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EVALUATION OF THE THERMAL PERFORMANCE OF INDUSTRIAL SHEDS VIA COMPUTER SIMULATIONS: OBTAINING T_G AND T_{WB} BY MEANS OF ITERATIVE ALGORITHMS FOR APPLICATION IN THE INDEX WBGT

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Abstract. In a broader context, the study of environmental comfort in buildings evaluates a new approach in relation to architecture, since it seeks to define a new treatment of the construction parameters considering, in short, the place, its surroundings, the climatic context and the practices of construction sites combined with environmental awareness. In Brazil, these discussions on energy efficiency are gaining importance, and the search for buildings with better thermal performance and lower energy consumption is more evidence. Thus, an analysis of the thermal performance is carried out via computer simulation of industrial sheds equipped with an internal source of high intensity heat, in order to assess the internal conditions of hygrothermal comfort. The influence of some configurations of the natural ventilation apparatus is studied, and the final annual results are compared with the limits of the wet-bulb globe temperature (WBGT), as a way of assessing occupational exposure to heat. The WBGT index consists of a thermal overload, defined by a mathematical equation that correlates the globe temperature and wet-bulb temperature measured in the workplace. The globe temperature (T_g) and wet-bulb temperature (T_{wb}) are not possible outputs to be obtained directly from the EnergyPlus software and, for this reason, they are found through the algorithms formulated from iterative techniques. Basically, three variables of environment are of interest: temperature, air speed, and relative humidity. The proposed algorithms converge properly and, when comparing the final annual results of the WBGT index with the limits provided for in the Brazilian regulatory standard NR-15, it is observed that the shed equipped with longitudinal and transversal ridge vents has better thermal performance, thus providing less time of discomfort due to the heat.

Keywords: thermal performance, natural ventilation, iterative methods, WBGT index.

1. INTRODUCTION

Working in a thermally uncomfortable environment, especially in hot environments, in addition to the general discomfort caused by the effort of the heart that will beat faster and the increase in blood circulation, it is known that people may experience nausea, nausea and even faint, symptoms those that are indicative of the need to suspend work (Scigliano and Hollo, 2001). In some cases, these symptoms may not be so obvious and individuals may not realize the stress they are being subjected to, which substantially increases the risk of accidents (Baeza *et al.*, 2006).

An evaluation of the thermal performance must take into account the climatic information characterized by the dry-bulb temperature, relative humidity of the air, solar radiation, wind direction and speed, since these variables are decisive for the evaluation of the thermal interactions between the external environment and internal through the building envelope (Baptista *et al.*, 1999, Boulard and Baille, 1995). The storage of thermal energy that occurs in the building closings influences the effects that these climatic variables have on the indoor air temperature, which will be more attenuated the greater the building's thermal inertia. In summary, when assessing the thermal performance of buildings, climatic data corresponding to a typical day are adopted, characterized by hourly values of the climatic variables throughout this day (Akutsu, 1998, Kovacic *et al.*, 2013). The WBGT is a heat stress index and its value represents the thermal environment to which an individual is exposed. This index is easy to determine in most environments. It should be regarded as a screening method to establish the presence or absence of heat stress, according to standards from ISO 7243 (2017).

This paper implements an algorithm for obtaining the hourly globe and internal wet-bulb temperature required to determine the WBGT index (wet-bulb globe temperature) which allows the evaluation of working conditions in an industrial environment subject to high temperatures.

2. ASSESSMENT OF OCCUPATIONAL EXPOSURE TO HEAT

Thermal stress is defined as the result of unfavorable microclimate conditions that require the intervention of the thermoregulatory system, since, for the proper functioning of the human organism, the body temperature must be maintained at around 37 °C. The Regulatory Norm for Safety and Hygiene at Work NR-15 (1978) - Unhealthy Activities and Operations, through Ordinance MTb N° 3,214, of June 8, 1978, in its Annex 03, provides for the Wet-Bulb Globe Temperature - WBGT, as a Brazilian legal technical index for assessing working conditions in environments with high temperatures. This index combines the air temperature (dry-bulb temperature), T_{db}; natural wet-bulb temperature (naturally ventilated environment), T_{wb}; and the globe temperature, T_g; and represents the weighted average of these measures. This index is obtained for indoor or outdoor environments without solar charge through "Eq. (1)":

$$WBGT = 0.7 \cdot T_{wb} + 0.3 \cdot T_g \qquad (1)$$

The WBGT is an index used in the industry for specifying levels of exposure to hot environments, safe for workers. T_{wb} is a type of temperature measurement that reflects the physical properties of a system consisting of the evaporation of water in the air and has the function of simulating the worker's skin, wet with sweat. T_g, on the other hand, is the temperature of a place, effective for several purposes, the majority being for the purpose of controlling the temperature of the medium (Boulard and Draoui, 1995).

The standard NR-15 (1978), Annex 03, establishes the limits of tolerance that the value of WBGT given by "Eq. (1)" for exposure to heat, in an intermittent work regime with periods of rest at the service location itself "Table 1".

