Quantification of indoor environments and study of thermal comfort in naturally hostel buildings in the tropical country, India

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Abstract. Hostel buildings prime objective is to provide better thermal environments to the students for their good health and learning performance. In India, a very few studies are done on the thermal environments of multi-storied naturally ventilated hostel buildings. We carried out a thermal comfort study in two mid-rise (~G+5 floors) naturally ventilated (NV) hostel buildings during monsoon season (August-September, 2018). The field study conducted for three consecutive weeks collecting 642 valid subjective responses with objective information regarding thermal parameters of 253 rooms. Statistical analysis of student's responses and measured thermal environment variables was performed for assessing inter buildings effects, different weather conditions (rainy or cloudy) and daytime duration (morning, afternoon and evening), respectively. The study finds the mean thermal neutrality at 29.9°C for the studied group using Griffiths' method. The results suggested that more than 80% of subjects were voting within central three categories when indoor operative temperature ranged between 28-32.1°C. The primary adaptive action of occupants includes switching on the fans (100%) followed by the opening of external doors (80%) and opening or closing of windows (55%) to restore thermal comfort in built environments.

1. Introduction

Recently the government of India had started a new educational policy to make India a knowledge hub to provide more skilled professionals in science, technology, academics, and industries [1]. Currently, in India, more than 10 million students of different age group reside in the hostel's buildings across different climatic zones of the country [1, 2]. This creates a huge demand for infrastructure in terms of hostel buildings to accommodate students and provide better shelter and facilities for their academic endeavors.

Hostel buildings are the special type of residential buildings where the prime objective of the built environment is to provide better thermal environments to the students for their good health and learning performance. Dalhan et al. [3] carried out a field study of thermal comfort in three high rise hostels in the hot and humid climate of Malaysia. The study conducted for more than four weeks collecting 298 responses from girl students. The study also assessed the effect of operative temperature on the thermal sensation of occupants during rainy and cloudy days [4]. Lai [5] has explored the user expectation and satisfaction criteria for hostel buildings considering the gap theory and an indicative post-occupancy evaluation approach. The study conducted by Dhaka et al. [6] assessed the existing thermal environment conditions and its effect on student's perception during summer season (August-November). The study finds the neutral temperature of about 30.2°C through regression analysis, with comfort bandwidth of 25.9-33.8°C. Analysis of results further assessed the acceptable airspeed and relative humidity of 0.41m/s and 36%, respectively. The study also analyzed the variation of thermal neutrality based on different occupancy and genders.

1.1 Objective of the study

The literature study presented in the previous section revealed that there are very few studies reported for hostel buildings so far. The studies conducted in India also reported that hostels buildings situated within composite climate are not thermally comfortable as per the comfort guidelines defined in national and international standards.

The present study evaluates existing thermal environment conditions in two multi-storeys newly constructed (constructed in last 5 years) hostel buildings situated at premises of National Institute of Technology University, Jalandhar which falls under the composite climate of India [7]. Statistical analysis of thermal environment conditions and their impact on occupant's subjective responses collected through the questionnaire was carried out in the monsoon season in India. The study also evaluated the effect of different weather conditions on the thermal environments of monitored rooms and their impact on subjective perception. The study further aims to explore the thermal adaptation behaviour of occupants to restore thermal comfort.

2 Research methods and materials

2.1 Investigated hostel buildings

Two modern, newly constructed mid-rise hostel buildings located at National Institute of Technology University, Jalandhar (31.326° N, 75.576° E, msl=+228 m) were selected for thermal comfort field study (Fig. 1). The hostel buildings were built of the brick wall of 0.20–0.23m (U-value=2.45 W/m²K) thickness and roofs of poured concrete slab with a thickness of 0.15m (Uvalue=3.1 W/m²K). Fenestration i.e. window assemblies in studied hostel buildings were the double glazed type

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with 0.04-0.08 m of thickness with aluminium frames (U-value=4.7W/m²K). Each floor of the studied buildings was consisting of 10-12 rooms with room floor area varied between 7-8.2 m².



