Building and Environment 92 (2015) 396–406

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

A thermal comfort field study of naturally ventilated classrooms in Kharagpur, India

Asit Kumar Mishra*, Maddali Ramgopal

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

ARTICLE INFO

Article history:
Received 3 February 2015
Received in revised form
27 April 2015
Accepted 21 May 2015
Available online 27 May 2015

Keywords:
Adaptive thermal comfort
Classrooms
Natural ventilation
Hot–humid climate
Adaptive opportunities

ABSTRACT

To assess occupant thermal comfort, field studies were carried out in naturally ventilated (NV) classrooms of Indian Institute of Technology Kharagpur. The location has a hot–humid climate. Surveys were taken during both semesters over the academic year 2013–14. Results of the surveys gave a regression neutral temperature near 29 °C while preferred temperature was found to be 26.8 °C. Using student responses to thermal acceptability question, 80% occupant satisfaction was found between 22.1 and 31.5 °C operative temperature. Over the survey duration, nearly 79% of responses accepted their thermal environment. Analysis of thermal preference and thermal acceptability votes showed a distinct preference amongst occupants for cooler than neutral sensation. Diurnal variation of temperature that would be acceptable to 80% or more occupants was found to be a 4 °C wide band. Study of student actions during surveys showed that fans were brought into play more often than windows. Variation of clothing showed strongest correlation with the day's minimum temperature. Overall, observations from the study showed broad comfort zones and significant level of occupant adaptation to the environment of NV classrooms.

1. Introduction

With 14.6 million enrolled students, higher education system of India is one of the largest globally. Over the past years, number of higher education institutes in India have seen compounded annual growth rate (CAGR) of 11% while student enrolment CAGR was 6% [1]. Taking these numbers as an indication, it is easy to see that coming years will witness a dramatic growth in higher education sector of India. This will mean significant growth in the sheer number of classrooms. Conscientious design of classroom thermal environment is necessary both because of the high occupant densities classrooms have and the adverse impact deficient thermal settings can have on the teaching-learning process. Judicious comfort standards will be an essential part of designing thermally comfortable and energy efficient classrooms. Formulation of such standards, that supplement Indian building codes and pave the way towards sustainable future development of India, would be immensely aided by the results of thermal comfort field studies.

Over the past couple of decades, a few studies have been carried out in naturally ventilated (NV) classrooms located in tropics [2–6]. Results of these studies showed that students adapted well to their NV classrooms. Comfort zones for these surveys were between 24 and 31 °C. Looking at the Indian context, Pellegrino et al. [7] carried out a short duration comfort study for NV classrooms in a couple of universities located in Kolkata. In two of our earlier works, we have reported findings from thermal comfort study for undergraduate laboratories [8,9]. To the best of our knowledge, no long term thermal comfort field study has been reported from Indian classrooms. Thus, to address this gap, the current study was undertaken with the following aims:

- To obtain year round data regarding occupant thermal sensation and acceptability for naturally ventilated classrooms in India
- To study student adaptive behaviour during classes and make observations on how such behaviour helps or hinders thermal adaptation
- To compare results from the classroom survey with those from the laboratory [8]; subjects in the laboratory had an appreciably higher metabolic rate

* Corresponding author.
E-mail addresses: asit.mishra@mech.iitkgp.ernet.in (A.K. Mishra), ramg@mech.iitkgp.ernet.in (M. Ramgopal).

http://dx.doi.org/10.1016/j.buildenv.2015.05.024
0360-1323/

Nomenclature

Abbreviations

AC	air-conditioning
APD	actual percentage dissatisfied
DBT	dry bulb temperature
MRT	mean radiant temperature
MTSV	mean thermal sensation vote
NV	naturally ventilated
PMOAT	prevailing mean outdoor air temperature
PS	percentage of acceptable votes/percentage satisfied
RH	relative humidity
RMT	running mean temperature
TSV	thermal sensation vote (individual's)

Symbols

p_w	partial pressure of water vapour in air, kPa
t_a	air temperature, °C
t_c	comfort temperature, using Griffiths' equation, °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
ΔT_c	$(t_{op} - t_c)$, °C

2. Methodology

Study was conducted in undergraduate classrooms of Indian Institute of Technology Kharagpur (IIT). Kharagpur, a small township in eastern India, has a tropical climate with dry winters – Köppen climate classification 'Aw'. The region primarily experiences three seasons, a hot summer with some sporadic rain, a warm and humid monsoon and a mild and dry winter. Due to the influence of south-west monsoon, the bulk of rainfall occurs over the months of July, August, September, and part of June and October.

