

# Chapter 11

## Modelling and Simulating the Thermal Comfort Aspects of Natural Ventilated Classrooms in Hot-Humid Climates



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### 11.1 Introduction

Increasing requirement of thermal comfort and improvements in living standards in developing countries has led to an increase in the amount of energy consumption of buildings. In India, the building sector represents about 33% of total electricity consumption, with the commercial and residential sector accounting for 8% and 25% respectively (Taulo 2012). In the next few decades, India is expected to have the world's largest set of young people. The compound annual growth rate of the higher education sector in India is mounting from 10.16% to 17.5% by 2025. The number of higher education institutions in India has seen more than 50 fold growth in the last six and half decades (Yeravdekar and Tiwari 2012). Also there is a growing urge to increase the quality of higher education in India. Studies show that, among other things, the quality of indoor environment affects the teaching and learning aspects of classrooms significantly (Mishra and Ramgopal 2015). Providing a thermally comfortable environment is shown to reduce absenteeism among the students. Passive cooling techniques have proven to be of great utility in such scenarios to reduce thermal discomfort (Pellegrino et al. 2016). These are techniques for achieving comfort by natural means, i.e., without consuming minimum or no additional energy so that a sustainable solution could be achieved. Hence they are preferred over active cooling systems which are highly energy intensive. Studies show that in case of naturally ventilated classrooms, the outdoor climate variations influence the behaviour of the occupants and their perception of comfort. This has resulted in development of several adaptive comfort equations for different climates (Mishra and Ramgopal 2015; Yao et al. 2010; de Carvalho et al. 2013; Nematchoua et al. 2014; Indraganti et al. 2014).

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Adaptive thermal comfort models suggest a wider range of acceptable temperatures by considering the adaptations of the subjects to the local outdoor climate. This opens up the scope for natural ventilation of buildings and use of various low energy passive systems (Givoni 1991; Omrany et al. 2016; Panchabikesan et al. 2017). There are various passive techniques used in buildings to control the natural flow of air and heat into the buildings (Omrany et al. 2016). But the performance of a passively cooled or naturally ventilated building depends strongly on the climatic conditions, so it is essential to evaluate the buildings for each of the climatic zones (Panchabikesan et al. 2017).

Toe and Kubota (2015) investigated vernacular passive cooling techniques and their potential application for improving indoor thermal comfort of naturally ventilated, modern brick terraced houses in Malaysia. Assessment of passive cooling techniques for high and low thermal mass building was done. Samani et al. (2016) compared different passive cooling techniques of shading, natural ventilation, reflective coatings (cool paints) and increased thickness of interior gypsum plaster for these buildings to tackle overheating in hot climates. The findings of this comparison bring insights into the effectiveness of passive cooling techniques that can be highly beneficial at the design level. The authors were able to achieve acceptability of 80% of ASHRAE 55 by the combined implementation of all techniques.

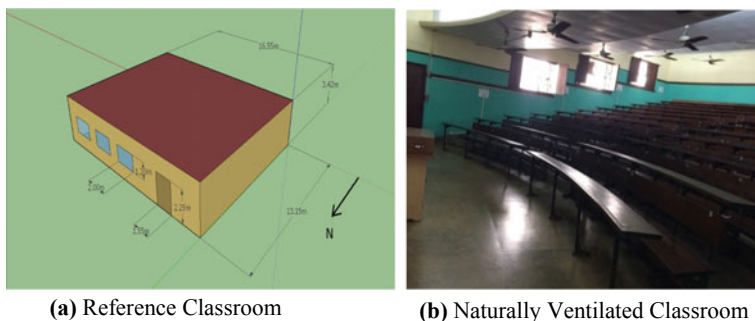
Though studies are already carried out on use of passive cooling methods, their application on thermal comfort of classrooms has not been reported. Hence in this paper, the improvement in thermal comfort levels of a naturally ventilated classroom located in a hot and humid climate is studied in a systematic manner. A reference classroom building conforming to National Building Code (NBC) of India (NBC 2005) is considered for the study. The performance of this building is simulated using EnergyPlus.

## 11.2 Development of Classroom Model and Validation

### 11.2.1 Reference Classroom Model

The classroom is modelled using EnergyPlus software (EnergyPlus 2015) with a legacy open studio plug-in as an auxiliary interface. The plug-in is installed in Google Sketchup and used to create the geometrical model of the reference classroom as shown in Fig. 11.1a. The geometry of the classroom was based on an actual, naturally ventilated classroom with 216 m<sup>2</sup> floor area and a height of 3.42 m as shown in Fig. 11.1b. The material properties are given in Table 11.1. The windows have solar transmittance of 0.837 and visible transmittance of 0.898.

