect the majority of the population (FOSSATI et al., 2016). In naturally conditioned buildings, heat exchanges occur under fluctuating conditions. The envelopes are heated and cooled periodically in these buildings due to external temperature variations and incident solar radiation. Consequently, they are less prone to constant internal conditions throughout the day (RIVERO, 1985).

In the development of relevant energy efficiency regulation codes in emerging countries, international standards are observed, such as the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). These standards are used as the basis for the development of thermal performance methods and comfort analysis. Janda and Busch stated that a strict standard for one country could be inefficient due to weather conditions, existing buildings, and local construction practices (JANDA; BUSCH, 1994; FOSSATI et al., 2016). Therefore, it is relevant to state that there is a predominance of warm climates in emerging countries such as Brazil, India, Mexico, and Pakistan (equatorial and tropical). In contrast, in the countries for which the regulation was developed, the climates are cold or temperate, which implies differences in heat transfer in the building and strategies for obtaining comfort conditions. According to Humphreys (HUMPHREYS, 1976), there is a significant discrepancy between the steady-state models of artificially conditioned buildings and those naturally conditioned in a transient state.

A review of energy efficiency codes and thermal performance standards in several countries was performed to understand the minimum criteria usually adopted for residential buildings. This review is presented in Table 1.

The review indicated that the commonly used thermophysical parameters adopted in the traditional prescriptive methods of evaluating the thermal performance of buildings are the thermal transmittance, solar absorptance, and the Heat Gain Coefficient (SHGC), or the heat gain coefficient, of the openings. The natural ventilation and the shading of the openings were also considered.

Table 1 –Summary minimum criteria adopted in energy efficiency codes and thermal performance standards in several countries

Country	Normative reference	Climate	Variables
United States	ASHRAE 90.2 (ASHRAE, 2018)	Arid, hot temperate, cold	Thermal transmittance (U) of opaque and translucent elements of envelopment; Solar heat gain coefficient (SHGC).
Argentina	IRAM 11.507 (INSTITUTO ARGENTINO DE NORMALIZACIÓN Y CERTIFICACIÓN, 1995) e IRAM 11.605 (INSTITUTO ARGENTINO DE NORMALIZACIÓN Y CERTIFICACIÓN, 1996)	Arid, hot temperate	Thermal transmittance (U) of opaque and translucent elements of envelopment; Air changes.
Chile	NCh 1079 (INSTITUTO NACIONAL DE NORMALIZACION CHILE, 2000)	Arid, hot temperate	Thermal transmittance (U) of opaque elements of envelopment; Shading of openings.
Mexico	NOM 020 (SENER, 2011)	Equatorial and tropical, arid, hot temperate	Thermal transmittance (U) of opaque elements of envelopment; Shading of openings.
Brazil	NBR 15.220-3 (ABNT, 2005), NBR 15.575-4 (ABNT, 2013a), NBR 15.575-5 (ABNT, 2013b) e RTQ-R (BRASIL, 2012)	Equatorial and tropical, arid, hot temperate	Thermal transmittance (U) of opaque elements of envelopment; Thermal capacity of opaque elements; Heat gain coefficient of opaque elements; Thermal capacity of external walls; Opening area.
India	Energy Conservation Building Code of India (USAID ECO-III Project, 2011)	Equatorial and tropical, arid, hot temperate	Thermal transmittance (U) of opaque and translucent elements of envelopment; Solar heat gain coeficient (SHGC); Thermal capacity of opaque elements; Absorptance of opaque elements; Air changes; Shading of openings.
Pakistan	Building Energy Code of Pakistan (PAKISTAN, 1990)	Arid, hot temperate, cold temperate	Thermal transmittance (U) of opaque elements of envelopment; Heat gain coefficient of translucent elements[1]; Natural ventilation.
China	JGJ 26 (MINISTRY OF CONSTRUCTION, 1986) e JGJ 134 (MINISTRY OF CONSTRUCTION, 2001)	Tropical, arid, hot temperate, temperate cold, polar	Thermal transmittance (U) of opaque and translucent elements of envelopment; Window to wall ratio (WWR) by orientation; Shading of openings.
Singapore	Energy Conservation in Building and Building Services (THE DEVELOPMENT & BUILDING CONTROL DIVISION (PWD), 1983)	Equatorial	Thermal transmittance (U) of opaque and translucent elements of envelopment; Absorptance of opaque elements; Window to wall ratio (WWR); Shading of openings; Heat gain coefficient of translucent elements[1].
Australia	NCC (ABCB - AUSTRALIAN BUILDING CODES BOARD, 2018)	Tropical, arid, hot temperate	Thermal resistance (R) of opaque elements; Shading of opaque elements; Absorptance of opaque elements; Thermal mass of external and internal walls, floors and roofs; Thermal transmittance (U) of translucent elements; Solar heat gain coeficient (SHGC); Shading of openings.
New Zealand	NZS 4218 (STANDARDS NEW ZEALAND, 2009)	Hot temperate	Thermal resistance (R) of opaque elements; Opening area.
Portugal	RCCTE (DIÁRIO DA REPÚBLICA, 2006)	Hot temperate	Thermal transmittance (U) of opaque elements of envelopment; Thermal delay of internal walls; Heat gain coefficient of translucent elements; Air changes.
Spain	Código Técnico de la Edificácion (MINISTERIO DE VIVIENDA , 2006)	Arid, hot temperate, cold temperate	Thermal transmittance (U) of opaque and translucent elements of envelopment; Thermal mass of opaque elements; Heat gain coefficient of translucent elements.

Note: 1) The analysis of the minimum requirements is done by the Overall Thermal Transfer Value (OTTV), calculated according to these variables.
Source: the authors.

By relying on the thermal resistance of the envelope, the contribution of natural ventilation and solar radiation are disregarded in the assessment methods. These parameters have significant relevance for thermal comfort in naturally ventilated buildings. The user's thermal comfort depends on variables such as air temperature, relative humidity, air velocity, and the average radiant temperature of the environment (AKUTSU; VITTORINO, 1997).

Some of the studies developed for hot climates around the world can be cited.

In China, the southern region of the country has long, hot summers; there is almost no winter and the humidity and solar radiation are high. China had approved a specific standard, JGJ 75 - Design standard for energy efficiency of residential buildings in hot summer and warm winter zone (2013) (MINISTRY OF CONSTRUCTION, 2013), that also establishes the minimum requirements for openings and shading coefficients according to the orientation and window-to-wall area ratio. The limit heat transfer coefficient allowed is the same as in the other cold climate regions of the country (LANG, 2004). Feng (FENG, 2004) observes that, for China's regions of hot summers and cold winters, factors such as heat gain during summer and natural ventilation during transition seasons should also be considered, since the process of heat transfer in the building envelope will be distinct in summer and winter. The heat transfer coefficient and the thermal inertia index are the most influential parameters on the thermo-energetic performance of buildings in this climate (FENG, 2004).

