Thermal Comfort Analysis in Both Naturally Ventilated and Air-Conditioned Classrooms in a Warm and Humid Climate

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Abstract. Thermal discomfort in schools can compromise students and teachers well being and health; in addition, many cognitive processes are influenced by thermal environment. One solution to avoid thermal discomfort in a tropical climate can be the installation of air conditioning devices. However, little do we know about the thermal comfort in air-conditioned school buildings, specially considering the particularities of a tropical climate. This study aims to analyse the perception and sensation of thermal comfort in school buildings. Naturally ventilated and air-conditioned classrooms of public schools in João Pessoa, northeast Brazil, were investigated. A number of 352 children, aged 8 to 11 years old, were interviewed. The research’s methodology consisted in measuring environmental variables (air temperature, mean radiant temperature, relative humidity, air velocity), while questionnaires were applied to the children, containing four questions regarding their sensation and preference towards the thermal environment. In the naturally ventilated rooms, we observed the average air temperature of 28,78 °C, with 45,53% of the children feeling discomforted by heat, and 22,77% of them discomforted by cold, also 47,97% of the children reported a preference for a colder room and 24,39% reported a preference for a warmer room. In the air-conditioned rooms, we observed the average air temperature of 26,99 °C, with 39,37% of the children discomforted by heat, and 25,57% of them discomforted by cold, also 55,68% of the children reported a preference for a colder room and 14,46% reported a preference for a warmer room. The study emphasizes the occurrence of different votes of thermal sensation at the same air temperature range. The results also showed divergence between PMV and children real votes in air-conditioned rooms, encouraging the questioning about the indiscriminate use of air condition systems.

1. Introduction

Studies of thermal environmental comfort in classrooms grow in order to identify children sensations and preferences. A thermal discomfort condition can compromise the teaching-learning process [1][2][3][4], however the issue is emphasized in researches with children, as they are considered more susceptible to environmental stimuli than adults [5].
The energy performance of school buildings it is also relevant. In Brazil, the use of artificial devices such as air conditioners has increased, however, there is no ensures that the implementation of such equipment will be a strategy that achieves the intended objectives. In addition to the amount of energy consumption and expense required to maintain these systems, there is evidence that artificially conditioned spaces have a higher level of thermal rejection by their occupants, especially environments with central air systems [6].

Studies of thermal comfort can be classified into two groups: the rational indices, that assess the heat exchanges under laboratory conditions; and empirical indices, which are performed in field and statistically relate the thermal sensation with conditions outside the environment [7]. To perform data analysis of these studies, predictive models can be used, such as: the Predicted Mean Vote (PMV) and the Predicted Percentage of Dissatisfied (PPD) [8]. Despite the widespread use of these methods, some authors have shown that PMV is not able to estimate the real sensation of thermal comfort of individuals acclimated to tropical climates, a predominant condition in the Brazilian territory, and may predict a more severe sensation of thermal discomfort than users actually experience [9].

In this context, this work has as object of study public schools located in the city of João Pessoa, a coastal city (7,11°S; 34,86°W), classified by Köppen as a Northeastern Sub Dry Climate, 3dth type, [10]. Having a humid tropical climate [11], João Pessoa recorded in 2018 the maximum average temperature of 31°C and minimum of 23°C, as well an average relative humidity between 53% and 94% throughout the year [12].

The evaluation of the real situations experienced by students is fundamental to provide a school space with better living conditions and contribute to a more qualified educational process. Therefore, the goal of this study is to identify and relate thermal environmental variables with thermal sensations and preferences for 8 to 11 years-old children, considering naturally ventilated and air-conditioned classrooms in a warm and humid climate.

2. Experimental procedure
The method used to conduct this research comprehends on-site survey, measurements of environment variables, and observations, which were statistically analyzed.

2.1. The case study schools
The analyzed buildings in this study were six public schools located in the city of João Pessoa. Four of these buildings are artificially thermal conditioned and two are naturally ventilated. In total, the measurements took place in twenty classrooms distributed among schools located in different neighborhoods of the city.

The age group of children from 8 to 11 years old was determined considering their ability in reading and understanding the questionnaire. The artificially conditioned school buildings have the same architectural design, with two floors, differing in the plot location, as well as in the orientation of the building. The air-conditioned buildings were constructed after 2004. The naturally ventilated schools have a similar architectural typology, a ground floor building constructed in the 1980 and 1990 years.

The data collection took place in July and August of 2018 (winter), on different days for each school. The city has only two seasons: winter (rainy season) and summer. The weather data during the inside measurements was obtained by Instituto Nacional de Meteorologia – INMET [12].