Table 1. WBGT limit values (°C) - Rest at the workplace

Intermittent work regime with rest at the workplace (hourly)	Type of activity		
	Weightless	Moderate	Weighty
Continuous work	until 30.0	until 26.7	until 25.0
45 minutes work 15 minutes rest	30.1 a 30.5	26.8 a 28.0	25.1 a 25.9
30 minutes work 30 minutes rest	30.7 a 31.4	28.1 a 29.4	26.0 a 27.9
15 minutes work 45 minutes rest	31.5 a 32.2	29.5 a 31.1	28.0 a 30.0
Work is not permitted without the adoption of adequate control measures	above 32.2	above 31.1	above 30.0

Source: NR-15 (1978).

3. METHODOLOGY

The research methodology used is based on the performance of parametric variations using the EnergyPlus computational simulation tool through a computer model based on an industrial shed. An industrial building equipped with an internal source of high intensity heat is studied by means of a computational model, located in the Brazilian climatic context in the region of the city of Belo Horizonte "Table 2", equipped with longitudinal and/or transversal ridge vents.

Table 2. Geographic location of the city of Belo Horizonte/MG/Brazil

Federal Unit	Bioclimatic Zone	City	Latitude	Longitude	Elevation (m)
MG	ZB3	Belo Horizonte	19.93S	43.93W	850

Source: NBR 15575 (ABNT, 2013).

3.1 About the simulated industrial building

"Figure 1" shows the 3 models of the simulated industrial shed. The differences attributed to the sheds are due to the increase in natural ventilation due to the increase in the height of the longitudinal ridge vent and the inclusion of transverse ridge vents. "Figure 2" and "Figure 3" show, respectively, the internal and external perspectives of the geometric model of the simulated industrial shed. "Table 3" shows the building materials constituting the envelope of the analyzed shed. The additional information related to the characterization of the internal thermal loads of this proposed and analyzed

industrial building: a heat source with a nominal power of 1 MW is adopted, characterizing a medium-sized industry and for artificial lighting a level of 500 lux, that is, 30 W/m², which results in a total heat released of 89,938.8 W and an occupation with 45 employees in moderate activities with an individual metabolic rate of 175 W.
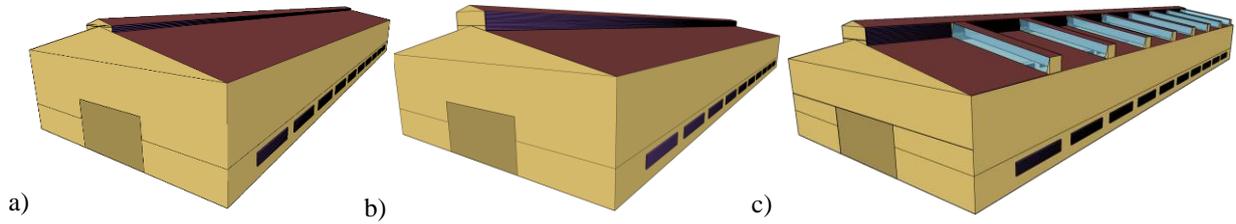

Figure 1. Computational model of the simulated industrial building: a) base model - 0.5 m ridge vent; b) shed with a 1.0 m longitudinal ridge vent; c) shed with longitudinal and transversal ridge vent.
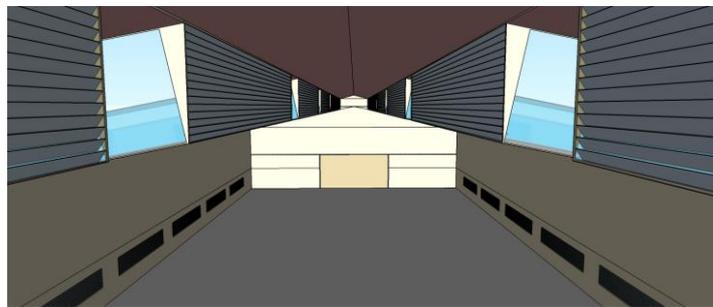

Figure 2. Internal visual perspective of the industrial shed equipped with longitudinal and transversal ridge vents.

Figure 3. External visual perspective of the industrial shed equipped with longitudinal and transversal ridge vents (with shadows).

Table 3. Thermophysical characteristics and absorbance of the materials of the industrial building.

Material	Roughness	Thickness (cm)	Thermal Conductivity κ (W/m.K)	Specific mass ρ (kg/m³)	Specific heat c (J/kg.K)	Absorbance		
						$α_t$ Thermal	$α_s$ Solar	$α_v$ Visible
Masonry wall (up to 3 meters high)								
Perforated concrete block	medium rough	20.0	0.57	1,040.0	830.0	0.90	0.60	0.60
Plastering mortar	medium rough	2.0	0.72	1,860.0	830.0	0.90	0.50	0.50
Floor								
Concrete	rough	10.0	1.75	2,400.0	1,000.0	0.90	0.70	0.70
Roof, Metal Closure and Ridge vent								
Galvanized steel sheet	smooth	0.2	55.0	7,800.0	460.0	0.90	0.25	0.25

Source: NBR 15220 (ABNT, 2005).

