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Thermal comfort in undergraduate laboratories — A field study in Kharagpur, India

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ABSTRACT

A thermal comfort field survey is carried out inside a naturally ventilated laboratory in the tropical climatic region of India. The building chosen is used for courses in an undergraduate engineering curriculum. We aimed at assessing how the occupants perceive their thermal environment in a free running building while carrying out their normally scheduled tasks. A total of 121 acclimatized subjects were interviewed and 338 responses were collected during the months of spring semester. Survey results show a strong correlation between indoor comfort conditions and outdoor temperature. Occupants show adaptability across a comfort zone that is well beyond recommendations of rational models. Overall, 78% of the responses found their thermal environment to be acceptable. Based on indoor temperature observations, we calculate comfort temperatures for the subjects using Griffiths' method. The comfort temperature values are then related with prevailing mean outdoor air temperature to give an adaptive comfort equation. Predictions from our equation show satisfactory to good agreement with the predictions from similar equations in comfort standards.

1. Introduction

Activities involved in teaching-learning process are known to be affected by the immediate thermal environment [1–3]. Thermal environment's effect on mental performance is necessarily associated with occupants' subjective evaluation of thermal comfort [1,4]. So thermal comfort of occupants in classrooms and other rooms related to educational facilities is of vital concern.

In India, the demographic eligible for attending institutes of higher education, i.e. 18–23 year old, makes up 11–12% of the national population [5]. Actual enrolment is nowhere near 100% of this age group, yet, at the beginning of the 2010–11 academic year, India had 14.6 million students enrolled in its 544 universities (or equivalent institutes) and 31,324 colleges [6]. Add to this the 0.7 million faculty members and that number beats the combined population of Finland, Ireland, and Norway! Further, data shows that both the number of institutions and enrolments in them are growing at more than 5% annually [5].

For providing thermal comfort in all these classrooms spread across a country having mostly tropical weather, AC can come to mind as a tempting and quick fix solution. Projections show India beating both USA and China by 2055 to become the world leader in energy consumption for AC [7]. But India's current energy scenario is hardly reassuring and forebodes a grim future. During the recession of 2009, while overall world energy demand decreased by 1%, India's total final energy consumption increased by about 10% [8]. Also in 2009, India became world's third largest energy consumer but with a 26% energy deficit [8]. More than a third of India's electricity consumption is in residential and commercial sectors and the electricity demand of these sectors has been growing at more than 8% [9]. In both of these sectors, a significant portion of the energy demand is from buildings while more than half the buildings India will have in 2030 are yet to be built [10]. All these statistics and estimations prove a great urgency for energy saving measures in Indian buildings.

While the National Building Code of India (NBC) [11] is 'the' guideline for building construction in India, until 2007, there were no codes or requirements to be satisfied for energy efficiency in new buildings. When it comes to AC in classrooms, the NBC prescribes a rather narrow comfort zone of 23–26 °C, 50–60% RH. In 2007, the Bureau of Energy Efficiency (a body under Ministry of Power, Government of India) brought out the Energy Conservation Building Code (ECBC) for achieving energy efficiency in large commercial buildings. But ECBC still takes NBC as the reference standard for both AC requirements and ventilation requirements in

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Nomenclature

Abbreviations

AC	air-conditioning
ACE	adaptive comfort equation
APD	actual percentage dissatisfied
DBT	dry bulb temperature
MRT	mean radiant temperature
MTCV	mean thermal comfort vote
MTSV	mean thermal sensation vote
NV	naturally ventilated
PMOAT	prevailing mean outdoor air temperature
PMV	predicted mean vote
PPD	predicted percentage dissatisfied
PS	percentage of acceptable votes/percentage satisfied
RH	relative humidity
RMT	running mean temperature
TCV	thermal comfort vote (individual's)
TCVS	thermal comfort votes in mid three points of scale
TSI	tropical summer index
TSV	thermal sensation vote (individual's)
TSVS	thermal sensation votes in mid three points of scale
WBT	wet bulb temperature

Symbols

p_a	absolute pressure of water vapour in air
t_a	air temperature
t_c	comfort temperature
t_g	globe temperature
t_m	daily mean temperature
t_{mm}	monthly mean temperature
t_{mrt}	mean radiant temperature
t_o	outdoor temperature index
t_{op}	operative temperature
t_{rmt}	running mean temperature
v_a	air velocity
Δt_c	absolute difference between comfort temperature predictions from different models

NV spaces [12]. For NV buildings, the ECBC User Guide does mention the adaptive model given in ASHRAE Standard 55 as an option for determining comfort [12].

