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Thermal Discomfort and the Precarization of Teaching Work in Municipal Schools of Eastern Manaus, Brazil

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Abstract

Thermal comfort is a fundamental condition for human well-being, work performance, and health, particularly in educational environments located in regions exposed to persistent heat and high humidity. In equatorial cities such as Manaus, inadequate thermal conditions in public schools may contribute to the precarization of teaching work and to adverse health outcomes among education professionals. This study aimed to analyze the influence of thermal discomfort on teaching activities, health, and well-being of teachers in municipal schools located in the East Zone of Manaus, Amazonas, Brazil. The research combined long-term climatic data on air temperature and relative humidity (1992–2023), field measurements conducted in classrooms and outdoor teaching areas during October and November 2024, and semi-structured interviews with teachers. Thermal conditions were assessed using the Thom and Bosen Discomfort Index (DI), while qualitative data were analyzed through thematic content analysis. The results revealed recurrent and elevated levels of thermal discomfort in Manaus, particularly between July and November, with field measurements indicating DI values ranging from 25.7 °C to 30.6 °C. The highest discomfort levels were recorded during the afternoon period, affecting both indoor and outdoor school environments. Teachers reported negative impacts on health and work performance, including fatigue, headaches, respiratory discomfort, and reduced capacity to carry out teaching activities, especially among Physical Education teachers exposed to direct solar radiation. The study concludes that thermal discomfort constitutes a structural factor in the precarization of teaching work in public schools in Manaus. Addressing this issue requires integrated public policies focused on school infrastructure, preventive maintenance, climate-sensitive architectural design, and recognition of thermal comfort as an essential dimension of educational quality and occupational health.

Keywords: Thermal discomfort; School environment; Teaching work; Occupational health.

1. Introduction

Since antiquity, climate has been an object of observation and analysis, influencing the ways in which human beings interact with the environment and organize their social practices. Historical forms of adaptation to climatic variability can be observed, for example, in clothing, architectural solutions, and daily routines. In this context, classical Greek thinkers such as Hippocrates, Strabo, and Aristotle were among the first to develop systematic interpretations of climate, relating atmospheric conditions to human health, behavior, and spatial organization.

However, contemporary approaches emphasize that climate should not be understood exclusively as a set of physical and natural phenomena. According to Sant'Anna Neto (2008), climate must also be analyzed from socioeconomic, political, and cultural perspectives, allowing for broader interpretative frameworks capable of explaining how climatic conditions interact with social inequalities, territorial organization, and power relations. This perspective is particularly relevant in urban contexts, where environmental conditions are unevenly distributed and directly affect different social groups.

In Brazil, since the early development of climatological studies, climatic elements such as temperature and humidity have often been associated with health conditions and the occurrence of tropical diseases. Over time, scientific advances have contributed to a more complex understanding of the climate–health relationship. Weather and climate are now recognized as contributing factors within a broader set of socio-environmental determinants of the health–disease process, rather than as isolated or deterministic causes. Sant'Anna Neto (2008) highlights that high humidity and excessive heat, when combined with precarious housing, inadequate working conditions, and the absence of environmental control mechanisms, intensify situations of thermal discomfort and environmental unhealthiness, reinforcing social inequalities.

The influence of climate on human well-being is not restricted to public health or urban outdoor environments; it also extends to indoor spaces, including schools. Educational environments are particularly sensitive to thermal conditions, as they directly affect cognitive performance, physical well-being, and the execution of pedagogical activities. According to Shigunov (1997), the analysis of environmental factors is essential for didactic and pedagogical planning, as adequate environmental conditions contribute to comfort, learning, and the overall quality of the teaching–learning process. Conversely, excessive heat in classrooms may generate adverse effects on the health and well-being of both teachers and students, compromising concentration, motivation, and academic performance.

Within this framework, thermal comfort can be understood as a fundamental requirement for effective educational practices. Nevertheless, in many Brazilian schools—especially in the northern region—thermal comfort is not guaranteed due to structural deficiencies, lack of investment in infrastructure, and limited access to climate control systems. Studies addressing thermal comfort in educational environments and its relationship with the work activities and health of education professionals remain scarce in Brazil, particularly in equatorial regions such as the Amazon, where high temperatures and humidity prevail throughout most of the year.