"Figure 4" illustrates the industrial shed (base model) and shows the application of the closure materials according to the division presented in "Table 3".
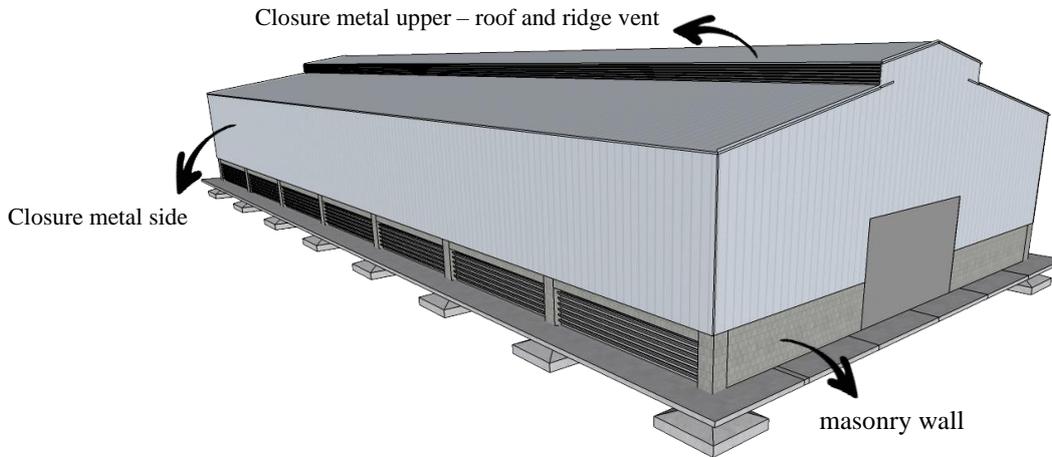

Figure 4. Closure materials for the industrial shed.

3.2   Computational approach

The EnergyPlus program (DOE, 2018) is used for parametric variations of the physical elements, natural conditions and for calculating the hours of discomfort after computer simulations. In the software, the airflow calculation model used is the AirflowNetwork. The pressure coefficients are automatically calculated by the program, since it is a building with rectangular geometry, this limiting condition for this. The simulations are configured to be carried out with the determined situation and opening factor 1 (100%) for all air inlet and louver openings, with the access gates always considered closed (opening factor 0). In use of light and rain protection devices, such as industrial shutters, present in all openings, the flow coefficient for each area is equal to 0.40 as recommended by Idel'cik (1969) *apud* Clezar and Nogueira (2009).

3.3   Obtaining the WBGT index

As previously mentioned, the assessment of exposure to heat occurs by comparison with the limits established by the NR-15 (1978), which provides for the WBGT index - wet-bulb globe temperature "Eq.1" as a Brazilian legal technical standard for the evaluation of working conditions in environments with high temperatures. This index combines the natural wet-bulb temperature (naturally ventilated environment), T_{wb}, and the globe temperature, T_g. However, temperatures T_{wb} and T_g are not possible outputs to be obtained directly by the EnergyPlus thermal simulation software, therefore, they are obtained from the algorithms made and shown below.

"Table 4" shows the algorithm for obtaining the hourly internal wet-bulb temperature for the total hours worked in the standard year ($t = 8760$ h). T_{wb} is obtained in an iterative way, knowing the dry-bulb temperature (T_{db}) and the relative humidity (RH) of a given state point. In this case, the dry-bulb temperature is gradually decreased, keeping the enthalpy value constant, until a state point is reached whose relative humidity value is equal or very close to 100%. At each iteration, the value of the humidity ratio, saturation pressure, partial vapor pressure and relative humidity is calculated, considering a wet-bulb temperature equal to the temperature used in the previous iteration decreased by a value previously chosen by the user (Miranda *et al.*, 2006). Since this method is performed with the use of computer programs, both the initial decrease and the stop condition must be very small values, which makes it possible to obtain more accurate results, demanding greater numbers of iteration (computational cost). An initial decrease of 0.001° C is considered in this algorithm, and the stop condition occurs when the difference is less than or equal to 0.1° C.

Table 4. Iterative methodology for obtaining the wet-bulb temperature - T_{db} (to be continued)

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1. READ the $\mathbf{T_{db}}$ and **RH** vectors that will store the dry-bulb temperature and humidity results relative, respectively, for each hour of work;
2. SOLUTION: t = 1, 2, ..., 8760.
    2a. Calculate p_{sv} (saturated vapor pressure) for dry-bulb temperature:
$$p_{sv} = 0.6108 \cdot \exp(p_{ar}^{0}), \text{ where: } p_{ar} = (17.3 \cdot {}^{t}T_{db}) / (237.3 + {}^{t}T_{db})$$
    2b. Calculate p_v (vapor pressure): $p_v = {}^{t}RH \cdot p_{sv} / 100$
    2c. Calculate the humidity ratio (w) for dry-bulb temperature: $w = 0.622 \cdot p_v / (P_a - p_v)$,

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Table 4. Iterative methodology for obtaining the wet-bulb temperature - T_{db} (end)

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where P_a = atmospheric pressure in kPa.