A study performed in Turkey compared the thermal performance of buildings in temperate and humid climates with hot and dry climates and identified that the thermal transmittance of the envelope and the total of the heat transfer are not sufficient to determine the actual thermal performance of the building, in the case of the stationary regime. According to this research, the thermal capacity of the envelope proved to be much more relevant than the insulation in a hot and dry climate for the energy efficiency of buildings (YILMAZ, 2007).

In Australian climates, masonry walls with higher thermal capacity than other conventional building systems were up to 60% more efficient than insulating systems (TECHNICAL NOTES ON BRICK CONSTRUCTION, 1997). Gregory et al. compared the thermal performance of several Australian building systems. They concluded that the thermal wall mass could significantly reduce energy use in residential buildings while maintaining the most comfortable indoor temperatures (GREGORY *et al.*, 2008).

Aste, Angelotti and Buzzetti (2009) analysed the influence of the thermal inertia of the walls on the energy performance of buildings for the humid subtropical climate of Northen Italy. They concluded that the use of walls with high thermal inertia in buildings results in the reduction of energy requirements for both heating and cooling, especially the latter (ASTE; ANGELOTTI; BUZZETTI, 2009).

The study developed by Cheng, Ng and Givoni (2005) for the hot and humid climate of Hong Kong concluded that the higher the incidence of radiation and the lighter weight of the building envelope, the greater the influence of solar absorptance on the building performance.

Studies performed in Brazil for different climates obtained similar results. For hot and humid climates, they observed that natural ventilation contributes significantly to improving thermal performance. The roof and wall absorptance was confirmed to be a variable for which the thermal performance is very sensitive (LOUREIRO, 2003; NEGREIROS; PEDRINI, 2013). For regions with a humid subtropical climate, studies analyzed the thermal response of buildings by considering the dynamic conditions of exposure to climate and verified that construction systems with higher thermal inertia present better thermal performance than systems with low thermal inertia (AKUTSU; VITTORINO, 1997; AKUTSU, 1998; LEÃO, 2006; BARRIOS; HUELSZ; RECHTMAN, 2011;

SILVA *et al.*, 2014). A strong correlation was obtained between the thermal resistance values of the walls and the maximum values of the thermal load, which corroborates the use of thermal resistance as a regulating element and indicator of thermal performance where there is a need for heating. The highest correlation observed was for the thermal capacity of naturally conditioned buildings (AKUTSU, 1998). In addition to high thermal inertia and light-coloured envelope, natural ventilation and shading of the openings are recommended (LEÃO, 2006; SILVA *et al.*, 2014).

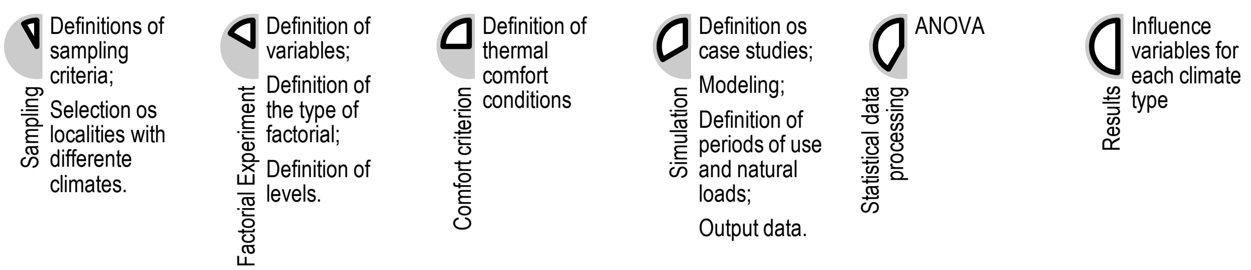
In summary, methods of evaluating thermal performance based on a high thermal resistance of the envelope are inadequate in buildings under transient regimes. Another thermal property, such as thermal capacity, can assume a critical role in the performance. Furthermore, other factors, such as the contribution of natural ventilation and shading of openings, are not usually approached by the standards and regulations of cold climate countries, but convert the key factors of human thermal comfort in hot climates (AKUTSU; VITTORINO, 1997; BARRIOS; HUELSZ; RECHTMAN, 2011). Therefore, the performance knowledge of buildings in transient conditions is fundamental. In particular, the influential variables for thermal performance and energy efficiency for this condition should be identified.

This paper aims to evaluate the thermal behaviour of naturally conditioned residential buildings for different hot climates (equatorial, tropical and subtropical) and establish the variables with the greatest influence on thermal performance through the factorial experiment.

Methodology

This work combined sensitivity analysis and computational simulations to analyze the variables having the greatest influence on the thermal performance of naturally-conditioned residential buildings constructed in hot climates. EnergyPlus 8.7.0 was the software selected for computing the thermal performance since it considered the transient regime of thermal exchange under the dynamic conditions of exposure to climate. The research steps are briefly presented in Figure 1.

Figure 1 - Summary of research steps



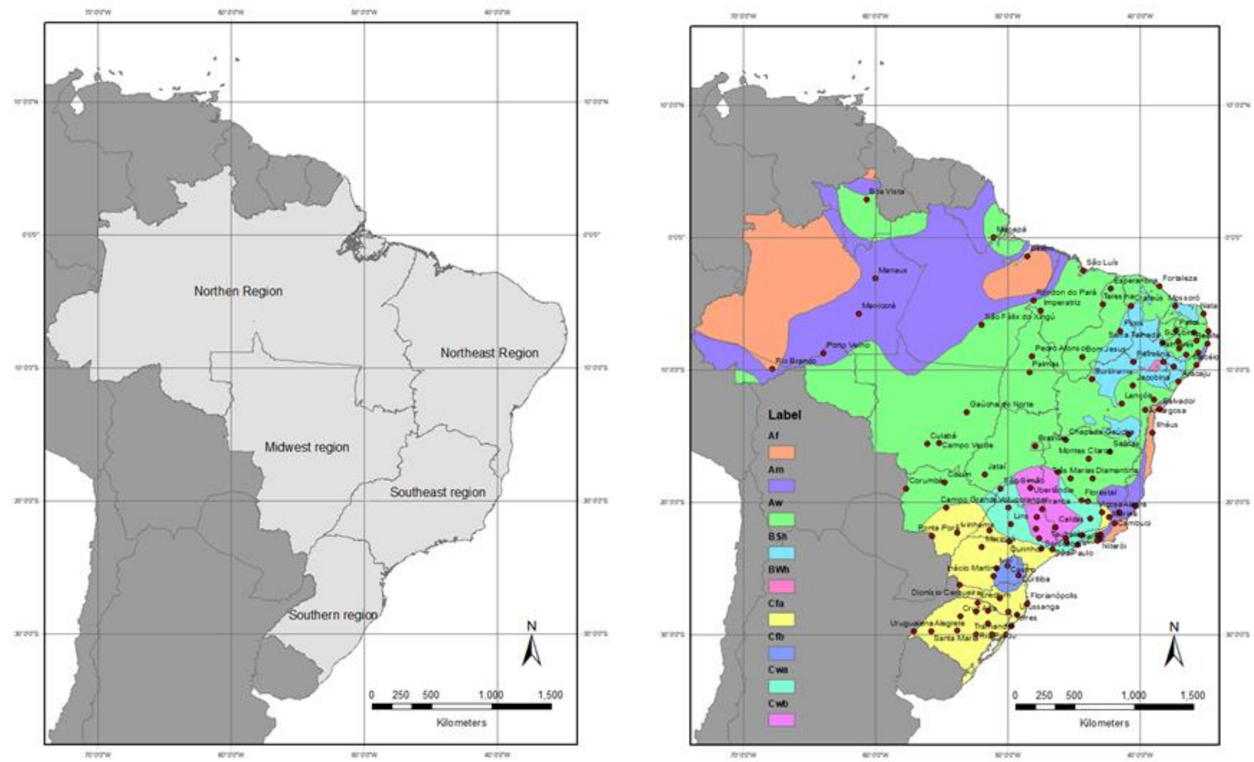
Source: the authors.

