Proceedings of 8th Windsor Conference: ***Counting the Cost of Comfort in a changing world*** Cumberland Lodge, Windsor, UK, 10-13 April 2014. London: Network for Comfort and Energy Use in Buildings, http://nceub.org.uk

# Adaptive comfort relations and comfort temperature ranges from a field study in undergraduate laboratories

**Asit Kumar Mishra and Maddali Ramgopal**

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

Abstract

To ascertain comfort levels and effectiveness of available adaptive opportunities for classrooms in the hot-humid regions of India, a thermal comfort field study was conducted in an undergraduate laboratory class in Kharagpur. The study, carried out between January and April 2013, had participation from 121 students and yielded 338 responses. Analysis of the results showed that comfort temperatures found in the field study had close resemblance to the predicted comfort temperatures evaluated from certain existing standard adaptive comfort equations. This was in spite of the standards having been developed using observations from studies that had occupants with distinctly lower metabolic rates than encountered in the current study. This is ascribed to the level of acclimatization among the subjects as well as the availability of more adaptive avenues/more flexibility, during laboratory classes.

Keywords: adaptive comfort; laboratory classes; natural ventilation; hot-humid climate; adaptive opportunities

## 1 Introduction

It is well accepted that thermal environment of classrooms has a significant impact on the teaching-learning process (Auliciems, 1972; Mendell and Heath, 2005). For a growing economy like India, where the number of educational institutions, as well as enrolments in them, is rising fast (UGC, 2008), any compromise of learning environments is unacceptable. Historically, Indian classrooms have been naturally ventilated (NV) along with ample use of fans. With India's energy deficit keeping as high as 26% recently (IEA, 2011), a sudden shift to use of air-conditioning in all the classrooms is unlikely and unsustainable.

Results from several recent field studies vouch for the ease with which Indians adapt to their local climate (Deb and Ramachandraiah, 2010; Dhaka et al., 2013; Indraganti, 2010; Indraganti et al., 2013; Pellegrino et al., 2012). From sustainability point of view, adaptive comfort standards would be an ideal choice for ensuring comfort in Indian classrooms. The user guide to Energy Conservation Building Code (ECBC), issued by Bureau of Energy Efficiency, Government of India, also mentions the adaptive comfort model given in ASHRAE Standard 55-2004 as an optional method for determining comfort in NV buildings (BEE, 2009). Current concerns for energy efficiency and sustainability mean that comfort standards of future will need to push the limits to save the proverbial extra penny rather than settle for narrow comfort bands. If the long term acclimatization of inhabitants in tropical climates could broaden the upper limits of comfort standards that would give building designers some important leeway. At the same time, a review of several field studies on thermal comfort found that researchers working in classrooms often observe classrooms to have lesser number of adaptive opportunities and more constraints in their use (Mishra and Ramgopal, 2013). To the best of our knowledge, the study done by Pellegrino et al. (2012) was the sole existing field study in Indian classrooms. So, to add to the body of research in this important area, a field study was conducted during the regular semester schedule of an undergraduate laboratory class. The objectives of this study were:

- Verify the suitability of using existing adaptive comfort equations for predicting comfort levels in Indian NV classrooms
- Ascertain if students are able to effectively adapt to their surroundings using the available opportunities
- Check if sustained metabolic rates that are slightly higher than the near sedentary levels, given for current adaptive standards, compromise the predictive power of such standards

A portion of the findings from this field study has been reported elsewhere (Mishra and Ramgopal, 2014). The previous work reported regression neutral temperature and temperature zones for thermal comfort using different criteria for assessing acceptability. Results showed that the students adapted to their NV surroundings well and a majority of them were comfortable over the range of 20 to 31 °C. An adaptive comfort equation (ACE) was also given based on survey data and predicted comfort temperatures from this ACE were compared to predictions from certain standard adaptive comfort models. The current work delves further along this line by comparing observed comfort temperatures of the survey population on all 12 survey days with prediction from different adaptive comfort models. Statistical significance of the deviations in predictions from different models is presented. Comfort temperature ranges over a single survey day, as opposed to the entire survey duration, are discussed. A brief analysis of adaptive opportunities available and their adequacy in facing the surroundings is also given.

