CHALLENGES OF ENVIRONMENTAL MONITORING WITHIN THE INTEGRATED RECYCLING COMPLEX OF THE FEDERAL DISTRICT/DF

OS DESAFIOS DO MONITORAMENTO AMBIENTAL DO COMPLEXO INTEGRADO DE RECICLAGEM NO DISTRITO FEDERAL

LOS RETOS DEL MONITOREO AMBIENTAL DEL COMPLEJO INTEGRADO DE RECICLAJE EN EL DISTRITO FEDERAL

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ABSTRACT
The Federal District Integrated Recycling Complex (CIR-DF) contributes significantly to reducing the environmental impact of the waste produced by the metropolis of Brasilia, as it provides for the recycling of materials that would otherwise be taken to landfills and employs around 450 collectors. That said, this work sought to monitor the air quality of the CIR/DF shed spaces, checking the concentration of CO2, temperature, and humidity, in the period of intense heat and drought, relating the data with measures of adaptive comfort in order to contribute with space management. The results showed that the CO2 concentration is below 3,900 ppm in 48 hours per week indicated by NR 15 from 2022. The temperatures verified between the six monitored days are, for the most part, below 50 % of the comfort zone and the humidity data are also below the 40 % limit indicated by NR 17 from 2022. Thus, the Complex faces challenges related to the internal environmental comfort of the sheds, which can be improved by applying strategies for air renewal that are more appropriate to the location.

KEYWORDS
Air quality; CO2 concentration; climate monitoring; urban climate; recycling; HOBO sensor.

RESUMO
O Complexo Integrado de Reciclagem do DF contribui significativamente para a redução do impacto ambiental do lixo produzido pela metrópole brasiliense, pois, proporciona a reciclagem de materiais que seriam levados para aterros sanitários, além de empregar cerca de 450 catadores. Posto isso, este trabalho buscou monitorar a qualidade do ar dos espaços de galpão do CIR/DF, verificando a concentração de CO2, temperatura e umidade, no período de intenso calor e seca, relacionando os dados com medidas de conforto adaptativo a fim de contribuir com a gestão do espaço. Os resultados apontaram que a concentração de CO2 está abaixo de 3.900ppm em 48h semanais indicados pela NR 15 form 2022. As temperaturas verificadas entre os seis dias monitorados estão, em sua maioria, abaixo de 50% da zona de conforto e os dados de umidade também estão abaixo dos 40% limite indicados pela NR 17 de 2022. Dessa forma, o Complexo enfrenta desafios relacionados ao conforto ambiental interno dos galpões, o que pode ser melhorado aplicando estratégias para a renovação do ar mais adequadas ao local.

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PALAVRAS-CHAVE
Monitoramento ambiental; reciclagem; qualidade do ar; salubridade.

RESUMEN
El Complejo Integrado de Reciclaje del Distrito Federal contribuye significativamente a la reducción del impacto ambiental de los residuos producidos por la metrópolis de Brasilia, ya que recicla materiales que de otra forma serían llevados a vertederos, además de emplear a cerca de 450 recicladores. Dicho esto, este estudio pretendía monitorizar la calidad del aire de los espacios del cobertizo del CIR/DF, comprobando la concentración de CO2, la temperatura y la humedad en periodos de calor intenso y sequía, relacionando los datos con medidas de confort adaptativo para contribuir a la gestión del espacio. Los resultados mostraron que la concentración de CO2 está por debajo de 3.900ppm en la semana de 48 horas indicada por el formulario NR 15 de 2022. Las temperaturas en los seis días monitorizados están en su mayoría por debajo del 50% de la zona de confort y los datos de humedad también están por debajo del límite del 40% indicado por la NR 17 de 2022. En consecuencia, el Complejo enfrenta a retos relacionados con el confort ambiental interno de las naves, que podría mejorarse aplicando estrategias de renovación del aire más adecuadas para el emplazamiento.

PALABRAS CLAVE
Monitoreo ambiental; reciclado; calidad del aire; salubridad.