2.2. Internal variables monitoring
The internal thermal variables collected were: air temperature, mean radiant temperature, relative humidity, and air velocity. The equipment used were: two TGD-300 thermal stress meters (0.5 °C accuracy) and one TARF 180 anemometer (+ 3% + 1 digit accuracy). For data collection it was assumed that the environments were homogeneous, therefore the equipment was installed at heights of 1.10 m and 0.60 m [8]. The equipment was located in the central area of the classrooms, the measurement started after 15 minutes (stabilization time).
2.3. Survey with children

The questionnaire application occurred simultaneously with the measurements of thermal variables. The assay used contained three questions: the first two were based on the ASHARE-55 questionnaire, adopting the 07 points scale (Table 1), however, with adaptation of the statement and the answers to the target audience. For the third question, the children could answer ‘yes’ or ‘no’ and justify its answer discursively. The first question referred to thermal sensation: ‘About heat or cold, how are you feeling now?’; while the second was about thermal preference: ‘About heat or cold, how would you like to be feeling now?’; the third question, that complements the questionnaire, concerns children's preference for artificially or naturally ventilated environments: ‘Do you prefer air-conditioned or non-air-conditioned environments?’.

Questionnaires were distributed and the research was briefly explained to the students. Sequentially, for each question, more explanation was given, when doubts persisted, the students were attended individually. The established subjective judgment scale can be encountered in Table 1.

| Scale questionnaire answers                  | ASHRAE-55 scale |
|----------------------------------------------|-----------------|
| Very warm (vote +3)                          | Hot             |
| Warm (vote +2)                               | Warm            |
| A little warm (vote +1)                      | Slightly warm   |
| Well, neither warm nor cold (vote 0)         | Neutral         |
| A little cold (vote -1)                      | Slightly cool   |
| Cold (vote -2)                               | Cool            |
| Very cold (vote -3)                          | Cold            |

2.4. Data Analyses

Collected data were organized in Excel spread sheets. The results were analysed comparing the thermal environment variables (independent variables) with the questionnaires answers (dependent variables). The answers were also compared to Fanger thermal comfort model. The PMV and PPD were calculated for the three types of clothing sets, taking into account operating temperature, air velocity, humidity and metabolic rate for each classroom (in each school). The CBE – Thermal Comfort Tool was used for the PMV and PPD calculation [13].

3. Results

3.1. Children’s profile, metabolic activity and clothing

The results include the participation of 352 children. A number of 123 students were from schools that used natural ventilation and 229 students were from air conditioned schools. The predominant age’s groups are: 35.51% of the respondents at the age of 10 years old; 32.39% of 9 years old, and 20.45% of 8 years old. The age of 11 years old totalled 10.51% of the respondents. Even, it was not the objective to investigate other ages, 1.42% of the pupils were at the age of 7, 12 and 14 year old.

At the time of field research, as well as in the 30 minutes preceding the monitoring of environment variables and the application of the questionnaire, the children performed typical reading and writing activities (considered sedentary or mild). Regarding clothing, all children wore a standardized school shirt with variations in the other pieces, composing lightweight clothing sets, typified in the research into three categories of thermal resistance. In order to standardize monitoring and questionnaire, metabolic activity (met) and clothes information (clo) were used according to ASHRAE [8] e ISO 7730 [14], corresponding to the metabolic rate of 1,0met e and thermal insulation level 0,35clo; 0,45clo e 0,50clo.
3.2. Classroom’s thermal environment

The operative temperature was calculated from the environment variables recorded during the field research. From the results, a minimum value of 25.32 °C and a maximum value of 30.16 °C were encountered. Figure 1 presents the results obtained in each classroom, differentiated by the strategy adopted (air conditioning – AC / natural ventilated – NV) and the shift in which the monitoring was performed (morning – am. / afternoon – pm.).

In Figure 1 it can be seen that in the morning, the thermal performance of naturally ventilated rooms (NV am.) is similar to the performance of air-conditioned rooms (AC am.). In the afternoon, the use of air conditioner (AC pm.) minimized heat conditions, which did not occur in naturally ventilated rooms (NV pm.).

![Figure 1. Operative and external temperature at: air-conditioned classroom’s morning monitoring (AC am) and afternoon monitoring (AC pm) and natural ventilated classroom’s morning monitoring (NV am) and afternoon monitoring (NV pm).](image)

3.3. Survey results

The Figure 2 shows the children real votes of sensation and thermal preference in naturally ventilated schools. A great part of the students, 31.71%, said that they were ‘well, neither warm nor cold’ (vote 0), however 45.53% pointed out different levels related to the sensation of heat (votes 1, 2 and 3). Relating the votes of thermal preference in these schools, it appears that although 31.71% of children indicated the sensation of thermal neutrality (‘well, neither warm nor cold’ – vote 0), a lower percentage (27.64%) stated that they would not like changes in the thermal environment (‘stay as they were’ – vote 0); demonstrating that 4.07% of children have a preference for changing, even considering the thermal condition satisfactory.
Figure 2. Thermal sensation votes in natural ventilated schools and thermal preference votes in natural ventilated schools.