2d. Calculate enthalpy (h) for dry-bulb temperature: $h = 1.006 \cdot {}^t T_{db} + w(2501 + 1.775 \cdot {}^t T_{db})$

3. ITERATIVE PROCESS: for k = 1, 2, 3, ...

If k = 1 then ${}^t T_{wb} = {}^t T_{db}{}^k - 0.001$ if not ${}^t T_{wb}{}^k = {}^t T_{db}{}^{(k-1)} - 0.001$

3a. Calculate the humidity ratio for T_{db}: $w^k = (h - 1.006 \cdot {}^t T_{wb}{}^{(k)}) / (2501 + 1.775 \cdot {}^t T_{wb}{}^{(k)})$

3b. Calculate p_v for T_{db}: $p_v{}^k = (w^{(k)} \cdot P_a) / (0.622 + w^{(k)})$

3c. Calculate p_{sv} for T_{db}: $p_{ar}{}^k = (17.3 \cdot {}^t T_{wb}{}^{(k)}) / (237.3 + {}^t T_{wb}{}^{(k)})$ where: $p_{sv}{}^k = 0.6108 \cdot \exp(p_{ar}{}^{(k)})$

3d. Calculate RH for T_{db}: $RH_k = (100 \cdot p_v{}^{(k)}) / p_{sv}{}^{(k)}$

3e. If $100 - RH_k$ for ≤ 0.1 stop and print ${}^t T_{wb}{}^k$ otherwise, continue until such condition is met (return to step 3).

4. DO IT: Return to step 2 until t = 8760

"Table 5" shows the algorithm for obtaining the annual internal globe temperature. T_g is obtained at from "Eq. (3)" isolating this variable through of "Eq. (2)". Of that equation, the only variable that is not a possible output to be extracted from EnergyPlus is the globe temperature. Thus, "Eq. (2)" is rewrite as follows:

$$T_{mr} = \sqrt[4]{\left(T_g + 273\right)^4 + 2.5 \cdot 10^8 \cdot v^{0.6} \cdot (T_g - T_{db})} - 273 \tag{2}$$

$$Eq = -T_{mr}{}^4 - 1092 \cdot T_{mr}{}^3 - 4.4718 \cdot 10^5 \cdot T_{mr}{}^2 - 8.1386 \cdot 10^7 \cdot T_{mr} + T_g{}^4 + 1092 \cdot T_g{}^3 + 4.4718 \cdot 10^5 \cdot T_g{}^2 +$$
$$+9.1386 \cdot 10^7 \cdot T_g + 2.50 \cdot 10^8 \cdot v^{0.6} \cdot T_g - 2.50 \cdot 10^8 \cdot v^{0.6} \cdot T_{db} \tag{3}$$

where: T_{mr} is the mean radiant temperature (°C); T_g is the globe temperature (°C); T_{db} is the air temperature (°C) and v is the speed of the air (m/s).

"Equation (3)" is defined as a strongly non-linear equation. The Newton-Raphson method is defined as an iterative method that uses the sequence convergence property to guarantee a fast convergence for the solution, from the moment that x_{n+1} approaches a close neighbor of x^*. Therefore, a premise of the method is to determine a function $y(x)$ such that the first derivative of the function f is $f'(x^*) = 0$ and thus ensure that, in a neighborhood close to x^*, a function f is such that $|f| \ll 1$. Basically, the Newton-Raphson method is given by "Eq. (4)":

$$x_{n+1} = x_n - \frac{f(x_n)}{f'(x_n)} \tag{4}$$

Therefore, the Newton-Raphson iterative method is chosen to find possible positive real roots of "Eq. (3)". In solving this equation, find the hourly T_g value for the total of 8760 hours of the city-type year simulated. In this algorithm, the initial guess for the T_g value equal to 30.0 °C and the maximum accepted tolerance value to find a root of the equation being equal to tol = 10^{-7} is considered. This as a way of ensuring a good convergence. The first derivative of "Eq. (3)" as a function of T_g is given by "Eq. (5)":

$$Eq'(T_g) = 4 \cdot T_g{}^3 + 3276 \cdot T_g{}^2 + 8.9436 \cdot 10^5 \cdot T_g + 8.1386 \cdot 10^7 + 2.5 \cdot 10^8 \cdot v^{0,6} \tag{5}$$

Table 5. Incremental iterative methodology to obtain the globe temperature - T_g (to be continued)

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1. INITIAL DATA OF THE ANALYSIS:

1a. T_{mr}, v and **T_{db}** matrices are read that will store, respectively, the mean radiant temperature values, air speed and dry-bulb temperature every hour.

2. SOLUTION: t = 1, 2, 3, ..., 8760.

3. NEWTON-RAPHSON ITERATIVE PROCESS: k = 1, 2, 3, ...

3a. Calculates the value of the objective function and its derivative

${}^t E_q = - {}^t T_{mr}{}^4 - 1092 \cdot {}^t T_{mr}{}^3 - 4.4718 \cdot 10^5 \cdot {}^t T_{mr}{}^2 - 8.1386 \cdot 10^7 \cdot {}^t T_{mr} + {}^{(k-1)} T_g{}^4 + 1092 \cdot {}^{(k-1)} T_g{}^3 + 4.4718 \cdot 10^5 \cdot {}^{(k-1)} T_g{}^2 +$

Table 5. Incremental iterative methodology to obtain the globe temperature - T_g (end)

$$+8.1386 \cdot 10^7 \cdot {}^{(k-1)}T_g + 2.50 \cdot 10^8 \cdot {}^t v^{0.6} \cdot {}^{(k-1)}T_g - 2.50 \cdot 10^8 \cdot {}^t v^{0.6} \cdot T_{db}$$

$${}^t E_q{}' = 4 \cdot {}^{(k-1)}T_g{}^3 + 3276 \cdot {}^{(k-1)}T_g{}^2 + 8.9436 \cdot 10^5 \cdot {}^{(k-1)}T_g + 8.1386 \cdot 10^7 + 2.50 \cdot 10^8 \cdot {}^t v^{0.6}$$

3b. Do it: $T_g^k = T_g^{(k-1)} - {}^t E_q / {}^t E_q{}'$

3c. If ${}^t E_q / {}^t E_q{}'$, go to 3d if not, calculate ${}^t E_q$ and ${}^t E_q{}'$ calculated in step 3a with T_g^k calculated in step 3b (return to step 3).