Fig.1 Investigated hostel buildings for field surveying

2.2 Identifying weather conditions

In the adaptive hypothesis, the outdoor micro-climates affects the indoor thermal conditions and hence occupants perception towards indoor environments [8]. Accordingly, the monitored weather conditions were classified into two categories: (1) rainy days and (2) clear or partially cloudy. Rainy conditions were refereed when there was an outburst of precipitation or the sky conditions were mostly haze type whereas clear or partially cloudy conditions were defined for partial clouds or no clouds in the sky. A total of 11 days and 8 days were observed clear and rainy days, respectively for the whole monitoring period.

2.3 Field survey and sample size description

A field study was conducted in two naturally ventilated multi-storey hostel buildings (referred to as Mega B and Mega F in this study) in the month of August and September 2018. During the three week monitoring period, each day is devoted in conducting the field survey and each floor in two hostel buildings were investigated. The field survey was conducted throughout the day i.e. morning (8:00-10:00AM), afternoon (12:00-2:00PM) and in the evening (5:00-7:00PM).

All subjects residing in the hostels were found to be belonged to Indian sub-continent, though they came from different provinces and states. The occupants were undergraduate and postgraduate students and residing in these hostels for more than one year. The subjects were healthy young adults and were in the age group of 18-26 years (sd =1.6). A total of 253 students participated voluntarily in the surveying from both hostel buildings which returned a total of 642 questionnaires completely filled.

2.3 Subjective questionnaire, protocols and instruments used

The surveying used in this study is of transverse type and "Right Here Right Now" questionnaire was administered to the occupants. The questionnaire developed and used in this study was adopted from previous studies conducted by the same author group in educational, residential and office buildings [9-12]. The responses of

subjects were captured using ASHRAE's seven-point thermal sensation [13] and Nicol's five-point scale of preference scale. Thermal acceptability was noted down as binary data, 0: Uncomfortable, 1: Comfortable. The second part includes the checklists of clothing ensemble, activity level and behavioral and environmental controls used by the investigated subject. A thermo-hygrometer (Tr-76Ui) measured the air temperature (Ta), relative humidity (RH) and CO₂ concentration indoors. A probe thermometer (Tr-52i) was used to measure globe temperature. A hot-wire anemometer (Testo-405 V1) was used to measure the indoor air speed. The measurements were taken at a height of 1.1 m above the ground level following the Class-II protocol as per ASHRAE 55-2013.

3 Results and analysis

3.1 Hygro-thermal parameters observed

The climate of Jalandhar city is very hot during peak summer season (May, and June) and chilling cold in the winter season (December and January). During the summer season, outdoor maximum temperature rises up to 45°C while during the winter season, minimum temperature falls down to 0°C. Around 70% rainfall is received during July–September months. The outdoor maximum temperature during monsoon season varies between 24–36°C, and relative humidity varies between 75–100 %. Such a combination of high temperature and high relative humidity during the monsoon season of this climatic zone may lead to thermal discomfort conditions for the occupants of a naturally ventilated building.

During the study, the ambient air temperature varied between 26.4-35.8°C (mean=33°C, sd =2.6) with mean relative humidity varied between 55–98% (mean= 73%, sd= 6.4). We recorded that mean outdoor temperature and relative humidity on rainy days was about 3.5° C and 20% higher than clear or partial cloudy days. The study further observed that indoor operative temperatures were about 1.5°C warmer on clear days in comparison to rainy days. Similarly, the relative humidity on a rainy day was about 5% lower than a rainy day and this difference was significant at p≤0.05