1. INTRODUÇÃO

The impacts caused as a result of the constant changes in the climate are observed in several natural, managed and human systems; examples include rainfall cycles, fishing, agriculture, tourism, heat-related mortality and others. In this context, it is estimated that anthropogenic activities caused an increase of 1.0°C above pre-industrial levels and is projected to reach levels of 1.5°C from 2030 to 2052 (IPCC, 2022). This rise in temperature fosters risks for the survival of human beings in issues such as food insecurity, water supply crises, health crises and economic growth, with the most severe impacts aimed at vulnerable populations (Ribeiro, 2008).

Greenhouse gas (GHG) emissions, considered the main cause of climate change (Braga, 2012), are mostly originated by urban activities such as transport, construction, industry, and energy consumption (BAI et al., 2018; Birol, 2010; Crippa et al., 2021). In addition, the urbanization of cities is growing, since, in 2019, 55% of the population lived in urban territory, as indicated by data from UNDESA (2019). The increase is expected to reach 68% by 2050 (Espíndola; Ribeiro, 2020). Therefore, there is an emergency, need to conduct the policies of cities to mitigate and adapt to climate change.

With regard to the planning of cities for mitigation and adaptation of climate change, carrying out more studies that provide consistent databases on the climatic aspects of urban areas to enable more objective and effective actions is essential. Therefore, monitoring data have been used to support research that analyzes air quality through sensors adapted to urban or rural environments, making it an important tool to enable data collection in an accessible way (Keys; Mota, 2020).

One of the urban activities that contribute to the increase in air pollution is waste. According to SEEG (2020), in 2019, the sector was responsible for releasing 96.000.000 tons of carbon dioxide, with the majority (65%) of emissions being incited by the disposal of waste in controlled landfills, dumps and sanitary landfills. Brazil, in 2014, produced about 70.000.000 tons of Urban Solid Waste (MSW) (Abrelpe, 2014), which are composed of numerous varied materials from households, urban cleaning, commerce, sanitation, industries, health, construction, transportation and mining (Colling; Dubeux, 2015).

The Federal District hosted one of the largest open dumps in Latin America, also known as the Structural Dump, which received 830,055 tons of solid waste in 2016 (SLU, 2016). However, in 2015 the activities of closing the dump began, which was effectively closed in 2018 (Brasil, 2015), giving rise to the inclusion of new waste treatment spaces that support the generation of jobs and that, as is the case of the Integrated Recycling Complex of the DF, were recently inaugurated in 2020 (Sema, 2020).

Therefore, linking the necessary mitigation and adaptation work to climate change in urban areas, especially in areas of greater environmental vulnerability, this article proposes a monitoring of air quality, focusing on the evaluation of CO2 concentration, of the shed space of the Integrated Recycling Complex of the Federal District, which will be done with the Hobo Mx CO2 Logger sensor. Air pollution is linked to the emission of solid, liquid, or gaseous particles, harmful to the environment and humans, and they are classified as natural and anthropogenic sources (Williams et al., 2014).

The anthropogenic sources, coming from man, are due to industrial activities, transportation, solid waste, and others (Vallero, 2007), which release gases that contribute to the increase in the emission of greenhouse gases (GHG). These are the gases: carbon dioxide (CO2), which is responsible for 60% of the greenhouse effect; methane (CH4), responsible for 15% to 20%; nitrogen dioxide (NO2), corresponding to 6% of emissions; chlorofluorocarbons (CFCs), responsible for up to 20% and O3, participating in the greenhouse effect in 8% (Huet, 2014).

In addition to observing the concentration of CO2 in anthropogenic activities, as a way to understand the impact of certain activities on the environment, carbon dioxide can be monitored as a way to evaluate ventilation rates, defining the amount of outdoor air that mixes with the indoor air of an environment. Understanding the concentration of this gas also makes it possible to determine the presence of other pollutants (Presily, 1996; Carmo, n.d.; Prado, 1999). According to Jensen and Schafer (1994), the amount of particulate matter in a healthy indoor environment is usually less than that in the external environment. However, without the use of air renewal control strategies in an indoor environment, it can achieve higher pollutant values than the external air (Higaskino; Figel; Yamada, 2007; Schirmer et al., 2011).

