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Artigo

Study of the natural ventilation for thermal comfort in Block C classrooms - ICTE/UFTM

Estudo do conforto térmico devido à ventilação natural em salas de aula do Bloco C - ICTE/UFTM

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ABSTRACT: Natural ventilation is an excellent passive air conditioning technique to promote comfortable thermal conditions in indoor environments for their users and to reduce power consumption by mechanical air conditioning systems. The aim of the present study is to assess the effectiveness of natural ventilation in a set of laboratories and classrooms in Uberlândia City, Minas Gerais State, Brazil, during a year of typical weather conditions. Environments' thermal simulations were carried out in *Energy Plus* software. The adaptive thermal comfort model was adopted, and effectiveness assessment was carried out based on the rate of occupied hours under thermal comfort (POC). Environments' indoor thermal loads and the possibility of closing doors and windows based on 6 different configurations were the main parameters assessed during the simulations. Results have shown that the insertion of indoor thermal loads can significantly change POC and reduce efficiency level by 34%. In total, 14 of the 21 assessed environments, subjected to the best natural configuration, presented the worst efficiency possible (label E), whereas the remaining ones recorded POC lower than 51%. This finding shows the need of using artificial air conditioning systems to make sure of thermal comfort in these environments during the remaining occupation hours.

Keywords: Adaptive thermal comfort, Energy Plus, POC, Natural ventilation.

RESUMO: *O uso da ventilação natural é uma excelente técnica de climatização passiva de ambientes internos por promover condições térmicas confortáveis para seus ocupantes e reduzir o uso de energia elétrica pelos sistemas mecânicos de condicionamento. Neste trabalho, estudou-se a efetividade da ventilação natural de um conjunto de laboratórios e salas de aulas localizadas na cidade de Uberaba-MG durante um ano típico. As simulações térmicas dos ambientes foram realizadas pelo programa Energy Plus, enquanto se adotou o modelo de conforto térmico adaptativo e avaliação da efetividade pela porcentagem de horas ocupadas em conforto térmico (POC). Os principais parâmetros variados durante as simulações foram as cargas térmicas internas dos ambientes e a possibilidade de fechamento de portas e janelas em 6 distintas configurações. Os resultados mostram que a inserção das cargas térmicas internas pode variar consideravelmente o POC permitindo reduções do nível de eficiência de até 34%. Dos 21 ambientes analisados, na melhor configuração da ventilação natural, 14 apresentaram a pior eficiência possível obtendo etiqueta nível E, enquanto os demais tiveram POC inferiores a 51%, que demonstra a necessidade de uso de sistemas artificiais de climatização para garantir o conforto térmico dos ambientes no tempo restante de ocupação.*

Palavras-chave*: Conforto térmico adaptativo, Energy Plus, POC, Ventilação natural.*

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INTRODUCTION

Energy efficiency is a recurrent topic, since one single service can be based on lower power consumption; consequently, it can also lead to smaller environmental and social impacts (DE VECCHI, 2011). More than 50% of the whole power produced in Brazil is consumed by buildings; power consumption in public and commercial buildings due to artificial air conditioning systems represents a fraction higher than 40% (BRASIL, 2007; BRASIL, 2016).

The creation of energetic classification regulations for buildings is among the measures adopted by several countries after the 1997 Kyoto Treaty (BAVARESCO; GHISI, 2016). Labels such as *Passivhaus* in Germany, BREEAM in the United Kingdom, LEED in the USA and ADENE-SCE in Portugal, stood out among these labels (GUIDETTI, 2016). Research related to Procel Edifica in Brazil have been in place since 2009; the so-called RTQ-C regulates the labeling system set for public, commercial and service buildings in the country (BAVARESCO; GHISI, 2016; TAVARES, 2011).

RTQ-C conformity labeling system has 5 efficiency classes ranging from “A” to “E”, wherein “A” is the most efficient and “E” is the least efficient. Performance calculations assess wrapping, illumination, and air conditioning systems, be them artificial or natural. The final building labeling is based on the weighed mean of 30%, 30% and 40% of partial labels given to wrapping, lighting and air conditioning systems, respectively (BRASIL, 2013).

Silveira (2014) argues that achieving thermal comfortable indoor environments is one of the essential aspects of a quality building. The adoption of this parameter only based on the use of artificial air conditioning is an expendable practice.

According to Roriz (2008), an architectonic project focused on valuing the harmony between building and climate can reduce air conditioning dimensioning and even make it expendable. The use of passive air conditioning techniques is desirable, either because it reduces environmental impacts linked to electric power production and distribution, or because of costs involved in the operation and maintenance of these gears (BECCALI et al., 2018; LEITE et al., 2019; MANZANO-AGUGLIARO et al., 2015). The adoption of natural ventilation in Brazil, which is a continental-dimension country that mostly presents warm and humid weather, is an excellent passive air conditioning strategy, since this technique is recommended to be used in seven of the eight Brazilian bioclimatic zones (ABNT, 2003; CASTAÑO, 2017).

