PARAMETERS THAT INFLUENCE THE THERMAL PERFORMANCE OF COMMERCIAL BUILDINGS: AN EXPLORATORY ANALYSIS

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ABSTRACT
This paper aims to understand the factors affecting the thermal performance of commercial buildings based on the Brazilian Inmetro Normative Instruction for Commercial Buildings Simplified Method. The study analyzed different thermal zone exposures and input parameters to assess their sensitivity in the output data. A reference office configuration was considered, and five zones were evaluated, including four perimetral zones and one internal zone. Also, two different cities with different climates were evaluated: Curitiba (Brazilian cold climate city) and São Luís (Brazilian hot climate city). Results showed that internal zones and ground floors presented the lowest cooling load values. Roof-exposed thermal zones were a concern in both climates due to higher cooling load results. The study also found that middle-floor exposures should be a concern in the city of Curitiba due to internal gains. Different solar exposures regarding climate and latitude were important to consider. Limitations included not evaluating the influences within parameters and not assessing the whole building, and future work should consider the impact of each thermal zone concerning the building shape.

Keywords: Envelope exposure, Patterns of use, INI-C.

1. INTRODUCTION

Improving the outlook of climate change requires reducing pollutant emissions and energy consumption. Thus, improving building performance evaluation methods is essential, and these methods must be developed based on the national scenario (IEA, 2021). Although international regulations serve as a basis for developing and applying energy efficiency measures, the reference conditions must suit the Brazilian climate (MELO et al., 2014).

In 2010, the Technical Quality Regulation for the Level of Energy Efficiency of Commercial Buildings (RTQ-C) was published. However, in 2021, Inmetro's Normative Instruction for Classifying the Energy Efficiency of Commercial, Service, and Public Buildings (INI-C) replaced the RTQ-C to improve the energy efficiency in buildings method. This new method evaluates the entire building by analyzing its systems, including the envelope. Two methods are used to evaluate the envelope: the simplified and simulation methods. Both methods compare the actual building with the reference building regarding cooling thermal load. The simplified method predicts the cooling load density by thermal zone using a metamodel explicitly developed for evaluating buildings in Brazilian cities and climates. The simulation method involves building energy simulation to evaluate the building in real and also in a reference condition.

Recent studies in Brazil have focused on INI-C, ranging from comparisons with RTQ-C to complete building evaluations. A recent study evaluates the results of the metamodel, varying building form factor, climate, façade opening percentages, glass type, and internal lighting load. This study obtained different thermal performance results based on the building's shape and climate (JORDÃO et al., 2021).

Another study developed by Pereira de Souza, Melo and Lamberts (2022) compared the results obtained by the simplified and the simulation method. The authors compared different building shapes, envelope configurations and cities regarding the cooling load, but only by varying roof, wall and glazing type, and suggested that future work should analyze other input parameters that describe the thermal zones.

Thus, it is necessary to identify the input parameters that affect the thermal performance of thermal zones, potentially leading to recommendations or strategies for improving thermal performance in commercial buildings.

2. OBJECTIVE

This paper aims to comprehend the parameters that affect the thermal performance of different types of thermal zone exposures in commercial buildings according to the Brazilian's Inmetro Normative Instruction for Commercial Buildings in one hot climate city and one in a cold climate.

3. METHOD

The following sections describe the simplified method of Brazilian's Inmetro Normative Instruction for Commercial Buildings, the study base case, the parameters and cities adopted, and the result analysis.

3.1. Brazilian Inmetro Normative Instruction for Commercial Buildings – simplified method

Also called "INI-C", the Brazilian Inmetro Normative Instruction for Commercial Buildings evaluates the whole building, dividing it into four systems: the envelope, HVAC systems, artificial lighting, and water heating. There are two methods to evaluate the envelope system of the building: the simplified one, through the metamodel (specifically designed to evaluate buildings in the Brazilian climate), and the simulation one, through building performance simulation. Both methods evaluate the envelope performance according to the cooling load density result of the building.

