MODELING OF PROTECTION AND SHADING DEVICES FOR NATURALLY VENTILATED INDUSTRIAL BUILDINGS

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ABSTRACT

When considering natural ventilation and upper openings designed for hot air release, it's observed that airflow naturally ascends due to geometric factors. This phenomenon, known as the chimney effect, allows hot air to exit the building without the need for mechanical ventilation intervention. Some authors have empirically determined that the installation of industrial venetian blinds can lead to a loss in internal airflow efficiency of up to 70%, primarily due to the presence of the ridge vent. However, in this study, the raised hypothesis regarding the influence of these devices on airflow through the openings and internal temperature could not be confirmed. Neither the modeling with shading elements nor the detailed technical characterization using the Shade object yielded the expected results. Further validation of the findings is advised through the utilization of dependable technical data from industrial venetian blind manufacturers, comparing it with experimental results.

KEYWORDS: *Industrial Venetian Blinds, Heat Source Spaces Evaluation and Industrial Workplace.*

I. INTRODUCTION

Uncomfortable work environments pose a significant challenge for workers. In situations of excessive heat and humidity, the human body can experience heat loss or gain in its effort to maintain equilibrium. Consequently, workers often experience discomfort and malaise, which can lead to reduced productivity and compromise occupational safety and health (Scigliano & Hollo [1]; Zhang *et al*. [2]).

In workplaces with multiple internal heat sources, it becomes necessary to alleviate thermal conditions through indoor air exchange. Typically, this involves the implementation of mechanical equipment, known as forced ventilation. To address the need for mechanical conditioning systems, natural ventilation can be harnessed to ensure suitable indoor conditions. This alternative is promising as it is crucial for maintaining thermal balance, enhancing the intensity of the physical heat exchange processes between the human body and the environment, improving air quality, and reducing indoor temperatures. Industrial buildings serve as significant examples of environments where ventilation is necessary, whether through natural, mechanical, or hybrid means (Tian *et al.* [3]; Zhang *et al*. [2]; Bach *et al.* [4]).

In Brazil, architectural designs for industrial buildings that prioritize thermal comfort are nearly non-existent. The potential of natural ventilation and daylighting is often underutilized, resulting in work environments that do not favor workers (Geraldi *et al*. [5]). An alternative to ensuring thermal comfort in industrial workspaces is the use of shading and protection devices, such as industrial venetian blinds. Proper positioning and design of these blinds can reduce internal solar radiation and allow for the entry of air, ultimately improving thermal comfort. Additionally, devices that facilitate air exchange, known as ridge vents, can be installed on the roof. Properly designed openings in these ridge vents are essential tools for enhancing thermal comfort in work environments (Chen *et al*. [6]). The assessment of occupational exposure to high temperatures is performed based on the standards established in NR-15 (BRAZIL, [7]). To quantify the temperature perceived by the worker, the Wet-Bulb Globe Temperature (WBGT) index is calculated, which simulates the worker's skin being wet with sweat (°C). It is calculated using Equation 1 as prescribed by ISO 7243 (ISO, [8]):

$$WBGT = 0{,}7T_{wb} + 0{,}3T_g \quad (1)$$

In which T_{wb} represents the natural wet bulb temperature (°C), and T_g is the globe temperature (°C).

In this context, the aim of this paper is to assess the influence of natural ventilation in industrial buildings with internal heat sources. This assessment involves parameterizing the openings for air intake and exhaust, which in this case are ridge vents equipped with industrial venetian blinds. The ultimate goal is to enhance occupational exposure conditions by comparing the WBGT results to the recommendations provided in NR-15 (BRAZIL, [7]). The benefits of natural ventilation in terms of the environmental exposure of building occupants have been studied over several decades. Among the various works, some that add technical information to this are highlighted in Table 1.

Table 1. Citation-reviewed articles (continued)

Author's	Period	Type of building	Objective	Method	Key contribution
Cruz-Salas *et al*. [28]	-	Residential (Room)	Experimentally study airflow when a room has a window on the windward side and an exhaust fan is in use.	Experimental setup: Rooms were created at a proportional scale, and fluid flow was measured using a water channel, with velocity measured by SPIV.	The orientation of the hood faces is the primary factor affecting performance. When two opposite faces are open without partitioning, it results in the greatest flow, which is four times greater than the reference case - a proposition similar to that of the ridge vent.
Fedyushkin [18]	-	Industrial	Conduct an evaluation of ridge vent models to assess their aerodynamic resistance efficiency.	Computational fluid dynamics (CFD) was used, and the results were validated through experiment-tation using a reduced-scale model.	The best results are achieved when the ridge vent is longitudinally oriented towards the north side of the building.
Meng, Wei & Zhai [29]	Summer and Winter	Industrial	Identify the key design factors influencing in natural ventilation: closure material and thermal environment.	EnergyPlus was used for dynamic temperature simulation, considering a range of <14°C to >30°C, with a focus on metal facades and constant air exchange. External temperatures were based on a cold climate city in China.	The heat transfer coefficient of the roofing material has the most significant impact on internal heating, followed by the use of ridge vent as the second most influential factor. The absorptance of the walls and roof, on the other hand, was found to be not significant.
Wang *et al.* [30]	Summer	Industrial	Evaluating the impact of natural ventilation on pollutant dispersion in hot environments.	CFD with 2D and 3D model and on-site measurements in adjacent industrial buildings.	Airflow is driven by the chimney effect, and pollutant migration to the ridge vent opening depends on the prevailing wind's direction (left or right).
Camargos *et al*. [9]	Extreme summer day	Industrial	Evaluating the impact of wind direction on ridge vent airflow in industrial buildings.	EnergyPlus simulation Directions: 0°, 45°, 90°, 135° and 180°.	Better results when the wind is blowing in parallel: ↓1ºC, ↑1ach, ↓10,7%
Dou *et al.* [27]	Summer and Winter	Industrial	Evaluating the performance of buoyancy-driven hybrid ventilation in industrial buildings with heat sources.	CFD simulation was conducted, and on-site measurements were taken for internal temperature and air velocity. The heat flux from the sources was determined to be 850W/m².	Sill: Recommended height is 1.2m. Temperature decreases with higher wind speeds. Critical speed: 2m/s. Applicable for both summer and winter.