Among the climatic elements that influence the user's feeling of comfort are the temperature and humidity of the air (Assis, 1990). The temperature variation is linked to the arrival of solar radiation and the energy change involved in the release of heat (Vianello and Alves, 1991), this element being the most perceptible to humans (Borges, 2009). It can be assumed that air humidity is lower in cities due to the phenomenon of heat islands, and, in turn, humidity plays an important role in promoting the evaporation of the environment. In addition, air displacement along with air humidity strongly influences thermal comfort, as they are related to heat loss by evaporation (Corbella; Yannas, 2003).

Adaptive thermal comfort, a theory that relates indoor temperature to outdoor air temperature, to verify comfort indices (De Dear; Brager, 1998; Humphreys; Nicol, 1998; Nicol; Humphreys, 2002; Humphreys, 2002; Humphreys; Rijal; Nicol, 2013) is the analysis used by Ashrare 55, normative that supports studies on thermal comfort. The neutral indoor air temperature rises as the average outdoor temperature increases (Buonocore, 2018). In addition, the adaptive model focuses on studying naturally ventilated buildings (Rupp; Ghisi, 2019), as is the case with the CIR sheds. The main objective of this research is to present the monitoring of the levels of CO2 contraction, temperature, and humidity in the sorting area of the shed. For this, it is evaluated whether the results obtained are plausible with the requirements of Regulatory Standard 15 - unhealthy activities and operations from 2022, Ashrare 55 and Regulatory Standard 17 – Ergonomics from 2022.

2. MATERIALS AND METHODS

2.1. Characterization of the study site

2.1.1. Local Weather

The climate of the Federal District, where the object of study is inserted, is marked by two distinct seasons, namely: a dry winter and a hot and humid summer (IBRAM, 2012). According to the Köppen classification, the Cidade da Estrutural, headquarters of the DF Integrated Recycling Complex, is part of the tropical climate of Altitude Cwa, whose temperature in the coldest period is below 18°C, with an average below 22°C, at the hottest time of year (Codeplan, 2020). Corroborating this information, Romero (2002) classifies the climate of Brasilia as high altitude tropical, which allows the DF territory an excellent degree of ventilation rates.

2.1.2. DF Integrated Recycling Complex

Located in the Complementary Industry and Supply Sector (SCIA), the DF Integrated Recycling Complex (CIR/DF) is inserted in the context of the Structural City, a region that encompassed one of the largest dumps in Latin America (Figure 01). After a series of measures by the government of the Federal District, from 2009 to 2018 (Capelari et al., 2020), the situation not only culminated in the closure of the dump, but also fostered the creation of the CIR, the current employment generation pole for collectors from the old landfill. The Complex, which went into operation at the end of 2020, currently consists of two sorting warehouses, parallel to each other, and another commercialization warehouse, occupying an area of 80.000 m2, which, in its beginning, housed between 450 and 500 collectors of recyclable materials (Ferraz, 2020) (Figure 02).

The activities carried out in the space of the warehouses begin with the arrival of waste by trucks, in the north part of the building and in the area for the disposal of selected material. This waste is placed in containers in the basement and transported to the sorting mats, which are on the upper floor, where the materials are separated by the collectors. The selected materials, such as plastic and glass, are sent to storage silos, known as bags, located on the ground floor of the warehouse, which also

Figure 01: Location map and aerial view of the CIR/DF study area.
Source: adapted from Google Maps and LaSUS/UnB, 2023.

Figure 02: Images of the sheds and facade of shed 1.
Source: LaSUS/UnB and Authors (2023).

houses the pressing area, secondary separation of recyclables and deposit of discarded material. Discarded material is taken to containers and redirected to landfills. The materiality of the building is composed of structural masonry and metallic structure, with fixed openings in the walls in matte transparent polycarbonate and with openings close to the roof that allow the renewal of hot air from inside the environment (Figure 03).