In this context, the present study aims to analyze the influence of thermal comfort on work activities, health, and well-being of education professionals in municipal schools located in the East Zone of Manaus, Amazonas, Brazil. The spatial focus of the research encompasses two municipal schools situated in an area characterized by high population density and significant demand for public education services. The selection of these schools considered factors such as differences in physical infrastructure, availability of air-conditioning systems, and the intensity of teaching activities, including both classroom-based and outdoor practical classes. The comparative analysis of these parameters is considered relevant for understanding how thermal discomfort operates as a structuring element of the precarization of teaching work and for highlighting its implications for educational quality and workers' health.

2. Materials and Methods

2.1. Study Area

The city of Manaus is the capital of the state of Amazonas and is located in the central portion of the Amazon Basin, the largest hydrographic basin in the world. The municipality has an estimated population of 3,941,613 inhabitants and a demographic density of approximately 181.01 inhabitants per km². Among the 62 municipalities of the state of Amazonas, Manaus ranks first in terms of population size and seventh at the national level among Brazilian municipalities (IBGE, 2025).

The study was conducted in two municipal public schools located in the East Zone of Manaus: Vicente Mendonça Júnior Municipal School and Governor Danilo de Mattos Areosa Municipal School (Figure 1). The East Zone was selected due to its high population density, intense urban occupation, and high demand for public education services. The choice of these schools considered differences in physical infrastructure, availability and functioning of air-conditioning systems, and the presence of both indoor and outdoor teaching activities, particularly practical classes conducted by Physical Education teachers.

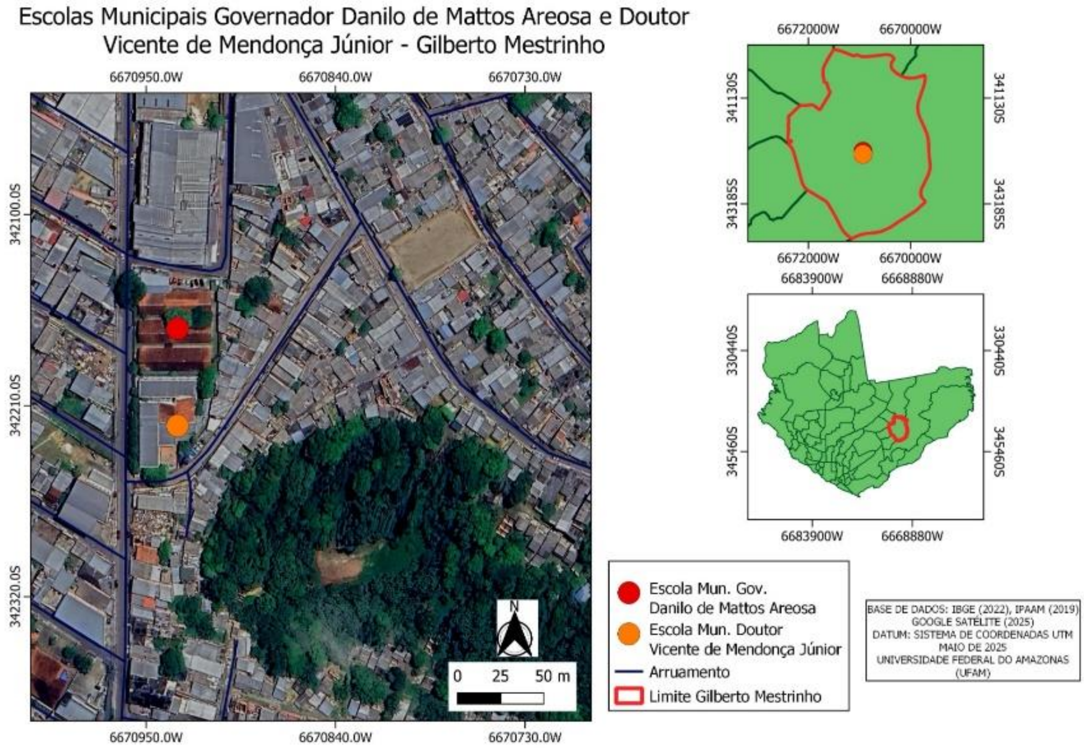

Figure 1. Location of study area: IBGE (2025); Google Satellite (2025).