## 2 Methodology

The study was conducted from January 2013 to April 2013 in undergraduate laboratories of the Indian Institute of Technology Kharagpur (IIT). Kharagpur has a Tropical savannah type (Aw) climate. The period from January to April comes under Spring semester schedule of the institute. This particular semester was chosen as it has both the warmest (April) and the coolest (January) months during which regular classes take place. This meant that a wide spectrum of adaptive behaviour among the students could be observed and it could be determined if the broad range of temperatures, faced over a relatively short duration of four months, adversely impacts adaptive abilities. Surveys took place on all twelve class days of the laboratory course during the semester. As is usual in the institute, laboratory classes were held during the post noon session. Details of the study location, description of the buildings, subjects, questionnaire and survey methodology employed can be found in the earlier work (Mishra and Ramgopal, 2014). Brief outline of methodology is provided in Table 1.

For the activity level during a typical laboratory class, a met rate of 1.6 was used, as per the recommendations in ISO 7730-2005 (ISO, 2005). All subjects had been residents of Kharagpur for at least two and a half years and all of them were Indian nationals. Hence, they had a significant level of acclimatization to the local climate.

Table 1. Survey methodology.

<table>
<tr><td>Survey questionnaire</td><td>Subjects briefly introduced to structure and purpose of the survey before being asked to answer the questionnaire.<br>Questions:<ul><li>Thermal sensation on ASHRAE scale</li><li>Thermal comfort on Bedford scale</li><li>Thermal preference</li><li>Acceptability of thermal environment</li><li>Air velocity sensation</li><li>Humidity sensation</li></ul></td></tr>
<tr><td>Survey activities</td><td><ul><li>Survey started 75 to 90 minutes after beginning of class</li><li>Time taken to complete survey activities: 35 – 40 minutes</li><li>Measurements of dry and wet bulb temperature and air velocity taken at shoulder height at five places around student groups (~10 in number) as they filled up questionnaire</li><li>One measurement of globe temperature per student group</li><li>No major variations in thermal conditions around different student groups. Hence, further analysis done with averaged out values of environmental parameters</li><li>Outdoor temperature data taken from the in-campus meteorological station run by the Department of Physics and Meteorology</li><li>Clo value estimated by matching student ensembles with a set of standard ensembles</li></ul></td></tr>
<tr><td>Instruments</td><td><table>
<tr><th>Instrument</th><th>Make</th><th>Range</th><th>Resolution</th><th>Remarks</th></tr>
<tr><td>Sling psychrometer</td><td>Local</td><td>0 to 120 °F</td><td>1 °F</td><td>Mercury thermometers</td></tr>
<tr><td>Globe thermometer</td><td>constructed</td><td>-10 to 110 °C</td><td>1 °C</td><td>Alcohol thermometer, plastic globe of 70 mm diameter</td></tr>
<tr><td>Anemometer</td><td>Lutron AM4201</td><td>0.1 to 30 m/s</td><td>0.1 m/s</td><td>Vane-type</td></tr>
</table></td></tr>
</table>

## 2.1 A summary of observations

A short summary of certain important outdoor and indoor parameters recorded during the survey days is given in Table 2. Minimum and maximum values for the mean thermal sensation vote (MTSV) on the seven point ASHRAE scale are also given in this table. Daily mean temperatures were calculated as an arithmetic mean of daily maximum and minimum temperature. The running mean temperature (RMT) given in the table is a seven day running mean which was evaluated in a method similar to that used in EN15251 (Nicol and Humphreys, 2010). Total number of students taking the survey on any day varied between 23 and 32.