And the pickers from the recycling cooperatives, users of the building, for the most part, wore long-sleeved blouses, long pants, socks, boots, masks, and gloves.

Figure 03: Facade with openings in the shed.
Source: LaSUS/UnB and Authors (2023).

2.1.3. Characterization of Monitoring

Monitoring was carried out in the two sheds between September 16 and 22, 2021, recording new data regarding temperature, humidity, and CO2 concentration every 5 minutes, using the HOBO Mx CO2 Logger sensor. The two HOBO sensors were installed 1.50 m from the floor on the upper floor of each shed, in the central-south part of the building, where the sorting activities are located on the mats, as shown in Figure 4 and 5 below:

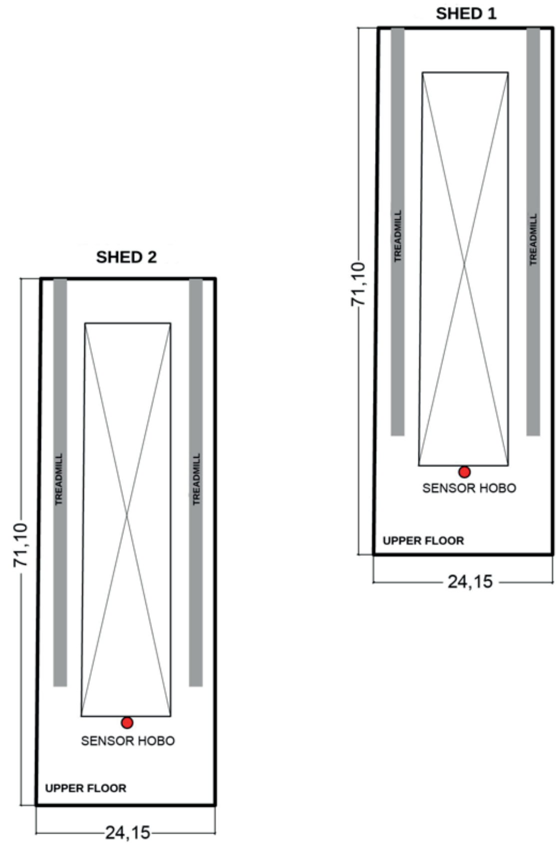

Figure 04: HOBO sensor location (floor plan).
Source: graphic produced by the authors.

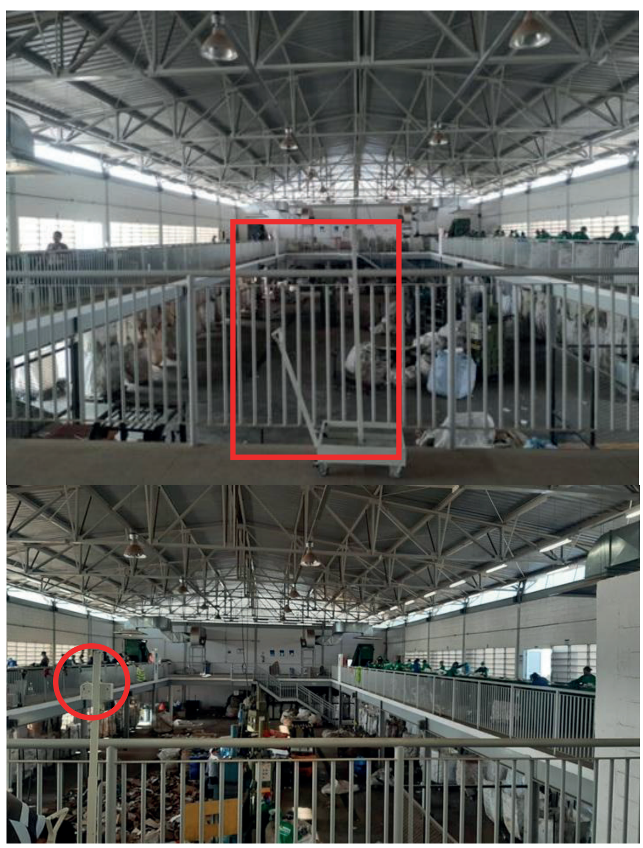

Figure 05: HOBO sensor location (photos).
Source: graphic produced by the authors.