2.2. Climatic Data

Climatic data on air temperature and relative humidity were obtained from the National Institute of Meteorology (INMET) for the city of Manaus, covering the period from 1992 to 2023. Monthly mean values were used to characterize long-term thermo-hygrometric conditions and to identify seasonal patterns associated with thermal discomfort. The data were organized and processed using descriptive statistical techniques, including calculation of mean, maximum, and minimum values. The analysis was conducted by decades in order to identify temporal variations in thermal conditions relevant to human thermal perception and to contextualize field measurements within long-term climatic behavior.

2.3. Data Collection and Analysis

Thermal conditions were evaluated using the Thom and Bosen (1959) Discomfort Index (DI), hereafter referred to as DI. This index has been widely applied in studies conducted in tropical and equatorial environments, as it integrates meteorological variables that strongly influence human thermal perception.

The DI is based on the concept of effective temperature (ET), which combines air temperature and atmospheric humidity to represent the thermal sensation experienced by individuals. In this study, the index was calculated using dry-bulb temperature (DBT) and wet-bulb temperature (WBT), according to the formulation proposed by Thom and Bosen (1959), as expressed in Equation (1):

$$DI = 0.4\,(DBT + WBT) + 4.8 \qquad (1)$$

where DBT represents the dry-bulb air temperature (°C) and WBT represents the wet-bulb temperature (°C).

As direct measurements of wet-bulb temperature were not available for the historical climatic series, WBT values were estimated from DBT and relative humidity (RH) data using the psychrometric approximation proposed by Tomasselli (2007, p. 107). This procedure ensured the consistent application of the DI to both long-term climatic data and field measurements collected in school environments. According to Thom and Bosen (1959), DI values below 21 °C indicate thermal comfort, whereas higher values represent increasing levels of thermal discomfort and potential health risks. The classification of thermal discomfort levels adopted in this study follows the thresholds presented in Figure 2.