The metamodel predicts cooling load density for each thermal zone of the building by describing the input parameters of the zones. Each thermal zone needs a description through the input parameters: orientation (azimuth), floor and roof exposure, type of zone (perimeter or core), ceiling height, shading angles, window-to-wall ratio, equipment, people, and lighting density, as well as occupation scheduling, infiltration, and envelope components (glazing, external wall and roof characteristics), equivalent to some simulation input parameters. Also, some climate information is required, such as latitude, altitude, wind speed, and solar radiation. The climate information is based on the weather file used in the simulation database, the INMET 2018. Besides, the metamodel has input range limits of application based on the database of the metamodel.

This study considers the thermal zone results of cooling load density in different parameter configurations to assess its influence on the thermal envelope performance.

3.2. Base case

The study's base case consists of the reference case of an office building according to the Brazilian INI-C (Inmetro Normative Instruction for Commercial Buildings). Table 1 presents the reference case parameters.

Table 1 – Reference building parameters for offices (INMETRO, 2021).

Parameter	**Value**
Equipment power density	15 W/m²
Lighting power density	14.1 W/m²
People density	0.1 person/m²
Occupied hours	10 h (from 8 am to 6 pm)
Infiltration	0.5 Air Changes per Hour (ACH)
Window-to-wall ratio	0.5
SHGC	0.82
Glazing thermal transmittance	5.7 W/(m².K)
Wall solar absorptance	0.5
Wall thermal transmittance	2.39 W/(m².K)
Wall thermal capacity	150 kJ/(m².K)
Roof solar absorptance	0.8
Roof thermal transmittance	2.06 W/(m².K)
Roof thermal capacity	233 kJ/(m².K)

Since the cooling load will be evaluated according to the density (kWh/(m².year)), the building area/shape is not important. On the other hand, different exposures of thermal zones are evaluated (such as orientation, floor and roof exposure, and internal perimetral zones). Thus, Figure 1 presents a representative building shape.

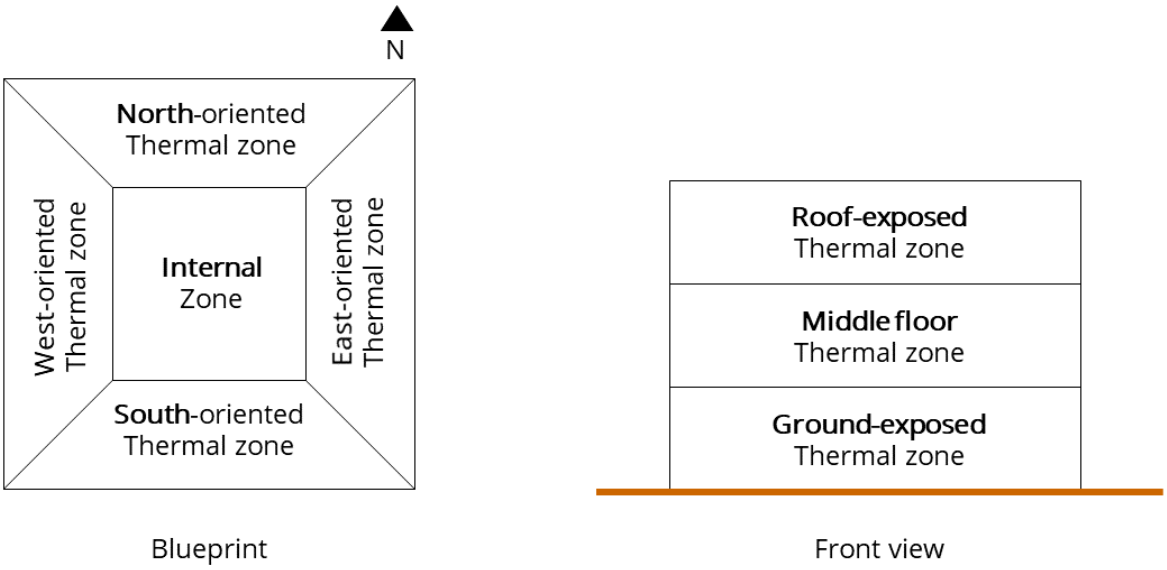

Figure 1 – Representative building blueprint and front view.