3.2 Analysis of subjective sensation and preferences

3.2.1 Thermal sensation (TSV), preferences (TP) and thermal acceptability (TA)

Fig. 2 shows the frequency distribution of TSV for individual buildings and on a pooled basis. A total of 76% of the total occupants voted within three central categories of TSV and can be assumed as comfortable. Only 2% of the occupant perceived their conditions cold while 22% of subjects reported indoor conditions warm and hot. Meanwhile, the mean value of TSV for pooled data was found to slightly higher than neutral (mean=+0.6, sd=1.2). In response to thermal sensations recorded, the corresponding thermal preferences were captured with the question "How would you prefer to feel?" Regarding their thermal preferences, it was noticed that about 68% occupants desired cooler environment and a very few subjects, about 6% preferred hot and warm conditions. About 26% of the subjects voted for no change in their existing thermal environment. Fig. 3 shows a cross-tabulated summary of TSV votes and TP votes. It can be seen from the figure that about 33% of subjects found the temperature neutral at the time of voting and want no change in temperature. Subsequently, more than 75% subject's wants cooler environment even they are voting neutral on TSV scale. About 85% subjects preferred 'no change' while voting cool on TSV scale, and a maximum of 15% subjects opined the same while voting warm. On the direct acceptability of question of thermal existing environmental conditions, about 70% of subjects voted comfortable while 30% felt uncomfortable.



Fig.2 Statistical distributions of thermal sensations votes for surveyed buildings



Fig.3 Cross distribution of thermal sensation and thermal preferences

Thermal sensation and preferences were also evaluated for the different weather conditions monitored during the field survey. About 71% and 87% of subjects voted on ± 1 TSV scale during clear or cloudy days and rainy days, respectively. While 26% of the subjects perceived their conditions warm and hot on a clear day in comparison to 9% votes on rainy days. These results are obvious as indoor operative temperature observed during a rainy day was about 1.5°C lower than a clear or cloudy day. The mean of TSV was observed +0.10(sd=1.1) and +0.82(sd=1.2) for clear days and rainy days, respectively and this difference was statistically significant at p ≤ 0.05 . This shows that in the present study, subjects feel neutral on a typical rainy day and slightly warmer on clear or cloudy days.

3.3 Comfort temperature

Griffith emphasized that whenever the indoor temperature range obtained from the field surveys is narrow, the regression method could not provide a reasonable estimate of comfort temperature. Also, the presence of behavioral adaptation in the data will tends to lower the regression coefficients [8,14,15] may deviate from actual thermal neutrality. So, for all these reasons we used the Griffiths' method [10] for the estimation of individual comfort temperature. Griffiths' comfort temperature was calculated by using equation (1).

$$T_{\rm C} = T_{\rm op} + \frac{0 - {\rm TSV}}{{\rm G}} \tag{1}$$

Where, Tc is the comfort temperature (°C), Top is the indoor operative temperature (°C), TSV is the thermal sensation vote, and G is the Griffiths' constant. The scale value for neutral sensation is represented by '0' in the equation. Analysis of mean indoor operative temperature for neutrality ('0' TSV scale) on the TSV scale has shown close agreement with comfort temperature obtained with 0.50 as Griffiths' coefficient (with least standard deviation) as shown in Table 1. The mean comfort temperature was also matched closely to the mean temperature for which TP is equal to '0: No change' of five-point scale. The mean indoor operative comfort temperature as calculated by Griffiths' method is 29.9° C (sd =2.15) on combined data (Fig. 4). The mean Griffiths' comfort temperature was also analyzed for different weather conditions. We noted that comfort temperature varied with a marginal difference of about 0.2°C between clear and rainy days but the difference was significant ($p \le 0.05$).

Table 1 Statistics of Griffiths comfort temperature

Mode	GC (°C ⁻¹)	T _{opC} (°C)		
		N	Mean	$\pm sd$
Naturally ventilated	0.25	642	28.8	4.2
	0.33		29.4	3.2
	0.50		29.9	2.1
	Voting Neutral	182	30.7	1.4

We further compared the mean comfort temperature obtained in the present study with other studies conducted in India during the summer season in India. The comfort temperature obtained in this study is comparable to the study conducted in Jaipur [10] and Hyderabad for residential buildings [16]. However, comfort temperature was observed higher than that of office buildings under similar climatic conditions [17]. Such deviation can be attributed to the fact that different thermal adaptation opportunity available to the occupants of office and hostel buildings. The hostel occupants enjoy the choices of clothing adjustment, use of environmental controls and its accessibility, and activity level whereas in office spaces these are very limited.



