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ANALYSIS OF THE THERMAL EFFICIENCY OF EDUCATIONAL LEARNING ENVIRONMENTS THROUGH NATURAL CONVECTION

Douglas Elias Cortiço
Diego Alves de Miranda
University of the Region of Joinville – UNIVILLE, Norberto Eduardo Weihermann, 230 - São Bento do Sul - SC.
douglascortico@gmail.com, diegoalves_klx@hotmail.com

Abstract: Thermal comfort is essential for study environments, since students achieve better performance and use of concepts. This facilitates and motivates concentration, development of logical reasoning and development in teams, since they do not have to worry about the environmental conditions of learning. The correct sizing of air conditioners is essential to efficiently provide the ideal condition of comfort to the individual. In this sense, this work developed a study on thermal efficiency through calculations involving natural convection, considering ideal conditions of thermal comfort, offering better yields in the individual's activities. In this way, there was a concern regarding the comfort of the academic environment, where its dimensioning occurs in an ideal way when taking into account all the factors inherent in the design of the rooms.

Keywords: Injection parameters, Gas outputs, Numerical simulation, Thermoplastics.

1.   INTRODUCTION

Currently, the use of air conditioners has been increasingly frequent in Brazilian homes, due to the increase in purchasing power of some Brazilians in conjunction with extreme weather conditions even in colder regions. This amount reaches 20%, with the southern region responsible for 32% of energy consumption dedicated to air conditioning systems, due to the characteristic climate with cold summers and winters. This implies the search for air conditioners that maintain a more effective thermal sensation efficiency (Lamberts, *et al*., 2014). Thermal comfort follows in parallel with the use of air conditioning systems aimed at optimizing the environment for carrying out the activities of individuals (Oliveira, 2017).

According to Wargocki and Wyon (2007), the human body directs energy to maintain comfort and well-being, causing inattention and low absorption of content. Also in this study, considering students aged 6 to 16 years, the authors proved that the decrease in temperature led to a 10% reduction in attention errors and increased response speed by around 28% and reading pace by 24%. According to Batiz et al. (2009), establishing an ideal temperature gradient, between 18 ℃ and 26 ℃, attention and memory are maintained, increasing good performance in the classroom.

On the other hand, Lucas and Silva (2017) proved that depending on the region in which one lives, there are different situations of thermal comfort due to the climatic conditions that each group of individuals is used to living with. This implies other more in-depth studies on parameters that extend beyond the ambient temperature, such as relative humidity, climatic conditions, among others, which were also evaluated by Falcão *et al*., (2019).

Within this context, this work aims to analyze the thermal efficiency in educational learning environments, taking the University of Joinville Region as a reference, considering the correct sizing of air conditioners. Natural convection calculations were used to find the heat transfer rate alternating different types of temperature and confronting it with the ideal thermal state determined in the literature.

2.   METHODOLOGY

This chapter will address the presentation of the physical problem, covering the tools and methods necessary for the successful study of thermal efficiency within the educational learning environment.

2.1.   Contorn Conceptualization of the Problem and Boundary Conditions

For this problem, the boundary condition was first established within the academic environment, where by collecting data from classrooms in this environment, it was possible to create a standard contour region for the study. The radiation was disregarded throughout calculations. Among the evaluated factors, as explained by Cortiço and Miranda (2021), an average was established between the internal dimensions of the walls of 11 rooms, such as the average number of occupants, average number of lamps and their power, number of equipment of air conditioning in the enclosure and its capacity. Using the average number of occupants, the analysis by Cortiço and Miranda (2021) was reconstructed considering 10, 30 and 50 occupants. Table 1 clearly exposes the factors for the follow-up of the work.

Table 1. Room data for dimensioning the cooling capacity.