3. RESULTS

In September 2021, according to INMET (2021), the analysis period of this research, the DF reached a maximum temperature of 35.4°C, on 09/22, at 4 pm, and a minimum of 13.8°C, on 09/04, at 09:00 am, as shown in the graph below, reaching a minimum humidity of 11%, on 09/19, at 04:00 pm.

The results obtained from monitoring the two sheds were organized into 03 shifts, namely: i. night (21:05-23:55), ii. Work shift (07:00-21:00) and iii. Early morning (00:00-06:55), considering that only on 09/19, Sunday, there would be no work shift.

The result obtained in shed 1 shows a maximum temperature of 34.5°C, on 09/20 (Monday), during the work shift, specifically at 2:20 pm. In addition, the minimum humidity reached in shed 1 was 13.69%, on 09/19 (Sunday), at 12:25 and 12:35. Regarding the CO2 concentration, the maximum of 552ppm was observed on 09/21, during the night, more specifically at 9:50 pm, in shed 1 (Figure 06).

Figure 06: Shed 1 (Temperature, Humidity, and average CO2).
Source: graphic produced by the authors (2023).

In shed 2, the maximum temperature reached was 34.7°C, on 09/21 (Tuesday) at 2:50 pm, and the minimum humidity was observed at 13.67%, on 09/19 (Sunday) at 12:35. In shed 2, it was also observed that the maximum CO2 was 555ppm, manifested on 09/21, at 21:55 (Figure 07).

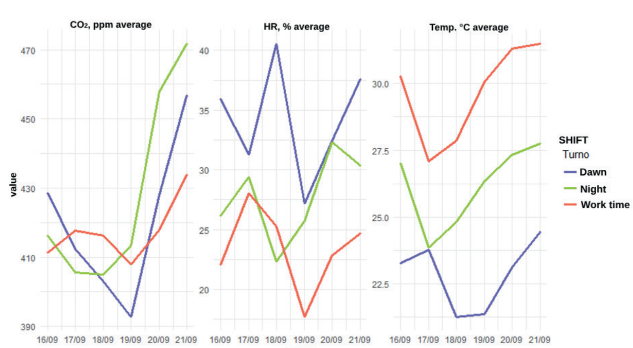

Figure 07: Shed 2 (Temperature, Humidity, and average CO2).
Source: graphic produced by the authors (2023).

According to Regulatory Norm (NR) 15 – Unhealthy Activities and Operations, from 2022 the maximum limits of worker exposure to CO2 concentration is 3,900ppm for 48h/week. However, bearing in mind that the working hours of CIR employees vary from 24h to 36h a week, the limit concentration of 2,925ppm was considered in this work, which considers the maximum of 36 hours a week of work. The observed result of CO2 concentration in the five days of work is below that mentioned by the standard. The temperature variable was analyzed according to ASHRAE 55, using the De Dear and Brager model (Pereira; Assis, 2010), with the equation below, to understand the level of thermal adaptive comfort of the sheds:

$$Tn = 0{,}310 \times T + 17{,}8\ °C$$

Being:

I) Tn = neutral temperature
II) T = external temperature, in this case obtained by INMET
III) With Tn +/- 3.5°C (80% acceptability)

The results were calculated from the hourly data and the comfort level of the six monitored days, resulting in the following sample:

SHED 1						
	16/09/21	17/09/21	18/09/21	19/09/21*	20/09/21	21/09/21
Comfort	29%	46%	33%	25%	21%	21%
Discomfort	71%	54%	67%	75%	79%	79%
SHED 2						
	16/09/21	17/09/21	18/09/21	19/09/21*	20/09/21	21/09/21
Comfort	29%	50%	42%	25%	21%	21%
Discomfort	71%	50%	58%	75%	79%	79%

Table 01: Percentage of thermal comfort per day.
Source: graphic produced by the authors (2023).