Table 1. Citation-reviewed articles (conclusion)

Author's	Period	Type of building	Objective	Method	Key contribution
Meng *et al.* [31]	Summer	Industrial	Development of a dynamic method for predicting WBGT while considering the influence of radiation effects.	EnergyPlus was used for calculating dynamic internal air temperature, while field measurements were taken using the JTR10 WBGT Sensor. Weather conditions were determined based on meteorological data.	Results were validated with on-site measurements, which showed an average T_{db} of 30.6°C and an average WBGT of 29.1°C. According to ISO 7243 and GB 17244, workers were exposed to overheating conditions for 63% of their working hours.
Chen *et al*. [6]	-	Industrial	Evaluate the impact of ridge vent construction parameters.	Computational fluid dynamics (CFD) with validation of results using a reduced-scale experimental model	Key parameters for chimney effect-induced ventilation include eaves height, width, and length.
Meng *et al.* [32]	Summer and Winter	Industrial versus acclimatized site	To investigate the impact of WBGT on physiological indices and subjective thermal perception.	Experimental: On-site measurements were conducted with 14 workers	Skin temperature, oral temperature, and heart rate of workers increase with WBGT, while blood pressure decreases.

This paper presents a structured framework organized into sections that address various aspects of the study. The Introduction serves to provide context for the problem, highlight its relevance, and outline the research objectives. The Materials and Methods section describes the computational models used and justifies their selection. It also encompasses the calculation of thermal loads, air opening sizing, simulation criteria, and discusses research limitations. The Results and Discussion section presents the study's findings, exploring the influence of ridge vent presence, air inlet opening parameterization, and considerations of industrial venetian blinds, while providing graphs, tables, and in-depth analyses. In the conclusion, key findings are summarized, and practical implications, recommendations based on the findings, and suggestions for future research are discussed.

II. MATERIALS AND METHODS

To calculate the WBGT for assessing occupational exposure conditions in a specific type of industrial building, parametric variations are performed on a reference computational model using EnergyPlus (version 8.7.0). The aim is to identify the best approach for modelling protection and shading devices within the study's scope, partially adapting the methodology proposed by Camargos *et al*. [9], as shown in Figure 1.

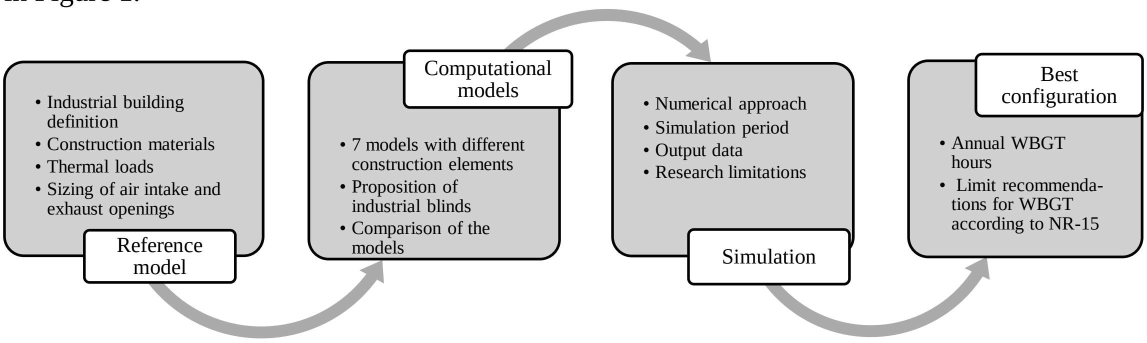


Figure 1. Methodology stages

2.1 Industrial building definition

Given the availability of information and materials needed for this research, we selected the industrial building previously analyzed by Camargos *et al.* [9] as our study subject. This structure has a built area of 3,000 square meters (medium-sized) and features a rectangular prism shape with an inclined roof consisting of a longitudinal ridge vent, as illustrated in Figure 2. Table 2 provides the industrial building measurements relative to its structural base.