Hence, there are 15 different thermal zone exposures: the five thermal zones of the blueprint, each in a different "front view" exposure: roof, ground or middle floor exposure. The base case ceiling height was 3 m with no insulation on the floor.

3.3. Building parameters

This research analyzed each input parameter separately, i.e., parametrically. Thus, besides the varied parameter, the reference building parameters (Table 1) were applied for every different thermal zone (Figure 1). Changes in internal loads, such as equipment and lighting power density, people density, occupied hours, and ceiling height, were applied in all thermal zones. Parameters dependent on external wall exposure were applied only in perimetral zones, such as glazing and wall characteristics, WWR, and infiltration. Also, parameters depending on external roof exposure were applied only on roof-exposed thermal zones. Table 2 presents the parameter variated and the values considered.

Table 2 – Input parameters varied.

Parameter	Values	Applied to
Equipment power density (W/m²)	4 – 10 – 16 – 22 – 28 – 34 - 40	All thermal zones
Lighting power density (W/m²)	4 – 10 – 16 – 22 – 28 – 34 – 40	
People density (person/m²)	0.05 – 0.1 - 0.15 – 0.2 – 0.25 – 0.3 – 0.35 – 0.4 – 0.45 – 0.5 – 0.55 – 0.6 – 0.65	
Occupied hours (h)	8 – 10 - 12 – 14 – 16 – 18 – 20 – 22 – 24	
Ceiling height (m)	2.6 – 3.1 – 3.6 – 4.2 – 4.8 – 5.4 – 6 – 6.6	
Infiltration (ACH)	0.5 – 1 – 1.5	Perimetral thermal zones
Window-to-wall ratio	0.1 – 0.2 – 0.3 – 0.4 – 0.6 – 0.7 – 0.8	
SHGC	0.21 – 0.32 – 0.43 – 0.54 – 0.65 – 0.76 – 0.87	
Glazing thermal transmittance (W/(m².K))	1.9 – 2.5 – 3.1 – 3.7 – 4.3 – 4.9 – 5.5	
Wall solar absorptance	0.2 – 0.3 – 0.4 – 0.6 – 0.7 – 0.8	
Wall thermal transmittance (W/(m².K))	0.5 – 1.15 – 1.8 – 2.45 – 3.1 – 3.75 – 4.4	
Wall thermal capacity (kJ/(m².K))	0.22 – 75 – 149 – 225 – 300 – 375 - 450	
Roof solar absorptance	0.2 – 0.3 – 0.4 – 0.5 – 0.6 – 0.7	Roof-exposed thermal zones
Roof thermal transmittance (W/(m².K))	0.51 – 1.27 – 2.03 – 2.79 – 3.55 – 4.31 – 5.07	
Roof thermal capacity (kJ/(m².K))	0.22 – 75 – 149 – 225 – 300 – 375 - 450	

The research considers each variation's minimum and maximum range as the minimum and maximum values available on the database. Also, the variations have the same interval within a parameter.

3.4. Cities

The study considers two cities: Curitiba-PR and São Luís-MA. They are cities in the metamodel database and located in different climates, according to the ASHRAE 169, representing the Brazilian cold and hot climate, respectively. Table 3 describes the Curitiba and São Luís climates.

Table 3 - Climates.

City	Climatic Zone (ASHRAE 169)	Latitude	Altitude
São Luís	0 A – Extremely hot and humid	2°34'S	935
Curitiba	3 A – Warm and humid	25°25'S	3.66

3.45 Result analysis

The study has 2750 cases, divided into two cities and 15 thermal zones.