Figure 3 shows the results of air-conditioned schools. Even using the artificial system, only 34.93% of students said that they were ‘well, neither warm nor cold’ (vote 0), while 39.30% of children indicated different levels related to discomfort by heat (votes 1, 2 and 3), and 25.76% of them indicated discomfort from cold (votes -1, -2 and -3). Totalling the amount of 65.07% of children reporting thermal discomfort. Regarding the thermal preference of the analysed children (Figure 3), there is a desire for a cooler environment from 55.90% of them (votes -1, -2 and -3). Relating this result to the thermal sensation votes, in which 39.30% of the children indicated a heat sensation (votes 1, 2 and 3), it is clear that even children who were comfortable (vote 0) or who indicated cold, preferred a colder environment.

Plotting the thermal sensation votes to the air temperature records in naturally ventilated environments (boxplot graph - Figure 4) it is possible to identify that the votes 0 (‘well, neither warm nor cold’) and 1 (‘a little warm’) showed a higher variability of air temperature conditions, with the lower limit at 27.10 °C and the upper limit at 30 °C, which means that the students presented a tolerance to higher temperatures. The neutrality condition occurred at an average temperature of 28.52 °C and a median of 29.15 °C. Different votes occurred at the same air temperature range. Analysing air temperature and thermal preference votes (Figure 4), it is observed a great air temperature variability related to the vote 0 (‘stay as they were’), with an average of 28.80 °C and a median of 29.15 °C. Still regarding thermal preferences, the students also gave their opinion about the use of air conditioning to promote thermal comfort in the classrooms – although it was an unavailable item in the environment where they were. Among the answers, 84.43% of the students said that they prefer air-conditioned environments (when compared to naturally ventilated), which may indicate a cultural or other influence.
This preference can be related to students desire for a cooler environment (votes -1, -2 and -3), which accounted for 47.97% of the children participating in the study (Figure 2).

In classrooms that use air conditioner (Figure 5), it is possible to highlight that most thermal sensation votes, whether related to cold discomfort, thermal neutrality or heat discomfort, as well as most thermal preference votes, occurred at similar temperature ranges; in other words, at the same temperature, a great variability in the votes is verified.

3.4. PMV model predictions vs. real votes

Based on the results of the student’s operative temperature index, air velocity, relative humidity, metabolic rate and thermal insulation level, the PMV [15] was verified according to ASHRAE-55 [8] in order to compare with the children real votes. In air-conditioned environments (Figure 6), the PMV – which estimated the sensation of comfort in all situations (values between ‘0’ and ‘1’) – underestimated both warm and cold sensation of the students, with the median of the real votes being -1 (‘a little cold’). In the case of naturally ventilated classrooms (Figure 6) the PMV approached the result of the real votes, whose median approached the vote 1 (‘feeling of low heat’).
4. Conclusions

The importance of thermal comfort in schools is undeniable; as in them children spend a considerable part of their day, developing their cognitive skills. Otherwise, the implementation of air conditioners in buildings schools has been increasing, especially in the warm and humid climatic context, as a strategy to mitigate heat discomfort.

The results of this study, however, demonstrate a similar thermal performance in classrooms that adopt the strategies of natural ventilation and air conditioners, in the morning. In this same understanding, among the total votes there is a very similar percentage that refers to thermal neutrality – or feeling of comfort: 31.71% in naturally ventilated environments, under conditions of average air temperature of 28.5°C; and 34.93% in artificially conditioned environments, under average air temperature conditions of 26.98°C. In addition, considering the votes on thermal environment condition in air-conditioned classrooms, 65.07% of the children reported discomfort, related to cold and heat discomfort.

Regarding thermal preference, in environments that use air conditioner, there is a significant amount of preference for a cooler environment (55.9%), simultaneously with the report of cold discomfort (25.76%). This fact demonstrates significant differences in thermal preference and points to the hypothesis of addiction to artificial cooling [16].

The results of this study show that the air-conditioning system used to mitigate heat discomfort causes cold discomfort and does not completely exclude heat discomfort. Finally, this study questions the efficacy of the indiscriminate adoption of air conditioning, in detriment of the adoption of bioclimatic strategies for the thermal comfort.

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