Brazil was chosen as a case study because it is a country of continental dimensions, comprising latitudes 5°16' N to 33°45' S and longitudes 34°47' W to 73°59' W, thus presenting great climatic diversity, encompassing equatorial (Af according to Köppen-Greiger), tropical (Am and Aw), hot and dry (BSh and BWh) and subtropical regions (Cfa, Cfb, Cwa and Cwb). In addition, Brazil has a complex topographic variation that impacts local climate conditions and further diversifies them.

Climate characterization of Brazil and sampling of localities

The bioclimatic zones proposed for Brazil by NBR 15,220-3 (ABNT, 2005) were used as the basis for climate characterization, to consider all of the existing climate diversity. Sampling was conducted with consideration given to the bioclimatic zones (Figure 2 - right), and latitude and geographical regions (for the definition of representative models of the buildings, see Figure 2 - left). Stratified sampling was applied to the bioclimatic zones and regions in the country, while random sampling was applied in the case of latitude.

Figure 2 - Regions of Brazil (left) and Brazilian climatic Köppen-Greiger classification (right)



Source: the authors

Following the sampling pattern adopted by Carlo (2008), a significant sample should include 98 locations for a universe of 5,520 Brazilian cities and an error of 10%. The localities were sampled by stratified sampling according to the frequency of bioclimatic zones in the Brazilian regions. The final sampling by bioclimatic zone and region resulted in Table 2.

Random sampling was then carried out by latitude, resulting in 12 more locations and better coverage of the Brazilian territory. Thus, a total of 110 locations were sampled. Only locations with climatic data in EnergyPlus Weather Format (epw) were considered available for sampling. The distribution of the selected locations is presented in Figure 3.

Table 2 - Number of samples by Brazilian bioclimatic zone according to NBR 15,220-3 [12] and by Brazilian region

Brazilian bioclimatic zone	Distribution in Brazilian territory (%)	Number of samples	Number of samples by region	
1	2.1	2	South	2
2	17.4	17	Southeast	3
			South	14
3	19.0	19	Midwest	1
			Southeast	13
			South	5
4	4.3	4	Midwest	1
			Southeast	3
5	5.8	6	Northeast	2
			Midwest	1
			Southeast	3
6	12.0	12	Northeast	2
			Midwest	5
			Southeast	5
7	13.0	13	North	2
			Northeast	10
			Midwest	1
8	26.4	25	North	6
			Northeast	17
			Midwest Southeast	1
				1
Total	100.0	98		98

Source: the authors.

Figure 3 - Final distribution of the localities sampled by the Brazilian territory

Source: the authors.

Factorial design

The factorial design was applied as a sensitivity analysis technique to determine which variables influence the evaluated climatic types. The factorial experiment of two levels was chosen, and the simulations to be performed were defined from it, replicating the tests of the experiment.

First of all, the parameters to be evaluated were defined from the variables found in the literature review in this work: thermal transmittance of roofs and external walls, the thermal capacity of roofs and external walls, the solar absorptance of roofs and external walls, the heat gain coefficient of translucent elements and natural ventilation. The internal walls and the slabs were not evaluated to simplify the analysis according to the number of variables and tests involved.

Five variables related to the walls and three related to the roofs were obtained (eight variables in total). The number of tests is equivalent to 2k in factorial in two levels, adding 32 tests for the external walls and 8 for the roof. In the case of multifamily reference models, for the ground and intermediate floors, only the walls' tests were performed without exposed coverage. For the top floor of the multifamily models and the single-family models, the tests were performed combining the variables of the external walls and roofs, totalling 256 tests. Furthermore, the analysis was performed for the four main orientations (north, east, south and west) and considered replicas in the factorial tests (repeated executions of the same combination of factor levels).

The combination of the varied parameters at predetermined values resulted in a parametric set of values, ordered according to factorial planning. Two variation levels were determined, a low (-) and a high (+) level, as seen in Table 3 and Table 4. The thermal transmittance and thermal capacity levels of walls and roof were established from extreme values found in real envelopes, according to the values specified in the Catalog of Thermal Properties of Walls, Roofs and Glass of the Ordinance INMETRO nº50 (MORISHITA *et al.*, 2013). Similarly, the heat gain coefficient of the openings had its levels determined in extreme values according to the Regulation of Characteristics of the Thermal Behaviour of Buildings of Portugal (PORTUGAL, 2006). The solar absorptance varied between two extreme values but within theoretically possible physical limits (from 0 to 1). The case of the existence of natural ventilation in the environments was considered.

Table 3 - Levels for factorial design for walls

Factor	FACTOR A	FACTOR B	FACTOR C	FACTOR D	FACTOR E
Level	Thermal transmittance of walls (U_{WALL}) [W/(m2.K)]	Thermal capacity of walls (CT_{WALL}) [J/(m2.K)]	Absorptance of walls (α_{WALL})	Heat gain coefficient of openings (SF_{OPEN}) [%]	Ventilation (Fvent)
Low (-)	3.70	49.9	0.1	0.9	0
High (+)	1.00	250.1	0.9	0.2	1

Source: the authors.

Table 4 - Levels for factorial design for roofs

Factor	FACTOR A	FACTOR B	FACTOR C
Level	Thermal transmittance of roofs (U_{ROOF}) [W/(m^2.K)]	Thermal capacity of roof (CT_{ROOF}) [J/(m^2.K)]	Absorptance of roof (α_{ROOF})
Low (-)	4.00	20.0	0.1
High (+)	1.00	200.0	0.9

Source: the authors.