Natural ventilation based on wind actions happens when airflow crosses the outdoor faces of a building and creates a pressure field. This process allows outside air to flow into and out the building through its openings and fissures; consequently, it carries part of the thermal power accumulated inside the building and reduces indoor temperature (AFLAKI et al., 2015; CASTAÑO, 2017; MITCHELL; BRAUN, 2018).

The network model was the methodology used to simulate natural ventilation. Based on this model, the outdoor face of the building uses the pressure node network interconnected to resistance created by openings, and it accounts for mass and power conservation balance (ALBUQUERQUE, 2014). RTQ-C simulations must take place in software presenting specific features proposed by regulations, to create a climatic file of the city and of the surrounding similar regions, based on temperature, air humidity, air direction and speed, and solar radiation; data collected for 8,760h/year (BRASIL, 2013; SILVEIRA, 2014). Subsequently, the analysis is carried out based on the rate of occupied hours under comfort (POC), which is defined by the occupied hours under comfort: total occupation hours ratio (BRASIL, 2013).

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Energy Plus and *Design Builder* are the most often used simulation software (ALBUQUERQUE, 2014; BRASIL, 2015; SILVEIRA, 2014) and *Design Builder* (PAULSE, 2016; TAVARES, 2011).

Silveira (2014) assessed a building's thermal comfort conditions based on simulating values for one single family building (63m²) in the following locations: Curitiba City, Paraná State; Campinas City, São Paulo State; and Natal City, Rio Grande do Norte State. These locations have adopted the comfort conditions proposed by ASHRAE 55 and NBR 15575. Silveira has observed deficiencies in standard NBR 15575, since it does not take into consideration the indoor heat sources in the simulation; consequently, it estimates longer thermal comfort hours than ASHRAE 55.

Tavares (2011) assessed the thermal comfort conditions of classrooms located in Uberlandia City, Minas Gerais State, Brazil, in software *Design Builder*. Air renovation rates were considered in the simulations due to constant natural ventilation. Tavares stated the possibility of ensuring 63.2% occupation hours under thermal comfort - 18.6% and 18.1% hours under discomfort due to cold or heat, respectively. Creating a reliable climatic file in the simulation, as well as in the use of the network model, to assess natural ventilation stood out among difficulties faced by this author.

Paulse (2016) assessed the thermal comfort conditions of classrooms in Goiânia County, Goiás State, Brazil; 24 wrapping types were assessed (ceiling and outside walls). Based on the initial project, the environments' POC ranged from 58% (worst case) to 68% (best case). Changes in wall and ceiling type, in model M19, recorded POC improvement ranging from 74% to 88%, and it points towards the fact that thermal comfort studies are desirable at project stage to choose building masonry and position. Paulse argues that the original system used as model for public schools' construction in the assessed city is not recommended for thermal development and it reflects on higher power consumption by the assessed building.

It is possible noticing that thermal comfort studies based on using natural ventilation in classrooms are highly desirable, because these are the environments where students spend most of their day and because the conditions faced in these locations can cause several psychological and physiological issues in their users. It is necessary ensuring the minimal environmental conditions for the full development of users' cognitive skills (LUCAS; DA SILVA, 2017).

As pointed out by RORIZ (2008), the occurrence of accidents and errors tends to reach values 30% higher than the average when environments' indoor temperature get distant from thermal comfort conditions; in other words, there is clear decrease in users' performance and efficiency when it happens.

The main aim of the current study was to analyze the thermal performance of a block of classrooms in Uberlândia City, Minas Gerais State, Brazil, based on simulations carried out in *Energy Plus* software. Natural ventilation was modeled based on the network model; on occupation, lighting, and electric gear rate parameters; and on the possibility of doors and windows opening in POC.

METHODOLOGY

The computer software *Energy Plus*® version 8.4 was used to analyze the mean temperatures of each thermal zone in the building. Classification known as "*Airflow Network*" and the methodology proposed by Pereira et al. (2013) were applied to natural ventilation modeling. The methodological procedures were divided into a) wrapping geometry and