The Brazilian simplified method for evaluating commercial buildings reports the cooling thermal load prediction to each thermal zone in kWh/(m².year). The study analyses the data using the mean, median and standard deviation results.

4. RESULTS

The first results presented are the distribution of cooling load density, filtered by type of floor (here described as vertical exposure) and orientation (here described as horizontal exposure). As mentioned in the method, INI-C evaluates the building envelope regarding cooling load density results only since the heating load density, even in cold climates in Brazil, is not significant. Figure 2 presents the results of all cases and categorizing by the different vertical exposures for both cities, and Figure 3 presents the same results but categorizing by the different horizontal exposures for both cities. All histograms have an interval of 5 kWh/(m².year) between each group.

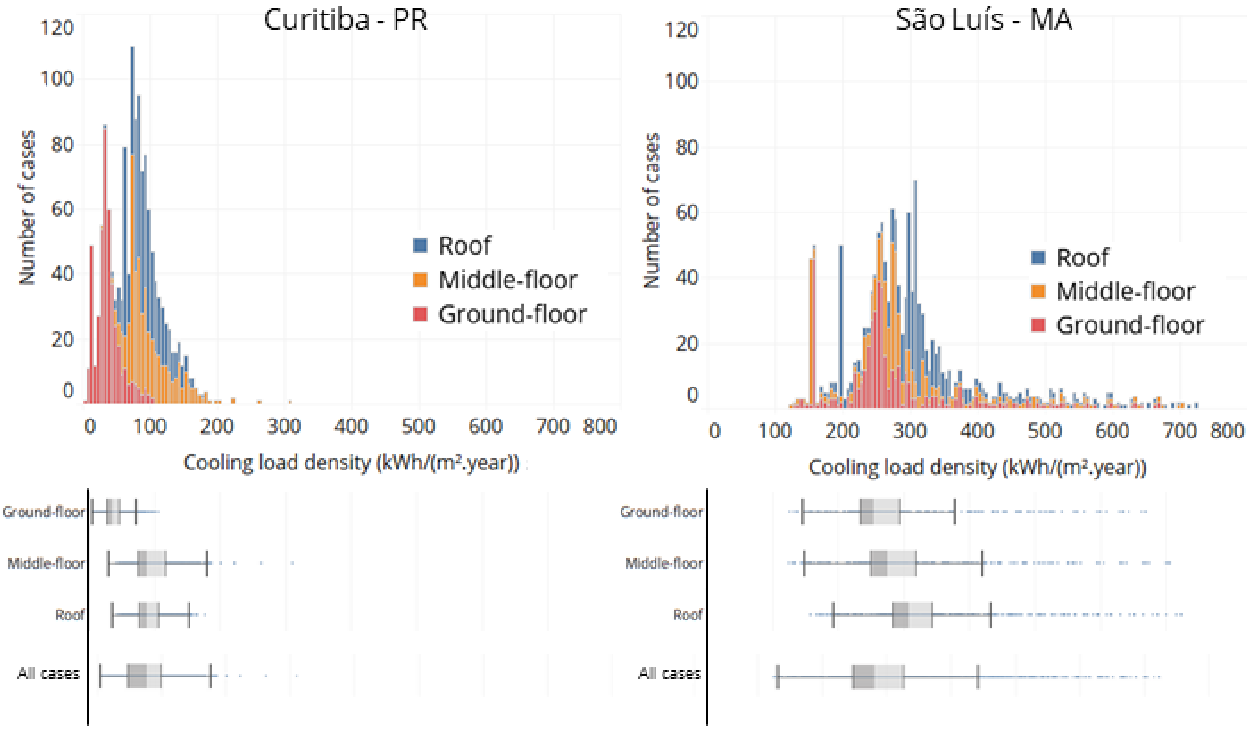

Figure 2 – Distribution of type of floor cases regarding cooling load density in both cities.