Ano	jan	fev	mar	abr	mai	jun	jul	ago	set	out	nov	dez
1994	25,3	25,2	25,4	25,5	26,0	25,8	25,8	26,2	26,6	26,5	26,2	26,0
1995	24,8	25,6	25,7	25,6	25,7	25,7	26,2	26,7	26,9	26,8	26,2	26,0
1996	24,6	25,6	25,7	25,5	25,8	26,1	26,2	26,6	27,1	26,7	26,3	25,9
1997	25,3	25,3	25,3	25,7	25,9	26,6	26,7	26,6	27,7	27,5	26,7	26,2
1998	25,8	26,0	25,7	25,9	25,9	26,1	26,5	26,7	27,0	27,3	26,3	26,3
1999	25,5	25,7	25,6	25,6	25,4	25,6	25,7	26,2	26,2	26,5	26,4	26,2
2000	25,2	25,1	25,1	25,1	25,4	25,7	25,5	25,9	26,2	26,3	26,5	26,1
2001	25,0	25,2	25,5	25,4	26,0	25,5	25,8	26,7	26,7	27,1	26,5	26,2
2002	25,4	25,6	25,9	25,9	26,2	25,6	26,3	26,9	27,1	27,1	26,4	26,2
2003	26,4	26,0	25,9	25,9	26,0	26,1	26,5	26,6	27,0	27,1	26,8	26,5
2004	26,5	26,0	25,8	26,0	26,0	26,0	26,2	26,5	26,6	27,1	27,2	26,6
2005	26,6	26,0	25,8	26,1	26,2	26,4	26,3	26,9	26,9	27,2	27,0	26,0
2006	26,3	25,9	25,9	26,0	25,9	26,5	26,4	27,1	27,4	27,8	26,4	26,1
2007	25,9	26,3	25,7	25,8	25,8	26,1	26,3	26,5	26,9	27,4	26,6	26,0
2008	25,6	25,9	25,2	25,8	25,7	25,9	26,3	26,5	26,6	26,7	26,6	25,8
2009	25,3	25,4	25,3	25,8	25,6	25,8	26,5	27,4	27,5	27,5	27,6	26,3
2010	25,9	25,9	26,5	26,1	26,3	26,3	26,5	27,4	28,0	27,7	27,5	26,4
2011	26,0	26,0	26,5	26,1	26,5	26,8	26,9	27,6	27,7	27,3	26,9	26,5
2012	25,7	25,5	25,8	26,1	26,4	26,9	26,9	27,5	27,5	27,5	27,3	26,5
2013	26,0	25,6	25,9	26,3	26,4	27,0	26,4	27,1	27,4	27,7	26,9	26,7
2014	26,4	25,8	26,0	26,4	26,3	27,0	26,5	27,1	27,9	27,2	26,8	27,0
2015	26,2	26,2	26,0	26,5	26,4	26,9	26,9	27,9	28,8	27,9	27,7	27,5
2016	27,1	26,7	26,4	26,6	26,7	26,9	27,2	28,0	28,1	28,2	27,8	26,9
2017	26,9	26,4	26,5	26,5	27,1	27,0	27,0	28,0	27,3	27,5	27,4	26,3
2018	26,0	26,1	26,4	26,2	26,6	26,8	26,9	27,8	27,7	28,0	27,3	26,1
2019	26,1	26,1	26,7	26,3	26,3	26,7	27,0	27,4	27,9	27,5	27,2	26,2
2020	26,6	26,6	27,0	26,4	26,5	26,8	27,3	27,6	27,8	26,9	27,0	26,6
2021	26,4	26,3	26,3	26,4	26,6	26,7	26,9	27,5	27,4	27,3	26,7	26,4
2022	26,1	25,9	25,7	26,3	26,6	26,4	27,1	27,5	27,8	27,6	27,0	26,6
2023	25,5	25,6	25,9	26,2	26,6	26,6	27,4	28,0	28,3	28,6	27,8	26,8

Figure 2. Monthly variation of the Thom and Bosen Discomfort Index (DI) in Manaus from 1994 to 2023

2.4. Field Data Collection

Fieldwork was conducted in the two selected schools on October 29, 30, and 31, and November 1, 2024, during both morning and afternoon periods. Air temperature and relative humidity were measured using a Minipa digital thermo-hygrometer, positioned inside classrooms and in outdoor teaching areas at heights consistent with the breathing zone of occupants. Measurements were recorded at regular time intervals throughout the school day, allowing the assessment of diurnal variations in thermal conditions. The collected data were organized in Excel spreadsheets and used to calculate the DI for each measurement period, generating tables and graphical representations that supported the analysis of thermal discomfort within the school environments.

2.5. Qualitative Data Collection and Ethical Considerations

In addition to the quantitative thermal measurements, qualitative data were collected through semi-structured interviews conducted with education professionals working at the selected schools. A total of ten teachers participated in the study, including five Geography teachers and five Physical Education teachers.

Participants were informed about the objectives of the research, the procedures involved, the voluntary nature of participation, and the guarantees of confidentiality and anonymity. The interview script included questions related to perceptions of thermal comfort, impacts of thermal conditions on health and work activities, difficulties encountered in classrooms and outdoor teaching spaces, and suggestions for improving thermal conditions in the school environment.

The qualitative data were analyzed using thematic content analysis, allowing the identification of recurring perceptions and experiences related to thermal discomfort and the precarization of teaching work. These perceptions were subsequently compared with the DI results to assess the correspondence between measured thermal conditions and teachers' subjective experiences.

All procedures involving human participants complied with ethical principles of research involving human subjects. Participation was voluntary, and informed consent was obtained from all interviewees. Personal identification data were not recorded, ensuring anonymity and confidentiality throughout the research process.