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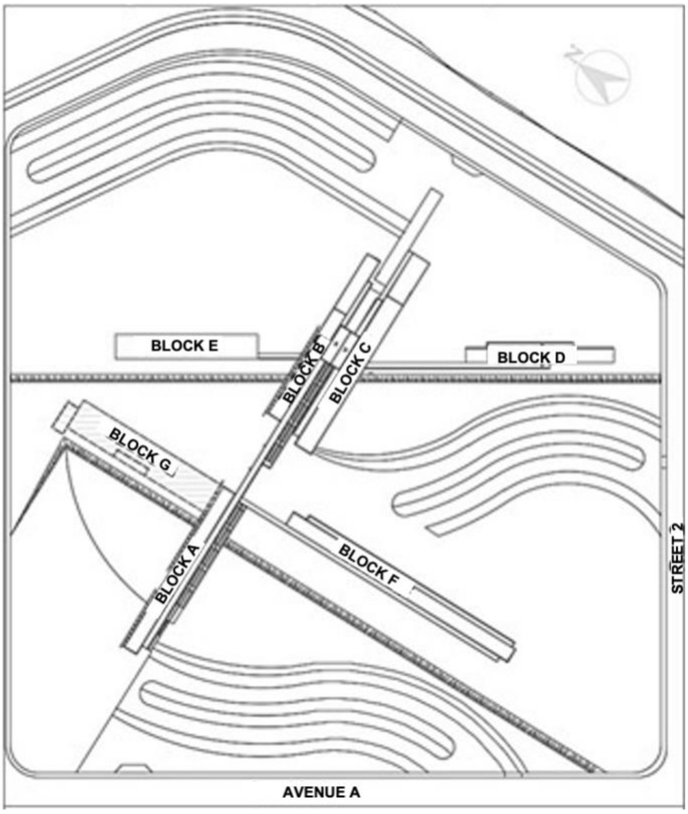
elements; b) defining indoor thermal load; c) natural ventilation transport parameters; d) climatic data and adaptive thermal comfort conditions; e) result analysis forms; and f) simulated cases.

Geometric definition and wrapping data

Block C, in the Technological and Exact Sciences Institute (ICTE), was the study site. The assessed building is in Federal University of Triângulo Mineiro campus, Uberaba City, Minas Gerais State, Brazil. This building comprises 21 environments, namely: 6 laboratories, 3 computer rooms and 15 classrooms distributed into 3 stores. **Figure 1** presents an upper view of this block of classrooms in the campus; most of assessed building's facades head North and South, whereas **Figure 2** provides views of the South and East faces (to the left), and partial view of the last store in the North face, whose main windows, and doors head right.

Figure 1. Block C location in UFTM campus



Source: Guidetti, 2016

This block is 73.6 m long, 8.3 m wide and 10.2 m tall. Each environment in it has 2 sliding windows (dimensions 1.07m x 5.0m) in the outdoor face, heading South, and 2 wooden doors (dimensions 2.1m x 0.9m). Room C101, which has metal access doors; and room C103 – on the border of a storage room – were the exceptions because they only have one access door, each.

The architectonic project provided by the university's city hall in the assessed campus counted on "*As Built"* development, throughout the present study, to develop the construction's geometry definition and the analyzed environments.

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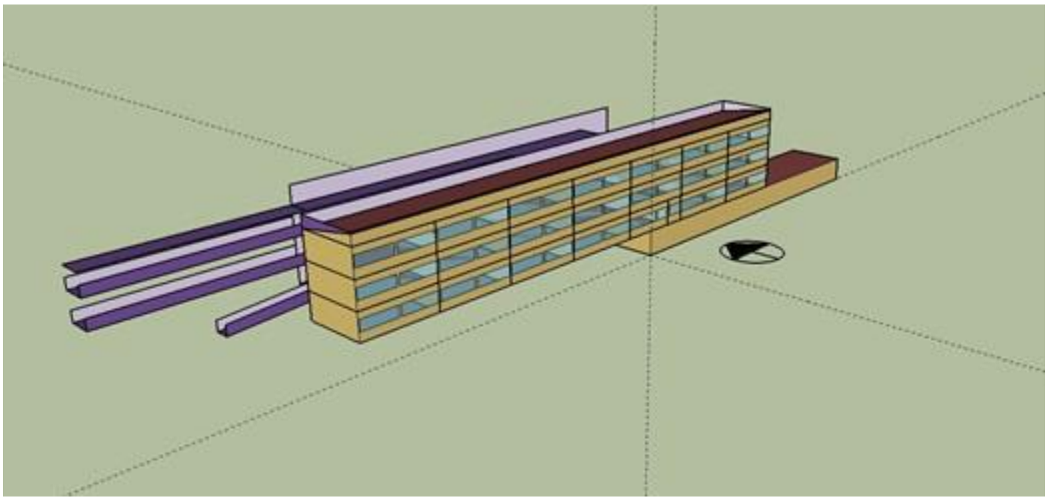
Figure 2. Outdoor views of the South (to the left) and North faces in the last store (to the right)

Figure 3 presents Block C model based on wrappings' geometric definitions of the 21 thermal zones; there were 7 zones per store and the shade facades of buildings around it (in purple). The geometric model was developed in *SketchUP 15®* software with *Legacy OpenStudio® plugin*. Based on this model, rooms C101 and C107 are located on the ground floor, room C101 heads to the East and room C107 heads to the West. Rooms C201 to C207, and C301 to 307, follow the same standards described above; however, they are in the second and third stores, respectively.

Figure 3. Block C model – Southeast Facade



The buildings' South, East and West face walls were 25.0-cm (in total thickness) and those in the North face wall, inside the building, recorded total dimension of 15.0 cm. They have 2 layers (indoor and outdoor) of mortar (2.5cm); it corresponds to 5.0cm in thickness and to 6-hole ceramic blocks (total dimensions of 20.0cm or 10.0cm, when lying or standing, respectively).

