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Significance of Air Movement for Thermal Comfort in Educational Buildings, Case Study of a Classroom

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Abstract: Research has shown that increased temperatures and low ventilation rates in classrooms can have negative impacts on work performance and health of the students. Its known fact that the better thermal comfort conditions in any space will have positive effects on the wellbeing of the persons using it. The major factors affecting thermal comfort are both environmental and personal. Environmental factors include air temperature, radiant temperature, air velocity and humidity. Personal factors include clothing insulation and metabolic heat. Movement of air is one of the important factors influencing thermal comfort of a space. This paper discusses about the relevance of increased air movement at higher indoor temperatures and humidity, and how it can improve thermal comfort conditions in a class room. A class room of an Institution has been chosen to test the point.

Keywords: Thermal comfort, Air movement, ventilation, environment.

1. INTRODUCTION

This paper highlights the significance of air movement for comfortable indoor environment for a classroom located in warm humid climate. Research has shown that increased classroom temperatures (Mendell and Heath, 2005; Wargocki and Wyon, 2007) and low ventilation rates (Bakó-Biró et al., 2012) can have a negative impact on college work performance and health of the students. However, there is limited information on student's thermal perception in classrooms and the thermal conditions deemed acceptable by them. Furthermore, the majority of research in this field regards student's thermal comfort conditions. On the contrary, several studies in the warmer climates have shown that increased air movement can comfortably counterbalance thermal discomfort at high indoor temperatures without compromising the overall acceptability of the environment (Mallick 1996, Nicol 2004, Brager 2000). The present paper discusses the importance of air movement in educational buildings to achieve thermal comfort.

2. THERMAL COMFORT

Thermal comfort is the condition of mind that express satisfaction with the thermal environment and is assessed by subjective evaluation (ANSI/ASHRAE Standards 55). The major factors affecting thermal comfort are both environmental and personal. Environmental factors include air temperature, air velocity, humidity and radiant temperature. Personal factors include clothing insulation and metabolic heat. Under isothermal and steady state conditions, the heat balance of the body can be described by these vital six variables. While there are numerous others minor parameters like health and light etc. which also influence thermal comfort, Fanger (1972) clarifies that comfort can be achieved by many different combinations of the above variables. The effect of any of these factors should not be considered independently as the effect of each of them depends on the level and conditions of the other factors, and also by the use of many fundamentally different technical systems (both passive and active). The effect of humidity and air velocity will be discussed in detail as below.

2.1 Factors influencing Thermal Comfort

2.1.1 Air Temperature

It is the temperature of the air surrounding the body. It is usually given in degrees Celsius (°C). Right temperature and air freshness are the most important about a building, (Griffiths, 1990). Freshness of air closely is related to the temperature (Croome & Gan, 1994).

2.1.2 Radiant Temperature

Thermal radiation is the heat that emits from a warm object. Radiant heat may be present if there are any heat sources in the environment. Radiant temperature has a greater influence than air temperature on how we lose or gain heat to the environment.

2.1.3 Air Velocity

It describes the speed of air moving across the people and may help cool them if the air is cooler than the environment. Air velocity is an essential factor in thermal comfort for example: still or stagnant air in indoor environments that are artificially heated may cause people to feel airless. It may also lead to a buildup odor in moving air in warm or humid conditions which can increase heat loss through convection without any change in air temperature physical activity also increases air movement, so air velocity may be corrected to account for a person's level of physical activity slight air movements in cool or cold environments may be perceived as a draught as people are particularly sensitive to these movements.

2.1.4 Humidity

Relative humidity is the ratio between the actual amount of water vapor in the air and the maximum amount of water vapor that the air can hold at an air temperature. Relative humidity between 40 and 70% does not have a major impact on thermal comfort. In rooms that are not air conditioned, or where the weather conditions outdoors may influence the indoor thermal environment and relative humidity may be higher than 70%. High humidity environments have a lot of vapor in the air, which inhibits the evaporation of sweat from the skin. In hot environments, humidity is substantial because less perspiration evaporates when humidity is high (80 %+). The evaporation of sweat is the main method of heat reduction.

