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Thermal comfort field study in undergraduate laboratories – An analysis of occupant perceptions

Asit Kumar Mishra*, Maddali Ramgopal

Department of Mechanical Engineering, Indian Institute of Technology Kharagpur, Kharagpur, West Bengal 721302, India

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A B S T R A C T

A thermal comfort field study was conducted in an undergraduate laboratory classroom involving 121 subjects giving 338 responses. The building is located in a tropical climatic region of India. In addition to objective measurements of indoor climate, subjective responses on perceptions regarding thermal sensation, thermal preference, air velocity, and humidity were also collected. We present here an analysis of the subjective preferences and disposition of the occupants. While acceptability of higher air velocities seems ubiquitous amongst our subjects, a high level of tolerance for humid environments is also observed. Most of the responses (78%) are accepting of their thermal conditions. The occupants do have a predilection towards cooler thermal sensations and higher air velocities. Since the location is in a warm and humid region where fans are used in almost every building, this observation fits expectations. Students effectively adapt their clothing according to prevailing weather and even subject their clothing to some atypical adjustments. They also make use of the fact that laboratories have lesser constraints on posture and movement than lecture classes. Overall, the students are affable to indoors of naturally ventilated buildings and at the same time are empathetic to a naturally ventilated building's environmentally friendly nature.

1. Introduction

India's higher education sector is seeing rapid growth both in terms of number of institutions and enrolments [1]. Ensuring thermal comfort in the large number of classrooms of these educational institutes is in national interest and a matter of urgency. For long, Indian classrooms relied on climate suitable design, natural ventilation, and ample use of fans to ensure student comfort. With recent economic development of India though, the desire for AC has made a gross and unjustifiable jump from the category of 'luxury' items to that of 'necessary' items. Educational institutes have started proffering air-conditioning in a bid to stay attractive to prospective students. While AC may be seen as an easy way out for providing thermal comfort, in terms of energy demand, the idea is hardly sustainable. Also, classrooms are ideal locations for what Indraganti has called "*thermal indulgence*" [2] since users never face a utility bill. Electricity shortage figures at 9.9% of overall and 16.6% of peak demand haunt India's growth story [3]. Every summer, India faces the double pronged problem of reduced electricity production due to reduced water levels in hydroelectric installations and increased demand in agricultural sector for irrigation and building sector for AC. The confluence of all these factors may make grid collapses similar to that of 2012 summer [4] more commonplace.

Comfort standards based on adaptive comfort models should come as a succour to Indian energy scenario. Recent studies [5–9] show that the Indian populace adapts with ease to the Indian climate. An occupant's ability to adapt to his/her environment would depend on the availability of adaptive opportunities. A review of thermal comfort field studies found several works done in classrooms remarking that students have less access to and reduced number of adaptive opportunities compared to home or office occupants [10]. At the same time, occupants' subjective judgement regarding their thermal environment is also an important factor affecting their mental performance. This relation with productivity has been observed in contexts of perception of thermal comfort by school students [11], subjective thermal sensation of office workers [12], and overall satisfaction of office workers with their thermal environment [13]. Even ASHRAE defines thermal comfort not as a measurable physiological variable but as a "state of mind" [14]. So in environments where subjects are exerting themselves mentally,

* Corresponding author. Tel. +91 8768073875.
E-mail addresses: asit.mishra@mech.iitkgp.ernet.in, writeto.asit@gmail.com (A.K. Mishra), ramg@mech.iitkgp.ernet.in (M. Ramgopal).

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Nomenclature

Abbreviations

AC	air-conditioning
AVSS	air velocity sensation scale
HSS	humidity sensation scale
MRT	mean radiant temperature
MTSV	mean thermal sensation vote
NV	naturally ventilated
PMOAT	prevailing mean outdoor air temperature
RH	relative humidity
RMT	running mean temperature
TPS	thermal preference scale
TSS	thermal sensation scale
TSV	thermal sensation vote (individual's)

Symbols

p_a	absolute pressure of water vapour in air (kPa)
t_a	air temperature (°C)
t_c	comfort temperature (using Griffiths' formula) (°C)
t_g	globe temperature (°C)
t_{mrt}	mean radiant temperature (°C)
t_{op}	operative temperature (°C)
t_{rmt}	running mean temperature (°C)
v_a	air velocity (m/s)

like a classroom, it is important to take into consideration how they perceive their thermal environment and the opportunities they get for adaptation.