With regard to humidity, the NR 17 from 2022 was used as a basis for evaluating the levels of humidity in spaces dedicated to work activities, which indicates the ideal limits between 40% and 60% of humidity per day. According to what is presented in Table 1, the evaluated results of the monitored humidity are all below the recommended by NR 17 form 2022 in most of the hourly data analyzed in the two sheds. Climate monitoring is one of several data generation methods to support climatological studies (Chaves; Mota, 2020), in order to contribute to actions to adapt and mitigate climate change, a topic that is currently so debated. The results obtained indicated that the CO2 concentration was within the national normative standards, however, the two sheds presented levels of thermal discomfort. It is important to highlitgh that the CO2 concentration was higher at night in both sheds which ocurr due to reduction of wind and due to increase in CO2 release by plants and live microorganisms.

It is important to point out that on 09/21 a large fire was registered near the study area located in the forest area of the Guards Cavalry Regiment (in Portuguese Regimento de Cavalaria de Guardas - RCG), also close to the area of the Brasília National Park. The date of worst thermal discomfort was verified on the same day that there was a forest fire near the sheds, which may have influenced the increase in discomfort verified in the monitoring. However, low humidity levels were verified days before the fire, which may have contributed to starting the fire and potentiating the proportions of burning in the area with dry vegetation (Figure 08).

In order to complement the data evaluated in the comfort analysis, the psychometric chart for the climate of Brasilia in September was verified using the Climate Consultant software version 6.0, whose calculation method is also based on ASHRAE 55. The result obtained was 28%. of hours of comfort compared to 72% of discomfort, calculated during the work shift (07:00 – 21:00) at the CIR, which is close to what was observed in the results of the adaptive comfort calculation presented in Table 01.

Figure 08: Aerial image of the fire site near the CIR/DF.
Source: Lasus/UnB (2023).