Slabs presented total thickness of 25.0cm; they had 15.0cm of concrete, 10cm of thermal-acoustic insulating material (EPS) and a thin layer of plaster. All these compositions

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were observed in loco, through pre-existing openings, during a technical visit to the building. **Figure 4** depicts views of wall openings (15.0cm) to the left and of the slab, to the right.

Lining was modeled at 15.8% slope, at maximum height of 1.3m; it was aligned to the South face, and to fiber cement covering (8.0 cm, in thickness).

Because there was scarcity of data about the windows' glass, we assumed it was simple glass (0.8cm, in thickness) capable of providing total thermal transmittance of 6.01 W/m^2K (CREDER, 2012) and solar factor of 0.87 (FROTA; SCHIFFER, 2001).

Absorbance value of 0.3 was adopted for slightly-wore walls in clear faces outside the block, and value 0.4 was adopted for light colored fiber cement tiles.

Figure 4. View of the 15-cm wall composition (to the left) and building slab (to the right)

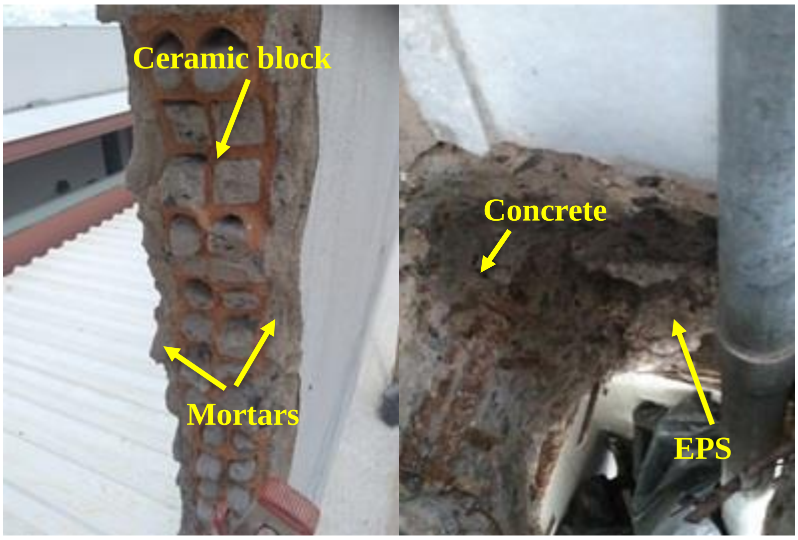

Table 1 shows the summary of the main thermal-physical properties and the dimensions of wrapping materials. EPS thermal properties, air chamber and glass were not inserted in this table; it only showed values recorded for the thickness and final thermal transmittance for opaque and transparent elements.

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Table 1. Main thermal-physical properties and dimensions of materials used in the simulation

Construction component	Material	Thickness (m)	Thermal cond. (W/mK)	Dens. (kg/m^3)	Specific heat (j/kgK)	Thermal transmit. (W/m^2K)	Absort. (α)
Opaque surfaces							
Wall 15 cm	Mortar	0.050	1.15	2000	1000	--	0.3
	Brick Ceramic	0.036	0.90	1600	920	--	--
	Air chamber	--	--	--	--	0.283	--
Wall 25 cm	Mortar	0.050	1.15	2000	1000	--	0.3
	Brick Ceramic	0.070	0.90	1600	920	--	--
	Air chamber	--	--	--	--	0.564	--
Slab 25 cm	Plaster lining	0.001	0.35	900	870	--	--
	Concrete	0.150	1.15	2200	1000	--	--
	EPS	0.100				2.500	
Coating	Fiber cement	0.080	0.95	1900	840	--	0.4
Wooden door	Wood	0.025	0.14	600	1600	--	--
Metal door	Steel	0.001	55.00	7800	460	--	--
Transparent Surfaces							
Window	Glass	0.008	--	--	--	6.01	0.87

Souces: ABNT, 2005; Creder, 2012; Frota e Schiffer, 2001

Indoor thermal loads

Indoor thermal loads represent the heat generation and dissipation observed inside the thermal zone. They can be classified based on people, lighting, and electric gear.

Dissipation rate of 130W/individual was adopted for each thermal load based on people, and it represents mean power expense of one person in light office work.

All environments had two ceiling lights, with 28W fluorescent lamps, and 80% efficiency; it represents 70W heat rate/ceiling light. The number of electric gears in each environment, and their power, were listed; most of them were table PCs, screens and TV sets, projectors and laptops.

Table 2 introduces these thermal loads based on type and environment – at its highest dissipation rate. This table allows observing that environments C107 and C307 presented the same values because they had similar profiles. Thermal zones C102 and C104 were computer laboratories; the highest electric equipment rates are linked to the presence of PCs and their peripherals.

Simulation simplification, which is based on time, estimated that these environments' occupation standard ranges from 7:00 am to 12:00 pm, from 01:00 pm to 06:00 pm, and from 07:00 pm and 10:00 pm, in weekdays, from January to December.