The envelopes adopted were varied according to the variables analyzed in the factorial and their respective levels. Four types of external walls and four types of roofs were established, as presented in Table 5. For the factorial design of the external walls, the roof did not vary, and the base roof was assumed for this experiment. Similarly, four types of roofs were established, and the external walls did not vary, so a base wall was adopted.

The device modeled for shading the openings was a horizontal slat, with a reflectance of 0.5. In the tests with shading, the presence of shading was considered throughout the day.

Table 5 - Variations of external walls and roofs according to the factorial design

Type of envelopment	Thermal transmittance [W/(m².K)]	Thermal capacity [J/(m².K)]	Absorptance
Base wall	3.70	49.9	0.1/0.9
Insulating wall	1.00	49.9	0.1/0.9
Heavy wall	3.70	250.1	0.1/0.9
Insulating and heavy wall	1.00	250.1	0.1/0.9
Base roof	4.00	20.0	0.1/0.9
Insulating roof	1.00	20.0	0.1/0.9
Heavy roof	4.00	200.0	0.1/0.9
Insulating and heavy roof	1.00	200.0	0.1/0.9

Source: the authors.

For each city, 40 experiments were carried out according to factorial, considering the external walls and the roof. Each experiment was performed for each of the rooms of prolonged permanence of the dwelling units under study (dormitories and living room), with four replicates related to the main orientations (north, east, south and west), totaling 480 tests for each of the two dwelling models analyzed at 110 localities. A total of 105,600 tests were executed.

Performance criteria

The adopted criteria for thermal performance analysis were the annual sum of hours of thermal comfort, according to the adaptive thermal comfort model of the ASHRAE Standard 55 (ASHRAE, 2013). This model was adopted based on studies that demonstrated that this model is suitable for both the hot (equatorial and tropical), hot and humid and the subtropical climate (PEREIRA; ASSIS, 2010). The acceptable operative temperature ranges for naturally conditioned spaces (T_n) were obtained from the prevailing mean outdoor air temperature ($T_{a,outdoors}$), according to Equation 1.

$$T_n = 0.310 \times T_{a,outdoors} + 17.8°C \pm 3.5 \quad (1)$$

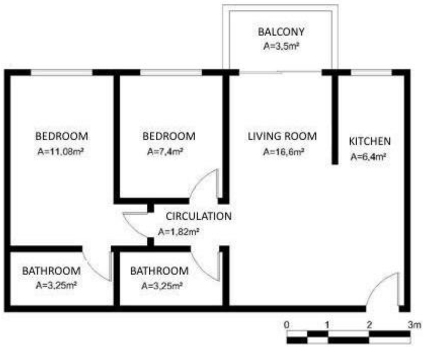
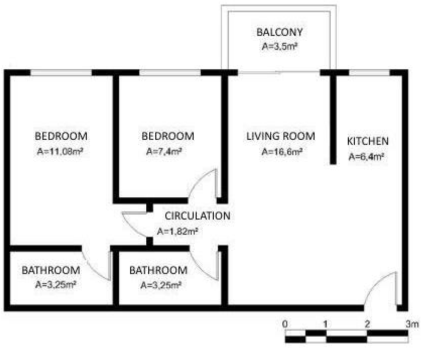
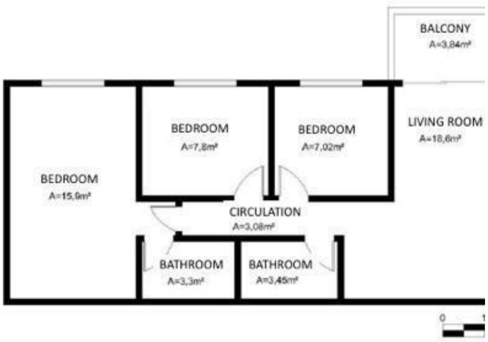
Case studies

The reference models' definition was based on studies about representative models of Brazilian residential buildings (MATOS, 2007; TEIXEIRA et al., 2015; SORGATO, 2009; IBGE, 2011; TELLES, 2016). In all country regions, there is a predominance of housing units of 2 (42.66% of households) and 3 (22.90% of households) dormitories. Moreover, a particular trend is observed in the Southern Region, where housing units of 3 dormitories predominate. In other regions of the country, there is a predominance of 2 dormitory units (PNAD, 2012).

The predominant residential typology is the single-family, representing 89.3% of the 62,849 buildings (PNAD, 2012). A trend for constructing verticalized residential buildings has been observed since the 1980s (PNAD, 2012; TELLES, 2016). Accordingly, the single-family typology (predominant typology) and the multifamily typology (expanding typology) were evaluated to characterize Brazilian residential buildings.

The models of representative residential buildings were defined according to the characterization of the Brazilian residential real estate by the regions in the country, accomplished by Telles (2016). The models designated for each region of the country by typology are presented in Table 6. All multifamily buildings were assumed to have 11 floors, the most recurrent in the country.

Table 6 - Brazilian representative buildings by region

Region	Single-family habitation	Multifamily habitation
North and Midwest	 Area = 30.7 m²	 Area = 53.3 m²
Northeast and Southeast	 Area = 55.5 m²	 Area = 53.3 m²
South	 Area = 55.5 m²	 Area = 66.8 m²

Source: adapted from Sorgato (2009), Teixeira *et al*. (2015) e Telles (2016).

Simulation settings and weather data

Each representative model was modelled according to its geometric characteristics, and each room of the residential unit was considered a thermal zone in EnergyPlus 8.7.0. In the case of multifamily buildings, 11 floors were considered, but only the first, the sixth and the last floors were analyzed. The walls in contact with adjacent housing units were considered adiabatic.

We decided to rotate the building to evaluate the orientations instead of considering the units with different orientations for the same ventilation and insolation conditions were maintained in all of the analyses.

The simulations were performed using the SWERA and TMY climatic files for annual simulations (LABEEE, 2010; RORIZ, 2012).

Schedules and internal loads

The input parameters for internal loads (people, lighting and equipment) and their respective routines followed what is specified by the Technical Quality Regulation for the Energy Efficiency Level of Residential Buildings (RTQ-R) (INMETRO, 2012), which sets an occupancy default of two users per dormitory. These parameters were maintained constant in all of the simulations performed, see Table 7. In the living room case, an internal equipment load of the equivalent of 120 W was considered, with a period of use from 14 to 22 h. The power density installed for lighting was 5 W/m² for the bedrooms and 6 W/m² for the living room.