2.2 Personal factors

2.2.1 Clothing Insulation

Thermal comfort is highly dependent on the insulating effect of clothing on the wearer. Wearing excess clothing or personal protective equipment (PPE) may be a main cause of heat stress even if the environment is not considered warm or hot. If clothing does not provide sufficient insulation, the wearer may be at risk from cold injuries such as frostbite or hypothermia in cold conditions. Clothing is both potential causes of thermal discomfort as well as control for it as we adapt to the climate in which we work. It is important to identify how the clothing contributes to thermal comfort or discomfort to improve the level of comfort.

2.2.2 Metabolic heat

The impact of metabolic rate on thermal comfort is acute. The more physical work we do, the more heat we produce and the more heat we produce, the more heat needs to be lost so we don’t overheat. A person’s physical characteristics should always to keep in mind when considering his/her thermal comfort, as factors such as their size and weight, age, fitness level and sex can have an impact on how they feel, even if other factors such as air temperature, humidity and air velocity are all constant.

3. SIGNIFICANCE OF AIR MOVEMENT AND VENTILATION IN WARM ENVIRONMENTS

3.1 Air Movement

Areas with deprived thermal comfort conditions are mainly due to the poor natural ventilation (Wang and Wang, 2005). Natural and mechanical ventilation provide the dual purpose of eliminating indoor surplus heat and contaminants in time. In fact, air movement is the only tactic to attain physiological comfort at high temperatures, as it affects both evaporative and convective heat losses from the human body. Air exchange efficiency and ventilation efficiency can both reflect the capacity for discard indoor contaminants of ventilation system (Su et al. 2009).

Air movement significantly affects body heat transfer by convection and evaporation. Air movement results from free (natural) and forced convection as well as from the occupants’ bodily activities. The faster the motion, the greater the rate of heat flow by both convection and evaporation. When ambient temperatures are within acceptable limits, there is no minimum air flow that must be provided for thermal comfort. The natural convection of air over the surface of the body allows for the uninterrupted dissipation of body heat. When ambient temperatures rise, however, natural air flow velocity is no longer adequate and must be artificially improved, such as by the use of fans.

In either case, when the temperature of the air affecting on an occupant is below the ambient temperature, the individual becomes more sensitive to air flow and may complain of drafts. Therefore, careful attention must be given to air distribution as well as velocity. The tendency of warm air to rise can greatly affect occupant comfort due to convective air motion, and thus influences the correct placement of the heat source in a room.

ASHRAE (Std-55, 2004) indicates that acceptable indoor air speed in warm climates should range from 0.2 to 1.50 m/s; yet 0.2 m/s for air conditioned environments. These ranges specified by ASHRAE do not explicitly address air movement acceptability, but focus mainly on overall thermal sensation and comfort. Zain et al. (2007) find that in warm humid climes an increase in air movement from 0.0 m/s to 0.7 m/s has substantially increased the PPS from 44% to 100% at temperatures around 28.69 °C. Maarof and Jones (2009) point out that at high temperature (>30 °C) and high humidity (>70%), continuous air moment is important, rather than spasms of air drafts. This evaluation is done in both questionnaire and experiment method.

4. FIELD STUDY

The field study presented here included pupil questionnaire and simultaneous measurement of the indoor variables which affect the thermal comfort. It was conducted in a naturally ventilated class room of a college building located in Vijayawada, India; a hot humid climate. The field studies were carried out for the period two weeks from 2-13 Nov 2015. The case study of the class room and the methodology applied are discussed below.

4.1 Survey Questionnaire

During the survey, the students were asked to provide the rating of their comfort inside the class room. The aim of this question was to identify the perceived impact of the thermal sensation on the overall comfort of the students. The assessment of student’s thermal sensation ASHREA rating scale was used.

4.2 Thermal sensation and thermal preference of the students

Fig: 1 and Fig: 4 show the thermal sensational vote (TSV) and thermal preference vote (TPV). The findings state that, the students were not comfortable most of the days. TSV for hot, warm and slightly warm were higher than the comfortable level. Their thermal preference was to be cooler. They are taking some adaptive measures in their clothing to keep them cool by wearing cotton clothes.