Room Dimensions (m) (AxLxC)	Air conditioning (BTU/h)	Number of People	Number of Lamps
2.91 m x 7.00 m x 10.00 m	1 – 12,000 2 – 18,000	10, 30 e 50	20/Room

Complementing the standard of the stipulated rooms, the temperatures that influence the problem to be studied were established. The ambient temperatures considered for thermal comfort start from a minimum value of 23.3ºC to 26ºC suggested respectively by Creder (2004) and Stoecker and Jones (1985), in addition to an average value between them of 24.7ºC analyzed by Tenement and Miranda (2021). In addition to the mentioned temperatures, temperature ranges were stipulated for the external face of the wall (T_{s1}) and the internal face of the wall (T_{s2}). Table 2 provides additional data for the analysis.

Table 2. Temperatures for dimensioning the cooling capacity.

Body Temperature (^{0}C)	Room Temperature (^{0}C)	T_{s1} (^{0}C)	T_{s2} (^{0}C)
37.5	23.3; 24.7 e 26	-5 up to 45	-10 up to 40

The boundary conditions considering all parameters for the calculations are shown in Figure 1.
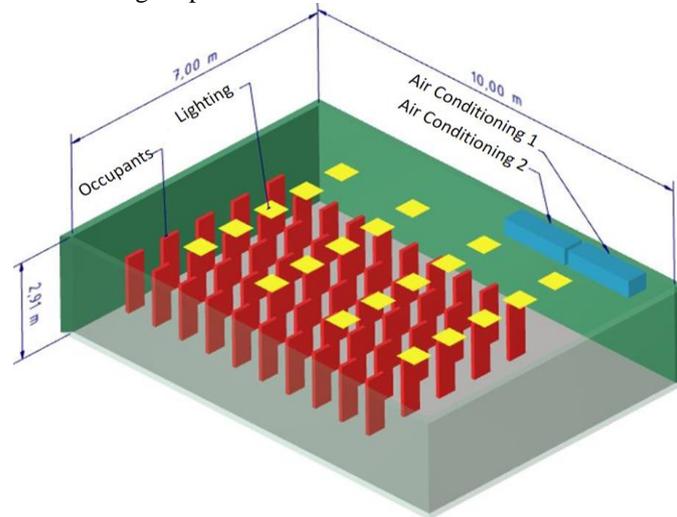

Figure 1. Data for dimensioning the cooling capacity.

2.2. Natural Convection

The adequate concept for the project, when we need to obtain heat transfer data in Watts to the environment, is Newton's Law of Cooling, explained by Bergman *et al*. (2014) and Çengel (2002), in Equation 1.

$$\dot{q}_{peaple} = \bar{h} A_s (T_s - T_\infty) \tag{1}$$

For the study of convection between the occupants of the enclosure and the environment, we will use the temperature of 37.5 ºC for the surface of the body (T_s), in which the literature suggests, inserting in the context of the previously mentioned comfort temperature range of 23.3 ºC, 24.7 ºC and 26 ºC, these being the ambient temperature (T_∞)

The area A_s for calculating the convection between the individuals and the internal environment of the room was obtained through Equation 2 referring to the surface of the human body, as described by Bois and Bois (1916), where, through their research, they concluded that the area of the human body (A_{DU}) was given by the exponential function of mass (m) and also by height (L):

$$A_{DU} = 0,202 m^{0.425} L^{0.725} \tag{2}$$

In the discretization of the human body to obtain the data, the concept of vertical plate will be considered, as previously shown in Equation 2. Thus, the deduction of data from ($\bar{h}$). mean convective coefficient, will be in the unfolding of Nusselt's formula, considering the value of L as the average height of the individual. The height was estimated according to data from IBGE (2008) being 1.67 m and mass of 66.7 kg. The value with convective coefficient can be easily obtained through the Nusselt number correlating with the value of L, using the concept of vertical plates.

$$\overline{Nu}_L = \frac{\bar{h}L}{k} \tag{3}$$

The Nusselt number is obtained by correlating Prandtl and Rayleigh numbers in which its result is obtained over the entire Rayleigh interval (Ra_L) for the case of the vertical plate. This concept is applied to most engineering calculations (Bergman, *et al*., 2014):

$$\overline{Nu}_L = \left\{ 0.825 + \frac{0.387 Ra_L^{1/6}}{\left[1 + (0.492/Pr)^{9/16}\right]^{8/27}} \right\}^2 \tag{4}$$