In Table 2, $t_{op}$ represents the operative temperature; $p_v$ represents the partial pressure of water vapour in air; $v_a$ represents the average air velocity; and APD represents the actual percentage dissatisfied, i.e., voting "Not Acceptable" on the survey questionnaire to the question regarding acceptability of indoor thermal conditions.

Table 2. Summary of observations.

| Parameter | Maximum | Minimum |
|---|---|---|
| **Outdoors** | | |
| Daily minimum | 25 °C | 9 °C |
| Daily maximum | 42 °C | 20 °C |
| RMT | 32.8 °C | 16.9 °C |
| Daily mean | 33 °C | 14.5 °C |
| **Indoors** | | |
| $t_{op}$ | 35 °C | 22 °C |
| $p_v$ | 3.04 kPa | 1.06 kPa |
| $v_a$ | 0.6 m/s | 0.05 m/s |
| Average clo | 0.91 clo | 0.44 clo |
| MTSV | 1.74 | -0.73 |
| APD | 59% | 0% |

## 3 Results and Analysis

Over the twelve days of survey, 342 responses were obtained from a group of 121 students. Of these responses, four had to be classified as 'invalid'. Such a classification was done when the subject answered 'no change' to the question on thermal preference and yet found the environment 'not acceptable' or when the subject voted for an extreme on the ASHRAE thermal sensation scale and preferred even more of the same sensation on the thermal preference scale. For further analysis, only the 338 responses that were not invalidated were used. The package R (R Core Team, 2012) was used in all the statistical analysis performed.

Comfort temperature on any particular survey day was calculated by using the MTSV and operative temperature recorded on that day, as inputs for the Griffiths' formula. A value of 0.5/°C was used for the slope in Griffiths' formula, following the recommendations of Humphreys et al.(2013). Since globe and operative temperatures were almost equal during all the survey days, Griffiths' formula was evaluated using operative temperature rather than globe temperature. This allowed the relationship between indoor comfort and outdoors to be expressed in terms of operative temperature.

### 3.1 Comparison of comfort temperatures with existing models

One of the goals at the start had been to check how well existing adaptive comfort models would be able to predict the comfort temperatures obtained from the field study. Certain differences between model predictions and study results were expected on two counts. One was the higher metabolic rate of the subjects; the other was long term acclimatisation of the subjects to a hot-humid climate. As standard adaptive models, the ACE given in EN15251 (Nicol and Humphreys, 2010) and ASHRAE Standard 55 (ANSI/ASHRAE, 2010) are taken. As the slope suggested by Humphreys et al. (2013) in Griffiths' equation was used, the results are checked against predictions of the equation put forth in the same work as well. The model proposed by Nguyen et al. (2012) for hot-humid climates of South East Asia is also taken for comparison considering the geographical proximity of India with South East Asia and certain shared cultural traits. A more recent model proposed by Toe and Kubota (2013) for hot humid climates, which they have derived using a meta-analysis of the ASHRAE RP-884 database, is another model considered in the comparisons.

Both ASHRAE Standard 55-2010 and EN15251 recommend adjustments to the comfort temperature in presence of enhanced air velocity. So, these adjusted values are also taken as two sets of predictions when comparing the field study data. With all the fans being off during January and February, air velocities remained close to 0 and thus comfort temperatures during these months were not adjusted. On the other days, comfort temperatures from EN15251 prediction were adjusted using the day's recorded average air velocity as an input to the formula: $7-\frac{50}{4+10\sqrt{v_a}}$ (Nicol and Humphreys, 2010). Since the average air velocity never exceeded 0.6 m/s, as a correction, 1.2 °C was added to the ASHRAE Standard 55 predictions (ANSI/ASHRAE, 2010). An overview of the different modes used for comparison is given in Table 3.

