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Simulation of the thermal conditions of a school building in Belo Horizonte (MG)

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Abstract: The conditions of internal thermal comfort play an important role in user satisfaction and, consequently, in the execution and productivity of their task. This study aims to analyze the thermal comfort conditions of the CEFET school main building, natural ventilated, in Belo Horizonte (Brazil). A building model thermal simulation was performed using the Design Builder®. Its internal thermal conditions were analyzed hourly, over a reference year. The results show an annual average of heat discomfort hours around 69% on the first floor, according to the adaptive comfort range of ASHRAE 55/2017. These results could ground passive and/or active strategies proposal for decision making in future actions to improve these or similar spaces.

Key words: thermal comfort; building simulation; natural ventilation; building school

1 Introduction

Thermal comfort is a subjective human condition that can influence a person's sense of well-being and metabolic performance (KEELING et al., 2016). An assessment of the influence of temperature on task performance led Cui et al. (2013) to conclude that discomfort caused by frequent temperature fluctuations can impair the learning process.

According to Mcdowall (2007), the maintenance of thermal comfort is directly influenced by the clothing worn by the individual, factors related to the local climate (temperature, relative humidity, air velocity), the building's structural characteristics, geographic orientation, the color of the building envelope surfaces, the glazed area, as well as the materials used for the floor, walls, and roof.

Computational resources are widely used to analyze the thermal comfort of an environment based on estimates of its thermal performance. Thus, it is possible to examine the interactions between the environment and its surroundings based on its structural properties and local climatic characteristics, as well as to evaluate the building's operational and occupancy routines (MAZZARELA et al., 2009).

Dos Santos et al. (2017) analyzed thermal comfort in public schools in the city of João Pessoa (PB). The results showed that the geographical orientation and construction characteristics favored heat retention in the environments. Passive interventions were suggested to improve the environmental conditions for users of public schools in the country.

Simulated studies of thermal comfort conditions in different naturally ventilated buildings at the CEFET Nova Gameleira Campus in Belo Horizonte, MG, indicated the need for complementary passive and/or active solutions to achieve a more significant percentage of hours within the adaptive comfort range of ASHRAE 55/2017 (OLIVEIRA et al., 2019; FREITAS; OLIVEIRA; LIMA, 2019; DUARTE; LIMA; OLIVEIRA, 2019).

Natural ventilation can be a beneficial strategy for cooling and maintaining the temperature of occupied spaces, especially in regions with a hot and humid climate (BITTENCOURT; CÂNDIDO, 2010). From a hygienic standpoint, ventilation is essential, as it allows for air renewal, ensuring good oxygen levels and removing potential toxic gases and pathogens that are harmful to human health (MORALES MAYA et al., 2014).

In this context, the objective of this article was to assess the thermal comfort conditions of naturally ventilated classrooms in the main building of the CEFET Nova Gameleira Campus in Belo Horizonte (MG).

2 Methods

To achieve the objectives of this research, four methodological steps were proposed:

1) Characterization of the study object;

2) Construction of a representative model of the building;

3) Computer simulation;

4) Analysis of the thermal comfort conditions of the environments.

2.1 Description of the subject of study

The subject of study is a building that forms part of CEFET Nova Gameleira (Figure 1), located in Belo Horizonte (MG). It is the oldest building on this campus, constructed in 1960 to house the School of Veterinary Medicine, which was later affiliated with the Federal University of Minas Gerais (UFMG, 2020). The building has two floors (Figure 2), with approximately 1,835 m² on the first floor and 3,260 m² on the second, in addition to a 153 m² basement comprising technical spaces. Its structure consists mainly of classrooms (Figure 3) and support rooms.

Figures 1, 2, and 3. Floor plan, main facade, and view of room 123. *Source: adapted from GOOGLE MAPS® (2020); Source: the authors (2, 3)

In addition, the building also houses computer labs, a faculty lounge, and an auditorium on the first floor (Figure 4), as well as planned faculty offices on the second floor, which is currently undergoing renovation to accommodate this new use.