3d. ${}^t T_g = T_g^k$

4. PRINT the tolerance values and the number of iterations needed for convergence.

5. RETURN to step 2 until t = 8760.

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4. RESULTS AND DISCUSSION

In order to compare the values of the internal temperature of the industrial shed with the limits and recommendations established in the NR-15 (1978). The computer simulation is carried out extracting as outputs the variables necessary for application in "Eq. (1)", a namely: site outdoor air dry-bulb temperature (T_{db}), mean radiant temperature (T_{mr}) and relative humidity (RH).

In view of this, assuming for the industrial shed studied here that workers would be developing moderate-type activity and adopting an intermittent work regime with rest at the workplace (by the hour), aiming at continuous detachment from work during the day, it has the maximum value for the WBGT index is equal to 26.7 °C "Table 1".

4.1 Weather conditions and simulation period

For the hourly and annual computer simulations of the industrial shed, climate data from the city of Belo Horizonte/MG, of the TRY type, available on the website of the EnergyPlus program are used. The city of Belo Horizonte is located in bioclimatic zone number 3 (ZB3) as recommended by the NBR 15.220 standard (ABNT, 2005). "Figure 5" and "Figure 6" show, respectively, the annual evolution of dry-bulb temperature and external relative humidity for the city of Belo Horizonte – MG. In "Figure 6", the hourly evolution of the maximum dry-bulb temperature (09/24), minimum (07/31) and relative humidity of the two extreme days of the annual file for this city is presented. In summer, the maximum dry-bulb temperature is 34.8 °C, while in winter the minimum is 8.9 °C. Therefore, following the data from the climate file, considering only the summer period (a mitigating condition for the increase in the internal temperature profile inside the analyzed building), all the hourly computer simulations are carried out for that day (09/24) during the 24 h assumed to be the function-work activities.
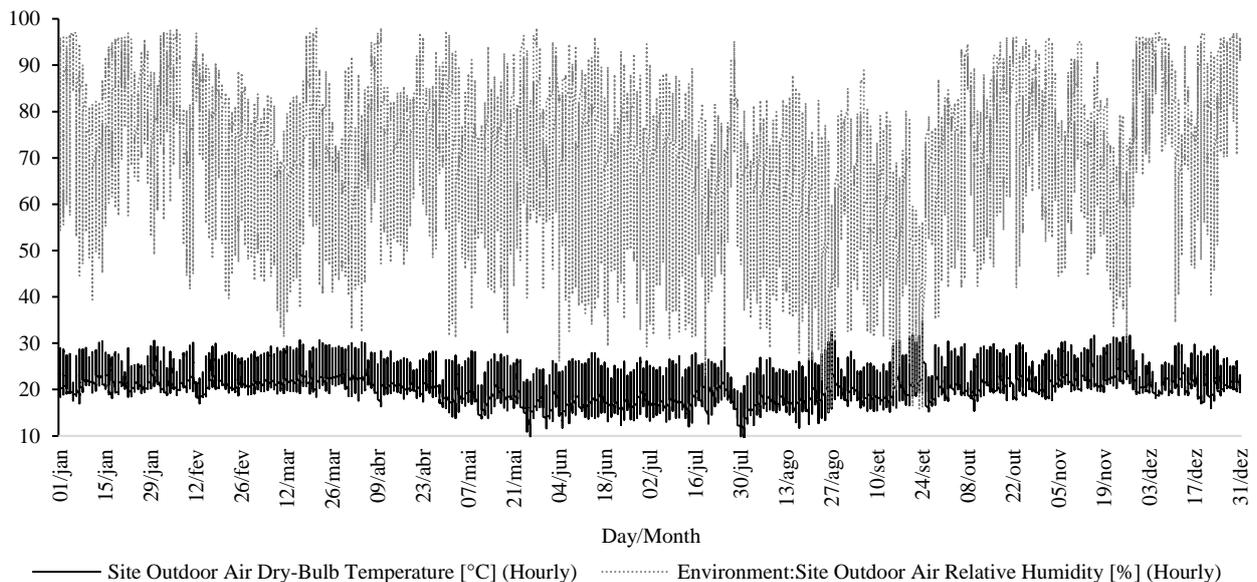

Figure 5. Site outdoor air dry-bulb and relative humidity annual for Belo Horizonte/MG/Brazil.
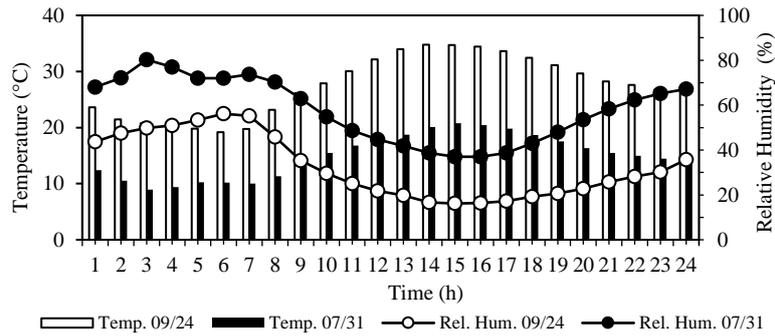
Figure 6. Extreme summer and winter weather conditions for Belo Horizonte/MG/Brazil.