Table 3. Overview of adaptive comfort models.

| | Comfort equation | Outdoors metric | Survey population | Correction for enhanced air velocity |
|---|---|---|---|---|
| **ASHRAE Standard 55** | $t_c$=0.31 $t_{out}$ + 17.38; $R^2$ = 0.70 | PMOAT | Worldwide | 1.2 °C (for 0.3 m/s < $v_a$ < 0.6 m/s) |
| **EN15251** | $t_c$=0.33 $t_{out}$ + 18.8; $R^2$ = 0.358 | RMT | European | $7-\frac{50}{4+10\sqrt{v_a}}$ (for $v_a$ > 0.1 m/s) |
| **Nguyen et al.** | $t_c$=0.341 $t_{out}$ + 18.83; $R^2$ = 0.52 | Monthly mean temperature | Hot, humid regions of South-East Asia | n.a. |
| **Humphreys et al.** | $t_c$=0.53 $t_{out}$ + 13.8; r = 0.89 | RMT (preferred) | Worldwide | n.a. |
| **Toe and Kubota** | $t_c$=0.57 $t_{out}$ + 13.8; $R^2$ = 0.64 | MOAT | Hot, humid regions from RP 884 database | n.a. |

For the comparisons, $\Delta t_c$ is defined as $\Delta t_c = t_c - t_{c,p}$, where $t_c$ is the comfort temperature from the field study and $t_{c,p}$ is the predicted comfort temperature from different models. Values of $\Delta t_c$ on the twelve survey days for the aforementioned different models are plotted in Figure 1. From Figure 1 it can be observed that both the ASHRAE model and ASHRAE adjusted model consistently under predict comfort temperatures of this field study. However, for both EN15251 and Standard 55 models, adjustments due to enhanced wind velocity bring the predictions closer to the measured values. It s also observed that the closest predictions come from Nguyen et al.'s model, Toe and Kubota model, and the EN15251 enhanced air velocity adjusted model.

Paired Wilcoxon signed rank test is used to check if differences found between predicted and observed values are significant. A first observation is that the prediction set from the adjusted models for ASHRAE and EN15251 are significantly different from the original model's prediction set (p value of 0.01 and 0.02 respectively). Among all the models considered, the models whose predictions are not significantly different from the observed values, at a 5% significance level, are the adjusted

EN15251 model, Toe and Kubota model, and Nguyen et al.'s model (p values of 0.30, 0.31, and 0.22 respectively).

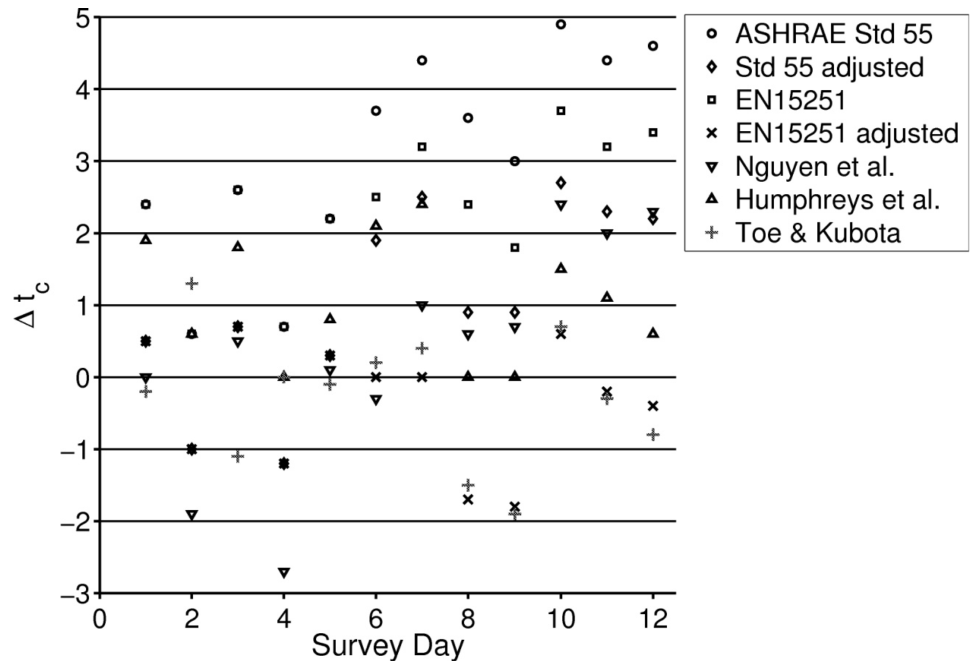


Figure 1. Differences in comfort temperature found between study results and predictions of existing models