Fig.4 Frequency distribution of Griffiths' comfort temperature obtained using Griffiths' slope of 0.5

3.4 Thermal comfort zone for investigated subjects

de Dear and Brager [18] in their meta-analysis for RP 884 have put forth different criteria for determining acceptability levels of occupants i.e. ±1 votes on ASHRAE scale; vote on direct acceptability; and '0': No change vote on TP scale. In the present study, the analysis was carried out for estimating the possible thermal comfort over which subjects are likely to accept their thermal environment considering votes on central three categories (-1 to +1). Firstly proportion of subjects voting within ± 1 TSV scale were binned on 1°C and then a polynomial regression fit is obtained between the proportion of comfortable votes and indoor operative temperature for all pooled data. It can be seen from the Fig. 5 that more than 80% occupants were voting comfortable when the indoor operative temperature was in the range of 28.0-32.1°C.

Interestingly, the findings corroborate the findings by Indraganti [16] and Kumar et al. [12] for their field studies conducted in residential buildings under the composite climate zone of India. We also plotted the proportion of votes with neutral voting on TSV scale. It was observed that a maximum of 40% subjects feels neutral in 80% acceptability zone of thermal comfort. A similar observation was made by Nicol and Humphreys [19] for their SCAT data in office buildings of European countries.

3.5 Occupants thermal adaptation behaviour

Adaptive thermal comfort principle is vocal about thermal adaptations [18], [19]. In adaptive comfort approach, the occupants are considered as active agents who respond to the changing indoor environments through various thermal adaptations. In the present study, we noted the different personal adaptations taken by subjects to make their conditions comfortable.



Fig.5 Acceptable comfort zone assessed using comfortable votes (\pm 1TSV) for surveyed hostel buildings

3.5.1 Variation in clothing insulation

The mean clothing observed was 0.30 (sd =0.9) which ranges between 0.19clo to 0.67clo. The clothing ensemble varied throughout the day i.e. from morning to evening. In the morning students wore light clothing ensemble i.e. a combination of t-shirt and shorts or lower with inner garments (mean=0.29clo, sd=0.9). While during afternoon students found engaged in their daily routine work of attending classes and other sports activities and thus clothing was a little higher (mean=0.42clo, sd=0.11) compared to morning time. However, contrary to Dalhan [4] findings, we observed no significant difference in clothing insulation considering different weather condition. The mean clothing was observed constant (mean= 0.29clo, sd=0.8) for both the clear and rainy days, respectively.

Studies have shown that the clothing insulation can be significantly regressed to see the dependence on indoor or outdoor temperature indices [10, 11]. Following the methods adopted by Indraganti and Rijal [20] for their Japan study, we grouped the clothing ensemble data by buildings and date and on regression with indoor operative temperature following equation (2) resulted.

$$I_{cl,tot} = -0.013 + 0.70$$

(N = 642, R² = 0.18, p < 0.001, S.E. = 0.089) (2)

This shows that a perturbation of about 8°C in indoor operative temperature is needed to change the clothing insulation of about 0.1clo.

3.5.2 Adaptive use of environmental controls

The subjects have adaptively operated the windows, doors, and fans to maintain comfortable conditions indoors. Subsequently, data was analyzed to know the priority wise use of these environmental controls as a behavioural adaptation of occupants. **Fig. 6** shows the proportion use of different environmental controls during the field study. Since, fans offer a significant adaptive opportunity for users at high indoor temperatures and high relative humidity, especially during summer and rainy season. During the survey, the mean air speed observed during fan operation was more than 1 m/s and reached a maximum of 3m/s. The next most-selected option was the opening of external doors (80%), while 50% of the occupants adopted the opening and closing of windows as their thermal adaptation measure. The preference of environmental controls also varied during different weather conditions. With the decrease in indoor operative temperature during rainy days, the proportion of fan use decreases subsequently in comparison to clear or partially cloudy days. However, the windows opening behaviour was almost similar and didn't observe any significant difference. This may be due to preventing the entry of mosquitoes and insects during rainy days which are a common environmental factor during heavy rains in this region.