Table 7 - Occupancy and lighting system patterns for weekdays and weekends (INMETRO, 2012)

Hour	Occupation		Lighting	
	Bedrooms (%)	Living room (%)	Bedrooms (%)	Living room (%)
1h -7h	100	0	0	0
8h-13h	0	0	0	0
14h-15h	0	50	0	0
16h-18h	0	50	0	100
19h-21h	0	100	0	100
22h-23h	100	0	100	0
24h	100	0	0	0

Source: the authors.

Natural ventilation modeling

Natural ventilation was simulated in the EnergyPlus "Airflow Network" module for a more accurate assessment. The"Airflow Network" allows the hourly values of airflow in the thermal zones to be estimated from the description of the geometry of the building, the orientation and location of the façades of the building and its openings, and the local climatic characteristics described in the weather data. Therefore, the airflow considered is variable and interactive with the thermal balance, a condition that is closer to reality. The program estimated the airflow in the environments (when the openings are opened) and the infiltration (when the openings are closed).

The program calculated the wind pressure coefficients. According to the program's manual, the discharge coefficients adopted were 0.65 for the doors and 0.60 for the windows (DOE, 2016). The entire analysis period was considered with and without ventilation, without implementing any opening control.

Statistical data processing

The data obtained by simulation are used as the input variables for factor analysis and statistically treated by variance analysis (ANOVA). The data analysis stage was performed in the statistical program Minitab version 17 to calculate the effect and interactions of the factors and, also, for the analysis of variance (ANOVA). Factors were considered as significant when they presented a test value greater than 0.05.

Results

Results of design factorial

Planned experiments are important tools for determining the subset of variables considered that influence on process performance. The influence of a factor is defined as the variation in the response resulting from the change in the level of the factor (low or high level, according to Table 3 and Table 4). The influence of each variable in the process is delimited by controlled changes in the process and the evaluation of the impact on the results obtained in the interactions. A variable is considered to have a positive influence when its presence in the factor results when there is an increase in comfort hours with the base case (all variables have low levels) and negative when there is a reduction in comfort hours. The percentage of influence is calculated according to the variable's contribution in the model and the errors inherent to the adopted model. Higher values of the variable proportionally indicate a greater contribution in the analyzed process, whether positive or negative.

The variables with the greatest influence on the thermal performance of the single-family and multifamily residential buildings were obtained for the 115 locations analyzed from the factorial. Furthermore, it was possible to define whether the variable(s) influence on thermal performance was positive or negative. The variables were classified as: without influence (without any marking), positive influence (+) and negative influence (-). The variables with the greatest influence, whether positive or negative, were highlighted in grey.

The results for the single-family reference model are presented in Table A1 and, for the multifamily reference model, in Table A2, both in Appendix A.

The results obtained for the single-family reference model indicate that the variables that presented the greatest influence were the absorptance of the walls, the thermal transmittance of the roofs and the absorptance of the roofs.

The absorptance of the walls was a factor of influence on thermal comfort in the single-family housing for all of the climates analyzed. Wall absorptance was the variable with the greatest negative influence on walls in 107 localities and represented a negative influence on thermal performance in 91.9% of cities. Exceptions to this were temperate climates (Campos do Jordão, São Joaquim, Tramandaí, Teresópolis, Inácio Martins, Lagoa Vermelha and Petrópolis). Thermal transmittance was a variable of positive influence for 36.4% of the analyzed localities, against the thermal capacity of the walls for 60.9% of localities. In the cities of Urussanga, Uruguaiana, Tramandaí and Passo Fundo (characterized as a temperate climate without a dry season), thermal transmittance was the variable with the greatest positive influence. In the other 36 localities, this variable had a positive influence, but it was not the variable with the greatest influence. In the other localities, there was no occurrence of the negative influence of this variable, but the influence was not significant. Otherwise, the thermal capacity of the walls showed a positive influence in most cities in which it had a significant influence. Its influence was negative for the humid and tropical subtropical climates at altitude (Petrópolis, Uruguaiana, Urussanga and São Joaquim). The locations in which the thermal capacity presented the greatest positive influence were São Paulo, Vitória da Conquista, Votuporanga, São Simão, Coxim, Cratéus and Lençóis, covering the savannah climates, tempered with a dry season and tropical savanna. This result emphasizes that the thermal capacity of the walls perform a major role in the thermal comfort of single-family residential buildings in hot weather. The thermal transmittance showed a positive influence in the subtropical climates, with a greater thermal rigor by cold, and on the hot, humid climates, with a greater thermal rigor by heat.

The variables related to openings, heat gain coefficient and natural ventilation indicated that ventilation is a relevant variable, influencing 60% of the analyzed cases. However, the heat gain coefficient influenced only 2.7% of the localities, indicating that it does not influence the thermal comfort of single-family buildings in a relevant way. One exception was the city of Surubim, with a warm semi-arid climate, in which the influence of the heat gain coefficient was relevant and positive. Ventilation indicated a significant influence in 66 locations, positively and negatively, indicating that it is a variable of relevance in the thermal performance of single-family residential typologies. In general, the influence was positive in tropical climates (68.2% of occurrences in which ventilation had a positive influence) and negative in hot and dry climates and subtropical climates. Ventilation was the variable with the greatest positive influence on thermal comfort in the tropical climate (34.5% of localities).

The results for the roofs revealed a very similar pattern in most localities. Generally, thermal transmittance is the variable with the greatest positive influence, thermal capacity has a positive influence, and solar absorptance is the greatest negative influence. The thermal transmittance of the roofs exhibited significant influence in 100% of the localities, in other words, for all climatic types. In 98.2% of the localities, it provided positive influence and in 95.5%, the greatest influence. Only in Campos do Jordão and Petrópolis (subtropical climates), the thermal transmittance showed a negative influence. Thermal capacity influenced thermal comfort in 105 locations (95.5%), being positive in 102 of these. In contrast, in humid temperate climates with mild summers, the influence of the thermal capacity of the roof may be negative (Campos do Jordão, São Joaquim and Inácio Martins). Roof absorptance was influenced in all cases, being positive in only 3.6% of the cases under analysis. In most analyses (97.3%), roof absorptance represented the variable with the greatest negative influence. In some cities with a subtropical climate with mild summers (Campos do Jordão, São Joaquim, Teresópolis, Inácio Martins and Petrópolis), absorptance exerted a positive influence.

Evaluating the results for the reference models of multifamily buildings, it was found that the variables of greatest influence were the absorptance of the walls, natural ventilation, thermal transmittance and solar absorptance of the roofs.

The thermal transmittance of the walls presented an influence in 28.2% of the cases; the influence was positive in all cases. In 16.4% of them, it represented the variable with the greatest positive influence on the thermal comfort of the building. The cities in which this variable had a positive influence have a subtropical climate and single-family buildings. Otherwise, thermal capacity showed both positive and negative influences in 74.5% of the localities, indicating that it is a relevant variable for the thermal performance of this typology. The thermal capacity displayed a negative effect in 14.5% of the cities located in a subtropical climate. In 60% of the localities, the effect of this variable was positive and was the main positive influence on thermal comfort in 21.8% of them. The solar absorptance of the walls was influenced in all the analyzed localities, and its effect was only positive in 4.5% of them. The positive influence of solar absorptance was only observed in subtropical climates with mild summers. In the other climates, the variable had a negative influence for 87.3%, representing the most negative influence.

