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Thermal acceptability assessment in buildings located in hot and humid regions in Brazil

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ABSTRACT

The objective of this paper was to perform an analysis on thermal acceptability in naturally ventilated (NVB) and air-conditioned buildings (ACB) located in hot and humid climates in Brazil. Experiments were carried out in April and November 2005 with 1.301 questionnaires based on ISO 10551:1995(E). Indoor and outdoor climatic variables were monitored simultaneously. The results revealed that 53% of the occupants of NVB and 78% of ACB were thermally satisfied. However, some restrictions were observed with the applications of the following methodologies: ISO/FDIS 7730:2005(E); ANSI/ASHRAE Standard 55:2004; Adaptive Temperature Limits (ATG) and prEN15251: 2005(E). Differences were observed between thermal sensation (TSV) and predicted mean vote (PMV) and between the subject's percentages expressing thermal unacceptability of the environment and the PPD calculated according to ISO/FDIS 7730:2005(E).

1. Introduction

Since the presentation of the Fanger model in 1970 [1], the evaluation of the thermal acceptability in indoor environments began to be expressed in terms of the PMV (Predicted Mean Vote) and PPD (Predicted Percentage of Dissatisfied) indices. Initially adopted as an international model in 1984 (ISO 7730) [2], the limits of $-0.5 \leq \text{PMV} \leq +0.5$ and PPD $\leq$ 10% which defined the environment thermal acceptability were altered by the annex A of the ISO/FDIS 7730:2005(E) [3] adopting3 bands or classes: A, B and C. Nevertheless, this new regulation was not enough to solve the question about the evaluation of the thermal acceptability in naturally ventilated buildings. Its indiscriminate application has generated discrepancies in different parts of the world. Among the probable justifications is the fact that the model was originally developed in acclimatized chamber where the environment is completely under the researcher's control.

In the search for a solution for this question, several methodologies have been suggested.

In this way, it was recently suggested a new classification to the thermal environments which are to be submitted to an evaluation of the thermal acceptability [4]. Others, which are more specific to the analysis of only the thermal acceptability, are also at our disposal, considering that the sensation, satisfaction and thermal acceptability also allow the required evaluation.

In relation to the thermal acceptability, specific object of this work, a research carried out in Hyderabad, India, revealed that the thermal unacceptability is low in elderly people, high in women and in people from a low economical class [5].

In order to obtain comfortable indoor environments, one can observe with relative frequency, the use of artificial acclimatization in an inadvisable way, a fact that besides contributing to the emission of gases, which pollute the atmosphere, is contrary to the patterns of energetically efficient buildings. However, we have to consider the publicizing of researches which aim was to search for technological alternatives to the production of thermally comfortable, ecologically correct and energetically efficient indoor environments [6,7]. This concern has reached the housing located in rural areas. Recently, the comparison between the thermal acceptability verified in rural and urban houses, indicated to the same operative temperature that both the thermal sensations votes and the percentage of votes of acceptability obtained in the rural area are higher than those from the urban area [8]. It has been deduced that such fact is probably due to the lower thermal comfort expectancy of the referred population.

According to the standards, thermal acceptability is indirectly inferred from Predicted Mean Votes (PMV) calculated from Fanger's model [1], ranging from negative (cool) to neutral to positive

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Table 1
Categories of thermal environment according to ISO/FDIS 7730:2005(E) [2] and prEN 15251:2005(E) [5] for conditioned indoor environments.

Category	Thermal state of the body as a whole	
	PPD (%)	PMV
A	< 6	−0.2 < PMV < + 0.2
B	< 10	−0.5 < PMV < + 0.5
C	< 15	−0.7 < PMV < + 0.7

(warm). The environmental quality is classified into three classes (or categories) according to ISO/FDIS 7730:2005(E) [3] and prEN 15251:2005(E) [9]. Table 1 summarizes these requirements. The work which discusses if the applicability of the "A" class proposed by the ISO/FDIS 7730:2005(E) [3] is realistic or desirable was presented recently [10]. As a conclusion, the authors state that the "A" class is unsustainable as a base of control of office buildings due to the cost of energy for the maintenance of the required specifications. ASHRAE Standard 55 [11] suggests a graphic method for typical indoor environments in a range of operative temperatures resulting in 80% of acceptability (Fig. 1a), based on the 10% dissatisfaction criterion for general (whole body) thermal comfort according to the PMV-PPD index.

If this classification can be questioned for conditioned indoor environments, in naturally ventilated building (NVB) the scenario is far more complex. Especially in NVB, the results of field experiments indicated that occupants consider temperature fluctuations acceptable and desirable. Considering these aspects, standards also provide methods in order to maintain 80% or 90% of thermal acceptability inside the environments. Specific requirements are therefore necessary, and they are particularly related to the occupants' free adaptation of their clothing to indoor thermal conditions.