The interpretation of the boundary layer, which is integrated into the calculation of the Nusselt number, is preformed through the Rayleigh number (Ra_L).

$$Ra_L = \frac{g\beta(T_s - T_\infty)L^3}{\alpha v} \tag{5}$$

2.3. Thermal Conduction

Heat transfer in the walls of a building can be obtained through conduction calculations deployed in the concept of thermal resistance (Bergman, *et al*., 2014; Çengel, 2002). Combining the concepts of convection and resistance, we have the following equation:

$$R_{tot} = \frac{1}{h_1 A} + \frac{1}{kA} + \frac{1}{h_2 A} \tag{6}$$

According to the data collected in the field, the walls of the rooms follow a construction pattern, with a thickness (x) of 18 cm, and for the area, the values of length and height of the walls were considered according to the standard considered in the Table 1. These data were also used to estimate the convective coefficient between the walls and the internal environment of the classroom. In this way, we estimate the heat transferred from the wall to the internal environment according to Equation 7:

$$q_x = \frac{T_{\infty,1} - T_{\infty,2}}{R_{tot}} \tag{7}$$

2.4. Refrigerating capacity

To obtain the required capacity of the air conditioning equipment, the total thermal load of the room must first be obtained. With that, complementing the idea, we will use the concept suggested by Creder (2004) where after obtaining the total load, it is transformed into BTU/h. This conversion is necessary, since this data can be different for each manufacturer. The heat from natural convection is expressed considering all the factors that contribute to this phenomenon (Creder, 2004). In order to quantify all the factors involved, we first consider the values of heat loss among occupants, and the value of heat loss from the average number of lamps available in the classroom, this fixed variable being quantified by $\dot{q}_{Lighting} = 460\ W$ according to data collection. At this stage, we considered the division into 3 amounts, 50, 30 and 10 occupants. This expression is written as follows, as shown in Equation 8:

$$\dot{q}_{internal} = \dot{q}_{peaple} + \dot{q}_{Lighting} \tag{8}$$

After quantifying these data being identified as $\dot{q}_{internal}$ for each group of occupants, we then added the heat from the conduction of the walls taking into account the temperature relationships of the walls and the environment mentioned above, this data being obtained by Equation 9:

$$\dot{q}_{total} = \dot{q}_{internal} + \dot{q}_{wall} \tag{9}$$

Thus, obtaining the data, it was possible to verify the capacity of the equipment in the rooms, with all the factors involved in the study.

3. RESULTS AND DISCUSSIONS

This chapter will discuss the results of this study.

3.1. Analysis of heat loss in relation to the number of occupants

The results of the amount of heat released in relation to the number of occupants, express a linear behavior, considering the temperature of 37.5 ℃ being this the most expressive for the convection between the occupants and the environment, as shown in Tables 3, 4 and 5:

Table 3. Convection of heat between 10 occupants and the internal environment – Body temperature $T_s = 37.5\,℃$.

Room temperature (T_∞)	$\dot{q}_{total\ internal\ (W)}$
23.3 ℃	1335.51
24.7 ℃	1222.39
26 ℃	1121.12

Table 4. Convection of heat between 30 occupants and the internal environment – Body temperature $T_s = 37.5\,℃$.

Room temperature (T_∞)	$\dot{q}_{total\ internal\ (W)}$
23.3 ℃	3086.54
24.7 ℃	2747.17
26 ℃	2443.37

Table 5. Convection of heat between 50 occupants and the internal environment – Body temperature $T_s = 37.5\,℃$.

Room temperature (T_∞)	$\dot{q}_{total\ internal\ (W)}$
23.3 ℃	4387
24.7 ℃	4271.96
26 ℃	3765.62

According to the data shown, the relationship between the number of occupants in the environment and the heat released is significant, as established by Cortiço and Miranda (2021). A second relationship in line with the authors' idea, which is important for the analysis, is also the amount of heat released between the number of occupants and the ambient temperature of 23.3 ℃. This occurs because the value of (ΔT) between the ambient temperature (T_∞) and the body temperature (T_s) is greater and, consequently, the value of the convective coefficient is also greater.