Similar to what was observed in the single-family typologies, among the variables related to the opening, the heat gain coefficient did not significantly influence the thermal performance of most cities, only being influential in 4.5% of them. Natural ventilation, conversely, presented a variable of strong influence (83.6%). In subtropical climates, its effect was negative. In tropical and arid climates, this variable assumes a positive influence (74.5%), and in 60% of them, it is the most influential.

The behaviour of the roof variables also had a similar pattern to those of the single-family typology. Thermal transmittance and solar absorptance were the most influential variables, representing 98.2% and 100% of the cases, respectively. Thermal transmittance was the variable with the greatest positive influence in 90% of the cities studied, and the solar absorptance of the roof was the one with the greatest negative influence (92.7%). The thermal capacity presented a positive influence (91.8% of the cases) and a negative influence in only 14.5% of the localities. In the case of subtropical climates with stronger cold thermal rigour, there is a change in the behaviour of the variables: thermal capacity has a negative influence, and solar absorptance has a positive influence.

In general, the behaviour between single-family and multifamily typologies followed a similar pattern. The solar absorptance of the surfaces and the thermal transmittance of the roof influence all of the climates studied. Nevertheless, it is observed that single-family buildings were more sensitive to the thermal transmittance of the wall (36.4% of cases versus 28.2% in multifamily buildings). In comparison, multifamily buildings were more sensitive to thermal capacity (74.5% in multifamily and 60.90% in single-family) and ventilation (83.6% in multifamily and 60% in single-family).

Influence variables by climate type

By evaluating the results obtained in factorial, we identified the variables of influence on thermal comfort in a hot climate. The summary of the results is presented in Table 8, exposing the variables of greatest influence, positive or negative.

Table 8 - Influence variables by climate type

Climate type	Variables of positive influence	Variables of negative influence
Equatorial (Af), Tropical monsoon (Am) e Tropical with dry season in winter (Aw) in the northern regions of Brazil and coastal regions of the Northeast and Southeast	F_{VENT}, U_{ROOF}, CT_{ROOF}	α_{WALL}, α_{ROOF}
Tropical with dry season in winter (Aw) in the Midwest, Northeast and Southeast regions, Arid (BWh) e Semi-arid (BSh)	CT_{WALL}, F_{VENT}, U_{ROOF}, CT_{ROOF}	α_{WALL}, α_{ROOF}
Subtropical with dry winter (Cwa e Cwb)	CT_{WALL}, F_{VENT}, U_{ROOF}, CT_{ROOF}	α_{WALL}, α_{ROOF}
Humid subtropical with hot summer (Cfa)	U_{WALL}, F_{VENT}, U_{ROOF}, CT_{ROOF}	α_{WALL}, α_{ROOF}
Humid subtropical with mild summer (Cfb)	U_{WALL}, α_{WALL}, F_{VENT}, U_{ROOF}, CT_{ROOF}	α_{ROOF}

Source: the authors.

By evaluating the results obtained in factorial, we identified the variables of influence on thermal comfort in a hot climate. The summary of the results is presented in Table 10, exposing the variables of greatest influence, positive or negative.

Conclusions

This article aimed to evaluate which variables influence the thermal comfort of naturally conditioned residential buildings in hot climates. For this analysis to be performed, the factorial experiment and computational simulation for 110 localities were adopted, evaluating the variables: thermal transmittance, thermal capacity, the solar absorptance of walls and roofs, heat gain coefficient of the openings and natural ventilation for single-family and multifamily typologies of residential buildings.

The results showed that:

- For the single-family typology, the solar absorptance of the walls and roof are the main variable of influence on the thermal performance of the building, defining its performance. In the case of localities with lower temperatures and mild summers, solar absorptance should be higher. In the case of hot climate localities, absorptance should have lower values. In addition to solar absorptance, the thermal transmittance of the roof has a significant influence on performance.
- For multifamily buildings, as well as the solar absorptance of the exterior walls and the roof and the thermal transmittance of the roof, ventilation is also a variable of important influence. The thermal capacity of the walls is a variable of influence but to a lesser extent.
- The main variables for ensuring thermal comfort in hot climates are the solar absorptance of the external walls and roofs, the natural ventilation and the thermal transmittance of the roof. The thermal transmittance of the walls was a variable of influence only in the subtropical climates, characterized by a lower thermal rigor by heat.
- In typical tropical regions, the thermal capacity of the walls will influence the thermal comfort of the building rather than the thermal transmittance
- In regions with a hot and humid climate (equatorial and tropical monsoon), the ventilation assumes relevance.

The results of this work corroborate the work already accomplished and indicate that, for passively conditioned buildings and in a regime of transient heat exchange in hot climates, radiation and ventilation are of relevance and, consequently, the thermal transmittance of the walls is not the best variable to describe the thermal behavior of the building. The walls' thermal capacity, the surfaces' absorptance and the natural ventilation assume this role in hot climates. Therefore, the thermal performance standards and energy efficiency codes of buildings in hot climates should be revised and adapted to the local climatic reality, considering their specificities, since the criteria adopted for cold climates do not apply to a hot climate. This means that there is a necessity for adequate thermal performance standards and energy efficiencies.

The present study presented some limitations regarding the number of cities analyzed due to the effort demanded by the analyses and some simplifications adopted to enable the analyses, such as analyzing only two models of residential buildings and not including the internal walls in the analyses.

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APPENDIX A – Results obtained in the factorial experiment for single-family and multifamily buildings

Table A1 - Results obtained in the factorial experiment for single-family buildings