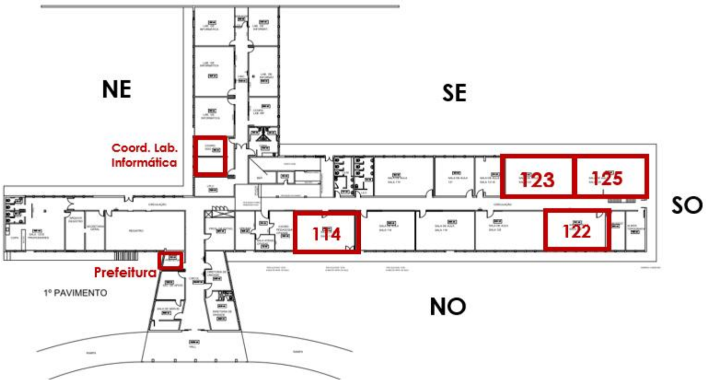

Figure 4. First floor plan. Source: adapted from SINFRA (2018)

2.2 Construction of the representative model

The representative model of the subject of this study was modeled in Design Builder® software as a single block, divided internally into thermal zones representing each room of the building (Figure 5).

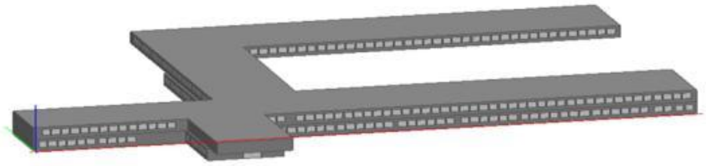

Figure 5. Schematic representation of the object of study. Source: adapted from Design Builder® (2020)

2.3 Computational simulation

Design Builder® software, version 2.3.6.005, was used to simulate the annual thermal comfort conditions of the subject of this study. To this end, the Typical Meteorological Year (TMY) climate file for the city of Belo Horizonte (MG) was used. The data presented in the meteorological file were evaluated using Climate Consultant 6.0® software to determine the wind directions and intensities for the climate of this location. The wind regime analysis can be seen in Figure 7.

As input data, the routines and density of use and occupancy for each zone were specified, as well as their respective internal loads. Data on the construction materials used were collected in the field, given that the provided design (SINFRA, 2018) did not include a descriptive report. The thermal transmittance of the building envelope was calculated according to the equation established in NBR 15.220-2 (ABNT, 2005). The solar radiation absorptance of its external surfaces was measured on-site, according to the procedure described by Sagoi et al. (2010), using a Vernier High Reflectance II portable spectrophotometer, with an uncertainty of ±0.10 (PEREIRA et al., 2016).

The internal heat loads of the spaces (lighting and equipment) were quantified through an on-site visit. The metabolic rate of the occupants was defined as office work (writing), equivalent to 60 W/m² per person (ASHRAE, 2017). For periods with higher temperatures (January through April and September through December), short-sleeved shirts and long pants were assumed, resulting in a value of 0.5 clo. For colder periods (May through August), light long-sleeved blouses, long pants, and a jacket were assumed, resulting in 1.0 clo. We assumed 41 people per room, including students and the teacher, while in support rooms we assumed 2 people per space. As input data, we used the operating temperatures (OT) of the selected environments for reference (Figure 4).

2.4 Analysis of thermal comfort conditions and possible improvements

The main school building, the subject of this study, has naturally ventilated classrooms and some artificially conditioned administrative spaces. This research considered only the rooms without artificial air conditioning, as indicated in Figure 4. Thus, reference rooms were defined for each facade. The OTs obtained in the simulation for the 8,760 hours of the year were analyzed, based on the adaptive comfort range established in ASHRAE 55 (ASHRAE, 2017) with 80% acceptance, to verify the thermal comfort conditions of the occupants in the building under study. This yielded the number of annual hours spent in comfort and in discomfort due to cold and/or heat.

3 Results

The on-site visits conducted at the study site were intended to collect data to be used as input for the simulation. Thus, for classrooms, the operating hours considered were from 7:00 AM to 9:00 PM on weekdays and from 8:00 AM to 12:00 PM on Saturdays, while for support rooms, the reference adopted was from 8:00 AM to 6:00 PM, Monday through Friday. The materials constituting the building envelope, presented in Table 1, were measured in the field, and their thermal properties were calculated in accordance with NBR 15.220 (2005). The external surfaces of the envelope featured a smooth layer of beige paint with a solar absorptance of 0.44.