This exercise yielded a few notable results. One was that use of adjustments for enhanced air velocities is very useful for accurate comfort temperature prediction especially when considering locations like India where fans are ubiquitous in NV buildings. Secondly, the overall good performance of Toe and Kubota and Nguyen et al.'s model showed that a model developed for similar climatic and cultural conditions would be better at predicting comfort temperatures of occupants. But most importantly, what is found is that in spite of a higher metabolic rate (more than 20% higher than that of seated office occupants), the neutral temperatures found in this study are not starkly different from the predictions of some of the existing ACEs. With increased activity, one might have expected a drop in the comfort temperatures. But the maximum difference found on any day is with the ASHRAE Standard 55 model where the model under predicts comfort temperature by 5 °C. This could be due to the level of acclimatization of the occupants along with other contributing factors. This is further discussed in Section 3.4.

### 3.2 Formulating an adaptive comfort relation with outdoors

As remarked upon in the previous section, different existing ACEs tend to use different indices for the outdoors. So, before trying to relate indoor comfort conditions with outdoors, a check was done to see if the different outdoor indices that might be used as input to the model are significantly different from each other. Once more paired Wilcoxon signed rank test is used and it is found that at a significance level of 5%, values for PMOAT, MOAT, RMT, and current month's mean temperature are not significantly different. Also, values of PMOAT calculated using 9, 11, and 13 day averages – instead of seven days – are not significantly different from the seven day PMOAT.

Regression equations are developed between the indoor comfort temperature and the following outdoor temperature indices: RMT, PMOAT-7 day, PMOAT-9 day, PMOAT-11 day, PMOAT-13 day, MOAT, and the current month's mean temperature. All these regression relations were found to be significant at 0.1% level. The $R^2$ values of these relations are given in Figure 2. $R^2$ values for the relations using RMT, PMOAT-7 day, and MOAT are not very different though the value is highest when using MOAT – similar to what Toe and Kubota (2013) found in their analysis. On the other side though, use of more number of days in calculating PMOAT reduces strength of relation quite rapidly. As any relation involving MOAT would require knowledge of the current day's temperature, such a relation would have limited utility as a dynamic/real-time prediction tool. In Equation 1, the regression relation between PMOAT-7 day ($t_{PMOAT}$) and $t_c$ is given, and in Equation 2, the regression relation between MOAT ($t_{MOAT}$) and $t_c$ is given.

$$t_c = 0.53 t_{PMOAT} + 15.23;\ \ \mathrm{R}^2 = 0.924,\ \ p < 0.001 \tag{1}$$

$$t_c = 0.49 t_{MOAT} + 15.45;\ \ \mathrm{R}^2 = 0.928,\ \ p < 0.001 \tag{2}$$

As already observed though, use of Toe and Kubota's model, or Nguyen et al.'s model, or the EN15251, with adjustment for higher air velocity, gives results that are statistically indistinct from the results that the above equations would provide. Thus, Equations 1 or 2 are not proposed as yet another ACE in the already existing multitude of ACEs. These equations are provided here to be informative rather than normative.

