Air Movement Preference and Thermal Comfort

A survey in classrooms during summer season in Brazil

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ABSTRACT: This research aims to explore the relationship between thermal and air movement preferences inside naturally ventilated buildings in the north-east of Brazil. Questionnaires relating to thermal acceptability were given whilst measurements (air velocity, air temperature, radiant air temperature and humidity), were simultaneously taken inside classrooms. This paper summarizes results for the summer season when 915 questionnaires were answered for the buildings' occupants. Results suggest that occupants demand far more air movement as an essential strategy in order to improve their thermal comfort conditions. In addition, it is also possible to notice a significant demand for complementary cooling strategy, such as fans.
Keywords: air movement preference, thermal comfort, air velocity, warm and humid climate.

INTRODUCTION

Many of the justifications for that shift from naturally ventilated indoor climates to HVAC during the late 20th century emphasised the risk of local discomfort, or draft, in situations where indoor air movement relies on natural processes instead of controllable mechanical ones. Previous studies have attempted to define when and where air movement is desirable and when it is not (i.e. draft). As concept, draught means an unpleased air movement and it is related with air temperature and air speed but also of several factors such as area and variability and part of the body which is exposed [1]. Wind chill in cold conditions is considered detrimental but air movement in neutral to hot environments is considered beneficial. This is because normally under conditions with air temperatures above 23°C, the body needs to lose heat in order to maintain a constant internal temperature [2].

Thermal comfort research literature indicates that indoor air speed in hot climates should be set between 0.2 - 1.50 m/s, yet 0.2 m/s has been deemed in ASHRAE Standard 55 [3] to be the upper limit of draft perception allowed inside air-conditioned buildings where occupants have no direct control over their environment [4]. The new standard 55 is based on Fanger's [5] draft risk formula, which has an even lower limit in practice than 0.2 m/s. None of the previous research explicitly addressed air movement acceptability, instead focusing mostly on overall thermal sensation and comfort [6].

Much of Brazil's territory is classified as having a hot, humid climate. In such regions, natural ventilation combined with solar protection, are the most effective building design strategies to achieve thermal comfort without resorting to mechanical cooling. However, the use of air-conditioning as the main cooling strategy inside the buildings has been increasing. Governmental data suggest that buildings are responsible for circa 30.7% of the energy final-use in Brazil (public and commercial sectors combined), [7].

However the benefits of people spending more time inside artificial and controlled environments during their daily activities in order to keep than "neutral" have been questioned. If we agree that thermal environments that are slightly warmer then preferred or neutral, can be still acceptable to building occupants (as the adaptive comfort model suggests [8, 9], then the introduction of elevated air motion into such environments should be universally regarded as desirable because the effect will be to remove sensible and latent heat from the body, so body temperatures will be restored to their comfort set-points [8].

The weight of research evidence to date suggests that neither the "risk" of draft nor the possibility of negative indoor air quality posed by elevated enthalpy in buildings with natural or hybrid ventilation systems are real enough to sacrifice the environmentally sustainable goals of bioclimatic design strategies [10].

This research aims to explore the relationship between thermal and air movement preferences inside naturally ventilated buildings in the north-east of Brazil. Maceió city is located in the north-east of Brazil, latitude 9º40' south to the Equator and longitude 35º42' west of the Greenwich meridian.

METHOD

This paper presents results from summer season in Maceió city when 915 questionnaires were filled out for occupants during the field experiments.

Measurement rooms The indoor environments were chosen according to following criteria: windows had to be easy to access and operate; rooms could not have a mechanical cooling system (refrigerated air-conditioning); rooms could have mechanical ventilation with unconditioned air (fans); opening and closing of windows had to be the primary means of regulating thermal conditions and the occupants had to be engaged in near sedentary activity (1-1.3 met), and had to be able to freely adapt their clothing.

Based on this, classrooms and design rooms of Federal University of Alagoas and also Centre of Superior Studies of Alagoas fitted these selection criteria, Figure 1: . In addition, these buildings presented large open spaces and natural ventilation was intentionally the main cooling strategy. In all buildings, the open spaces were easily controlled collectively by the occupants and ceiling fans provided supplemental air movement inside the rooms.


a)


b)

Figure 1: Classrooms (a), design rooms (b).

Occupants The field research included 183 occupants during the summer season. The resulted data were organized in order to understand the occupants' profiles including individual characteristics such as gender, age, weight and height. As a consequence, it is possible to identify a non uniform distribution between the number of female and male subjects (66% and 34%, respectively). In relation to the subjects' ages, a variation between the ages of 17 and 27 years was noted.

The activities performed by the occupants of these environments were assessed as sedentary with a variation between 58 and 93W/m² because the subjects stayed seated whilst drawing or writing,. The clothes were light - around 0.3 clo, estimated according to clothing garment check-lists in ASHRAE 55 [3], Figure 2.