The windows used in the building were sliding windows (one fixed pane and one movable pane), and the assumed opening schedule was 50% during the occupancy period; specifically, from 7:00 a.m. to 9:00 p.m. on summer days and from 9:00 a.m. to 6:00 p.m. on winter days. The glass used was 4 mm clear glass with a 3M® film that transmits 69% of visible light.

Table 1. Building envelope components. Source: the authors

Envelope materials	Thickness [mm]	Thermal transmittance [W/m²K]
Metal roof tiles	0.0065	1.290
Air space	0.050	
Solid concrete slab	0.150	
Gypsum ceiling	0.020	
Facades: (interior mortar)	0.020	1.940
8-hole ceramic block (3x2 cm)	0.100	
External mortar	0.020	

Regarding internal loads, the light fixtures used in classrooms and support rooms were Aledis® Turbo LED T8 lamps with a power rating of 21 W and a color temperature of 4000 K. An average of 7.9 W/m² was assumed for lighting gains, and 9.5 W/m² in classrooms for equipment. For the support rooms, two computers were considered, each with a power of 20.5W, and Dell® P2317H monitors with 18W, totaling 38.5W per machine. Thus, 4.2W/m² was adopted for the city hall and 1.0W/m² for the Laboratory Coordination office.

The specified input data were used in the computer simulation to determine the hours of comfort and discomfort in the environments. The results obtained for classrooms 123, 125, 114, and 122, the campus administration building, and the Computer Labs Coordination Office can be seen in Figure 6.

During the month of July, a significant drop in operating temperatures (OTs) was observed in the rooms over the last 15 days due to school vacations. It was also noted that the OTs in Room 123 are slightly higher than those in Room 125. This can be explained by the fact that room 123 has only one exterior wall facing southeast (SE) and features a significant amount of glazing, thereby affecting heat exchange with the outside environment, whereas room 125 has two exterior walls (SE and southwest—SW), thus facilitating greater heat exchange.

The results obtained for rooms 114 and 122 facing the Northwest (NW) facade show that the temperatures in these rooms were higher than those observed in room 123. This can be explained by the fact that the NW facade is exposed to the sun in the afternoon, when temperatures are typically higher, combined with low wind intensity (Figure 7).

The room temperatures (RTs) in the administration building during winter were higher than those in the laboratory coordination office. This can be explained by the position and duration of sunlight exposure during winter, which affect the administration building area more than the laboratory coordination office. It is worth noting that the administration building on this campus receives sunlight for most of the morning, while the laboratory coordination office receives less sunlight in the morning and afternoon.

Data analysis also allowed for estimating the percentage of comfortable and uncomfortable hours throughout the year in each environment (Table 2). It was found that the NW facade had 84.4% of hours that were uncomfortable due to heat, based on a reference year. This reinforces the data presented in Figure 6, in which the temperatures of the rooms facing the northwest showed OTs close to, and sometimes above, the upper limit of the acceptable comfort range.

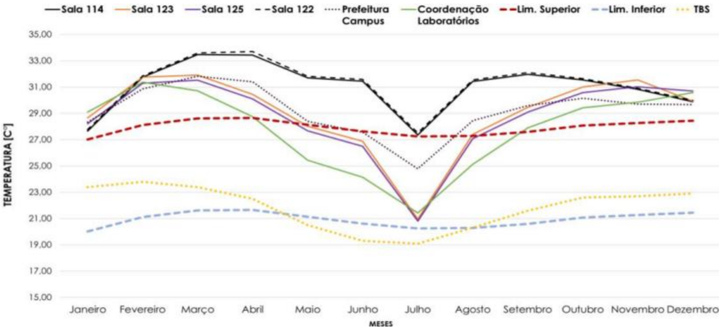

Figure 6. Operative temperature profiles of rooms, comfort limits, and Dry-Bulb Temperature (DBT). Source: the authors

The average difference in the number of hours of thermal comfort for rooms facing the NW and SE facades is approximately 16.45%, or approximately 1,441 hours per year. This difference is due to the location of the classrooms, as the NW facade receives greater solar radiation in the afternoon.