Table 2. Measurements of the industrial building

Volume eight			Volume of air (m³)
Masonry enclosure (m)	**Metal closure (m)**	**Ridge section (m)**	
3	6	13.50	33,000

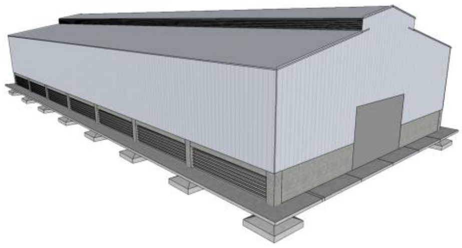


Figure 2. Three-dimensional industrial building model

2.2 Materials for construction and closures

The study focuses on a industrial building situated in Belo Horizonte, MG, Brazil, which falls within bioclimatic zone 3, located at latitude 19.93S, longitude 43.93W, and an altitude of 850m according to NBR 15.575-1 (ABNT, [10]). Table 3 displays the construction materials used to describe the envelope of the industrial building under investigation. It's worth noting that these material selections are based on those commonly found in the city.

Table 3. Thermophysical characteristics of construction materials

Material	Solar absorptance (α_s)	Thickness (cm)	Conductivity κ(W/m.K)	Specific mass ρ(kg/m³)	Specific heat c(J/kg.K)
Masonry wall (up to 3 meters in height)					
Concret block	0.60	20.0	0.57	1,040.0	830.0
Mortar	0.50	2.0	0.72	1,860.0	830.0
Floor					
Concret	0.70	10.0	1.75	2,400.0	1,000.0
Roof, lateral closure, upper closure, and ridge vent					
Galvanized steel sheet	0.25	0.20	55.0	7,800.0	460.0

Source: NBR 15.220-2 (ABNT, [11]).

2.3 Thermal loads

According to ISO 8996 (ISO, [12]) and ISO 7730 (ISO, [13]) standards, when engaging in moderate activities within work environments, such as operating machinery or workbenches, individuals generate a metabolic activity (MET) of up to 175W per person. For these activities, clothing with an average thermal resistance of 1 clo or 0.155 m²°C/W is worn year-round. Based on Neufert [14], the average occupancy in industrial production and manufacturing environments is estimated at one person per 70m², allowing us to project an average occupancy of up to 45 workers in the industrial building. Furthermore, we assume a 24-hour operation as the industrial routine.

Regarding electrical loads, Bordignon [15] notes that nominal powers and voltage levels vary by industry, but for a medium-sized industry, by adopting the average voltage from a process unit substation, motors can have powers of up to 1.5MW. In our simulations, we consider the presence of a 1MW nominal heat source inside the industrial building. In terms of artificial lighting, Lacchini [16] emphasizes that a lighting level between 300 and 750 lux is required for moderately critical and prolonged tasks with medium details. By adopting a lighting level of 500 lux for the industrial buildings, we dissipate a power of up to 30W/m² into the environment. Based on calculations by Camargos *et al*. [9], the heat generated by artificial lighting amounts to 89,938.8W, as can be seen in Table 4.

Table 4. Thermal loads of the industrial building

Heat source power (W)	Lighting (W)	Workers (W)
1,000,000.0	89,939.8	7,875.0

2.4 Sizing of air inlet and outlet openings

The method proposed by Clezar & Nogueira [17] is employed to calculate the dimensions of the openings in the industrial building. To determine the necessary natural ventilation rate based on the assumed internal thermal load, we utilize the algorithm developed by Camargos *et al.* [9], which is programmed in the Fortran language and outputs data in .HTML or .CSV format. The ridge vent height is determined as the ratio between the air outlet area (A_k) and the total area of the air openings (A_a). The results obtained by Camargos *et al.* [9] are presented in Table 5, which includes information such as air inlet area (A_e), air outlet area (A_s), ridge vent height (A_l), and internal heat source power (P), thereby characterizing the reference model of the industrial building.

To determine effective strategies for thermal conditions and air quality in industrial building and to compare annual WBGT values with the limits established by NR-15 (BRAZIL, [7]), a reference model is essential for conducting parametric simulations. This reference model, denoted as Model A (Table 6), is established based on the dimensions and construction characteristics of the industrial building (Table 2), the construction materials used (Table 3), the assumed thermal load (Table 4), and the areas of the openings (Table 5).