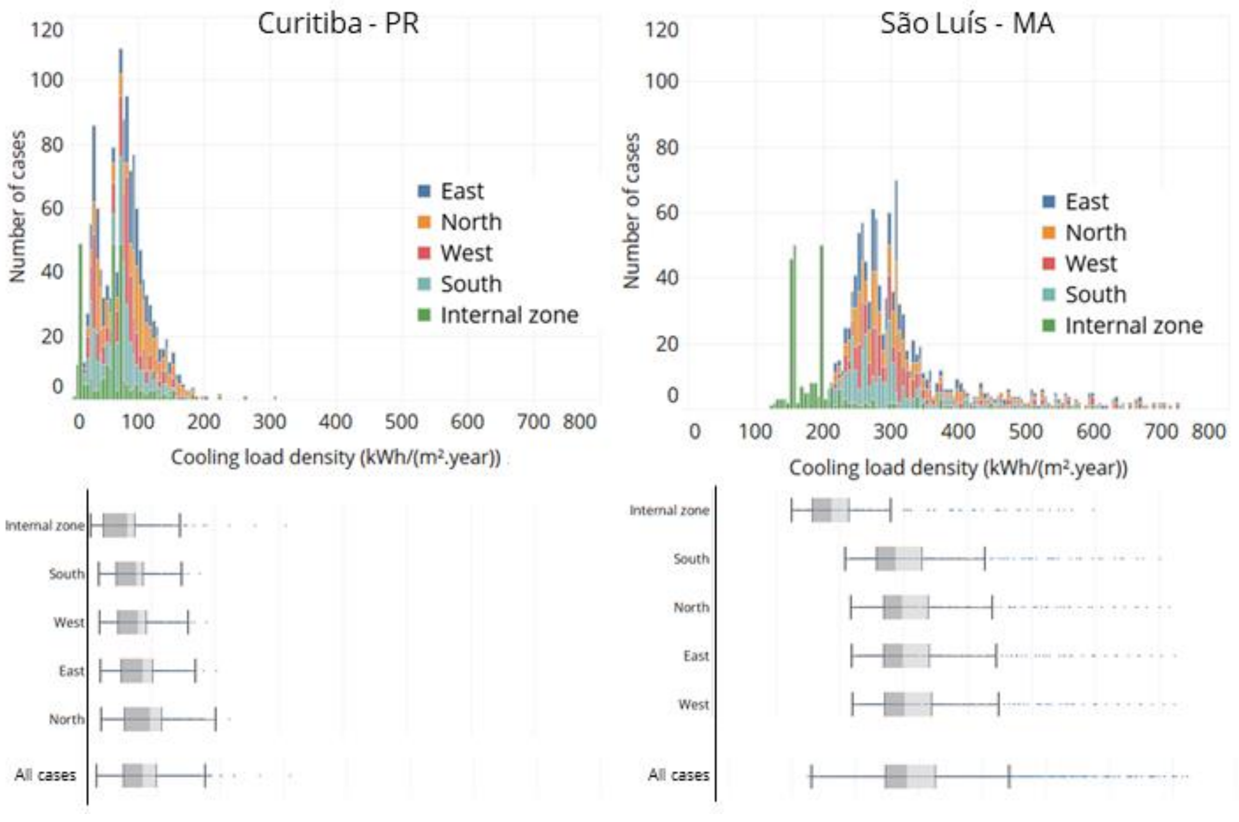

Figure 3 – Distribution of horizontal exposure cases regarding cooling load density in both cities.

The histograms are analyzed according to each thermal zone's vertical exposure (roof, middle-floor and ground floor) and horizontal exposure (east, north, west and south façade, and internal zone). The distribution of the types of exposures separately is different and deserves further analysis. It is important to state that the thermal zones with lower values of thermal load are different regarding the climate.