4.2 Thermal performance assessment

Based on best results from previous simulations for best condition of natural ventilation and the influence of the closure systems evaluated, it is shown in the "Table 6" the best configuration for the physical interventions adopted in this paper.

In terms of the lowest internal temperature peak for the industrial shed, there is as the best configuration found regarding: presence and height of the ridge vent longitudinal, position of the air inlet openings and presence and distance of the ridge vent transversal. With this result, it is intended to contribute to the improvement of conditions of work through the internal hygrothermal conditions of large buildings, especially those with a high intensity internal heat source.

Table 6 - Better configuration of the industrial shed

Elements and devices providing natural ventilation				
Longitudinal ridge vent		Position of air intake openings	Transversal ridge vent	
Presence	Height		Presence	Spacing
Yes	1.50 m	1.20 m	Yes	10 m

Therefore, a computer simulation is carried out for the industrial shed characterized with such a configuration and its internal temperature peak is compared with the base model, for the day with extreme summer outdoor air dry-bulb temperature for the city from Belo Horizonte/MG. From the results shown in "Figure 7", it is possible to observe that, armed with the final configuration, there is a significant reduction in the industrial shed's internal temperature profile throughout the simulated day. In the case of the outdoor temperature peak (15 h), this reduction in the internal temperature reaches 5.4 °C. This result corroborates the statements that advocate the importance of a careful selection of the construction materials constituting the wrapping of the buildings, as well as emphasizes the importance of natural ventilation for the achievement of acceptable conditions of thermal discomfort, especially in industrial environments (Chu and Lan, 2019).
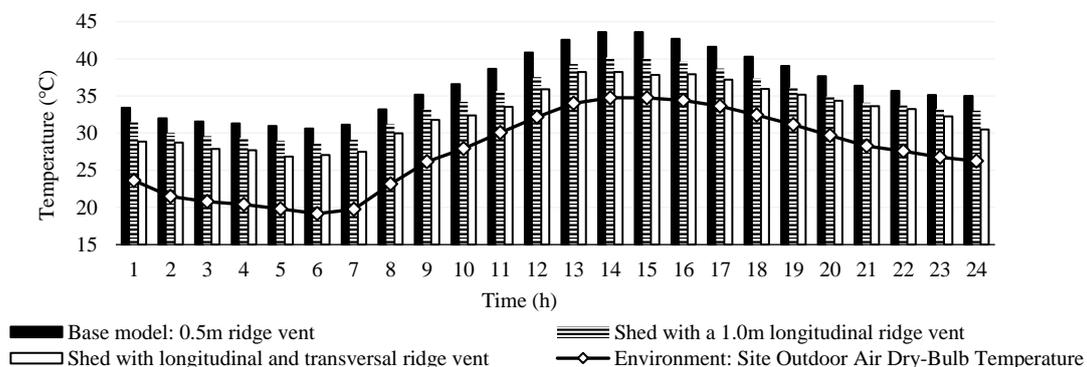

Figure 7. Comparison of T_{db} for the 3 configurations of the analyzed industrial shed.

4.3 Annual evaluation - WBGT Index

"Figure 8" shows the annual evolution of the WBGT index of the base model shed. Taking the limit established by the NR-15 (1978), it can be seen that, in this configuration, the internal temperature exceeds the recommended for the continuous work regime for most of the year. From the chart above, the maximum value of WBGT obtained is 33.5 °C recorded on 11/16, and the minimum value is 19.2 °C recorded on 07/31. Note that relative humidity (RH) directly

influences the WBGT, since T_{wb} is explicitly dependent on RH, and in the calculation T_{wb} represents 70 % of the value of this index. Therefore, despite the peak of dry-bulb temperature outside Belo Horizonte being on September 24, for that same day, there are the smallest peaks of indoor relative humidity in the shed, which contributes to the decrease of the day's WBGT index.
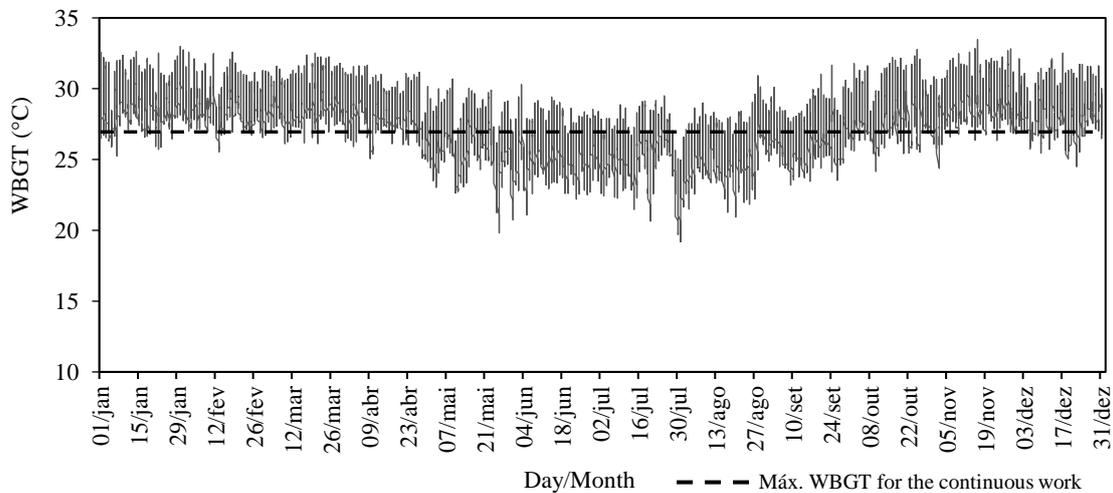