Surveys were of longitudinal design and followed one course each during Autumn 2013 and Spring 2014 respectively. Both courses were taught in the same classroom. Spring semester in IIT is from January to April while the Autumn semester is from mid-July to November. The Autumn semester, unlike the Spring has a mid-semester break of about 10 days. The survey took place on 5 days during Autumn of 2013 and 7 days during Spring semester of 2014.

2.1. The classroom and the subjects

The room (room code: CR–310) is on the top floor of a building whose major axis is along East–West direction. All the rooms in the top floor of this building are used as classrooms. The East–West orientation of the major axis of the building and the complete top floor being utilized as classrooms is a feature shared by several of the neighbouring departmental buildings as well. The building has pillared construction with brick and mortar filling. Doors of CR–310 open into a corridor while the walls on east and west are internal walls. Windows are on north façade of the room and are single glazed with mild steel frames. Windows are 1.8 m wide and 1.5 m high, with continuous overhangs about one meter deep. Dimensions of CR–310 are as follows: ceiling height 3.4 m, length 6.7 m, breadth 8.3 m Fig. 1 gives the room layout and an idea on room furnishings.

The survey followed two courses taken in CR–310 – one during Autumn and one during Spring. The Autumn course had 31 students enrolled while the Spring course had 51 students. Fifteen students were common to both courses, putting the number of unique subjects at 67. The student population was a mix of undergraduate and graduate students, with age between 19 and 26 years. All subjects were Indians and were assumed to be acclimatized to the local climate. Every effort was made to minimally inconvenience the classes during which surveys were conducted. To this end, at the beginning of each semester, students were briefly introduced to the nature and purpose of the surveys. What was particularly impressed upon the students was that they should feel free to provide their forthright responses and that the survey was not asking for a mandate regarding usage of air-conditioning in the classrooms. Towards later survey days during each semester, in a behaviour eerily similar to that observed by Teli et al. [11] in their study with primary school children, some students queried as to why they had to fill in the same questionnaire repeatedly.

2.2. Collection of survey data

2.2.1. Indoor environmental parameters

Information regarding instruments used for measuring indoor environmental parameters is given in Table 1. The black globe thermometer was made in-house by placing an alcohol thermometer at the centre of a 70 mm diameter plastic ball. The ball was painted black and coated with lamp black. This globe thermometer had also been used in our previous studies [8,12].

For the classes during which surveys were conducted, measurements were taken during the last 20 min of the class. Paper questionnaires were given to students for filling up during the last ten minutes. Since the classes were either one or two hours long, the subjects thus had ample time to attain a stable metabolic rate. Measurements were taken at six points around the room for air temperature (t_a), relative humidity (RH), and air velocity (v_a). Globe temperature (t_g) was measured at one central location in the room. Approximate measurement locations are specified in Fig. 1. All measurements were taken at approximately shoulder level of occupants. While measuring air velocity inside the classroom, it was noted that little to no wind came in through windows. This may be ascribed to the building being surrounded by other buildings and tree lining. Thus the air velocity measured was almost solely due to the fans. When the fans were not used, no perceptible air velocity was recorded. From the t_a and RH values, partial pressure of water vapour in air (p_w) was calculated using the Vaisala Humidity Calculator 3.0 [13]. Values of t_a, p_w, and v_a recorded across the six points were later averaged and used for all further analysis.

Mean radiant temperature (t_{mrt}) was calculated from Equation (1) [14].

$$t_{mrt} = \left[(t_g + 273)^4 + \frac{1.1 \times 10^8 v_a^{0.6}}{\varepsilon D^{0.4}} \times (t_g - t_a) \right]^{1/4} - 273 \qquad (1)$$

In the above equation, ε is surface emissivity for the globe and was taken as 0.95 while D is diameter of the globe in meters.

Room operative temperature (t_{op}) was calculated using the formula: $t_{op} = \frac{h_c \cdot t_a + h_r \cdot t_{mrt}}{h_c + h_r}$ [14]. A constant value of 4.7 $W/m^2 \cdot$ °C [14] was assumed for the radiative heat transfer coefficient (h_r). Convective heat transfer coefficient (h_c) was calculated from the correlations for "persons seated with moving air" in ASHRAE Fundamentals Handbook (Table 6, Chapter 9) [14].

2.2.2. Subjective questionnaire

English, being medium of instruction in all courses, was chosen to frame the questionnaire. An attempt was made to keep