Ground-floor zones (vertical exposure) are the majority of zones with lower values of cooling load in Curitiba, and the façade exposure, or no external horizontal exposure, does not necessarily have the same impact. Analyzing the distribution of Curitiba cases compared to all cases, the only distribution that differs from the overall distribution is the ground-floor exposure (vertical exposure).

Different occurs in São Luís: the lowest values of cooling load come from internal zones (horizontal exposure), and the ground floor does not necessarily present the lowest values. The distribution of the cases, compared to the distribution of all of the cases, shows that the only parameter related to the exposure that has a distribution very different from the general one is the internal zone distribution.

That means that, in an office building in Curitiba (Brazil's coldest climate), the more exposure to the ground, the better to reduce cooling loads. On the other hand, in an office building in São Luís (Brazil's hottest climate), the less area with wall exposure, the better.

Further numerical analysis was applied. São Luís had a mean value of 300.77 kWh/(m².year) and a median of 279.55 kWh/(m².year) with a standard deviation of 106.86 kWh/(m².year) considering all 1,375 thermal zone cases. Nevertheless, as presented in Figure 2 and Figure 3, internal zones are most likely to have lower values of cooling load density. While middle and ground floors have mean values of 295.01 and 277.62 kWh/(m².year), respectively, roof-exposed floors have a mean cooling load density of 325.67 kWh/(m².year).

For Curitiba, Considering all 1,375 thermal zone cases, the mean and median values of cooling load density are 75.91 and 76.21 kWh/(m².year), respectively, with a standard deviation of 38.28 kWh/(m².year). As the ground floor still has the lowest mean and median values of cooling load density, 36.23 and 33.68 kWh/(m².year), respectively, the middle floor presents a mean value of 98.20, higher than the mean value of roof exposure of 90.88 kWh/(m².year), but the median is similar. When analyzing the internal and perimetral zones, although Curitiba also has the lowest mean and median cooling load density values for internal zones, in perimetral zones, it presents different behavior than São Luís. Table 4 presents the results of each horizontal.

Table 4 - Mean, median and standard deviation of each façade and floor.

City	Parameters	Horizontal exposure					Vertical exposure		
		east	north	west	south	internal	ground	middle	roof
São Luís	mean	326.32	325.69	328.94	312.96	209.94	277.62	295.01	325.67
	median	296.65	296.29	299.57	285.32	185.13	253.54	273.92	307.24
	standard deviation	99.51	98.61	99.68	96.24	89.09	102.88	110.49	110.32
Curitiba	mean	81.97	91.65	75.19	71.26	59.47	36.23	98.20	90.88
	median	85.46	96.50	78.06	74.39	60.34	33.68	87.44	87.35
	standard deviation	35.64	39.65	33.25	31.33	42.88	19.00	35.04	35.96

Regarding the parametrically varied input parameters in Table 2 in the method, Figure 4 represents each parameter's cooling load density results in the boxplot. The range of cooling load density is different to the cities to improve the visibility of results, ranging from 0 to 300 kWh/(m².year) in Curitiba and from 100 to 800 kWh/(m².year) in São Luís.

Analyzing the parameters applied to all thermal zones, equipment and lighting density changes can influence the thermal zones similarly, considering the same power density magnitude (mean values and standard deviation are similar). People density and occupied hours have different impacts on climate: the number of occupied hours in Curitiba can enhance the cooling load density much more than the people density during the day, and the opposite happens in São Luís. It means having more people inside the building during the day enhances the cooling necessity in extremely hot climates much more than occupying the same building for 24 hours but with fewer people. The same does not occur in warm climates: occupying the building for a more extended period of the day (with people and loads) can improve cooling necessities more than having more people inside the building during the day. It enhances the impact of equipment and lighting power density on cooling loads in warmer climates. As for the ceiling height, it has a more significant impact on the extremely hot climate.