3.2. Relationship between the convective coefficient $(\bar{h})$ and the ambient temperature (T_∞)

The second analysis regarding the conduction of heat from the walls to the internal environment relates the values of the convective coefficient and the internal temperature of the wall of the room. Figure 2 expresses the behavior for the analysis.
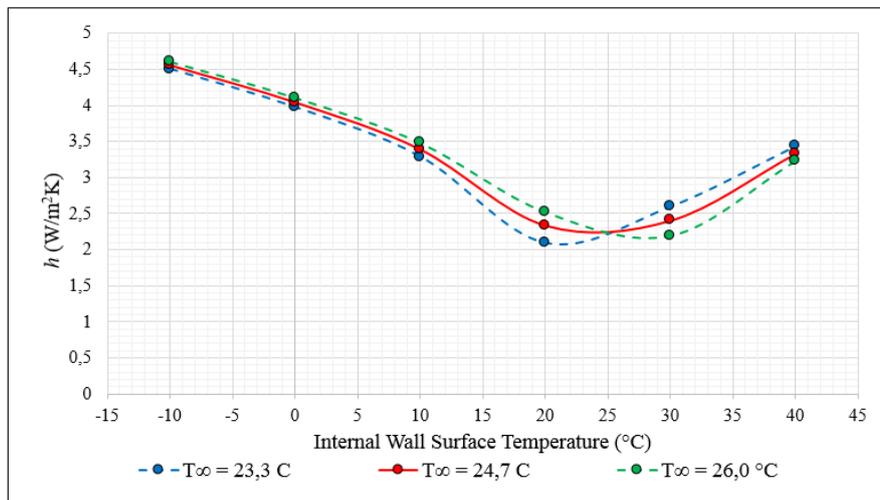

Figure 2. Variation of $(\bar{h})$ as a function of the temperature of the inner face of the wall (T_{s2}).

The results of the convective coefficients contribute to the understanding of the phenomenon of heat exchange. For surface temperatures (T_{s2}) extremely below the ambient temperature (T_∞) the value of $\bar{h}$ becomes more expressive. Likewise, this behavior is observed at temperatures from (T_{s2}) above T_∞. This occurs because the values of ΔT are higher under these conditions, compared to the temperature conditions of (T_{s2}) close to the temperatures T_∞ where the difference between them is less expressive.

3.3. Total heat loss in the boundary condition

Through the heat loss by convection of the occupants of the room and the conduction of heat from the walls, it was possible to quantify the total heat loss of the system. The sets of graphs that demonstrate the different behaviors for 10, 30 and 50 people, considering the thermal comfort temperatures are shown in Figure 3.
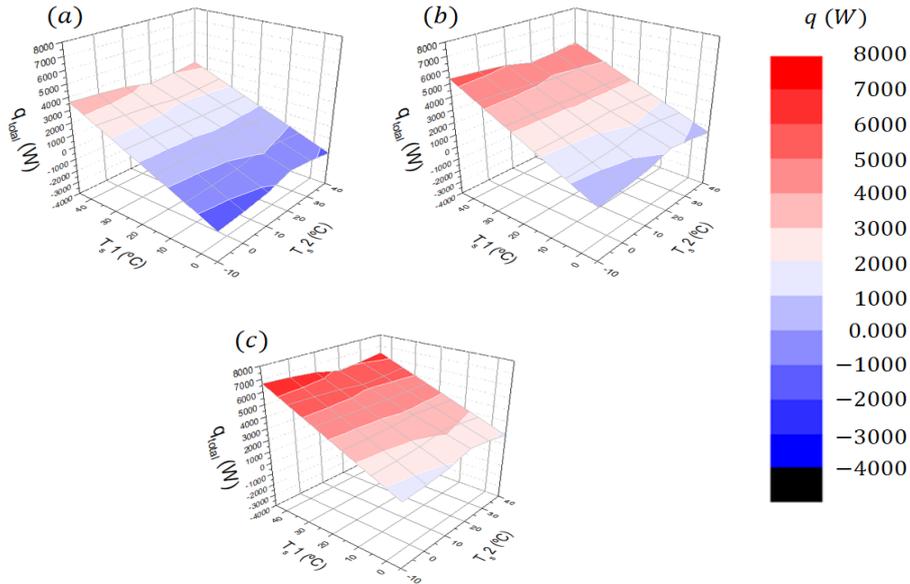