Table 5. Areas of the air inlet and outlet openings

Designation	Airflow rate (m^3/s)	A_e (m^2)	A_s (m^2)	A_l (m)	P (MW)
Reference Model	122.13	85.40	42.69	0.50	1

2.5 Computational models

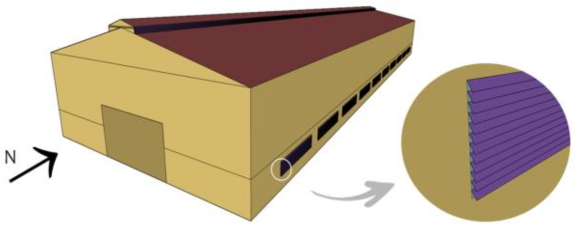
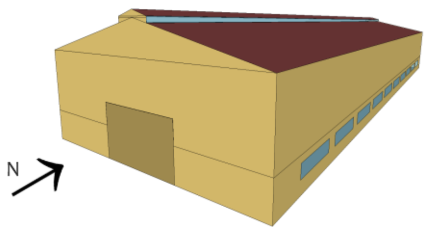
The six industrial building models analyzed in this study are listed in Table 6. To visualize them graphically in SketchUp (version 2017), is use the Euclid plugin (version 0.9.4.4), which enables exporting in .IDF format compatible with the EnergyPlus program (version 8.7.0). In Table 7, you can find the volumetric representation of models (A and B), with a focus on the industrial building openings modeled using industrial venetian. The fins of these devices have commercial dimensions of 10cm and are spaced at 10cm intervals. These features are created using the Shading:Building:Detailed object.

Table 6. Analyzed models

Model	Designation	Definition	A_e (m^2)	A_s (m^2)	A_l (m)	Position of the A_e (m)	Presence of industrial venetian blinds
A	Reference model	Tables 2 to 4	85.40	42.69	0.50	1.20	Yes (A_e e A_s)
B	Industrial building without industrial venetian blinds	Model A	85.40	42.69	0.50	1.20	Not applicable [1)]
C.1	Parameterization of the position of the entry openings areas	Model A	85.40	42.69	0.50	0.80	Yes (A_e e A_s)
C.2		Model A	85.40	42.69	0.50	1.40	Yes (A_e e A_s)
C.3		Model A	85.40	42.69	0.50	1.60	Yes (A_e e A_s)
C.4		Model A	85.40	42.69	0.50	1.80	Yes (A_e e A_s)

Note: 1) The configuration is not applicable to this model.

Table 7. Presentation of the computational models

Variation	Volumetry
Model A	
Model B	

All six models analyzed have the ridge vent oriented to the north, in accordance with the recommendation of Fedyushki [18]. Computational simulations of the industrial environments are conducted without physical partitions between workstations, as outlined by Lacchini [16]. Consequently, only one thermal zone is considered, assuming unobstructed environments with a homogeneous air mass. All simulated industrial buildings models feature industrial venetian blinds in the openings and ridge vent. The walls are divided into two sections (at 3m and 9m in height), enabling the characterization of two distinct building components, as detailed by Camargos *et al*. [9].

2.6 Comparisons between the different industrial building models

Four comparisons are conducted to evaluate the impact of construction parameters on the internal temperature of industrial buildings: Comparison 1 - Model A versus Model B: This assesses EnergyPlus sensitivity when accounting for the presence of ridge vent modeled as shading elements and using the Shade and Blind objects; Comparison 2 - Model A versus Models C: This examines the influence of the position of air inlet openings equipped with industrial venetian blinds and; Comparison 3 - Best configuration: Annual WBGT results.

2.7 Numerical simulation data

EnergyPlus is widely used software by engineers, architects, and researchers to conduct thermo-energetic simulations in buildings, encompassing aspects such as thermal load, energy analysis, heating, cooling, ventilation, lighting, and process loads. According to Department of Energy (DOE, [25]), starting from version 1.3.0 of the program, the air flow calculation model is referred to as AirflowNetwork. Gomes [19] notes that through this module, it becomes possible to simulate the performance of air distribution systems, calculating air flow between different thermal zones and considering factors like wind influence or forced ventilation systems. Camargos *et al*. [9] also highlight that the AirflowNetwork module takes into account window and door opening requirements, natural ventilation conditions, and the specific usage and occupancy routines of the climatic location under analysis.

Pressure coefficients for the rectangular building geometry are automatically calculated by the program based on studies by Swami & Chandra [20], as mentioned by the Lawrence Berkeley National Laboratory (LBNL, [21]). The simulations assume a ventilation scenario with all air inlets (A_e) and ridge vent completely open (opening factor 1), while the gates remain closed (opening factor 0), as indicated by Camargos *et al.* [9]. The heat balance is performed using the Conduction Transfer Function (CTF) algorithm, considering only sensible heat. Algorithms for internal and external convection are selected following American National Standards Institute/American Society of Heating, Refrigerating and Air-Conditioning Engineers guidelines (ANSI/ASHRAE 55, [22]). The time interval between simulations is divided into four parts, representing 15-minute intervals. Ground temperature data are obtained from Loura [23], as the NBR 15.575 (ABNT, [10]) does not specify a specific method for obtaining them. Additionally, the linear initialization method is adopted for simulations of natural ventilation by chimney effect, ensuring proper airflow direction during the simulation, as recommended by Neves [24].

2.8 Simulation period

Figure 3 illustrates the annual variation of external air temperature (T_{db}) in Belo Horizonte, specifically in the Pampulha region.