Figure 2: Occupants' typical clothes during "summer" season.

Measurement equipment Air temperature, humidity and mean radiant temperature were measured with a microclimatic station. This equipment is able to take measurements and store the data collected into a data logger during the measurement period. Instruments such as globe thermometer, the psychrometer (dry and wet-bulb temperatures) and the hot wire anemometer were applied.

In addition, complementary air speed measurements were carried out near to each occupant simultaneously whilst they filled out the questionnaire. Air velocity values were registered with a portable hot wire anemometer which was oriented according to the dominant airflow direction indicated by smoke sticks.

Measurement procedures Measurements included morning and afternoon periods, for at least two hours in each period. The occupants' activities were not interrupted in order to characterize the typical use of the rooms. In addition they were allowed to adapt their environment using ceiling fans, task lighting and also controlling the openings (to close or to open doors/windows).

The microclimatic station was located in the centre of the room and it was regulated to cater for two heights. The first height was 0,60m, corresponding to the subjects' waist height inside the classrooms. The second height was 1,10m which corresponded to the subjects' waist height inside the project rooms. The measurements recorded were average of five minutes for air speed and also for the other variables (globe temperature, air temperature and humidity).

Individual air velocity values were registered with portable hot wire anemometer located near to the occupants and at the same work plan height. These measurements were carried out simultaneously whilst they filled out the questionnaire. The hot wire anemometer was oriented according to the dominant airflow direction indicated by smoke sticks. Based on the air velocity's standard deviation it was possible to analyze the turbulence intensity.

RESULTS

Operative temperatures recorded during the field experiments were up to 28°C and humidity levels up to 65%. Thermal sensation votes were concentrated into "neutral", "slightly warm" and "warm" (38%, 36% and 22%, respectively). Only 3% of the occupants indicated "hot" as their thermal sensation, less than 2% for "slightly cool" and none of them voted for "cold". Figure 3 summarizes occupants' thermal sensation.

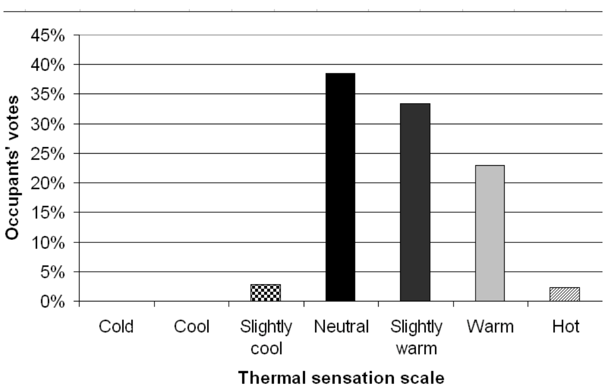

Figure 3: Occupants' thermal sensation.

Regardless to occupants' thermal preference, 53% preferred "no change" and 47% "cooler" as an overall distribution for all recorded operative temperatures. These thermal preference values are coherent to thermal sensation votes when the majority of occupants indicated to be "neutral", "slightly warm" and "warm", particularly for summer conditions, Figure 4. Thermal sensation votes were binned according to operative temperature values. According to these data it is possible to note that there is a slightly decrease of occupants' preferences for "no change" as well as an increment of those preferring "cooler". Figure 5 summarizes occupants' thermal preference for operative temperature values.

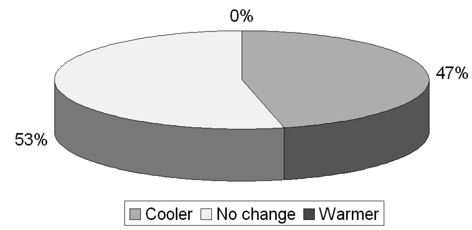

Figure 4: Occupants' thermal preference.

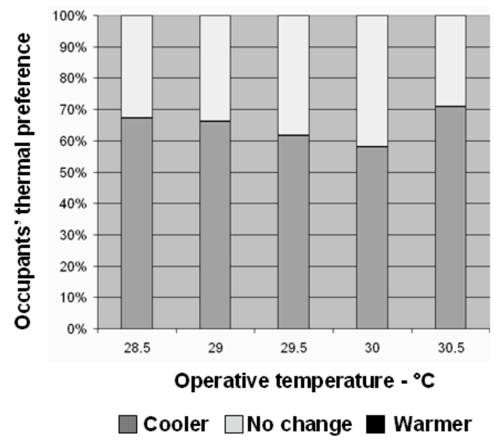

Figure 5: Occupants' thermal preference binned for operative temperature values.

Overall thermal preferences results indicated that there is a strong relationship between the occupants' preference for "cooler" and also "more air velocity" (Table 1). For those occupants' voting for "no change" as their thermal preference, 74.5% also indicated "no change" as their air velocity preference. Inside these same thermal preference votes, 21.2% indicated air velocity preference for "more" and only 4.3% of the occupants' voted for "less air velocity". Similar results were also found even for the cooler season conditions and results can be viewed in Cândido et al [11].