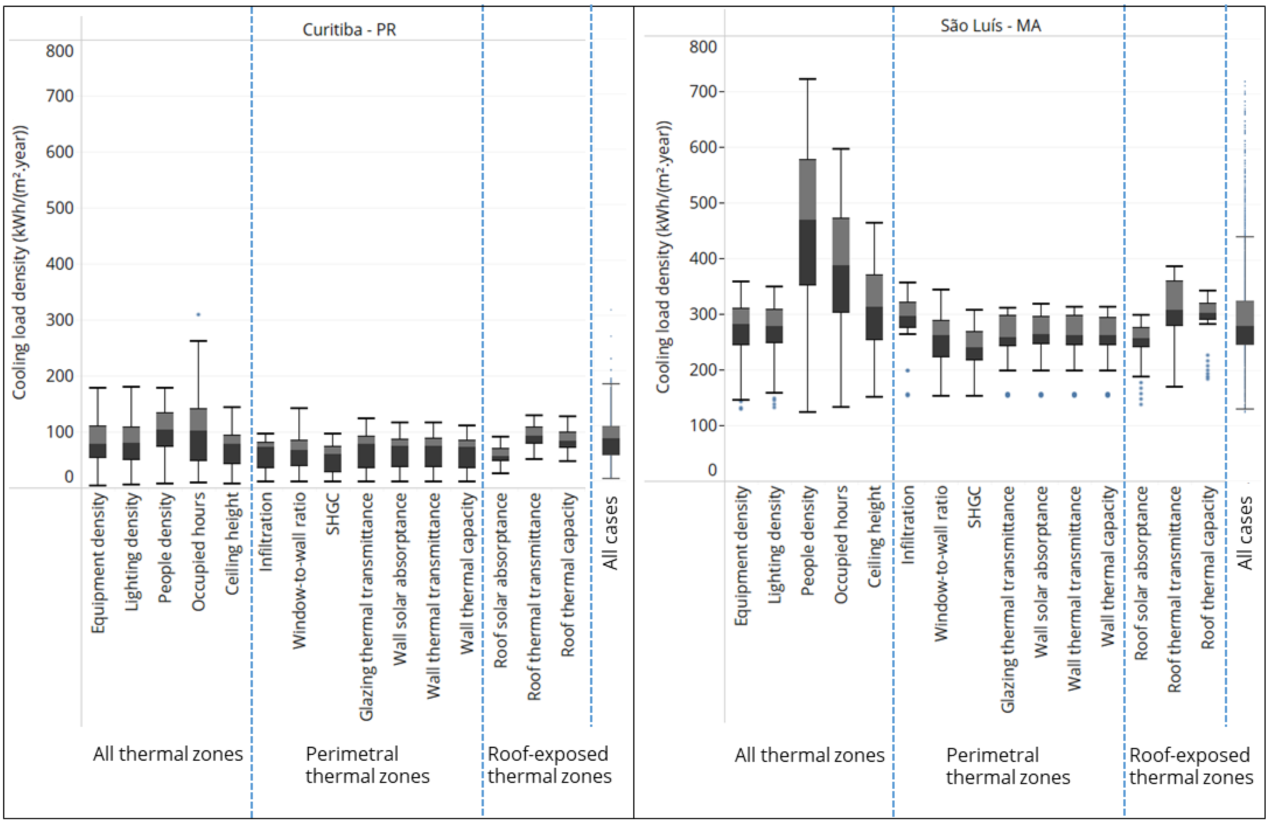

Figure 4 – Cooling load density boxplot of each parameter.

Table 5 also presents the numerical results of the parameters with the highest values of coefficient of variation and the respective standard deviation. For São Luís, only the parameters with more than 20% of the coefficient of variation were considered, and for Curitiba, only the parameters with more than 45%.

Table 5 - Results of standard deviation and coefficient of variation for the most sensible parameters.