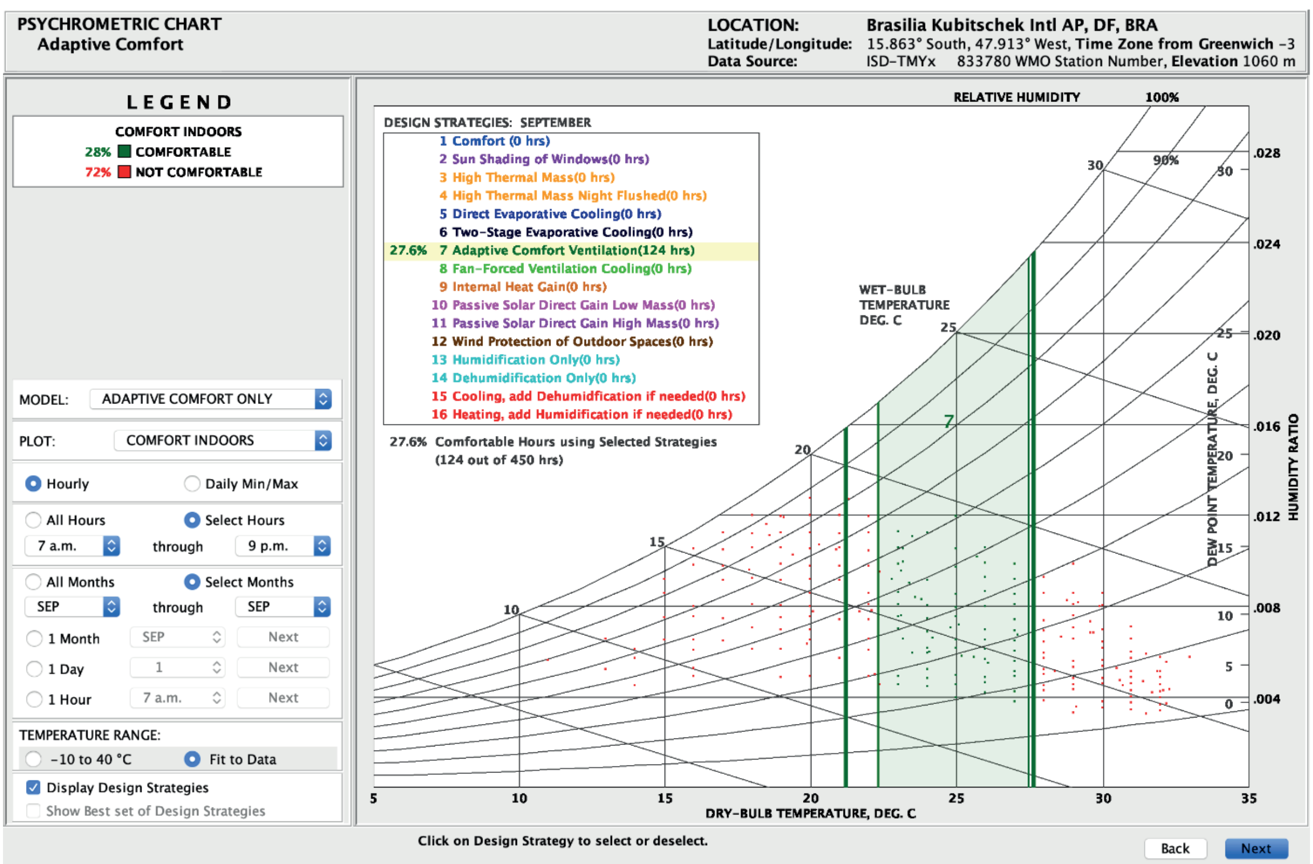

Figure 09: Psychometric map of Brasilia in September, from 07:00 to 21:00.
Source: Climate Consultant 6.0 with Typical Meteorological Year (TMY) climate data from 2004 to 2018.

The strategy that best contributes to improving indoor thermal comfort is ventilation, as shown in the result of Figure 09, also linked to the concept of adaptive comfort, that is, when the user manages to improve the comfort of the thermal environment (Buonocore, 2018). Therefore, applying strategies that increase the hours of ventilation in this period would be ideal to increase the internal comfort of the sheds, since the main openings for ventilation are fixed tilting, with a very narrow opening, and exposed to solar radiation, which can lead to an increase the temperature of the air entering the building (Figure 10).

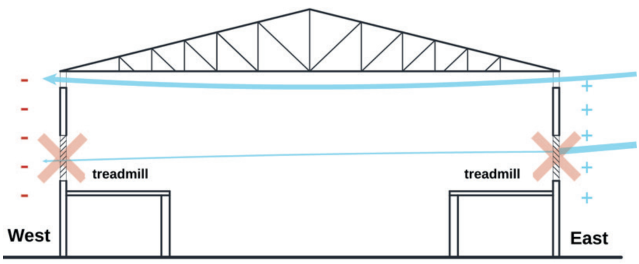

Figure 10: Schematic section of the current ventilation of the sheds.
Source: produced by the authors (2023).

However, since the sorting activity on mats performed in the shed makes it difficult to install mechanical ventilation to ease the feeling of heat, it is suggested to adapt the openings, integrating them with a mechanical exhaustion system to improve the renewal of the internal air. Therefore, it is important to design the openings and exhaust fans in such a way as to combine the movement of air due to the action of the wind and the difference in temperature (Borré, 2013).

The ventilation inlet should face the prevailing winds, also known as the positive pressure zone, which in this case are to the east, with the air outlets placed at the outer low-pressure end. Furthermore, to amplify the efficiency of air renewal in the sheds, it is interesting to use mixed methods with natural air insulation and mechanical exhausters, for example. Because, in this way, the internal air pressure becomes lower than the external one, allowing a greater flow of air into the interior of the sheds. Regarding the installation of axial exhaust fans, located on the wall, they should be located in the opposite part to the air reception and at the highest possible level in relation to the floor (Macintyre, 1990; Borré, 2013) (Figure 11).