In a recent work we reported some of our findings from a thermal comfort field study done in an undergraduate laboratory during regular class hours [15]. Our findings showed that the students adeptly dealt with the thermal environment of the NV building and found the indoors to be acceptable over a range of 20–31 °C. We also found that comfort temperatures found for our student population, using Griffiths' formula, had fair agreement with established adaptive comfort standards. When increase in comfort temperature due to enhanced air velocity was taken into account, the match improved. In the current work we analyse the subjective votes and preferences of the students in the field survey. We look into how satisfied they are with different parameters of their thermal environment and how this perception reflects in their preferences and overall acceptance. We also look into what kind of strategies are put to work by students in adapting to their environment and what may be done to improve the efficacy of such strategies.

2. Study methodology

Detailed methodology of the study, choice of subjects and location, and objective measurements taken are discussed in an earlier work [15]. We briefly outline salient points of the study methodology here. The study followed a laboratory course work for undergraduate students in Indian Institute of Technology (IIT) Kharagpur, India. Kharagpur is located in West Bengal, which is an eastern Indian state. Köppen classification gives Kharagpur a Tropical savannah (Aw) type climate. Historical temperature data (obtained from the Department of Physics and Meteorology's in-campus weather station) shows that January is the coolest month while May is the warmest and April comes in a close second. But since summer breaks begin from the end of April, regular classes are not held during the year's warmest month. The survey was carried out during the Spring semester of the Institute that starts with January and ends with April. Observations were taken during 12 days from January through April, 2013.

Survey responses were taken from 121 students, aged between 19 and 21 years. A total of 338 valid responses were gathered from them. These students had completed at least five semesters of course work in IIT Kharagpur and thus, were assumed to be well acclimatized to the local climate. Before being asked to answer the survey questionnaire, subjects were briefly introduced to the structure and purpose of the survey. A clear impression was made that they only need to give their frank and carefully thought opinions and they should not assume that the survey has anything to do with future installation of air-conditioning in the labs and classrooms. During the surveys, sometimes individual students did pose queries regarding understanding the import of certain questions. Such queries were rare though.

2.1. Data collection

Survey activities were initiated 75–90 min into the class. This was done to have the metabolic rate of the students stabilize after they walked or cycled from their hostels to the class. During the class, groups of students, about 10 in number, worked with different experimental set ups. Environmental parameters – dry bulb and wet bulb temperature (DBT, WBT), globe temperature and air velocity – were measured simultaneously as students filled up the survey questionnaire. Table 1 gives details regarding the instruments used in the survey. The two thermometers used in the psychrometer and the thermometer that was use to build the globe thermometer were initially calibrated between the range of 10 and 40 °C by using a reference thermometer from Zeal© (range −10 to 50 °C, resolution 0.5 °C). For each group of students, five readings were taken for DBT, WBT, and air velocity in the immediate vicinity of where they were working. As the globe thermometer required a longer time to get to a stable reading, only one globe temperature was recorded per group of students. While we calculated mean radiant temperature (MRT) using globe thermometer readings, operative temperature was obtained from a weighted average of DBT and MRT. The convective heat transfer coefficient was used as a weighting factor for DBT while radiative heat transfer coefficient was used to weight MRT. We assumed the radiative heat transfer coefficient to be constant at 4.7 W/m^2 °C. Convective heat transfer coefficient was calculated from the relation given in ASHRAE Handbook of Fundamentals (Table 6, Chapter 9) [16] for use with standing persons in moving air.

The measurements showed that there were no major variations of thermal conditions between different sections of the lab. So, further analysis was done using averaged values of both environmental data and student votes. The *R* statistical computing package was used for all statistical analysis [17]. While performing regression with the day-average values, a weight factor equal to the number of students surveyed on each corresponding day was used.

Table 1
Survey instruments.

Instrument	Make	Range	Resolution	Remarks
Sling psychrometer	Local	0–120 °F	1 °F	
Globe thermometer	Constructed	−10 – 110 °C	1 °C	Globe of plastic ball, 70 mm diameter
Anemometer	Lutron AM-4201	0.1–30.0 m/s	0.1 m/s	Vane-type