3. Results

3.1. Climatic characterization of Manaus

The climate of Manaus is classified as equatorial, characterized by high temperatures, elevated relative humidity, and low annual thermal amplitude (Strahler, 2005, apud Aleixo et al., 2023). Monthly mean air temperatures in the region generally range between 25.8 °C and 27.9 °C, while seasonal thermal amplitude varies between 1 °C and 2 °C (Marengo & Nobre, 2009).
Rainfall seasonality defines two main climatic periods in the region: a rainy season, locally known as the "Amazonian winter", extending from December to May, and a drier period, known as the "Amazonian summer", from June to September. The months of October and November represent a transitional phase between these two periods.

3.2. Long-term thermal discomfort conditions (1992–2023)

The analysis of the Thom and Bosen (1959) Discomfort Index (DI), calculated using monthly mean air temperature and relative humidity data from 1992 to 2023, revealed a recurrent pattern of elevated thermal discomfort in Manaus. The highest DI values were consistently recorded between July and November, corresponding to the dry and transitional seasons. During these months, DI values frequently exceeded thresholds indicating that more than 50% of the population experiences thermal discomfort, according to the adopted classification (Table 1).

When analyzed by decades, the results showed an increase in the number of months classified as thermally uncomfortable in the most recent period. In the third decade of the analyzed series, elevated DI values began earlier in the year and extended until December, indicating an expansion of periods associated with thermal discomfort.

Table 1. Thermal discomfort classification based on Thom's Discomfort Index (DI)

DI (°C) range	Level of thermal discomfort
$DI < 21.0$	No thermal discomfort
$21.0 \leq DI < 24.0$	Less than 50% of the population feels discomfort
$24.0 \leq DI < 27.0$	More than 50% of the population feels discomfort
$27.0 \leq DI < 29.0$	The majority of the population feels discomfort
$29.0 \leq DI < 32.0$	Very strong and dangerous discomfort
$DI \geq 32.0$	Medical emergency state

Source: Thom & Bosen (1959).

3.3. Field measurements of thermal discomfort in schools

Field measurements conducted in October and November 2024 showed consistently high DI values in both schools during the monitoring period. The calculated DI values ranged from 25.7 °C to 30.6 °C, indicating conditions of thermal discomfort throughout the school day. In both schools, higher DI values were predominantly recorded during the afternoon period, between 1:00 p.m. and 5:00 p.m. The lowest DI values generally occurred during early morning hours, although these values still exceeded the threshold at which more than 50% of the population experiences discomfort.

Table 2. Thom's Discomfort Index (DI, °C) calculated for the analyzed schools (October–November 2024)

Date	Time	Vicente Mendonça Júnior School	Danilo de Mattos Areosa School
29/10/2024	07:00	26.1	27.4
30/10/2024	07:00	26.6	29.0
31/10/2024	07:00	26.1	27.7
01/11/2024	07:00	26.0	26.4
29/10/2024	09:00	25.8	27.4
30/10/2024	09:00	27.7	29.2
31/10/2024	09:00	25.7	28.7
01/11/2024	09:00	26.5	27.6
29/10/2024	11:00	26.6	28.5
30/10/2024	11:00	26.6	28.5
31/10/2024	11:00	25.7	27.7
01/11/2024	11:00	25.8	28.3
29/10/2024	13:00	27.3	29.6
30/10/2024	13:00	27.7	30.6
31/10/2024	13:00	26.3	27.9
01/11/2024	13:00	27.2	28.8
29/10/2024	15:00	27.8	30.0
30/10/2024	15:00	26.9	29.1
31/10/2024	15:00	26.8	27.6
01/11/2024	15:00	26.9	29.1
29/10/2024	17:00	30.4	29.8
30/10/2024	17:00	26.3	30.0
31/10/2024	17:00	25.8	28.6
01/11/2024	17:00	27.8	28.0

3.4. Comparison between schools

Despite the geographical proximity of the two schools, differences in DI values were observed. At the Vicente Mendonça Júnior Municipal School, the highest DI value (30.4 °C) was recorded on October 29, 2024, at 5:00 p.m. At the Governor Danilo de Mattos Areosa Municipal School, the highest DI value (30.6 °C) was recorded on October 30, 2024, at 1:00 p.m.