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Table 2. Maximal thermal Loads/type (people, lighting, and electric gear per environment) and environment

Classrooms	Thermal loads		
	People (W)	Lighting (W)	Electrical Equipment (W)
C101	2990	560	1000
C102	6630	560	6375
C103	4550	420	4375
C104	6500	560	6250
C105	6500	560	3125
C106	3900	630	1375
C107	7800	630	125
C201	7800	630	125
C202	7800	630	125
C203	7800	630	125
C204	7800	630	125
C205	7800	630	125
C206	7800	630	125
C207	7800	630	125
C301	7800	630	125
C302	7800	630	125
C303	7800	630	125
C304	7800	630	125
C305	7800	630	125
C306	7800	630	125
C307	7800	630	125

Natural ventilation transport parameters

It is necessary estimating pressures on the buildings outside surface and the resistance to leakage through openings and/or gaps on fenestration surfaces to calculate ventilation rate inside the environments.

Wind pressure coefficient estimates were calculated in *Energy Plus*® software, based on the "*AirflowNetWork: SimulationControl*" classification system, as proposed by Swami and Chandra (1988, apud PEREIRA *et al.*, 2013) – aspect ratio between building width and length (0.112). This calculation allows if nearby buildings and obstructions do not influence the wind speed and direction found in the climatic file; consequently, they influence the pressure coefficients correlations proposed by this methodology.

Two situations were taken into consideration when it comes to airflow dynamics through windows and doors.

With respect to the first situation, windows were closed, and airflow took place through their slits. It was necessary estimating discharge coefficients (non-dimensional), flow exponent (non-dimensional) and their respective flow coefficient (kg/s.m).

As for the second situation, doors and windows were opened and wind flow took place through the useful ventilation area. This situation demanded defining the discharge coefficient and the useful ventilation area rate.

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Table 3 provides the two possible opening conditions (open or closed) and their respective data transport parameters recorded for wooden doors, outdoor windows, and hallway windows. The window located to the South, closer to the East, was considered, whereas the window heading to the hallway followed similar position: heading to the North face (**Figure2**).

It is essential highlighting that outdoor windows and the hallway window in environment C103 were always closed due to the presence of server-racks in the room.

Table 3. Physical parameters for load loss and fenestration transports

Condition	Parameter	Open Type				
		Wooden door	Outdoor window 1	Outdoor window 2	Hallway window 1	Hallway window 2
Closed	Flow coefficient (kg/s.m)	0.001	0.0001	0.0001	0.0001	0.0001
	Flow exponent	0.65	0.65	0.65	0.65	0.65
	Discharge coefficient	0.001	0.001	0.001	0.001	0.001
Open	Discharge coefficient	0.6	0.6	0.6	0.6	0.6
	% Useful ventilation area	100%	38.8%	40.9%	38.5%%	35.7%

Climatic data and adaptive thermal comfort conditions

Simulations were carried out in Uberaba City, Minas Gerais State, Brazil, at bioclimatic zone 3. They used the TMY climatic file of Almeida Franco airport, which is available at the webpage of the Energetic Efficiency Laboratory of Federal University of Santa Catarina[1]. This file is based on time to assess temperatures of dry and humid bulb, solar irradiation rates, nebulosity, and other entry-data necessary to simulate a typical meteorological year during the 2003-2017 period.

Humphreys (1976) proposed that adaptive thermal comfort depends on the study site's mean temperature. Based on this hypothesis, and by using the concepts proposed by Dear and Brager (ASHRAE 55, 2010), the thermal comfort operative temperature was found through equation 1 (BRASIL, 2015).

$$T_{op,c} = 18,9 + 0,255 T_{m,ext} \quad (1)$$

Wherein, $T_{op,c}$ is the comfort operative temperature and $T_{m,ext}$ is the monthly mean outdoor temperature, both expressed in °C. Comfort zone definition was based on 90% acceptance, due to the addition of 2.5°C and on the subtraction of 2.2°C from the operative temperature; it was done to set the maximal and minimal comfort recorded for each month, respectively.

Figure 4 depicts the mean temperatures, and the adaptive comfort zone, all year round, for each month, in separate. It was possible observing that May and June are the

[1] http://www.labeee.ufsc.br/downloads/arquivos-climaticos/inmet2018, accessed on 2020/04/22.