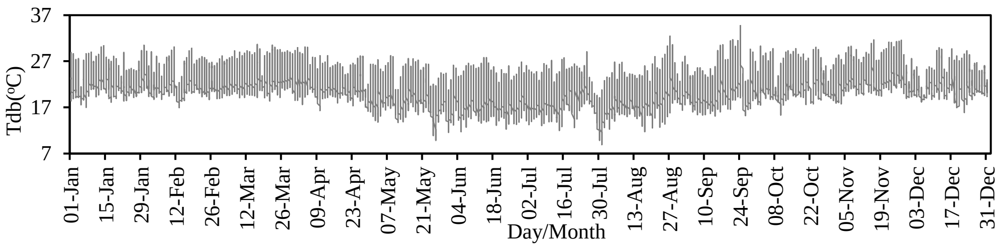


Figure 3. Annual evolution outdoor T_{db}

This data is based on the Test Reference Year (TRY) climatic dataset (LBNL [21]). This dataset is derived by excluding years with extremely high or low monthly average temperatures and represents the year that closely aligns with the climatological normal. In Figure 4a, the hourly variations in external air temperature are depicted, with maximum values of 34.8°C (on 24/09) and minimums of 8.9°C (on 31/07). The figure also displays records of maximum relative humidity, reaching 80% (on 31/07), and a minimum of 17% (on 24/09) on the hottest and coldest days in the city.

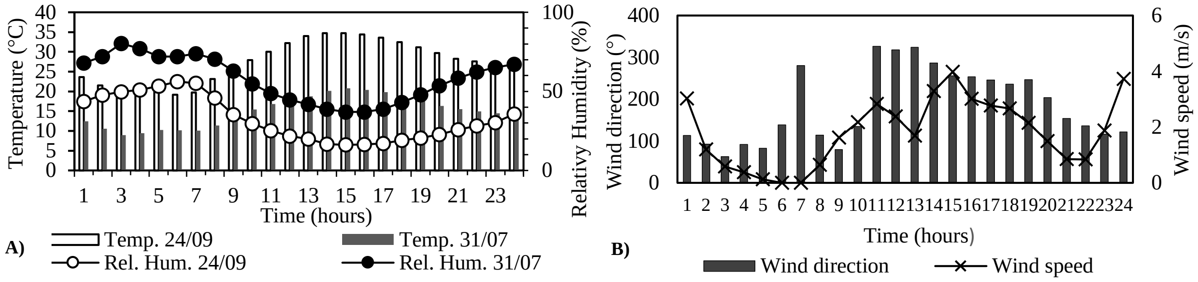


Figure 4. External conditions: A) Extreme summer and winter day; B) Predominant wind direction and speed.

Considering the worsening of internal temperatures in the industrial building during the summer, simulations are conducted at hourly intervals throughout a day of activity, with September 24th chosen as an extreme scenario. Figure 4b displays the predominant wind direction and average wind speed in Belo Horizonte/Brazil during this day. At the most critical time in terms of external temperature (2:00PM), the prevailing wind blows from the west to the east at a direction of 286° (left side of the plan) with an average speed of 3.29 m/s. Consequently, the simulation covers the entire day to expedite the response time and assess the impact of the ridge vent on the industrial building openings, emphasizing the most significant results.

2.9 Outputs

Twelve simulations are conducted to analyze and interpret the results. The output data includes air temperature (T_{db}) in degrees Celsius, mean radiant temperature (T_{mr}) in degrees Celsius, relative humidity (RH) in percentage, wind speed (v) in meters per second, wind direction in degrees, indoor air change rate (ach), total solar radiation transmitted and absorbed in Watts, and ridge vent airflow (Q) in cubic meters per second. Wet bulb temperature (T_{wb}) and globe temperature (Tg) in degrees Celsius are determined following the recommendations of Camargos *et al*. [9]. The WBGT is calculated using Equation 1. Specific data for the analyzed industrial building are stored in an .IDF (Input Data File), containing the necessary objects for the simulation. Additionally, an .EPW (EnergyPlus Weather File) file, containing detailed hourly climate data, is required. The simulation results are presented in spreadsheets in .CSV format or on a web page in .HTML format.

2.10 Research limitations

While EnergyPlus is an advanced tool for thermo-energetic simulation, the accuracy of results depends on input data quality and user assumptions. This research has limitations related to humidity and prevailing wind's influence on ridge vent flow, the software's inability to simulate airflow displacement, standardized occupant clothing, simulations limited to an extreme summer day for evaluating construction parameters, and no consideration for surrounding conditions and neighboring industrial buildings.

III. RESULTS AND DISCUSSION

The data is acquired through simulations using EnergyPlus (8.7.0). Comparisons are conducted on internal air temperature (in °C), solar radiation rates (in W), and airflow through the ridge vent (Q in m³/s) among the six computational models listed in Table 6, with the aim of determining the most suitable configuration for the industrial building, considering the impact of the industrial venetian blinds present in all building openings.