Fig.6 Adaptive use of environmental controls observed during the field study

4 Discussion

The mean comfort temperature observed in this study found a close resemblance to the results from obtained the other studies conducted in hostel dormitories and residential buildings in India and around the world. For instance, Dalhan et al. [3] observed a mean neutral temperature of 28.8°C for their field study in high rise hostel buildings in hot-humid climatic conditions during monsoon season. The mean clothing insulation observed was 0.40clo on clear days while a little higher about 0.60clo during rainy days. The study also noted that mean value of TSV varied from +1.3 to +1.5 when mean indoor operative temperature fluctuated between 28.9-30°C. The results from the present study were very similar to the findings of [4] regarding the significant differences between observed indoor operative temperatures based on different weather conditions and daytime durations. Similarly, the neutral temperature of 30.2°C for traditional hostel buildings was reported by

Dhaka et al. **[6]** for Jaipur city in a composite climate of India during the summer season. The mean clothing was 0.41 clo (maximum-0.82clo, minimum-0.19clo) during the study. A similar observation on clothing pattern was noted by us during the whole monitoring period. However, the use of environmental controls in present study varied significantly with that of Jaipur study, where the student's preferred opening and closing of windows as their primary adaptive behaviour followed by use of fans and door opening. Contrary to it, we observed that occupants from present study preferred the use of elevated speed through the switching on ceiling fans followed by opening and closing of doors and lastly windows to restore thermal comfort.

Interestingly, the results from the present study also observed close to the findings of Indraganti et al. [16] where a mean comfort temperature of 29.3°C was noticed for occupants residing in multi-storey residential apartments in Hyderabad, India. The comfort range obtained was also found close to the present study, ranging between 28-32°C. However, in another study for office buildings in Hyderabad city, predicted a mean comfort temperature of 28.1°C which is slightly lower than this study [17]. Further analysis regarding perturbation required for change of 0.1clo showed a close match with studies conducted by Indraganti et al. [16]. The study predicted a perturbation of 8°C for such change while later noticed a variation of 10°C for indoor temperature.

5 Conclusion

A questionnaire-based field study of thermal comfort following ASHRAE 55 class-II protocols [13] were conducted in two multi-storey hostel building during monsoon season in a composite climate of India. The study collected about 642 valid subjective thermal responses for indoor different thermal variables. Subsequently, we measured indoor thermal parameters using high precision and digital instruments. Collected data were evaluated to study the effect of existing thermal environmental conditions on occupant's perception considering different weather conditions and daytime duration. Following are the main conclusion derived from the results and analysis.

- 1. The study observed that indoor operative temperatures were on average 1.5°C warmer on clear days in comparison to rainy days. The mean of TSV was observed close to neutral (mean TSV=+0.10, sd=1.1) for rainy days and slightly warm (mean TSV=+0.82, sd=1.2) during clear days, respectively.
- A total of 76% of the total occupants voted within three central categories of TSV i.e. ±1TSV. The mean indoor operative comfort temperature predicted by Griffiths' method (G=0.5°C-1) is 29.9°C (sd =2.15) in naturally ventilated hostel buildings.
- About 80% occupants voted within ±1 TSV when the operative temperature ranges between 28-32.1°C. Also, the overall thermal acceptability was

higher during rainy days (\sim 81%) than on a clear or cloudy day (\sim 65%).

- 4. Primary behavioural adaptive action preferred by occupants was switching on the ceiling fan (100%) followed by opening of external doors (80%) and windows (50%) to maintain thermal comfort indoors.
- 5. We observed that clothing insulation correlated moderately with indoor operative temperature and also found varying with floors as well as weather conditions. The study also ascertains that a perturbation of about 8°C in indoor operative temperature is needed to make a change of 0.1 clo

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