The surfaces, floor, and roof of the geometrical model are converted to objects in a single thermal zone and the boundary conditions are given by specifying them as exposed to outdoor or unexposed as the internal surface. The roof and all the walls



**Fig. 11.1** a Reference classroom. b Naturally ventilated classroom

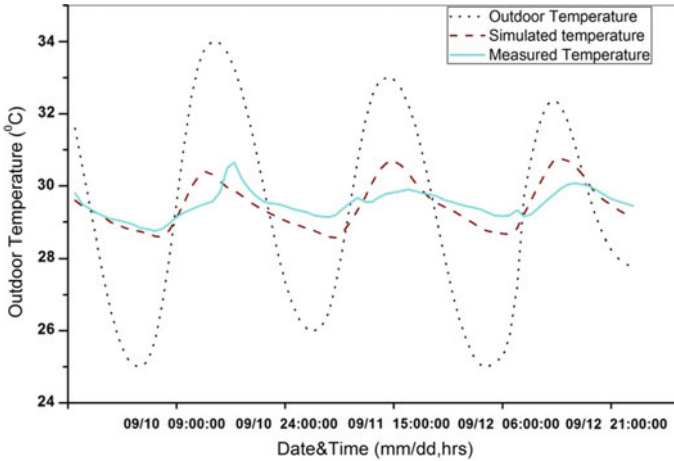
**Table 11.1** Materials and their properties

Component	Area (m <sup>2</sup> )	Material	Conductivity (W/mK)	Density (kg/m <sup>3</sup> )	Specific heat (J/kgK)
Walls	183.3	200 mm brick with masonry plaster	0.89	1920	790
Roof	216	200 mm thick concrete with masonry plaster	1.11	800	920
Floor	216	200 mm thick concrete with masonry plaster	1.11	800	920
Windows	14.4	3 mm clear glass in mild steel frame	0.9	–	–
Doors	6.9	25 mm wood	0.15	608	1630

except the west wall are exposed to outdoor conditions. The outdoor conditions are provided by weather files to EnergyPlus which contains typical hourly data of solar radiation, temperature, wind speed, humidity, and atmospheric pressure. Simulations are carried out for the Indian city of Kolkata (22. 6° N, 88.4° E).

### 11.2.2 Validation of the EnergyPlus Model

To verify the modelling procedure and boundary conditions specified, several measurements of temperatures and relative humidity are taken inside the classroom shown in Fig. 11.1b and are compared with the simulated hourly average indoor air temperatures for three days. Measurements are taken using temperature and humidity sensors to sense the inside room temperature and relative humidity, globe thermometer is used to estimate mean radiant temperature and Hobo data logger is used to record the data. Measurements were taken for a span of 84 h. The simulation was performed by taking the reference classroom model with 500 mm thick

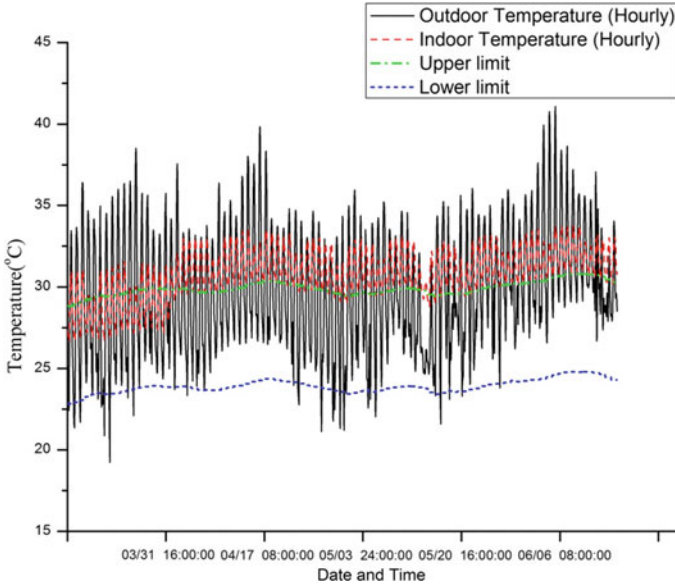


**Fig. 11.2** Comparison between measured and simulated operative temperatures

walls and 200 mm concrete slabs for roof and floor. For convenience, the classroom was considered without any occupants with windows being closed for 84 h. Measurements were also taken at various positions inside the classroom and a variation of  $\pm 1.5$  °C was found. Since the variation is not very large, it is neglected and a uniform temperature is considered across the classroom. The simulated results in terms of operative temperature are compared with the calculated operative temperatures of the actual classroom using the measured temperatures. Figure 11.2 shows the comparison between simulated values and values obtained from measurements. In spite of some uncertainty in the input values provided for simulation a reasonably good agreement can be seen between the simulated and measured values indicating the correctness of the approach.