3.1 Comparison 1: Model A Versus Model B

The results obtained from the comparison between models A and B are presented in Figure 5. As indicated in Table 6, the sole difference in construction between these models lies in the presence of industrial venetian blinds in the openings. It is apparent from the results that simply modeling shading elements (using the Shading:Building:Detailed object in the .IDF file) in EnergyPlus does not have any effect on the hourly variations in the internal air temperature of the industrial building (Figure 5a), the ach (Figure 5b), the symmetrical airflow through the ridge vent sides (Figure 5c), or the volume of infiltrated air (Figure 5d). These findings contradict the initial hypothesis of this study and do not align with the empirical results found in the literature. For instance, Scigliano & Hollo [1] suggest that the presence of protective and shading elements in openings can limit airflow into the building by up to 70% of the specified flow rate. Consequently, it is possible to infer that the high internal thermal load of the industrial building may have played a role in this negligible difference in results. This is why we opt to consider the material characteristics of the venetian blinds' fins. Nevertheless, the results depicted in Figure 5e and Figure 5f clearly illustrate that modeling these shading elements significantly impacts the total solar radiation rate transmitted through the openings of Model A's industrial buildings when compared to Model B.

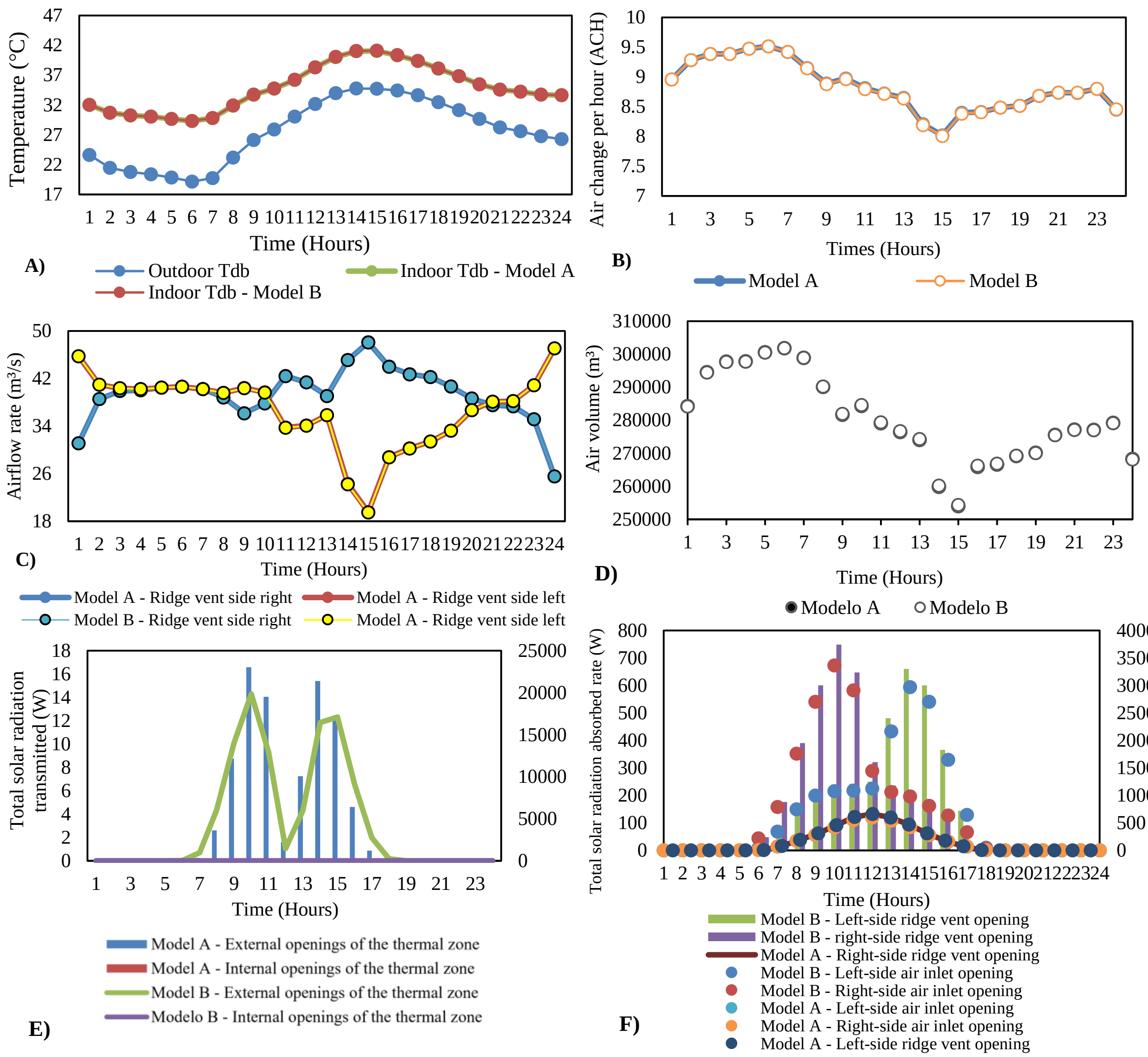


Figure 5. Comparison 1: A) Internal and external T_{db} (in °C); B) Internal air change per hour (ACH); C) Internal air flow through the ridge vent (in m³/s); D) Infiltrated air volume (in m³); E) Total solar radiation rate transmitted through internal and external openings in the thermal zone (in W); F) Total solar radiation rate absorbed through the openings (in W).