Figure 8. Annual evolution of WBGT for the base model shed (Figure 1a)

"Figure 9" shows the annual evolution of the WBGT index of the shed equipped with a 1.50 m high longitudinal ridge vent (Figure 1b). Taking the limit established by the NR-15 standard (1978) for this index, it can be seen that, in this configuration, the internal temperature also exceeds the recommended for the continuous work regime for most of the year. The graph shows that the maximum value of WBGT obtained is 32.5 °C recorded on 11/16, and the minimum value is 18.6 °C recorded on 07/31. Note that, for the extreme days of WBGT in this configuration, there is a reduction of up to 1° C for 11/16 and a reduction of up to 0.6° C for 7/31 compared to the base model (Figure 1a).

"Figure 10" shows the case of the shed equipped with longitudinal and transversal ridge vents (Figure 1c). It appears that the maximum value of WBGT obtained is 29.1 °C registered on 02/18, and the minimum value is 13.8 °C registered on 07/30. The extreme days for the WBGT index differ from those registered in the other evaluated configurations, and this is due to the inclusion of the transverse ridge vents. These directly infer from the environmental variables wet-bulb temperature and relative humidity, since through these devices there is a considerable increase in the rates of indoor air renewal and air infiltration volume into the industrial shed.
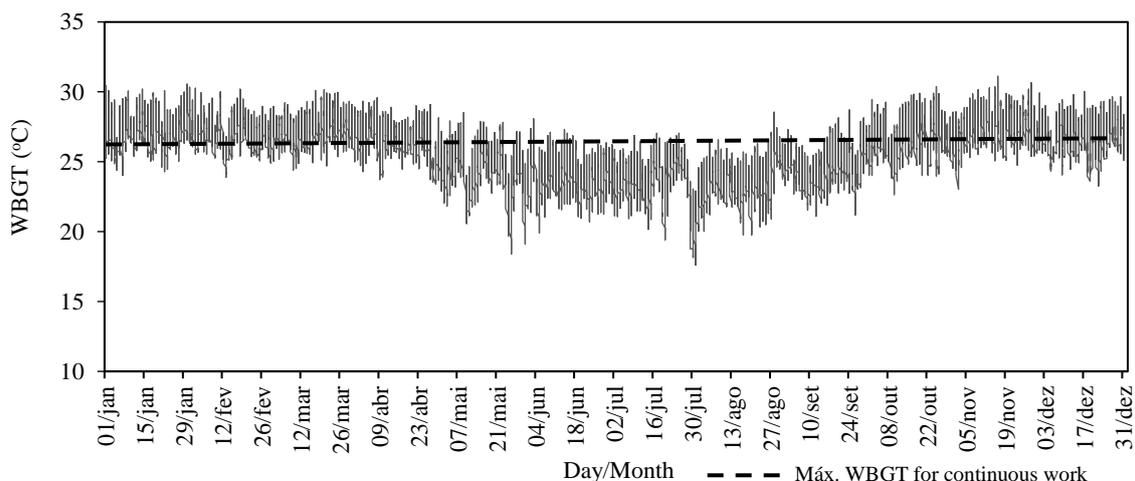

Figure 9. Annual evolution of WBGT for the shed with longitudinal ridge vent (Figure 1b)

It can be noted, with this set of results, that the physical interventions suggested in this work directly contribute to improve the global thermal performance of the industrial building studied and tend to contribute to the improvement of working conditions, as well as to increase the feeling of well-being and in the productivity of all involved (Kondola, 1990).
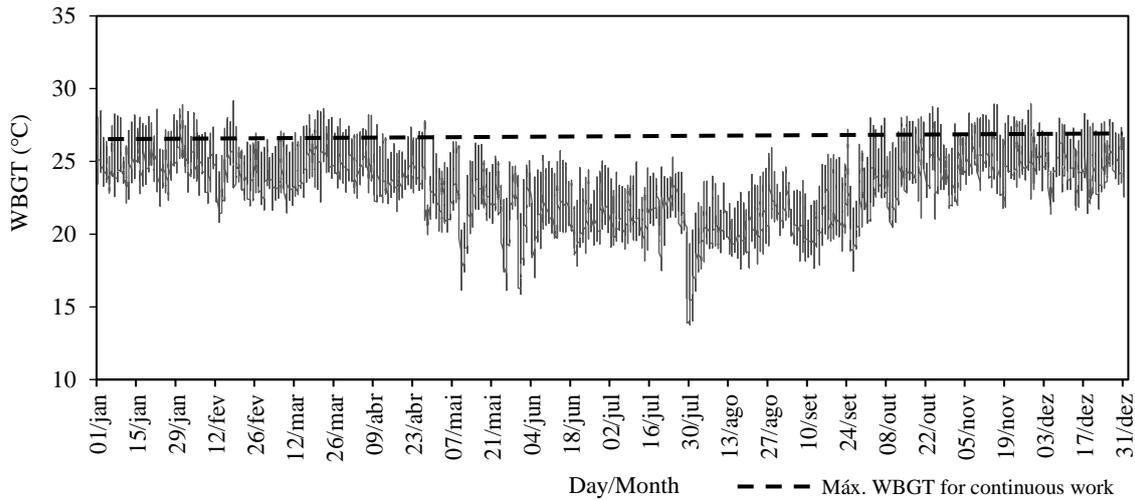
Figure 10. Annual evolution of WBGT for the shed with longitudinal and transversal ridge vents (Figure 1c).