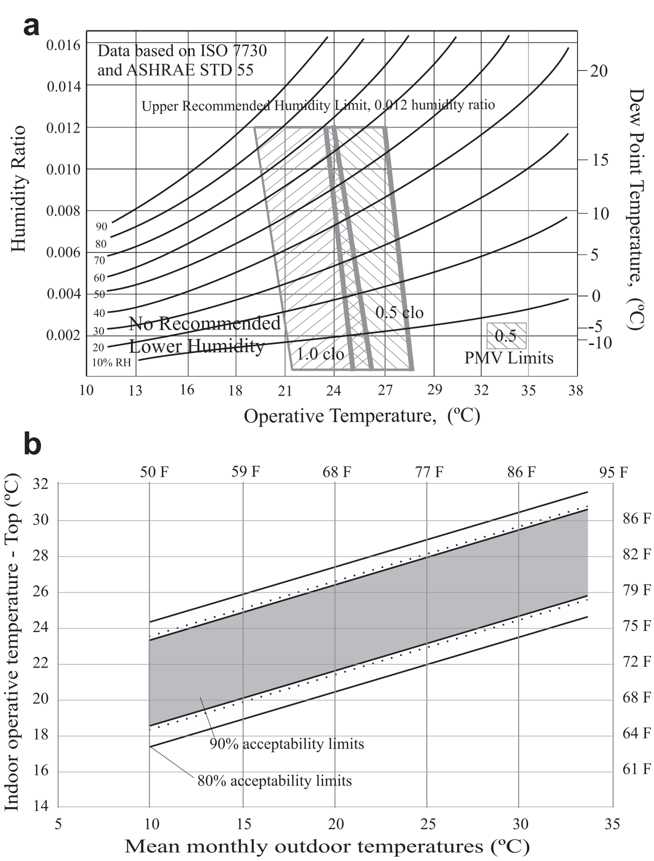

Fig. 1. (a) Acceptable operative temperature ranges for typical indoor environments according to ANSI/ASHRAE Standard 55:2004. (b) Acceptable operative temperature ranges for naturally conditioned spaces according to ANSI/ASHRAE Standard 55:2004.

ANSI/ASHRAE Standard 55:2004 [11] suggests an optional method for determining acceptable thermal conditions in NVB (see Fig. 1b). According to the graph and based on indoor comfort temperatures, limits for 80% and 90% of thermal acceptability are possible. This criterion is applicable for spaces equipped with operable windows, without mechanical cooling system (mechanical ventilation is allowed) with occupants engaged in almost sedentary activities and being able to freely adapt their clothing insulation. The operative temperature limits proposed are monthly mean outdoor temperatures lower than 10 °C or higher than 33.5 °C. prEN 15 251:2005(E) [9] also suggests a graphic method in order to define thermal acceptability for NVB.

The applicability of Fanger's PMV model [1] on which those classes are based has raised discussions and controversies because studies showed discrepancies between the occupants' TSV and PMV, particularly when the experiments were developed inside real buildings. Alternative models have been presented. [12–28]. However, those discrepancies are not just related to the normalized model of calculus of the PMV. Recently, a new formula of calculus was presented due to the discrepancies verified with the application of the model proposed by Fanger after an experiment carried out in a hot and humid region [29].

Especially for hot and humid climates, where design strategies for NVB or ACB resulted in different envelopes for thermal indoor conditions, standards and methods play important roles. Keeping in mind that a significant part of the research used as reference for standards has been developed in cold and temperate climates, the hypothesis that methods and targets can vary for hot and humid contexts is reasonable.

This paper focuses on thermal acceptability analysis inside ACB and NVB located in hot humid regions in Brazil, considering the requirements and methods proposed by the following standards: ISO/FDIS 7730:2005(E) [3], prEN 15 251:2005(E) [9], ANSI/ASHRAE Standard 55:2004 [11] and Adaptive Temperature Limits (ATG) [30].

2. Method

The method consists in a comparative analysis between the results for thermal acceptability values from field experiments and the requirements specified in ISO/FDIS 7730:2005(E) [3], prEN 15 251:2005(E) [9], ANSI/ASHRAE Standard 55:2004 [11] and Adaptive Temperature Limits (ATG) [30]. Questionnaires (1301) based on ISO 10551:1995(E) [31] and comprehensive measurements of the indoor climatic were analyzed simultaneously. Detailed information about climate background, indoor environments and measurement protocol are given below.

Table 2
Mean monthly outdoor air temperatures in Corumbá, Coimbra and Campo Grande.

City	Month	Mean outdoor temperature			
		1961/1990		Field experiment period	
		Max	Min	Max	Max
Corumbá and Coimbra	April	30 °C/32 °C	20 °C/22 °C	32 °C/34 °C	20 °C/22 °C
	November	32 °C/34 °C	22 °C/24 °C	34 °C/36 °C	22 °C/24 °C
Campo Grande	April	28 °C/30 °C	18 °C/20 °C	30 °C/32 °C	22 °C/24 °C
	November	30 °C/32 °C	18 °C/20 °C	30 °C/32 °C	20 °C/22 °C

Source: www.cptec.inpe.br/clima/monit/monitor_brasil.shtml (02.10.2005)