A comparison of the data in Table 2 for the SW- and NE-facing environments reveals that the SW facade provided the greatest number of hours of thermal comfort compared to the NE facade, a fact that is also evident in Figures 6 and 7. This condition can be explained by the sun's position during winter, since solar radiation in the NE region tends to be greater than in the SE, and also by the average wind direction and intensity, which allows contact with the room's exterior surface, facilitating greater heat exchange with the surrounding space.

Figure 6 and the analysis presented in Table 2 indicated that the highest number of hours of thermal discomfort due to heat occurred in Room 122. An analysis of Figure 7 shows low wind intensity for the NE direction, toward which the facades of Rooms 144 and 122 face. The second floor was not evaluated due to the rooms being vacant as a result of ongoing renovations.

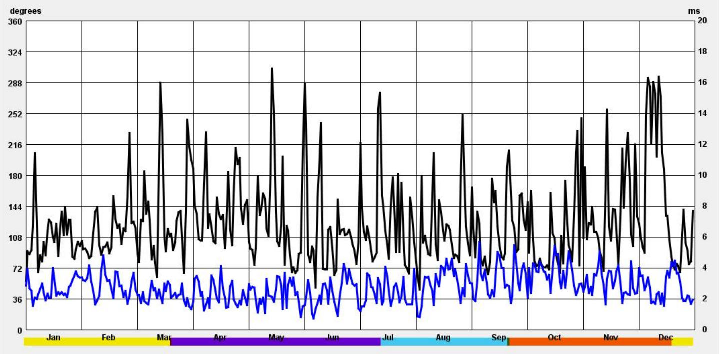

Figure 7. EPW wind regime analysis. Source: the authors

In summary, the uncomfortable conditions observed in this study were also noted by Oliveira et al. (2019), Freitas, Oliveira, and Lima (2019), and Duarte, Lima, and Oliveira (2019). In several buildings at this same institution, design strategies were found to be inadequate for ensuring thermally comfortable conditions. Furthermore, since these are existing buildings, the options for optimizing indoor thermal conditions through passive means are more limited and involve a greater degree of intervention with higher operational costs compared to the design phase of the project.

Table 2. Percentage of annual hours of comfort and discomfort. Source: the authors

Facade	Thermal Zone	Hours of discomfort				Hours of comfort	
		Cold (hours)	%	Heat (hours)	%	Hours	%
Northwest	Room 114	0	-	7284	83.20	1,476	16.80
Northwest	Room 122	0	-	7,395	84.40	1365	15.60
Southeast	Room 123	244	2.80	6053	66.30	2707	30.90
Southeast	Room 125	287	3.30	5744	62.30	3,016	34.40
Northeast	City Hall	21	0.20	5,834	66.40	2926	33.40
Southwest	Lab Coordinator	114	1.31	4354	49.70	4292	48.99

4 Conclusion

The methods employed in this study resulted in an estimation of the annual thermal discomfort conditions of the analyzed environments. Similar to other studies, the northwest-facing environments presented higher operative temperatures (OT) and, therefore, the highest number of hours of thermal discomfort due to heat throughout the year compared to the other orientations.

The possible reasons for the building's environments not meeting thermal comfort ranges were: the building's location, which allowed for high solar incidence on the facades during the day, increasing thermal gains, as well as the high occupancy density of the environments—a factor that significantly influenced the increase in the environments' OT—in addition to low wind intensity. This study contributed to expanding the analytical basis for the thermal comfort conditions provided by school buildings, thereby aiding decision-making for future space improvement initiatives. It is suggested that passive and/or active strategies be studied to improve the thermal comfort conditions of this building.

The use of brises could be tested to reduce direct sunlight exposure in the rooms, and appropriate air conditioning systems could help lower indoor temperatures. Additionally, on-site measurement of indoor temperatures is recommended for model calibration, thereby enabling results that more accurately reflect the building's actual behavior.

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Conflicts of interest

The author declares no conflicts of interest regarding the publication of this paper.

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