The lowest DI value recorded at the Vicente Mendonça Júnior School was 25.7 °C during the morning period on October 31, 2024. At the Governor Danilo de Mattos Areosa School, the lowest DI value was 26.4 °C, recorded at 7:00 a.m. on November 1, 2024. *These values are detailed in Table 2.*

3.5. Air temperature measurements

Air temperature measurements recorded during fieldwork indicated values ranging from 25.1 °C to 32.6 °C across the two schools. The lowest temperature (25.1 °C) was recorded at the Vicente Mendonça Júnior School on November 1, 2024, while the highest temperature (32.6 °C) was recorded at the Governor Danilo de Mattos Areosa School on October 30, 2024, at 1:00 p.m. Higher temperatures were consistently observed during the afternoon period in both schools.

Table 3. Air temperature (°C) recorded in the schools during fieldwork (October–November 2024)

Date	Time	Vicente Mendonça Júnior School	Danilo de Mattos Areosa School
29/10/2024	07:00	26.9	28.2
30/10/2024	07:00	27.5	28.7
31/10/2024	07:00	26.9	27.9
01/11/2024	07:00	26.5	27.7
29/10/2024	09:00	25.9	29.4
31/10/2024	09:00	25.9	26.8
01/11/2024	09:00	25.8	29.5
29/10/2024	11:00	26.5	29.2
30/10/2024	11:00	26.5	29.2
31/10/2024	11:00	26.3	28.7
01/11/2024	11:00	26.6	29.0
29/10/2024	13:00	25.1	29.0
30/10/2024	13:00	27.0	32.6
31/10/2024	13:00	25.7	28.5
01/11/2024	13:00	26.1	30.1
29/10/2024	15:00	27.2	30.9
30/10/2024	15:00	26.1	30.1
31/10/2024	15:00	26.0	29.1
01/11/2024	15:00	26.1	30.1
29/10/2024	17:00	31.3	29.5
30/10/2024	17:00	25.2	29.3
31/10/2024	17:00	25.4	28.1
01/11/2024	17:00	30.9	29.4

3.6. Relative humidity measurements

Relative humidity values recorded during the fieldwork ranged from 50% to 80%. The lowest relative humidity (50%) was recorded at the Governor Danilo de Mattos Areosa School during the afternoon period, while the highest relative humidity (80%) was recorded at the same school during the late afternoon.

At the Vicente Mendonça Júnior School, relative humidity values generally remained above 55%, with higher values occurring during the morning hours.

Table 4. Relative humidity (%) recorded in the schools during fieldwork (October–November 2024)

Date	Time	Vicente Mendonça Júnior School	Danilo de Mattos Areosa School
29/10/2024	07:00	58	70
30/10/2024	07:00	54	64
31/10/2024	07:00	55	74
01/11/2024	07:00	60	60
29/10/2024	09:00	53	56
30/10/2024	09:00	63	56
31/10/2024	09:00	55	66
01/11/2024	09:00	67	71
29/10/2024	11:00	61	66
30/10/2024	11:00	52	60
31/10/2024	11:00	64	60
01/11/2024	11:00	54	64
29/10/2024	13:00	55	52
30/10/2024	13:00	62	50
31/10/2024	13:00	62	67
01/11/2024	13:00	67	60

29/10/2024	15:00	64	50
30/10/2024	15:00	57	57
31/10/2024	15:00	68	66
29/10/2024	17:00	56	58
30/10/2024	17:00	51	54
31/10/2024	17:00	55	61
01/11/2024	17:00	66	80

3.7. Teachers' perceptions of thermal discomfort

Qualitative data obtained from semi-structured interviews indicated that thermal discomfort is widely perceived as a factor negatively affecting teachers' health and professional activities. Among the respondents, 70% reported that thermal discomfort has direct negative effects on their health, while 20% stated that it compromises the performance of their work activities. Additionally, 10% of the participants associated thermal discomfort specifically with respiratory-related health problems.