Taking into account the building's orientation, it is evident that the peak solar radiation occurs at 10:00 AM, with a difference of up to 119,800% between them. Model A transmits only 16.6W, while Model B transmits 19,859.9W. Consequently, it is apparent that modeling shading elements allows for simulating solely the influence of these protective devices on solar radiation and shading within the building.

The objects Blind and Shade are used in EnergyPlus to model shading elements in buildings with the goal of reducing the penetration of sunlight and heat into the interior. The Blind object represents internal blinds and allows for control over their position, tilt angle, solar transmittance, and reflectance. In contrast, the Shade object represents external shading elements like sunshades, awnings, and architectural features. It provides control over the tilt angle, shadow depth, and solar transmittance. Both objects play a crucial role in simulating a building's thermal and energy performance, optimizing thermal comfort and energy efficiency (DOE, [25]). In the context of this study, the Shade object aligns more closely with the construction scenario under analysis. Technical information is provided in the object to best describe the fins of the industrial venetian blinds in the building. This information includes parameters such as solar transmittance (0adm.), solar reflectance (0.5adm.), visible transmittance (0adm.), visible reflectance, hemispherical infrared emissivity (0.5adm.), infrared transmittance (0adm.), thickness (0.02m), and conductivity (0.23W/m.K). It's worth noting that other parameters of the object were simulated using EnergyPlus default values (DOE, [25]).

Figure 6 displays the results obtained for internal air temperature (in ºC) and airflow through the ridge vent (Q in m³/s) from the simulation of the industrial building using the Shade object in the .IDF file for Model A. It is evident from both Figure 6a and Figure 6b that even with a more detailed modeling of the fins of the industrial venetian blinds, there is no impact on the airflow results, nor is there a significant alteration in the internal temperature profile of the building. As a result, it can be concluded that Shades in EnergyPlus resemble blade-type devices, much like industrial venetian blinds. Unlike curtains (Blinds), the optical properties of ridge vent are highly dependent on the angle of incidence. Furthermore, depending on the angle of the fins and the angle of incidence of direct sunlight, some of the direct solar radiation can pass between the fins, resulting in a component of transmitted direct radiation (Dias *et al.* [26]). Consequently, it is essential to obtain technical information from commercial manufacturers to accurately characterize this element and obtain results that align more closely with the project's real-world conditions. Additionally, it's worth noting that an experimental approach may prove beneficial for obtaining thermal properties of the material used in the industrial venetian blinds fins and for comparing practical values of airflow through the openings.

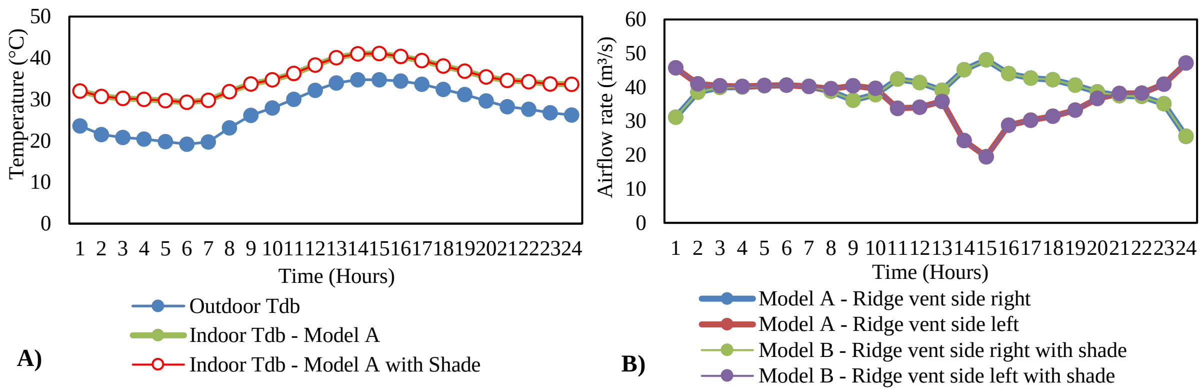


Figure 6. Comparative 1 Model A with shade: A) Internal and external air temperature (in ºC); B) Airflow through the ridge vent (in m³/s)

3.2 Comparison 2: Model A Versus Model C

Figure 7 displays the results of the comparison between models A and C. As indicated in Table 6, the sole construction difference between these models is the height of the A_e. It is evident that, within the construction constraints, the A_e's position has minimal impact on the internal temperature profile of the industrial building, consistent with the findings of Camargos *et al.* [9]. However, lower flow rates through the ridge vent are observed in models with taller A_e. Therefore, more favorable results are achieved when the A_e is situated at lower positions (sill at 1.20m) (Model A), aligning with the conclusions of Dou *et al*. [27] and in accordance with key recommendations in the literature, such as those from Cruz-Salas *et al*. [28] and Meng, Wei & Zhai [29].