Adaptive thermal comfort standards have shown great promise in reducing energy consumption of buildings, without sacrificing occupant comfort. Several studies done for NV classroom occupants in tropical regions (Köppen climate classification type A) have borne out significant levels of adaptation amongst occupants [13–16]. These studies have come up with comfort zones between 22 and 31 °C and neutral temperatures in the range of 26.5–29 °C. These findings are an obvious testament to the fact that comfort is not exclusively found within the confines of a conditioned building.

Field studies in India also attest to remarkable levels of occupant adaptation both to the local climate and to NV buildings. In a very early comfort study done in Calcutta, Rao reported a comfort temperature of 25.8 °C DBT [17]. Sharma and Ali [18] did a very comprehensive study on comfort, developing the sole empirical index of thermal comfort based on Indian subjects and Indian conditions — TSI. They found that a TSI value of 27.5 °C elicited maximum percentage of comfortable votes. Over the past decade, there has been a significant rise in the number of thermal comfort studies being done across India. A summary of some such studies in presented in Table 1.

Pellegrino et al. have also reported a short duration comfort study done in NV classrooms of two universities in Kolkata [23]. This study was over a couple of days and during the summer month of May. As would be expected from the adaptive hypothesis of comfort, the neutral temperature obtained in this survey came out to be rather high (30.9 °C). To the best of our knowledge, apart from the study by Pellegrino et al., no other studies have been reported from Indian classrooms. Considering the importance of comfort requirements in classrooms and the fast growing number of institutes for higher education in India, classroom thermal comfort needs serious attention. Our study was aimed at finding the level of thermal comfort and acceptance amongst students of an undergraduate course during their regular semester classes. We also aimed to ascertain if the adaptive comfort model can be applicable at sustained metabolic rates that are slightly over ASHRAE Standard 55-2010 current specification of 1–1.3 met [24]. So we decided to survey the conditions during a laboratory class.

Table 1
Summary of recent Indian studies.

Location	Building type	Conditioning	Regression neutral temperature
Hyderabad [19]	Residences	NV	29.23 °C
Chennai [20]	Railway waiting lounge	NV	31.93 °C
Hyderabad [21]	Offices	NV	26.4 °C
		AC	26.3 °C
Chennai [21]	Offices	NV	26.1 °C
		AC	27.5 °C
Jaipur [22]	Student dormitories	NV	30.15 °C

Our main objectives for this study were:

- Assessing occupants' perception of thermal comfort in a free running building during their regular classes.
- Determining the range of temperature found most suitable by these occupants.
- Determining if adaptive comfort principle can be applied at slightly higher than sedentary metabolic rates.
- Establishing a path and framework for future studies.

2. Study methodology

2.1. Location, building, and subjects

2.1.1. Study location and duration

Kharagpur – located in the eastern Indian state of West Bengal – has a climate classification of Tropical savannah type (Aw) under the Köppen system. Summers are hot and humid, monsoon months are slightly cooler than summer but more humid, and the winter months are cool. Maximum outdoor temperature during summer days often crosses 40 °C. Temperatures during winter nights have also been known to fall below 10 °C. Historical monthly mean temperatures over past ten years (collected from the in-campus weather station manned and operated by the Department of Physics and Meteorology of Indian Institute of Technology (IIT) Kharagpur) show that January is the coolest month while May is the hottest.

The comfort survey was done in a laboratory classroom of IIT Kharagpur which is a premier institutes of technical education in