Regarding the occurrence of pathological symptoms in the work environment, 40% of the teachers reported experiencing symptoms such as rhinitis, fatigue, malaise, headaches, and episodes of decreased blood pressure. In contrast, 20% stated that they had not experienced any health symptoms, while 40% were unable to clearly identify or report the presence of symptoms, suggesting difficulties in recognizing or associating health effects with thermal conditions.

The spatial context in which teaching activities take place is illustrated in Figure 3, which presents the location and physical surroundings of the two schools analyzed. In addition, Figure 4 documents the working conditions faced by Physical Education teachers during practical classes, highlighting the inadequacy of outdoor spaces and direct exposure to solar radiation, factors that contribute to increased thermal discomfort during work activities.

Figure 3. Research schools: a) Municipal School Gov. Danilo de Mattos Areosa and b) Vicente Mendonça Junior School. Source: Google Earth (2024).

a)  b) 

Figure 4. Conditions faced by Physical Education teachers to conduct practical classes at the Municipal School Dr. Vicente Mendonça Júnior: a) inadequate outdoor space for practical activities; b) exposure to direct solar radiation during class time.

4. Discussion

The results obtained in this study demonstrate that thermal discomfort is a persistent and structurally embedded condition in the school environments analyzed, particularly during the afternoon period and in the dry and transitional seasons in Manaus. The long-term climatic analysis (1992–2023) indicates that elevated thermal discomfort is not an episodic phenomenon, but rather a recurring and increasingly prolonged condition, corroborating previous studies that describe the equatorial climate as characterized by sustained high temperatures and humidity with limited thermal relief throughout the year (Fisch et al., 1998; Marengo & Nobre, 2009).

At the local scale, field measurements revealed that indoor and outdoor school environments frequently operate within Discomfort Index (DI) ranges classified as affecting more than 50% of the population or representing strong and dangerous discomfort. These findings align with Silva (2001) and Labaki et al. (2001), who argue that unfavorable thermal conditions negatively influence productivity, work quality, and human performance. In educational settings, such conditions directly interfere with the execution of teaching activities, concentration levels, and the overall functioning of the teaching–learning process.

The afternoon period consistently presented the highest DI values in both schools, which coincides with the period of greatest physiological heat stress. This temporal pattern is particularly critical for Physical Education teachers, whose work activities are predominantly conducted in outdoor environments without adequate shading or roofing. As documented in Figure 3 and 4, the exposure to direct solar radiation during practical classes intensifies thermal stress and places these professionals in a situation of heightened occupational vulnerability. These findings are consistent with Shigunov (1997), who emphasizes that the lack of adequate physical spaces and infrastructure compromises both pedagogical quality and teachers' health.

The qualitative results reinforce the quantitative findings, revealing that teachers clearly perceive thermal discomfort as a factor that negatively affects their health and work performance. The reported symptoms—such as fatigue, headaches, rhinitis, malaise, and drops in blood pressure—are commonly associated with prolonged exposure to heat and high humidity, particularly in environments lacking effective thermal regulation. According to Cairrão (2019), excessive heat initially induces fatigue and drowsiness, reducing alertness and increasing the likelihood of errors, which compromises both professional performance and learning outcomes.

The difficulty reported by a substantial proportion of respondents in clearly identifying or articulating health symptoms related to thermal discomfort is also a relevant finding. This may indicate a process of normalization of adverse environmental conditions, in which chronic exposure to thermal stress becomes perceived as an inherent and unavoidable aspect of the teaching profession. Souza and Souza (2017) describe this phenomenon as part of the broader process of teacher malaise, in which illness results from the cumulative interaction of organizational, environmental, and structural factors rather than from isolated causes.