4.4 Analysis of hours of discomfort

"Figure 11" show the total of hours of monthly discomfort for the three configurations of the analyzed industrial shed. It is observed that the shed with the best configuration proposed in this work has a total of monthly hours which exceeds the value of 26.7 °C of the WBGT, quite negligible compared to other settings for this same industrial building, with no time being recorded above this limit for the months of May to August, a fact that does not happen for another configuration proposed in this paper.
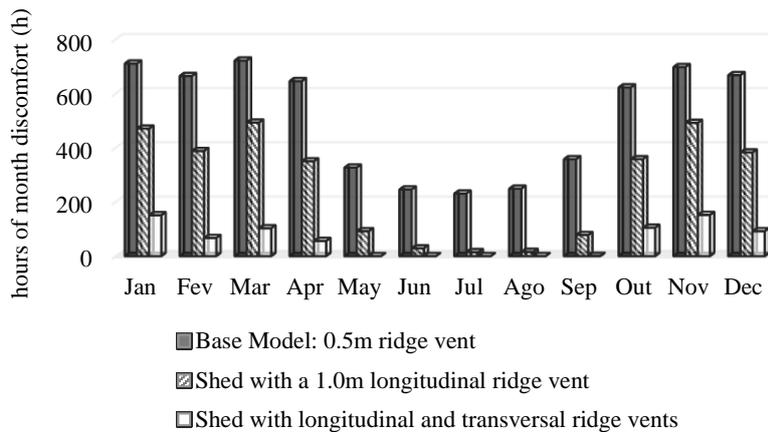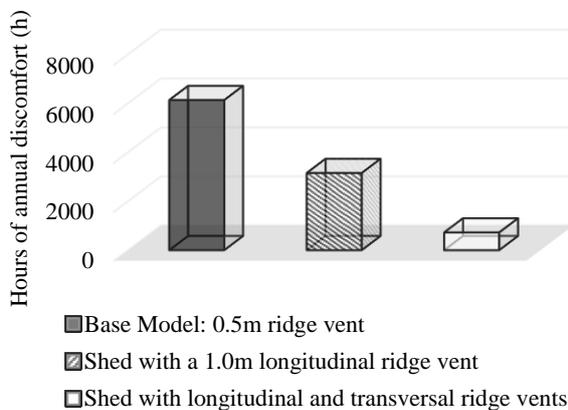

Figure 11. Total hours of month discomfort.

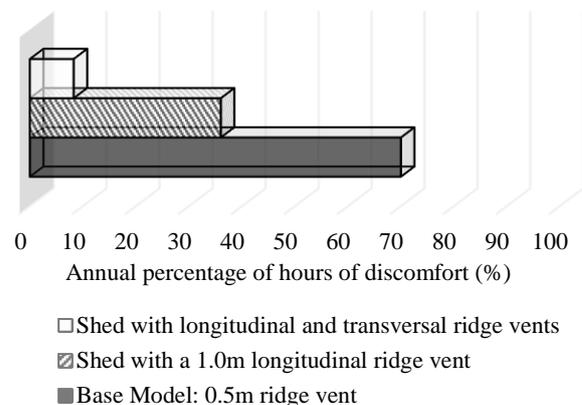Figure 12. Total hours of annual discomfort.

Figure 13. Annual percentage of hours of discomfort.

"Figure 12" and "Figure 13" show, respectively, the total and percentage of hours of discomfort for the three configu-

rations of the industrial shed. Comparing them, it is clear that there is a difference of up to 5411 h less local discomfort felt by workers in the development of moderate activities in this same work environment, corresponding to only 8.25% of the total hours above the limit stipulated by WBGT by the NR-15 (1978) in the case of the shed with longitudinal and transverse ridge vents compared to the other configurations of the same shed.

Finally, the total hours of discomfort are systematized by comparing some configurations for the same industrial shed based on the best results obtained in this paper. The final results corroborate the prerogative raised in this work about the important relationship between the total air outlet area and thermal performance, in the case of sheds equipped with internal sources.

5. CONCLUSION

The final results corroborate the prerogative raised about the important relationship between the total air outlet area and thermal performance, in the case of sheds equipped with internal sources. It is noted, with this set of results, that the algorithms obtained good convergences since the results were consistent with the results from the simulation with EnergyPlus. These results demonstrate that the construction interventions suggested in this work directly contribute to improve the global thermal performance of the industrial building studied, through the increase of natural ventilation (coming from the use of ridge vents), and tend to collaborate to improve working conditions, as well as increasing the sense of well-being and productivity of all involved.

6. REFERENCES

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7. RESPONSIBILITY NOTICE

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