### 11.2.3 Thermal Performance of the Model

After verifying the correctness of the approach with actual data on an existing classroom, next the reference classroom as per NBC standards is constructed in EnergyPlus (Fig. 11.1a). Based on NBC recommendations (NBC 2005), the classroom is considered to have an occupancy of 54 i.e. 0.25 person/m<sup>2</sup> with classes being held from 8 a.m. to 6 p.m. with one hour recess from 1 p.m. to 2 pm. An activity level of 1 met (58.2 W/m<sup>2</sup>) is considered for the students, who are assumed seated. An average heat transfer area (DuBois area) of 1.8 m<sup>2</sup> per person is considered based on ASHRAE recommendations. Simulations are run from March 15 to June 15, which is the typical summer duration in sub tropical climate of India for a typical metrological year. TARP (Thermal Analysis Research Program) algorithm is used for calculating inside and outside surface convection heat transfer

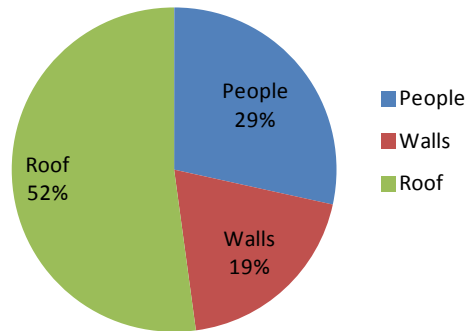


**Fig. 11.3** Variation of simulated operative temperatures inside the reference classroom

coefficients. The adaptive thermal comfort limits for the effective temperature inside the classroom are based on 80% acceptability limits of EN 15251 standards (EN 15251). It is seen that for the reference classroom the simulated temperatures inside the classroom are mostly outside the comfort limits as shown in Fig. 11.3, indicating the need for improving the thermal comfort. To understand the reasons for high indoor temperatures, contributions of heat transfer for a typical summer day from major heat sources are calculated and are shown in Fig. 11.4.

As shown in Fig. 11.4, the heat gain through the roof contributes maximum heat due to direct solar radiation of the exposed roof. This is followed by contribution due to occupants, walls (9% due to exposed east wall) and windows. Hence to improve the thermal comfort aspects, during summer months, passive cooling

**Fig. 11.4** Contribution of different heat sources to room heat gains on 21st June



techniques which can reduce these heat gains are to be identified and evaluated. Several passive techniques like increased thermal insulation, increased thermal mass, cool roofs, shading, overhangs, night ventilation, etc., can be considered. In this study, based on the heat gain distribution and ease of implementation, the following measures are considered and evaluated: occupant density, class scheduling, window overhangs and wall shading, nocturnal ventilation, and reflective coatings (cool paints).

### 11.3 Results and Discussion

Results are obtained by introducing the methods identified for mitigating the discomfort. These are: overhangs to block heat gain from windows, tree shadings to block the east wall heat gain, cool paints to block roof heat gain, night ventilation to offset heat gain by walls, and scheduling to regulate heat gain by occupants according to peak outdoor conditions. The individual effect of each of these and their cumulative effect on comfort are obtained from simulations. The details used in the simulation for each technique are discussed in following subsections. The simulations performed for the reference classroom (baseline model) defined earlier. Results for the baseline model for summer months indicate 21.32% of total summer comfort hours and only 9.1% of occupied comfort hours. The results obtained from simulation for each of the techniques listed above for summer months (March 15 to June 15) are discussed in the following subsections.

#### 11.3.1 Scheduling

Generally, classes are held for the whole duration of working hours in an educational institution. For the reference classroom, it is from 8 a.m. to 6 p.m. with a recess for one hour, i.e., from 1 to 2 p.m. In this study, two other schedules are taken into consideration, one with classes held for alternate hours in the specified classroom and the other being no classes in the duration when peak outside temperature occurs, i.e., from 1 to 3 p.m. The impact of these three schedules on indoor temperature and thermal comfort of occupants has been assessed. Figure 11.5 shows the variation of indoor temperature with number of hours for May 20th and 21st. Both alternate and peak scheduling, results in decreasing the peak temperature inside the classroom. The study suggests that if peak scheduling is applied, there is a noticeable increase in occupied comfort hours as compared to baseline scheduling, even though this alone is not sufficient. Alternate scheduling may not be acceptable due to practical reasons for classrooms.