Locality	Köppen classification	Bioclimatic zone	External wall			Opening		Roof		
			U	CT	α	FS	F_{VENT}	U	CT	α
Maringá	Cfa	1		+	-			+	+	-
Campos do Jordão	Cfb	1	+		+		-	-	-	+
São Joaquim	Cfb	1	+	-	+		-	+	-	+
Castro	Cfb	1	+		-		-	+		-
Curitiba	Cfb	1	+		+		-	+	+	-
Bento Gonçalves	Cfb	1	+		+		-	+	+	-
Caldas	Cwb	1	+		-		+	+	+	-
Cruz Alta	Cfa	2	+		-		-	+	+	-
Passo Fundo	Cfa	2	+		-		-	+	+	-
Santa Maria	Cfa	2		+	-			+	+	-
Urussanga	Cfa	2	+	-	-			+	+	-
Uruguaiana	Cfa	2	+	-	-			+	+	-
Torres	Cfa	2	+		+		-	+	+	-
Erechim	Cfa	2	+		-		-	+		-
Alegrete	Cfa	2	+		-		-	+	+	-
Rio Pardo	Cfa	2	+		-		-	+	+	-
Piracicaba	Cfa	2		+	-			+	+	-
Tramandaí	Cfa	2	+		+			+	+	-
Ivaí	Cfb	2	+		-		+	+	+	-
Lagoa Vermelha	Cfb	2	+		+		-	+	+	-
Dionísio Cerqueira	Cfb	2	+		-		-	+		-
Inácio Martins	Cfb	2	+		+		+	+	-	-
Curitibanos	Cfb	2	+		-		-	+	+	-
Teresópolis	Cfb	2	+		+		-	+	+	+
Florestal	Cwa	2		+	-		+	+	+	-
Petrópolis	Af	3		-	+		-	-		+
Salinas	Aw	3		+	-		+	+	+	-
Ponta Porã	Cfa	3		+	-			+	+	-
Porto Alegre	Cfa	3		+	-			+	+	-
Florianópolis	Cfa	3	+	+	-			+	+	-
São Paulo	Cfa	3	+	+	-			+	+	-
Sorocaba	Cfa	3		+	-			+	+	-
Taubaté	Cfa	3		+	-		+	+	+	-
Ourinhos	Cfa	3		+	-			+	+	-
Lins	Cfa	3		+	-			+	+	-
Muriaé	Cfb	3	+	+	-		+	+	+	-
Paraty	Cfb	3		+	-		+	+	+	-
Belo Horizonte	Cwa	3		+	-		+	+	+	-
Viçosa	Cwa	3	+	+	-		+	+	+	-
Resende	Cwa	3	+	+	-			+	+	-
Barbacena	Cwb	3	+	+	-			+	+	-
Diamantina	Cwb	3		+	-			+	+	-
Brasília	Aw	4		+	-		+	+	+	-

Locality	Köppen classification	Bioclimatic zone	External wall			Opening		Roof		
			U	CT	α	FS	F_{VENT}	U	CT	α
Três Marias	Aw	4		+	-		+	+	+	-
Ribeirão Preto	Aw	4		+	-		+	+	+	-
Uberlândia	Aw	4		+	-		+	+	+	-
São Carlos	Cfa	4		+	-			+	+	-
Franca	Cwa	4		+	-			+	+	-
Ivinhema	Aw	5		+	-			+	+	-
Garanhuns	Aw	5		+	-			+	+	-
Niterói	Aw	5		+	-		+	+		-
Alegre	Aw	5		+	-			+	+	-
Cambuci	Aw	5		+	-			+	+	-
Vitória da Conquista	Cfb	5		+	-		+	+	+	-
Jataí	Aw	6		+	-			+	+	-
João Pinheiro	Aw	6		+	-		+	+	+	-
Montes Claros	Aw	6		+	-			+	+	-
Monteiro	Aw	6		+	-			+	+	-
Presidente Prudente	Aw	6		+	-			+	+	-
Votuporanga	Aw	6		+	-	+	+	+	+	-
Campo Grande	Aw	6		+	-		-	+	+	-
Campo Verde	Aw	6		+	-			+	+	-
Buritirama	Aw	6		+	-			+	+	-
Coxim	Aw	6		+	-		+	+	+	-
Gaúcha do Norte	BSh	6		+	-		-	+	+	-
Chapada de Gaúcha	BSh	6		+	-			+	+	-
Serra Talhada	BSh	6		+	-			+	+	-
São Simão	Cwa	6		+	-		+	+	+	-
Teresina	Aw	7		+	-	+		+	+	-
Cratéus	Aw	7		+	-	+	+	+	+	-
Imperatriz	Aw	7		+	-			+	+	-
Cuiabá	Aw	7		+	-		+	+	+	-
Arcoverde	Aw	7		+	-			+	+	-
Bom Jesus do Piauí	Aw	7		+	-	+		+	+	-
Picos	Aw	7		+	-		-	+	+	-
Palmas	Aw	7		+	-		-	+	+	-
Pedro Afonso	Aw	7		+	-		+	+	+	-
Paulo Afonso	BSh	7			-			+	+	-
Patos	BSh	7		+	-			+	+	-
Mossoró	BSh	7		+	-			+	+	-
Petrolina	BSh	7		+	-			+	+	-
Salvador	Af	8	+		-		+	+	+	-
Belém	Af	8	+		-			+	+	-
Ilhéus	Af	8			-		+	+	+	-
Rio Branco	Am	8			-		+	+	+	-
Maceió	Am	8	+		-		+	+	+	-
Manaus	Am	8	+		-		+	+	+	-
Macapá	Am	8	+		-		+	+	+	-
João Pessoa	Am	8	+		-		+	+	+	-
Recife	Am	8	+		-			+	+	-

Locality	Köppen classification	Bioclimatic zone	External wall			Opening		Roof		
			U	CT	α	FS	F_{VENT}	U	CT	α
Aracaju	Am	8	+		-		+	+	+	-
São Félix do Xingú	Am	8			-		+	+	+	-
Manicoré	Am	8	+		-		+	+	+	-
Porto Velho	Am	8			-		+	+	+	-
Vitória	Aw	8	+		-		+	+	+	-
São Luís	Aw	8	+		-		+	+	+	-
Jacobina	Aw	8		+	-		+	+	+	-
Lençóis	Aw	8		+	-		+	+	+	-
Fortaleza	Aw	8			-			+	+	-
Corumbá	Aw	8		+	-	+	+	+	+	-
Campina Grande	Aw	8		+	-		+	+	+	-
Surubim	Aw	8		+	-	+	-	+	+	-
Rio de Janeiro	Aw	8	+		-		+	+	+	-
Natal	Aw	8			-		+	+	+	-
Boa Vista	Aw	8			-		+	+	+	-
Esperantina	Aw	8			-			+	+	-
Palmares	Aw	8		+	-			+	+	-
Feira de Santana	Aw	8			-			+	+	-
Amargosa	Aw	8		+	-		+	+	+	-
Rondon do Pará	Aw	8	+		-		+	+	+	-
Pão de Açúcar	BSh	8		+	-			+	+	-

Source: the authors.