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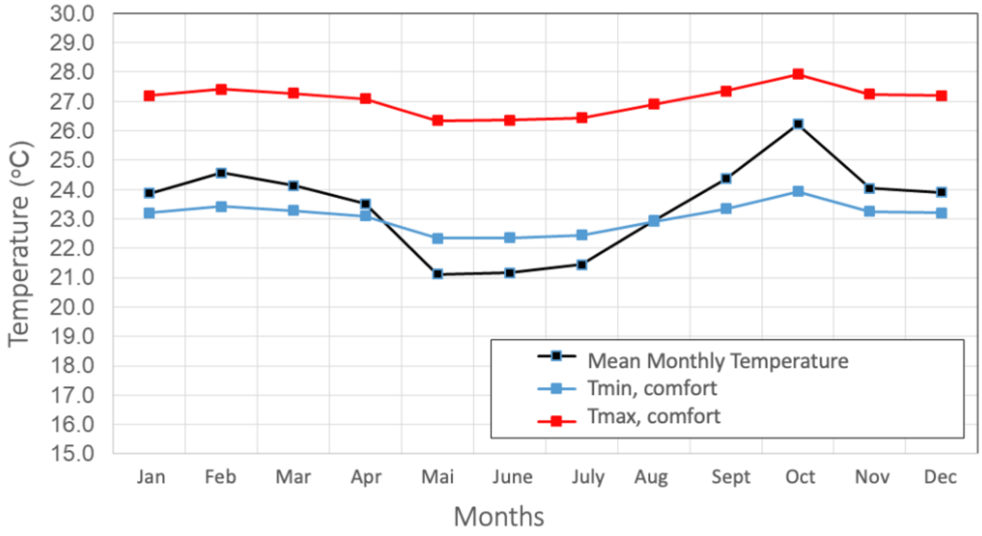
moths accounting for the lowest mean temperatures of the year. Assumingly, doors and windows were only open when indoor temperature was higher than, or equal to, 22.1°C.

Figure 4. Variation in mean monthly temperature ($T_{m,ext}$), and in maximal and minimal adaptive thermal comfort temperatures



Result analysis forms

Occupied hours under comfort (POC) rate was defined as occupied hours under proved comfort:total occupied hours ratio in the simulations (BRASIL, 2013). This parameter uses RTQ-C to assess effective natural ventilation use.

Simulations lasted 8,760hours/year, although the building is only occupied for 3,380 hours/year. When the highest indoor environment temperature reaches the maximal comfort temperature, it gets uncomfortable due to the heat; on the other hand, if this temperature is lower, the environment gest uncomfortable due to the cold. The occupied room will reach the adaptive comfort parameters, in case of any situation other than the aforementioned ones.

Simulated cases

Two sequences of simulations were carried out. One of them was done to assess the influence of indoor thermal loads on POC and the other one assessed the influence of closed doors and windows on natural ventilation.

RESULTS AND DISCUSSIONS

The first sequence of simulations assessed the impact of indoor thermal loads on POC. Initially, the thermal comfort of environments without (Sv) and (Cv) was analyzed based on the possibility of achieving natural ventilation, without indoor thermal load using. Subsequently, thermal loads were added due to equipment and lighting, and to occupation rate fractions ranging from 25% to 100%. **Table 4** presents POC values per environment due to indoor thermal load rates observed in these simulations.

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Table 4. Environments natural ventilation assessment based on indoor thermal loads

Classrooms	POC (%)						
	Structure		Thermal load of equipment and lighting at 100% Variations in the heat load of people				
	NV	WV	0%	25%	50%	75%	100%
C101	44,6	54,8	50,1	49,8	48,9	48,4	47,7
C102	37,6	56,1	32,9	31,1	29,6	27,5	25,8
C103	34,5	57,0	31,0	29,2	27,2	25,2	22,5
C104	40,3	56,2	33,3	31,7	30,0	28,0	26,2
C105	45,7	58,7	45,9	44,4	42,1	40,5	38,7
C106	47,7	59,0	49,5	49,3	49,0	48,5	48,3
C107	54,1	56,3	52,1	50,8	50,9	50,2	49,1
C201	40,0	53,6	51,2	50,4	50,5	50,3	49,4
C202	31,4	54,7	51,2	50,7	50,6	50,4	49,3
C203	28,6	54,4	51,4	50,7	50,8	50,4	49,1
C204	29,9	54,9	51,4	50,7	50,8	50,6	49,3
C205	33,3	55,5	51,4	50,8	50,8	50,7	49,4
C206	34,6	55,7	51,5	50,8	50,8	50,9	49,4
C207	42,7	54,2	51,2	50,4	50,2	50,2	49,5
C301	40,3	52,9	51,2	50,1	50,4	50,0	50,3
C302	32,5	54,1	51,1	50,1	50,4	50,4	50,4
C303	31,4	54,4	51,0	50,1	50,4	50,7	50,4
C304	31,9	54,3	51,1	50,0	50,5	50,7	50,3
C305	32,5	54,3	51,1	50,1	50,4	50,7	50,4
C306	33,1	54,5	51,2	50,1	50,4	50,7	50,4
C307	41,1	53,2	51,1	50,1	50,3	50,1	50,0

NV- no ventilation (ventilation through slits only).
WV- with ventilation (ventilation through openings).