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Table: 1- Thermal comfort scale used in the surveys

Scale value	ASHREA thermal sensation (TS)	Air movement sensation (AMS)	Humidity sensation	Thermal preference
-3	Hot	Much too still	Much too dry	Hot
-2	Warm	Too still	Too dry	Warm
-1	Slightly warm	Slightly still	Slightly dry	Slightly warm
0	Comfortable, neutral	Comfortable, neutral	Comfortable, neutral	Comfortable, neutral
1	Slightly cool	Slightly breezy	Slightly humid	Slightly cool
2	Cool	Too breezy	Too humid	Cool
3	Cold	Much too breezy	Much too humid	Cold

Source: ASHRAE Standard 55-2004:5, De Dear and Brager, 1998 and Humphreys 1996:140

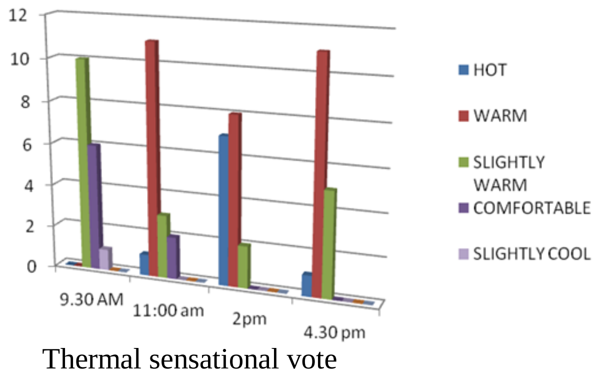

Fig: 1 Thermal sensational vote (TSV) and respondents

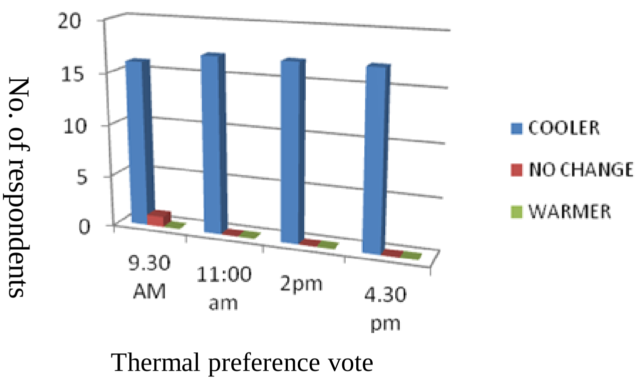

Fig: 4 Thermal preference vote and No. of. Respondents

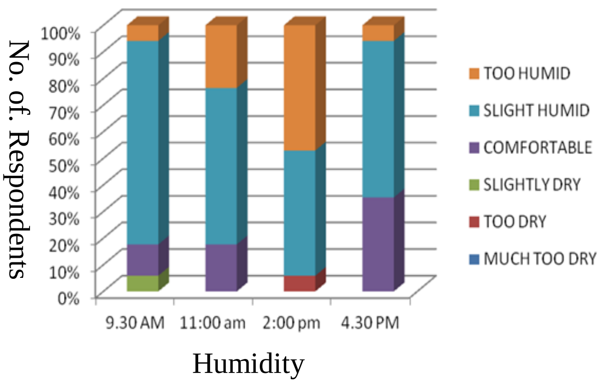

Fig: 2 –Humidity scale and percentage of respondents

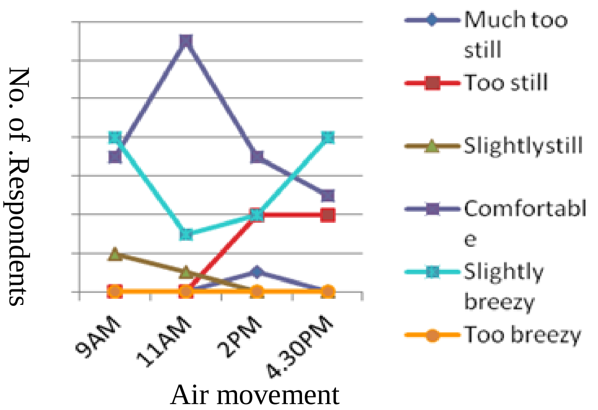

Fig: 3 Air movement sensations and No .of. Respondents

4.3 Perception of overall comfort and tiredness

The students were asked to say about their comfort in class room during the survey (Question 10 in the Appendix). The aim of this question was to identify the perceived impact of the thermal sensation on the overall comfort of the pupils. Fig shows their responses in relation to their thermal sensation votes. Majority of the students were not comfortable with the thermal condition inside. All of them felt tired and some of them had headache, eye irritation and drowsiness.