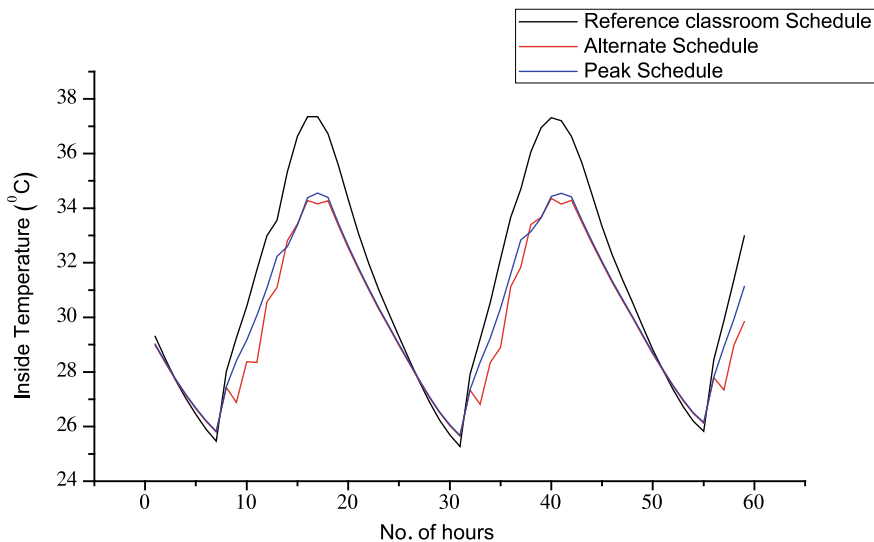


Fig. 11.5 Inside temperatures on 20th and 21st May for different type of schedulings

### 11.3.2 Occupant Density

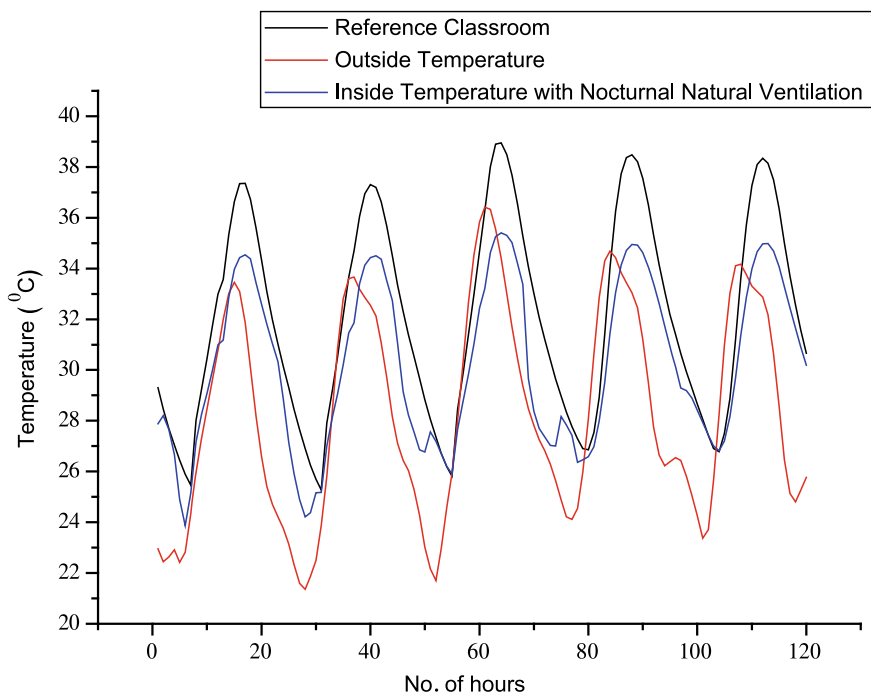
It can be seen from Fig. 11.4, that contribution of occupancy load is about 29% which is a very significant amount, therefore simulation is performed where the occupancy rate is varied from 0.5 to 0.25 person/m<sup>2</sup> in steps which is the occupancy range for educational institutions according to National Building Code (NBC 2005) and its effect on total comfort hours is analyzed. Study considered three occupancy variations of 108, 70, and 54. It could also be noted that there is a increment of 3% in occupied comfort hours as the occupancy is changed from 108 to 54.