This table compares the structure without ventilation to that with natural ventilation, but without indoor thermal loads; it shows POC improvement in all environments, since it is likely observing open doors and windows. Environment C20 recorded improvement by 25.7% in comfort hours when the two cases were analyzed; it is explained by increase in air renovation rate. POC increase in classrooms presenting the widest areas heading to the outdoor environment (C101, C107, C201, C207, C301 and C307) was slightly lower than that of other environments, mainly in room C107. This finding can be explained by the thermal inertia of energy flow through the walls, which mitigates indoor temperature variation in these zones. This variation in room C107 was also mitigated by the thermal zone contact to the soil.

We also analyzed **Table 4** and compared POC recorded for environments of the Cv structure to equipment and lighting thermal loads (0%). It was possible observing decreased comfort conditions in all environments, and it was more significant in environments C102 and C104, due to high heat dissipation rates resulting from electric devices (**Table 2**).

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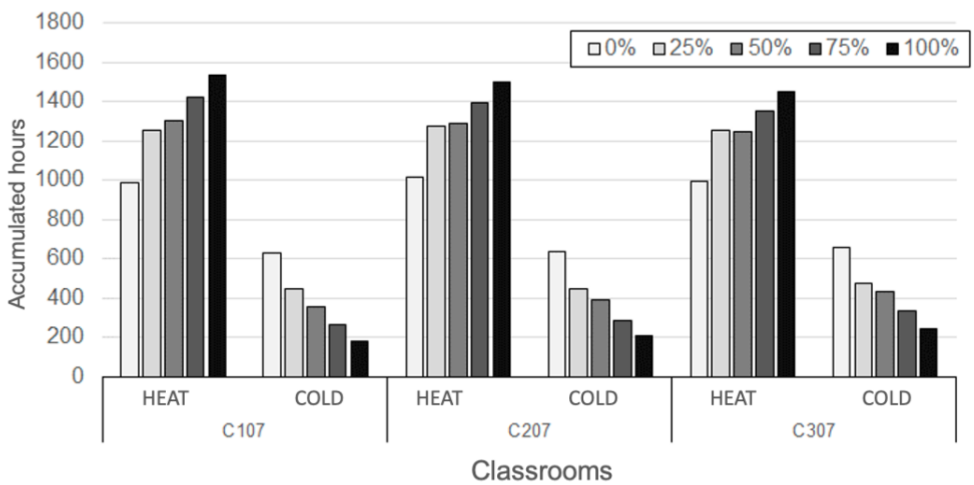
If one changes the environments' people occupation rate, it is possible observing decrease in thermal comfort conditions in most classrooms due to increase in the number of people. In some cases, there was POC increase due to this value's stabilization, or to its subsequent decrease, as observed for rooms C201 and C204. This effect resulted from the number of comfort hours and from the sense of cold, which tended to decrease because of increase in occupation rate. On the other hand, the number of hours under higher indoor temperature tends to exceed the maximal temperature limit. In other cases, the number of hours under temperature lower than the minimal limit set to the comfort zone is larger than the number of hours when temperature leaves the comfort zone and enters temperatures that cause the feeling of heat.

Figure 5 presents accumulated hours due to thermal discomfort in environments C107, C207 and C307 due to rates of occupation by people. It is possible observing a larger number of hours accounting for the feeling of heat because of a larger number of people in them. On the contrary, there was decrease in the number of hours when indoor temperature was below the lower comfort temperature limit.

Figure 5. Accumulated hours of thermal discomfort in rooms C107, C207 and C307 recorded for total occupation capacity rates of 0%, 25%, 50% and 100%



It is important highlighting that results in **Tables 4** and **5** corroborate the arguments by Silveira (2014), according to whom, the use, or not, of indoor thermal loads has significant influence on thermal comfort conditions. In case the natural ventilation of Block C was analyzed based on RTQ-C standards, all environments would get label D (50%≤POC<60%) in situation Cv. However, when it comes to using 100% indoor thermal loads, only 7 environments would get label B, whereas the remaining 14 ones would decay to label E (POC<50%).

This finding points out that the POC analysis, applied to building-labeling based on the RTQ-C methodology, must take into account the highest indoor thermal load value, which is the worst case scenario. Based on these results, the care managers must take at the time to infer the largest number of students in each environment, without assessing the occupation rates suggested in the project, is another point to be highlighted.

The second sequence of simulations investigated the 6 possibilities of doors and windows' opening, whereas some other windows and doors would be always closed.

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Thermal loads recorded for lighting and electric gear reached 100%; occupation rate reached 75%.

Table 5 provides the likely opening situations – based on the widest ventilation-useful area in the North or South facades (A_{maior}) - and the smallest opening useful area:widest useful area (AR) ratio. Case 0, or reference case, is the same presented in Table 4, at 75% occupation. We only took into account classrooms C107 and C307, because they presented similar opening availability and indoor thermal load profiles.