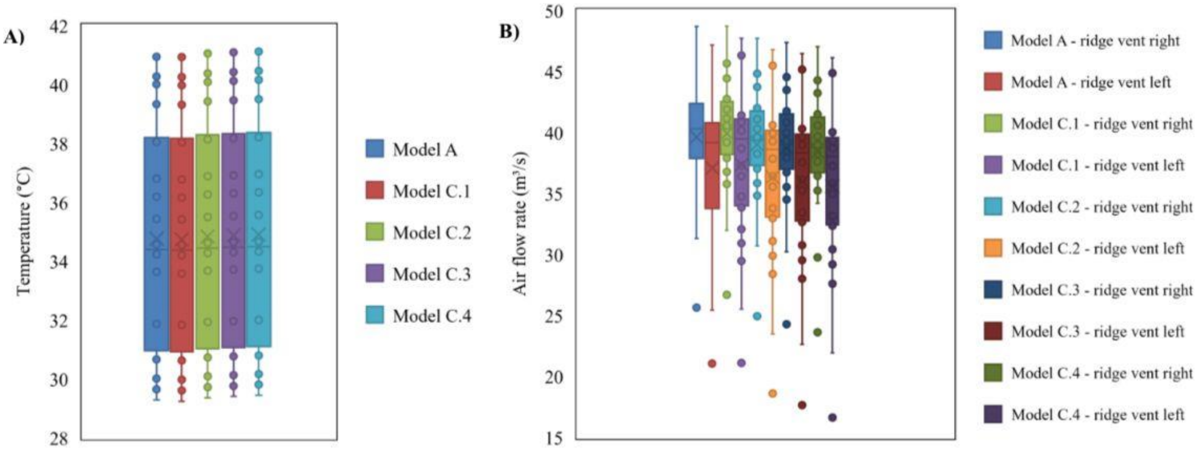


Figure 7. Comparison 2: A) Internal air temperature (in °C); B) Airflow through the right and left ridge vent openings (in m³/s).

3.3 Comparison 3: Best Configuration - Annual WBGT Results

Occupational heat exposure is assessed using the WBGT (Equation 1), as established in NR-15 (BRAZIL, [7]). In the case of the industrial building, Model A is compared to the recommended limit set by the regulatory standard, which is 26.7°C, as shown in Figure 8. Qualitatively, it is evident that the building meets the recommended limits of the regulation only on the coldest days of the year.

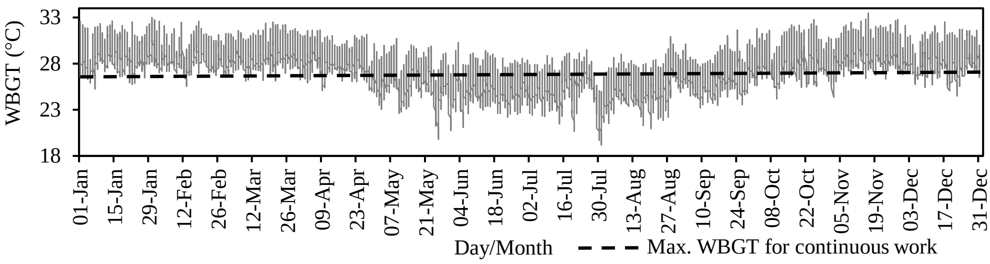


Figure 8. Annual WBGT results for Model A.

IV. Conclusion

The thermal conditions of the workplace have a direct impact on productivity and the quality of services provided by workers. Ensuring thermal comfort at the workplace requires careful planning to maintain suitable temperature and humidity levels. When dealing with heat sources, it is important to prioritize this aspect, and making the most of the benefits of natural ventilation can contribute to achieving desired occupant satisfaction levels.

This article aimed to evaluate the effectiveness of shading and protection elements, such as industrial louvers, in industrial buildings. Computational simulations were conducted to obtain representative environmental variables for the thermal conditions in this working environment. Models were created using SketchUp software (version 2017), and thermal analyses were performed with EnergyPlus (8.7.0). The required output data included air temperature, mean radiant temperature, indoor relative humidity, wind speed, predominant wind direction, indoor air exchange rate, total rates of solar radiation transmitted and absorbed through openings, indoor air flow rates through ridge vent openings, wet bulb temperature, globe temperature, and WBGT.

The assessment of maximizing the use of industrial venetian blinds revealed that there is no significant direct influence on reducing internal temperature, airflow, volume of infiltrated air, or indoor air exchange rate. However, there is an effective reduction in the rates of solar radiation absorbed and transmitted through the industrial building openings. These results suggest that the high internal thermal load may limit the validation of the initial hypothesis. Notably, modeling industrial venetian blinds as shading elements effectively reduces the absorption of solar radiation within the environment. Additional parametric analyses were conducted to evaluate the impact of the height of the air intake openings on reducing internal temperature and airflow through the ridge vent. A sill height of 1.20m was identified as the most favorable for achieving satisfactory results. Finally, an WBGT evaluation showed that the industrial building (Model A) can meet the satisfactory conditions stipulated by NR-15 [7] only during the winter season and on colder days.

In summary, the study did not achieve its objective using the employed methodology and resources. It is essential to acknowledge the limitations of this research, and future work should include experimental tests to facilitate a more in-depth discussion of the topic.

Declaration of Competing Interest

The authors affirm that they possess no identifiable conflicting financial stakes or personal connections that might have seemed to exert an impact on the research presented in this paper.

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