Figure 3. Total heat loss (q_x) in relation to the external surface temperature (T_{s1}) and the internal surface temperature (T_{s2}) of the walls for $T_{inf} = 23.3$°C for (a) 10 people, (b) 30 people and (c) 50 people.

As shown in Figures 3, 4 and 5, it was possible to obtain a ratio of the total heat loss (q_{total}) of the number of people added to the heat loss from the walls for each combination of (T_{s1}) and (T_{s2}), within the scope thermal comfort temperatures of 23.3 °C, 24.7 °C and 26 °C.
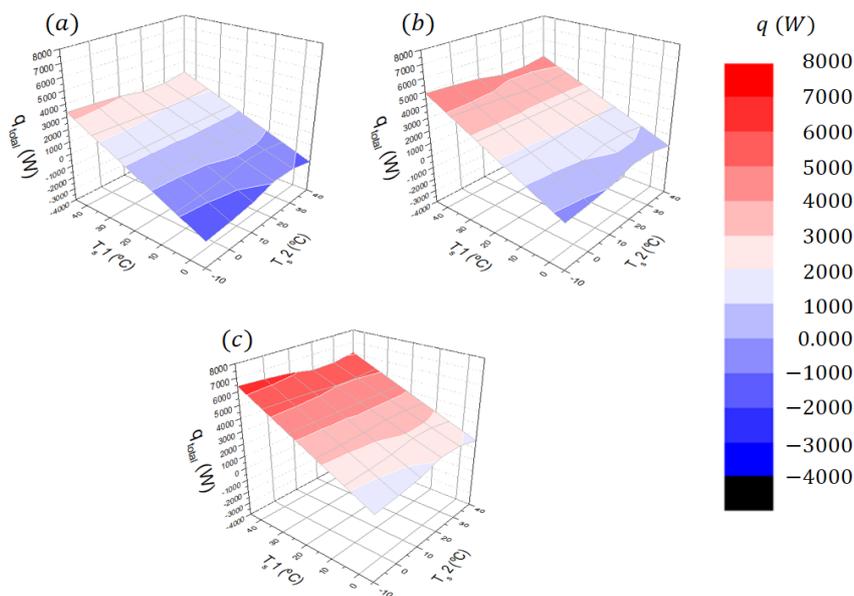

Figure 4. Total heat loss (q_x) in relation to the external surface temperature (T_{s1}) and the internal surface temperature (T_{s2}) of the walls for $T_{inf} = 24.7$°C for (a) 10 people, (b) 30 people and (c) 50 people.
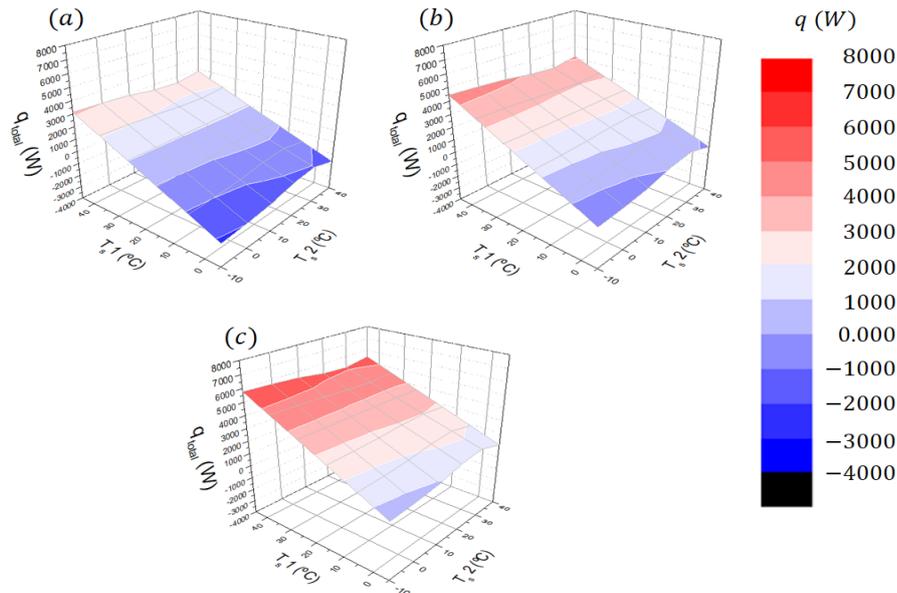
Figure 5. Total heat loss (q_x) in relation to the external surface temperature (T_{s1}) and the internal surface temperature (T_{s2}) of the walls for T_{inf} = 26ºC for (a) 10 people, (b) 30 people and (c) 50 people.