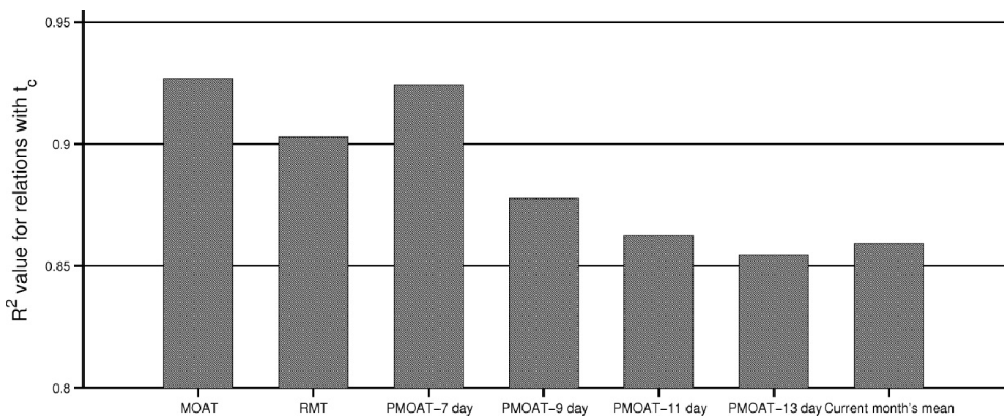


Figure 2. $R^2$ values of correlations using different indices of outdoor temperature

### 3.3 Temperature ranges for ensuring comfort

The results had shown that over the entire survey duration, 80% occupants were comfortable over a temperature range of 20 to 31 °C (Mishra and Ramgopal, 2014). This however represents the effects of an entire range of adaptive abilities occupants employed as the season changed from winter to summer. For example, over the survey duration, minimal clothing value observed was 0.39 clo while maximal was 0.99 clo. Over a single day or in particular during the three hour duration of the class, full spectrum of adaptive opportunities can rarely be brought into play. It was required to see what range of change in operative temperature during class timings on a day would still leave 80% of occupants comfortable. To this end, the method used by Nicol and Humphreys (2007) of correlating the deviation between $t_c$ and $t_{op}$ during survey period ($\Delta t_n = t_c - t_{op}$) with the percentage of occupants who found their thermal environment to be acceptable (PS) on that day is utilised. Equation 3 gives a second order polynomial fit between $\Delta t_n$ and PS.

$$PS = -3.6\Delta t_n^2 + 3.22\Delta t_n + 96.38; \quad R^2 = 0.91, \quad p < 0.001 \tag{3}$$

Coefficient of the first power of $\Delta t_n$ in Equation 3 failed to achieve significance at 5% level (p=0.15). So, ignoring contribution of the first-order term, Equation 3 is rewritten as:

$$PS = -3.6\Delta t_n^2 + 96.38; \quad R^2 = 0.91, \quad p < 0.001 \tag{4}$$

Equation 4 thus shows that around 4% people would be dissatisfied even if there is a perfect match between $t_c$ and $t_{op}$. It also shows that corresponding to an 80% value for PS, $\Delta t_n$ value needs to be ≈ ± 2 °C. This value is quite similar to the value obtained by Nicol and Humphreys (2007) from their analysis of the SCATS database. However, this finding comes with a qualifier. The current studies were all limited to post noon periods. So, the temperature ranges experienced by the occupants were not typical of the whole day's but rather of the hottest part of the day. Thus, the swing of 2 °C that is found to be okay with 80% of the subjects may not be extrapolated to express the temperature swings allowable over an entire day. Rather, such a range is representative of the comfort ranges for the warmer half of a day. The comfort temperatures found during the survey days along with the ACE line for PMOAT and allowed temperature drifts are presented in Figure 3.