From a regulatory perspective, the thermal conditions observed in the analyzed schools are incompatible with the parameters established by Brazilian Regulatory Standard NR-17, which defines acceptable thermal conditions for work environments, particularly in air-conditioned spaces (Brazil, 2022). Even in classrooms equipped with air-conditioning systems, thermal comfort was not consistently achieved due to inadequate maintenance, air leakage, malfunctioning equipment, and excessive occupancy. These structural deficiencies contribute to the precarization of teaching work, as they undermine the minimum conditions required for safe, healthy, and effective professional practice.

The results also highlight inequalities within the school environment itself. While classroom teachers may intermittently access air-conditioned spaces such as teachers' lounges, Physical Education teachers remain disproportionately exposed to thermal stress due to the absence of covered sports facilities. This intra-institutional disparity reflects broader patterns of unequal distribution of environmental comfort and occupational protection, reinforcing the argument that thermal discomfort operates as a structuring element of precarious working conditions in public education.

Finally, the suggestions proposed by teachers to improve thermal comfort—including maintenance of air-conditioning systems, enhancement of natural ventilation, architectural adaptations, shading of outdoor areas, and reduction of class sizes—demonstrate an awareness of both technical and managerial solutions. These recommendations are consistent with the principles of bioclimatic architecture and user-centered school design discussed by Kowaltowski et al. (2012), who emphasize that the physical characteristics of educational buildings directly influence motivation, well-being, and pedagogical effectiveness.

Overall, the findings indicate that thermal discomfort in schools should not be treated merely as an environmental or climatic issue, but as a multidimensional problem that intersects with occupational health, educational quality, and social inequality. Addressing this issue requires integrated public policies that combine infrastructure investment, preventive maintenance, climate-sensitive architectural design, and recognition of teachers' working conditions as a central component of educational systems.

5. Conclusions

This study analyzed thermal discomfort in municipal schools located in the East Zone of Manaus and examined its implications for teaching work, health, and well-being of education professionals. The results demonstrate that thermal discomfort is a recurrent and structurally embedded condition in the analyzed school environments, particularly during the afternoon period and in the dry and transitional seasons characteristic of the equatorial climate of the Amazon region.

The long-term climatic analysis (1992–2023) revealed an expansion of periods associated with elevated thermal discomfort in Manaus, while field measurements conducted in 2024 confirmed that both indoor and outdoor school environments frequently operate within Discomfort Index (DI) ranges classified as affecting more than 50% of the population or representing strong and dangerous discomfort. These conditions were observed even in classrooms equipped with air-conditioning systems, indicating that the presence of cooling infrastructure alone does not guarantee adequate thermal comfort when maintenance, building design, and occupancy conditions are inadequate.

The qualitative findings showed that teachers perceive thermal discomfort as a factor that negatively affects their health and professional performance. Reported symptoms such as fatigue, headaches, malaise, respiratory discomfort, and episodes of reduced blood pressure indicate that prolonged exposure to heat constitutes a relevant occupational health risk. The difficulty reported by some participants in clearly identifying these effects suggests a normalization of adverse thermal conditions, reinforcing the notion that thermal discomfort is integrated into the everyday experience of teaching work.

Thermal discomfort was identified in this study as a structuring element of the precarization of teaching work, particularly for Physical Education teachers who conduct practical classes in uncovered outdoor spaces and are directly exposed to solar radiation. The unequal distribution of thermally adequate environments within schools highlights internal disparities in working conditions and underscores the need to consider environmental comfort as an essential component of occupational equity in public education.

The findings emphasize that improving thermal conditions in schools requires integrated actions that go beyond isolated technical solutions. Public policies should prioritize investments in school infrastructure, preventive maintenance of cooling systems, climate-sensitive architectural design, shading of outdoor teaching areas, and adequate class sizing. Recognizing thermal comfort as a fundamental dimension of educational quality and teachers' health is essential for promoting safer, more equitable, and more effective teaching–learning environments in equatorial urban contexts such as Manaus.

Future research should expand the scope of analysis to include a larger number of schools, longer periods of field monitoring, and the integration of additional thermal comfort indices and physiological indicators. Such efforts will contribute to strengthening the empirical basis for climate-adaptive educational policies and for the protection of education professionals' health in regions exposed to persistent thermal stress.

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