These results corroborate the result obtained by Cortiço and Miranda (2021), maintaining the idea that the number of occupants is strongly related to the amount of heat transferred to the environment, that is, the greater the number of occupants, the greater the concentrated heat. in the environment. In addition, they also show that for high ΔT values, this relationship becomes more expressive, especially at an ambient temperature of 23.3 ºC, where we also find higher values of convective coefficients, as shown in Figure 2.

Finally, we also verified the presence of negative values of heat loss in the three temperatures, mainly in situations with a small number of occupants, where we understand that the heat is transferred from the environment to the surface, helping to cool the contour region.

3.4. Thermal efficiency in the boundary condition

In the results of the thermal efficiency of the system, we first took as a basis the results obtained by Cortiço and Miranda (2021) who in their research concluded that the necessary cooling capacity for the environment would be 16000 BTU/h considering an extreme value for 50 occupants with T_∞ of 23.3 ºC, considering the oversized project for the situation.

Based on this premise, the necessary efficiency was then calculated for the extreme value of heat transferred to the environment in the different scenarios of the study. With these values in hand, it was possible to compare with the minimum and maximum available capacity of available BTU/h, as well as the BTU/h value idealized by Cortiço and Miranda (2021).

Analyzing the data obtained in the study, we observed that the sizing of the cooling capacity of the equipment in the classrooms includes, with a considerable margin, all the situations studied, considering the maximum value of 30,000 BTU/h of the two devices in operation. However, the necessary thermal capacity obtained by Cortiço and Miranda (2021) would only meet the need for cooling at a maximum temperature of 26 ºC of thermal comfort for up to 30 people, and up to 10 people at thermal comfort temperatures of 24.7 ºC and 26ºC. These results show us that, despite the strong relationship between the heat transferred and the number of occupants, adding the heat losses due to lighting, it becomes insufficient for the adequate dimensioning of the refrigeration equipment to maintain the thermal comfort of the environment.

Finally, an alternative to air conditioning equipment was also identified, with the possibility of using two devices with capacities of 12000 BTU/h.

4. CONCLUSIONS

The analysis of thermal efficiency in the academic environment through the method of natural convection and heat conduction was developed within a boundary condition considering the thermal comfort temperatures suggested by the literature and the thermal capacity data suggested by Cortiço and Miranda (2021). When we compare the method suggested by the authors in isolation from natural convection with the addition of the heat conduction method with the walls of the environment, there is a notable difference between the values of the thermal capacity necessary to maintain the conditions of comfort in the environment.

As for the data from the necessary cooling capacity, to supply the heat loss from convection and heat conduction, it is concluded that the available equipment is sufficient to maintain the conditions of thermal comfort in the academic environment. In addition, it emphasizes the importance of a deep analysis of all the factors that influence the thermal efficiency when carrying out the dimensioning of air conditioning in the projects.

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6.   RESPONSIBILITY NOTICE

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