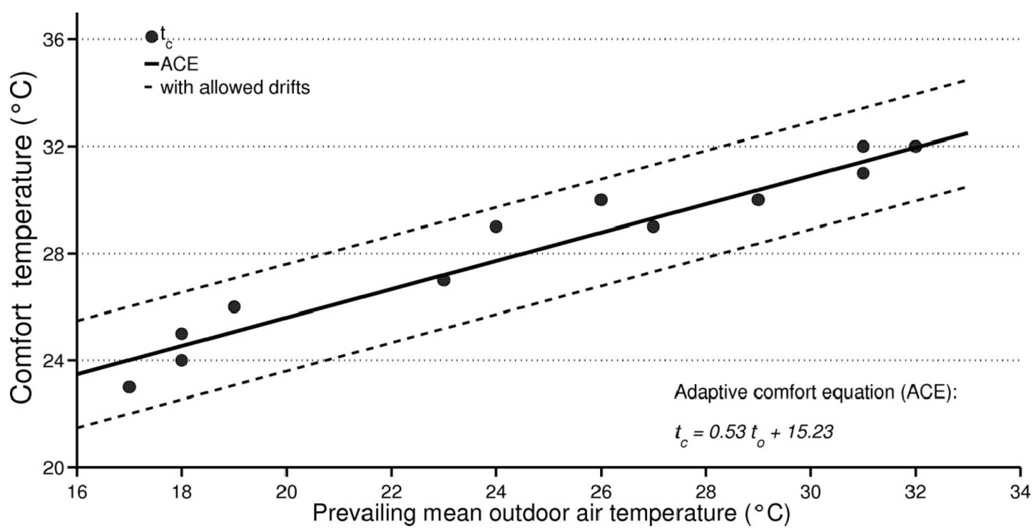


Figure 3. Comfort temperatures and adaptive comfort equation

### 3.4 Adequacy of adaptive opportunities in laboratories

Activity levels and patterns for laboratory and lecture classes are markedly different. Apart from the higher activity level, laboratory classes are also longer. For example, in IIT, while average lecture classes are of one hour, average laboratory classes are three hours long. On the positive side though, students have a lot less restriction on their adaptive behaviours. They do not have to occupy specific seats and maintain a consistent posture. They are free to move about and break the monotony. During summer months, students were observed to take multiple breaks for drinking water (drinking water being provided within the lab premises). They clustered around or under fans while not actively engaged with their respective experimental set ups. Changes made to clothing were frequent. During winter, depending on the conditions, students take off or zip up their jackets, sweat-shirts. In summer, they tend to loosen the first couple of buttons on the shirt/t-shirt or fold up the sleeves of full sleeve shirts.

As discussed in Section 3.1, the higher metabolic rate did not cause a lowering of comfort temperatures as given from certain accepted adaptive comfort models. The availability of more adaptive opportunities in settings of the current study, compared to those available in lecture classes or offices, is believed to be the reason behind this. As discussed by Baker and Standeven (1996), availability of adaptive opportunities can ameliorate the stress produced by a thermal stimulus. While this thermal stimulus could be in terms of temperature, it could also be in terms of metabolic activity. Thus, an enhancement in available adaptive opportunities is found to be able to successfully deal with slightly increased met rates and currently existing adaptive comfort models are able to predict comfort conditions without being grossly erroneous. It is however likely that at a certain point increased metabolic rate will be high enough that enhanced adaptive opportunities will not be effective. Finding where this tipping point occurs would require further studies.

## 4 Conclusion

Results from the current field study validated the use of EN15251 model, with adjustment for higher air velocity, Toe and Kubota's model, and Nguyen et al.'s model for predicting comfort conditions in NV classrooms of the hot-humid regions of India. This emphasizes on the use of adjustments for air velocity when using an ACE for locations where use of fans is widespread as well as highlights the fact that an ACE developed from data collected in similar climatic conditions can often be more useful than a global model.

In agreement with ASHRAE Standards 55 recommendations, PMOAT calculated over seven days was found to be a suitable index for outdoor conditions. And in what can be termed as a further validation of the principles of adaptive comfort, greater adaptive opportunities were observed to successfully counteract slightly higher metabolic rates without any appreciable changes in comfort zones.

## Acknowledgements

The cooperation extended to us by our subjects is acknowledged. We also deeply appreciate the help and support from laboratory staff members: Mr. R. Dey and Mr. P. Roychowdhury. For giving us access to historical and current temperature data, we are thankful to Prof. B. K. Mathur of the Department of Physics and Meteorology. Our thanks also go to Prof. P. K. J. Mohapatra, Department of Industrial Engineering, for the insights provided by him on statistical methods and analysis.