Approximately 10% of the occupants' thermal preference for "cooler" also indicated air velocity preference for "no change". Up to 88% of the occupants preferred "more air velocity" while only 1.7% preferred "less air velocity'.

Table 1: Overall thermal and air velocity preferences.

Thermal preference	Air velocity preference		
	More	*No change*	*Less*
No change	21.2%	74.5%	4.3%
Cooler	88.3%	10.1%	1.7%

Air velocity preference was binned for both operative temperature and air velocity values as indicated on Table ***2***. As an overall distribution it is possible to note that occupants' air velocity preference for "no change" increases with higher air velocities.

Table 2: Air velocity preference binned for operative temperatures and air velocity values.

Operative temp. (°C)	Mean air velocity (m/s)	Air velocity preference		
		More	*No change*	*Less*
28.5	0.25	78.4%	21.6%	0.0%
	0.50	60.0%	40.0%	0.0%
29.0	0.25	91.7%	8.3%	0.0%
	0.50	81.1%	18.9%	0.0%
29.5	0.25	73.8%	20.2%	6.0%
	0.50	64.0%	32.0%	4.0%
30.0	0.25	71.2%	25.4%	3.4%
	0.50	71.1%	21.1%	7.8%
30.5	0.25	56.4%	38.5%	5.1%
	0.50	71.4%	28.6%	0.0%

For mean air velocity of 0.25m/s the majority of occupants' air velocity were related to "more". On the other hand, it is important to notice that the number of responses for "less air velocity" was never greater than 5.1%.

When air velocity was up to 0.25m/s fewer people asked for "more air velocity" when compared to the percentages requesting for lower air velocity values. Despite the air velocity increment, the number of occupants asking for "less air velocity" was less than 7.8% for all operative temperature values.

Inside these environments, occupants were allowed to adapt their rooms' openings and also ceiling fans as explained before. Table 3 summarizes both occupants' air velocity and thermal preferences and also their preference for complementary passive cooling (openings and fans).

For mean air velocities of 0.25m/s, 27% of the occupants indicating both thermal preference for "no change" and "no change" for air velocity also preferred complementary passive cooling from fans. When occupants' air velocity preference was for "more" their preference for complementary cooling percentage was 73%. For mean air velocities of 0.5m/s, occupants preferring increment from complementary cooling was 65% and 35% for air velocity preferences of "more" and "no change", respectively.

Table 3: Occupants' air velocity and thermal preferences and preference for complementary cooling (ceiling fans).

Thermal preference	Mean air velocity (m/s)	% of occupants' preference for complementary cooling binned for air velocity preferences.		
		More	*No change*	*Less*
No change	0.25	73%	27%	0%
	0.50	65%	35%	0%
Cooler	0.25	92%	8%	0%
	0.50	83%	17%	0%

Occupants voting for "cooler" as their thermal preference but "no change" for air velocity indicated preference for complementary cooling in only 8% (mean air velocity of 0.25m/s). However, this percentage increased for 92% for occupants preferring "more" air velocity. For mean air velocities of 0.5m/s, occupants' preferences for complementary cooling were 17% and 83% for air velocity preferences of "no change" and "more", respectively.

These percentages indicated occupants' strong demand for more air velocity and also complementary cooling. These results combined suggested that air velocity increment inside these buildings is an essential strategy in order to provide occupants' thermal comfort.

For all combinations of thermal, air velocity and also complementary cooling preferences, the percentages of occupants demanding "less" air velocity was zero. These results suggest a significant demand for higher air velocities inside these buildings.

CONCLUSIONS

This paper presented results related to air movement preferences and thermal comfort inside naturally ventilated buildings in Brazil.

For summer season, operative temperatures were up to 28°C. Regardless to occupants' thermal sensation, their votes were concentred into "neutral", "slightly warm" and "warm". Combined to these results, the majority of answers for thermal preference were for "no change" and "cooler".

Particularly for air velocity preferences, results suggested that the majority of occupants indicated necessity for "more air velocity" both for values of 0.25 and also 0.50 m/s.

When asked about their necessity for complementary cooling, the majority of occupants' demanded more increment. These results crossed with thermal and air velocity preferences showed their significant necessity for more air velocity.

Based on this and in combination to the operative ranges, it was possible to identify the demand to higher air velocity values. This demand should be considered as an essential item for occupants' thermal comfort. Draft risk is definitely not the main complaint related to the occupants' activities for a hot, humid climate such as Maceio city as previous studies suggested [5, 12].

Air velocity acceptability studies should be carried out in order to a better understating of occupants' tolerances. In addition, these results are an important input data for future standards focusing on an architecture more compromised with energy efficiency and therefore sustainability.

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