Table 5. Open windows and doors' configuration adopted to assess impacts on natural ventilation

Case	Situation	A_{maior} (m^2)	AR
0	All windows and doors can be opened	5.50	0.98
1	1 outdoor window and 2 always closed windows	5.50	--
2	1 hallway window and 2 always closed windows	5.42	0.68
3	Always closed wooden doors	5.42	0.34
4	1 and 2 hallway windows and 1 of the wooden doors in always closed	5.42	0.34
5	Only 1 outdoor window and one of the wooden doors with the possibility of opening, the other facades	2.71	0.68
6	All windows and doors closed.	--	--

Table 6 provides POC recorded for environments C107 and C307 based on configurations presented in **Table 5**.

With respect to case 6, according to which all doors and windows are closed, and ventilation only happens through slits, it was not possible getting thermal comfort at any occupation time. This finding shows that this ventilation system does not lead to air renovation rates at levels good enough to dissipate the accumulated heat.

POC, in case 1 – closed outdoor windows –, decrease by 21%, on average, in comparison to the reference case, and most of such decrease took place in classrooms located in the core area of the block. This finding also resulted from lack of crossed ventilation, which provides better natural ventilation efficacy.

As for case 2, according to which hallway windows 1 and 2 are closed, there is slight POC decrease – lower than 1%, in comparison to case 0. Based on this case, although there is decrease in ventilation useful area in the North face, it did not significantly interfere with crossed ventilation.

There was moderate loss in thermal comfort conditions both in cases 3 and 4 (5.7%, on average), when they were compared to the reference case. It was possible observing similarity between the widest open area in a facade - in this situation (A_{maior} equals 5.42m^2) - and AR (0.34).

When case 5 was compared to the reference, it was possible observing significant decrease in POC (11.5%, on average). Although this case presented the same AR recorded for case 2, the largest useful area of the facade, for ventilation, was 50% lower than that of

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case 2. This finding showed significant decrease in the potential use of crossed ventilation. Only case 2 presented slight reduction in comfort conditions in the environment among the 6 simulated situations. Cases 3 and 4 presented moderate comfort reduction, and this finding does not recommend their use. The same was observed for cases 1, 5 and 6.

Table 6. Impact of open doors and windows configuration on classrooms' POC

Classrooms	**POC (%)**						
	CASE						
	0	**1**	**2**	**3**	**4**	**5**	**6**
C107	49,1	33,8	49,0	45,4	45,3	39,1	0,0
C201	49,4	30,0	49,4	45,0	45,1	39,1	0,0
C202	49,3	27,1	48,9	43,6	43,6	35,7	0,0
C203	49,1	25,9	48,9	42,9	43,2	35,3	0,0
C204	49,3	26,4	48,8	43,1	43,3	35,6	0,0
C205	49,4	27,4	49,1	43,7	43,8	36,3	0,0
C206	49,4	28,3	49,2	44,0	44,0	37,0	0,0
C207	49,5	30,9	49,6	45,5	45,3	39,3	0,0
C301	50,3	30,0	49,8	45,9	46,3	41,2	0,0
C302	50,4	28,6	50,3	45,5	45,2	39,0	0,0
C303	50,4	28,0	50,2	44,9	45,1	38,8	0,0
C304	50,3	28,0	50,3	44,9	45,2	38,9	0,0
C305	50,4	28,2	50,3	44,8	45,2	38,9	0,0
C306	50,4	28,5	50,4	45,0	45,1	39,1	0,0
C307	50,0	31,0	49,9	46,3	46,4	41,2	0,0

Based on results in **Tables 5** and **6,** it is important highlighting that, although natural ventilation can keep the environment acclimatized for at least 40% of its occupation time, it is necessary using artificial air conditioning systems during the remaining hours. This need was even higher in environments C102 and C104 since they presented POC lower than 30%.

CONCLUSIONS

Based on simulation results, it was possible observing better natural ventilation configuration and worse indoor thermal load rate; only 7 of the 21 analyzed environments were granted with level D label, the remaining ones were classified as E level. Data corroborated the need of using artificial air conditioning systems to ensure thermal comfort conditions all year long - when it is not achievable only by natural ventilation.

With respect to indoor thermal loads, it was possible noticing that their use significantly influences POC results and that it can also decrease natural ventilation efficiency by 1 label. It happens because of higher power concentration in environments where it is not only removed by air renovation. Accordingly, simulations must assess POC based on the highest indoor thermal load rates, rather than on the analysis of structure

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conditions based on natural ventilation using.

As for the open doors and windows' configurations, openings in classrooms must not be closed when they reach 75%, or more, of their maximal occupation, due to users' feeling of thermal heat in 100% of the time. In smaller scale, it is not recommended to close all outdoor windows, to only use one of the outdoor windows or to only open one of the doors, because these configurations could lead to POC reduction by 23.2%.

Given the need of using artificial air conditioning systems in the analyzed spaces, and of rational power employment in public buildings, it is recommended to carry out future studies about the following topics:

- Assessing different artificial air conditioning systems and techniques, such as cooling through vapor compression, mechanical ventilation with, or without, the use of evaporative cooling and its impact on buildings' power consumption.
- Analyzing the labeling level of wrapping systems, lighting and total of buildings based on RTQ-C methodology.

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