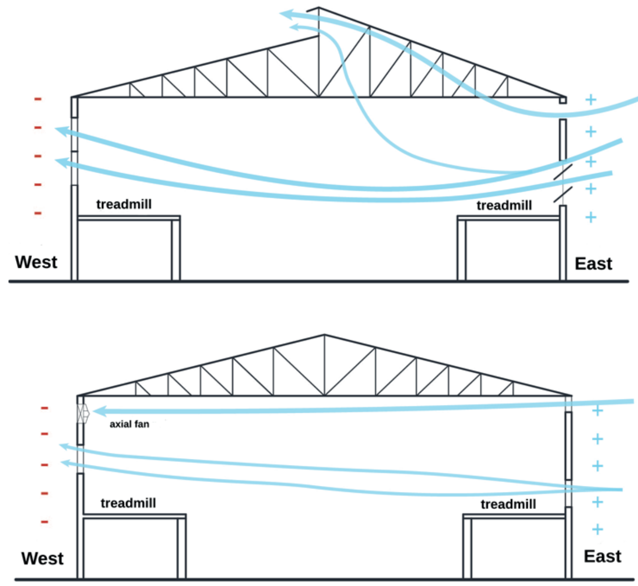

Figure 11: Examples of ventilation strategies in industrial warehouses.
Source: Strategies adapted from Macintyre (1990) for cutting the sheds under study.

4. CONCLUSIONS

The evaluation of temperature, humidity and CO2 concentration variables can support studies to improve quality in the workplace. It is important to highlight that important Brazilian norms that define CO2 concentration values, such as NBR 16.401-3:2008 and Anvisa Resolution No. 9, do not assess naturally ventilated environments. In this way, it is possible to perceive that there is still a strong incentive for professionals in the construction sector to opt for artificial climate control strategies, in comparison with low impact strategies, which are more adapted to the local climate, such as the use of natural ventilation or hybrid.

Furthermore, it was noticed that many norms found are not specific to spaces for handling recyclable material, as in the case of the use of NR17 from 2022 as a normative basis for the observation of humidity data in the internal environments of the sheds. Therefore, another important point of reflection is the lack of regulations that support the improvement of the quality of spaces dedicated to solid waste management activities in Brazil, as a potential barrier to the transformation of this sector in favor of mitigation and adaptation of cities to climate change.

The environment monitored in this research, the DF Integrated Recycling Complex, is the result of the reformulation of policies aimed at improving working conditions in the urban solid waste management sector, offering greater dignity to the work carried out by cooperatives in the Federal District, in comparison with the situation found previously with the old Structural Dump. Furthermore, the material received by the CIR often arrives together with organic waste, making the handling of recyclables more complex and unhealthy for the collector. Therefore, implementing policies that can contribute to the quality of the waste delivered to the CIR, through education programs and social awareness about the disposal of recyclable materials, is essential for improving the quality of work in this environment.

However, in order to complement the research, it is interesting to carry out studies that can assess the presence of other local atmospheric pollutants, due to the arrival of various types of waste at the site. In addition, to be able to deepen the research on thermal comfort, monitoring it in the winter period and applying a questionnaire with all collectors in different climatic contexts to understand the demands of extreme climatic periods.

It can be considered that analyzing the internal environment of the Integrated Recycling Complex of the DF is extremely relevant for the context of the country's capital, as this space receives waste from different regions to be recycled, avoiding the disposal of undue materials in controlled landfills. And especially in the context of a pandemic, in which urban solid waste management activity is classified as essential, obtaining a well-ventilated and healthy space contributes to the health of the collectors present, who can carry out their important work in times of health crisis. Therefore, it is very important for society to produce more studies in spaces such as the Complexo, in order to make the management of urban waste increasingly appropriate, innovative and sustainable in Brazil.

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