Table A2 - Results obtained in the factorial experiment for multifamily buildings

Locality	Köppen classification	Bioclimatic zone	External wall			Opening		Roof		
			U	CT	α	FS	F_{VENT}	U	CT	α
Maringá	Cfa	1	+	+	-			+	+	-
Campos do Jordão	Cfb	1	+	-	+		-	-	-	+
São Joaquim	Cfb	1	+	-	+		-		-	+
Castro	Cfb	1	+		+		-			-
Curitiba	Cfb	1	+	-	+		-	+	+	-
Bento Gonçalves	Cfb	1	+		+		-	+		-
Caldas	Cwb	1	+	+	-		+	+		-
Cruz Alta	Cfa	2	+	-	-			+	+	-
Passo Fundo	Cfa	2	+	-	-			+	+	-
Santa Maria	Cfa	2	+		-			+	+	-
Torres	Cfa	2	+		+		-	+		-
Urussanga	Cfa	2	+	-	-			+	+	-
Uruguaiana	Cfa	2	+	-	-			+	+	-
Tramandaí	Cfa	2	+	-	+			+	+	-
Rio Pardo	Cfa	2	+	-	-			+	+	-
Erechim	Cfa	2	+	-	+			+	+	-
Alegrete	Cfa	2	+	+	-			+	+	-
Piracicaba	Cfa	2	+	+	-		+	+	+	-
Ivaí	Cfb	2			-		+	+	+	-
Lagoa Vermelha	Cfb	2	+	-	+			+		-
Dionísio Cerqueira	Cfb	2	+	-	-			+	+	-
Curitibanos	Cfb	2	+	-	+			+	+	-

Locality	Köppen classification	Bioclimatic zone	External wall			Opening		Roof		
			U	CT	α	FS	F_{VENT}	U	CT	α
Inácio Martins	Cfb	2	+	-	+			+		+
Teresópolis	Cfb	2	+	-	+		-	+	+	+
Florestal	Cwa	2		+	-		+	+	+	-
Petrópolis	Af	3		-	+		-	-		+
Salinas	Aw	3		+	-		+	+	+	-
Ponta Porã	Cfa	3		+	-	+	+	+	+	-
Porto Alegre	Cfa	3		+	-			+	+	-
Florianópolis	Cfa	3		+	-		+	+	+	-
São Paulo	Cfa	3	+	+	-			+	+	-
Sorocaba	Cfa	3		+	-		+	+	+	-
Taubaté	Cfa	3		+	-		+	+	+	-
Ourinhos	Cfa	3	+	+	-		+	+	+	-
Lins	Cfa	3		+	-			+	+	-
Muriaé	Cfb	3		+	-		+	+	+	-
Paraty	Cfb	3	+	+	-		+	+	+	-
Belo Horizonte	Cwa	3		+	-		+	+	+	-
Viçosa	Cwa	3	+	+	-		+	+	+	-
Resende	Cwa	3	+	+	-		+	+	+	-
Barbacena	Cwb	3	+	+	-		-	+	+	-
Diamantina	Cwb	3		+	-		+	+	+	-
Brasília	Aw	4		+	-		+	+	+	-
Três Marias	Aw	4		+	-		+	+	+	-
Ribeirão Preto	Aw	4		+	-		+	+	+	-
Uberlândia	Aw	4		+	-		+	+	+	-
São Carlos	Cfa	4		+	-			+	+	-
Franca	Cfa	4		+	-		+	+	+	-
Ivinhema	Aw	5		+	-		+	+	+	-
Garanhuns	Aw	5		+	-		+	+	+	-
Niterói	Aw	5	+	+	-		+	+	+	-
Alegre	Aw	5		+	-		+	+	+	-
Cambuci	Aw	5		+	-		+	+	+	-
Vitória da Conquista	Cfb	5		+	-		+	+	+	-
Jataí	Aw	6		+	-	+	+	+	+	-
João Pinheiro	Aw	6		+	-		+	+	+	-
Montes Claros	Aw	6		+	-		+	+	+	-
Monteiro	Aw	6		+	-	+	+	+	+	-
Presidente Prudente	Aw	6		+	-			+	+	-
Votuporanga	Aw	6		+	-	+	+	+	+	-
Coxim	Aw	6		+	-		+	+	+	-
Campo Verde	Aw	6		+	-		+	+	+	-
Campo Grande	Aw	6		+	-		+	+	+	-
Buritirama	Aw	6		+	-		+	+	+	-
Chapada de Gaúcha	BSh	6		+	-		+	+	+	-
Gaúcha do Norte	BSh	6		+	-		+	+	+	-
Serra Talhada	BSh	6		+	-		+	+	+	-
São Simão	Cwa	6		+	-		+	+	+	-
Teresina	Aw	7			-		+	+	+	-

Locality	Köppen classification	Bioclimatic zone	External wall			Opening		Roof		
			U	CT	α	FS	F_{VENT}	U	CT	α
Cratéus	Aw	7		+	-		+	+	+	-
Imperatriz	Aw	7		+	-		+	+	+	-
Cuiabá	Aw	7		+	-		+	+	+	-
Arcoverde	Aw	7		+	-		+	+	+	-
Bom Jesus do Piauí	Aw	7		+	-		+	+	+	-
Picos	Aw	7		+	-		+	+	+	-
Palmas	Aw	7		+	-		+	+	+	-
Pedro Afonso	Aw	7		+	-		+	+	+	-
Paulo Afonso	BSh	7		+	-		+	+	+	-
Petrolina	BSh	7		+	-		+	+	+	-
Mossoró	BSh	7			-		+	+	+	-
Patos	BSh	7		+	-		+	+	+	-
Salvador	Af	8	+		-		+	+	+	-
Belém	Af	8			-		+	+	+	-
Ilhéus	Af	8			-		+	+	+	-
Rio Branco	Am	8			-		+	+	+	-
Maceió	Am	8			-		+	+	+	-
Manaus	Am	8			-		+	+	+	-
Macapá	Am	8			-		+	+	+	-
João Pessoa	Am	8			-			+	+	-
Recife	Am	8			-		+	+	+	-
Aracaju	Am	8			-		+	+	+	-
Manicoré	Am	8			-		+	+	+	-
Porto Velho	Am	8			-		+	+	+	-
São Félix do Xingú	Am	8			-		+	+	+	-
Jacobina	Aw	8		+	-		+	+	+	-
Lençóis	Aw	8		+	-		+	+	+	-
Fortaleza	Aw	8			-		+	+	+	-
Vitória	Aw	8			-		+	+	+	-
São Luís	Aw	8			-		+	+	+	-
Corumbá	Aw	8			-		+	+	+	-
Campina Grande	Aw	8		+	-		+	+	+	-
Surubim	Aw	8		+	-		+	+	+	-
Rio de Janeiro	Aw	8			-		+	+	+	-
Natal	Aw	8			-		+	+	+	-
Boa Vista	Aw	8			-		+	+	+	-
Esperantina	Aw	8			-		+	+	+	-
Palmares	Aw	8		+	-		+	+	+	-
Feira de Santana	Aw	8		+	-		+	+	+	-
Amargosa	Aw	8		+	-		+	+	+	-
Rondon do Pará	Aw	8			-		+	+	+	-
Pão de Açúcar	BSh	8		+	-		+	+	+	-

Source: the authors.

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