### 11.3.3 Wall Shading and Window Overhang

The depth of the window overhang is taken based on the projection factor (=depth of overhang/height of the window) of 0.83 which is in accordance with (Sadafi et al. 2011). The width of the overhang is same as the width of the window. Shading with trees along the east wall of the room is also simulated. Trees are kept 4 m away from the east wall and 5 m in height. They are distributed in such a way that they cover the whole width of the east wall, i.e., 13 m. Results show that with these measures, the total comfort hours increases to 24.23% (from 21.23 % of baseline) of total hours and occupied comfort hours increases to 11.79% (from 9.1%) of total comfort hours for summer months. Since these measures are easy to implement, they are recommended.

### 11.3.4 Nocturnal Natural Ventilation

To study the effect of nocturnal ventilation, the schedule of opening windows is given at night time when the outdoor temperature is lower than inside temperature. For simulation, it is assumed that all the windows are kept open from 9 p.m. to 6 a.m. From Fig. 11.6, it can be observed that the outdoor dry bulb temperature is lower than the inside temperature during the night hours. To utilize this environmental condition for the benefit of building cooling, windows were kept open at night time, which resulted in decreasing the peak temperature occurring inside the classroom with respect to reference classroom. Figure 11.6 shows that the peak temperature occurring inside the classroom for four days of May 20th–23rd have reduced by about 2 to 3 °C, leading to an increase in the percentage of comfort hours.



**Fig. 11.6** Comparison of inside and outside temperature on 20th May to 23rd May for Nocturnal Natural Ventilation



### 11.3.5 Use of Reflective Coatings (Cool Paints)

According to ASHRAE standards, paint materials having a solar reflectance value of 0.7 or more are characterized as cool paints. Hence for simulation purposes, paint materials having solar reflectance values of 0.7 or more (solar absorptance values of 0.3 or less) are considered for reflective coatings of roof and walls. Since the roof is the main contributor with 52% of total heat input to the classroom, it is the most crucial component. However, in the simulation, cool paints are applied on the roofs as well as walls. Results are obtained for solar absorptance values varying from 0.1 to 0.3. As expected use of cool paints have proven to be of greatest impact as it directly reduces the heat transfer from the roof which contributes to 52% of heat gain to the room.

### 11.3.6 Effect of Individual and Combined Techniques for Complete Year

Based on the results obtained for summer months, study is extended to cover the complete year. Results obtained for summer months as well as complete year are summarized in Table 11.2. Comfort hours are defined based on the adaptive

**Table 11.2** Combination of various passive cooling techniques and their effect on thermal comfort for summer months and all year around

		Summer months		All year around	
Passive cooling technique		Percentage of occupied comfort hours (%)	Percentage of comfort hours (%)	Percentage of occupied comfort hours (%)	Percentage of comfort hours (%)
Reference classroom		9.1	21.32	23.73	37.60
Scheduling	Alternate	10.69	21.86	23.33	38.17
	Peak	11.38	21.37	28.13	37.86
Occupancy	108	6.12	20.34	20.38	36.35
	70	8.51	21.06	22.69	37.19
	54	9.10	21.32	23.73	37.60
Nocturnal natural ventilation		10.29	32.05	24.31	41.92
Shading and window overhang		11.79	24.23	26.88	40.86
Cool paints	0.3	16.71	38.22	42.46	53.74
	0.2	21.49	45.52	48.69	58.91
	0.1	31.05	57.84	60.42	65.31
Nocturnal natural ventilation + shading and overhang + cool paints (absorptance = 0.1)		34.03	62.63	66.5	69.12

thermal comfort limits model as reported for naturally ventilated classrooms by Mishra and Ramgopal (2015). From the Table 11.2 it can be seen that qualitatively the impact of the various measures is same for summer as well as whole year, though quantitatively there is a huge difference. From the table it can be seen that the cumulative effects of all the methods suggested increase the occupied comfort hours for summer months from 9.1 to 34.03%, whereas the total comfort hours for the same months the increase is from 21.32 to 62.63%. These values for whole year are 23.73–66.5% (occupied comfort hours) and 37.6–69.12% (total comfort hours).

## 11.4 Conclusions

Effects of several simple and easily implementable measures on thermal comfort aspects of naturally ventilated classrooms are obtained through building simulation using Energy Plus. Results show that cumulatively these measures increase the occupied comfort hours for summer months from 9.1% of the baseline to 34.03%. The greatest impact is provided by the use of highly reflective cool paints as the classroom has an exposed roof. Since the total comfort hours increase from 21.32 to 62.63%, shifting the classes entirely into cooler hours of the day may be most beneficial. Some of the other measures that can be considered are use of mechanical night ventilation, use of phase change materials and evaporative cooling of roof.

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