City	Parameter	Standard deviation	Coefficient of variation
São Luís	People density	**144.43**	**31%**
	Occupied hours	**108.87**	**28%**
	Ceiling height	**80.96**	**26%**
	Infiltration	62.39	22%
	Window-to-wall ratio	52.31	21%
Curitiba	Occupied hours	**57.78**	**57%**
	Equipment power density	39.71	49%
	Lighting power density	38.96	49%
	Window-to-wall ratio	30.77	48%
	Solar Heat Gain Coefficient	25.19	46%
	Glazing thermal transmittance	30.75	46%
	Ceiling height	32.44	46%

The perimetral thermal zones' results also present different patterns for both climates. Lower WWR and SHGC can reach much lower cooling load results in São Luís compared to lower values of glazing thermal transmittance and wall properties. It does not necessarily happen in Curitiba. Curitiba is more likely to reach lower cooling results with lower WWR and SHGC by analyzing mean and median cooling values but not the lowest results. It is important to state that, in Curitiba, the lowest the glazing thermal transmittance values, the highest the cooling load. In addition, the differences in results of glazing U-value are most related to the thermal zone exposure and not significant due to the glazing U-value changes. The same happens to the wall characteristics: the significant differences in the boxplot are related to changes in thermal zone exposure and not due to the values, concluding that these changes are not necessarily meaningful in reducing cooling loads in both cities.

Finally, lower solar absorptance and U-value result in lower cooling loads in roof-exposed thermal zones. While in warm climate zones, the most crucial roof parameter to reduce is solar absorptance, in São Luís, the U-value is as important. Even with a solar absorptance of 0.8, a low roof U-value can reach lower cooling load results than only changing the roof solar absorptance in São Luís, and it does not happen in Curitiba. On the other hand, the roof thermal capacity does not play such an essential role in São Luís as much as in Curitiba. In both cities, the higher the thermal capacity, the lower the cooling load.

5. CONCLUSIONS

This paper aimed to comprehend the parameters that affect the thermal performance of commercial buildings according to the Brazilian's Inmetro Normative Instruction for Commercial Buildings Simplified Method.

The study considered different thermal zone exposures and changed the input parameters parametrically to analyze the sensitivity of the parameters. A reference office configuration was considered as a base case in which all parameters were evaluated parametrically. Four perimetral zones (north, east, west and south-oriented) and one internal zone were considered. Each thermal zone presented different scenarios of exposure: ground-exposed, roof-exposed or both ceiling and floor in contact with other floors. All cases were analyzed for the city of Curitiba and São Luís.

Results show that the internal zone and the ground floor present the lowest mean and median cooling load values for both cities compared to other exposure types. Roof-exposed thermal zones are a concern in both climates due to higher median cooling load results. Nevertheless, the results show that the middle-floor exposures may be a concern in Curitiba, mainly due to internal gains. The mean orientation values are also different: while the east and west façade in the city of São Luís has mean cooling load higher than the north and the south, the north façade presents a higher mean cooling load in Curitiba. Different solar exposures due to climate and latitude should be a concern.

Finally, people density and occupied hours have different impacts on climate: having more people inside the building during the day enhances the cooling necessity in extremely hot climates much more than occupying the same building for 24 hours but with fewer people. The same does not occur in warm climates: occupying the building for a more extended period of the day (with people and loads) can improve cooling necessities more than having more people inside the building during the day. It enhances the impact of equipment and lighting power density on cooling loads in warmer climates. Also, lower WWR and SHGC can reach much lower cooling load results in the city of São Luís compared to lower values of glazing thermal transmittance and wall properties.

Overall, the results show that different thermal zone exposures lead to different thermal performance measures needed in the building. Also, as expected, climate should be an important parameter to analyze.

The limitations of the present work consisted of only varying each parameter parametrically and not evaluating the influences within parameters. Thus, shading angles should also be a parameter. Besides, only the thermal zones were evaluated, not the whole building.

Future work should consider the impact of each thermal zone in a building, relating it to the building shape. It means that the floor area of the thermal zone should be taken into account, and by that, each thermal zone would have a different impact, as well as the parameter change.

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