**Abbreviations**

| | |
|---|---|
| ACE | adaptive comfort equation |
| APD | actual percentage dissatisfied |
| MOAT | mean outdoor air temperature (daily mean) |
| MTSV | mean thermal sensation vote |
| NV | naturally ventilated |
| PMOAT | prevailing mean outdoor air temperature |
| RMT | running mean temperature |

## References

ANSI/ASHRAE, 2010. Standard 55-2010. Thermal comfort conditions for human occupancy. ASHRAE, Atlanta.

Auliciems, A., 1972. Classroom performance as a function of thermal comfort. International Journal of Biometeorology, 16(3), pp 233-246.

Baker, N. and Standeven, M. , 1996. Thermal comfort for free-running buildings. Energy and Buildings, 23(3), pp 175-182.

BEE. 2009. Energy Conservation Building Code user guide. Bureau of Energy Efficiency. New Delhi, India.

Deb, C. and Ramachandraiah, A., 2010. Evaluation of thermal comfort in a rail terminal location in India. Building and Environment, 45(11), pp 2571-2580.

Dhaka, S., Mathur, J. , Wagnerb, A. , Agrawal, G. D. and Garg V., 2013. Evaluation of thermal environmental conditions and thermal perception at naturally ventilated hostels of undergraduate students in composite climate. Building and Environment, 66, pp 42-53.

Humphreys, M. A., Rijal, H. B., and Nicol, J. F., 2013. Updating the adaptive relation between climate and comfort indoors; new insights and an extended database. Building and Environment, 63, pp. 40-55.

IEA, 2011. Energy balances of non-OECD countries. International Energy Agency. Paris, France.

Indraganti, M., 2010. Using the adaptive model of thermal comfort for obtaining indoor neutral temperature: Findings from a field study in Hyderabad, India. Building and Environment, 45(3), pp 519-536.

Indraganti, M., Ooka, R., and Rijal, H. B., 2013. Field investigation of comfort temperature in Indian office buildings: A case of Chennai and Hyderabad. Building and Environment, 65, pp 195-214.

ISO, 2005. ISO 7730: Ergonomics of the thermal environment Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria. 3rd edn., Geneva.

Mendell, M. J. and Heath, G. A., 2005. Do indoor pollutants and thermal conditions in schools in influence student performance? A critical review of the literature. Indoor Air,15(1), pp 27-52.

Mishra, A. K. and Ramgopal, M., 2013. Field studies on human thermal comfort – An overview. Building and Environment, 64, pp 94-106.

Mishra, A. K. and Ramgopal, M., 2014. Thermal comfort in undergraduate laboratories – A field study in Kharagpur, India. Building and Environment, 71, pp 223-232.

Nguyen, A. T., Singh, M. K., and Reiter, S., 2012. An adaptive thermal comfort model for hot humid South-East Asia. Building and Environment, 56, pp 291-300.

Nicol, F. and Humphreys, M., 2007. Maximum temperatures in European office buildings to avoid heat discomfort. Solar Energy, 81(3), pp 295-304.

Nicol, F. and Humphreys, M., 2010. Derivation of the adaptive equations for thermal comfort in free running buildings in European Standard EN15251. Building and Environment, 45(1), pp 11-17.

Pellegrino, M., Simonetti, M., and Fournier, L., 2012. A field survey in Calcutta. Architectural issues, thermal comfort and adaptive mechanisms in hot humid climates. Proceedings of 7th Windsor Conference: The changing context of comfort in an unpredictable world, NCEUB, Windsor, UK.

R Core Team, 2012, R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. URL: http://www.R-project.org

Toe, D. H. C. and Kubota, T., 2013. Development of an adaptive thermal comfort equation for naturally ventilated buildings in hot-humid climates using ASHRAE RP-884 database, Frontiers of Architectural Research, 2(3), pp 278-291.

UGC (2008), Higher education in India – Issues related to Expansion, Inclusiveness, Quality and Finance. Secretary, University Grants Commission, New Delhi.