4.4 Results:

Hence, the present thermal environment is not satisfactory among the students and their thermal preference is to be cooler with some mechanical ventilation. In order to minimize the humidity and to improve thermal condition inside the class room, airflow should be increased thus providing a comfortable environment and to prevent any health issues

5. MEASUREMENT OF INDOOR VARIABLES

The environmental parameters were measured during the survey using TESTO 480 professional multifunctional instrument. According to the ISO 7726 standards "Ergonomics of the thermal environment - Instruments for measuring physical quantities" (ISO, 2001). The parameters that were used included: air velocity, radiant temperature (globe thermometer with diameter=150mm), ambient air temperature, Abs pressure and relative humidity. The above parameters were measured at a height

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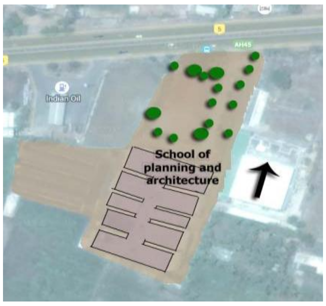
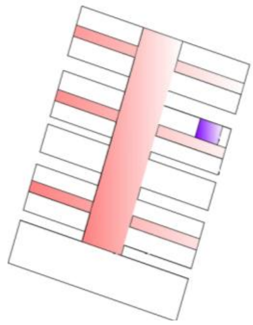
of 0.9m, based on the recommendation of ISO 7726 (ISO, 2001).

5.1 Case study:
The school of planning and architecture located in a mixed land use area (Educational and industrial)on National Highway in Vijayawada, Andhra Pradesh. The building consists of 4 floors spread in wings on either side of the corridor as shown in middle picture, and the building is facing east side. The building was constructed as a frame structure with brick walls and it was constructed in 2000.
March first year sustainable architecture class room was taken for the research which is on the first floor of the building facing west side connected with a 2m wide corridor on one side, 2m wide open courtyard on east side for ventilation, other two sides have no openings. The study was conducted in the South East oriented class room and it is single-side ventilated. The class room consist 17 students with the age group of 22-25 years. The measurements were taken four times a day with considerations such as 1.when the windows opened, doors opened, 2.when the windows closed, doors closed. The measuring timings were 9.30am, 11.00 am, 2.00pm and 4.30pm.

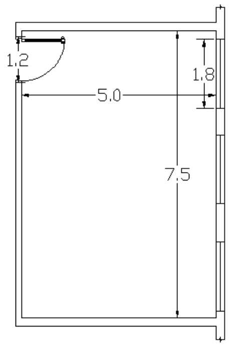


Source: Author
Fig: 5 Location of the building



Source: Author

Fig: 6 Location of the class room



Source: Author

Fig: 7 Class room interior lay out

The class room is located in wind shaded area with single-side ventilation. The room and three windows measure 5mx7.5m and 1.8m, respectively and windows are placed at equal distance.

Table: 2 Desirable wind speeds for Thermal comfort conditions

Dry Bulb Temperature °C	Relative Humidity (Percent) 30	40	50	60	70	80	90
	(Wind Speed, m/s)						
28	*	*	*	*	*	*	*
29	*	*	*	*	*	0.06	0.19
30	*	*	*	0.06	0.24	0.53	0.85
31	*	0.06	0.24	0.53	1.04	1.47	2.10
32	0.20	0.46	0.94	1.59	2.26	3.04	+
33	0.77	1.36	2.12	3.00	+	+	+
34	1.85	2.72	+	+	+	+	+
35	3.2	+	+	+	+	+	+

*None
+Higher than those acceptable in practice.

Source: SP: 41 (S&T)-1987, pg 80

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Table: 3-Minimum wind speed for thermal comfort conditions

Dry Bulb Temperature °C	Relative Humidity (Percent) 30	40	50	60	70	80	90
	Wind Speed, m/s						
28	*	*	*	*	*	*	*
29	*	*	*	*	*	*	*
30	*	*	*	*	*	*	*
31	*	*	*	*	*	0.06	0.23
32	*	*	*	0.09	0.29	0.60	0.94
33	*	0.04	0.24	0.60	1.04	1.85	2.10
34	0.15	0.46	0.94	1.60	2.26	3.05	+
35	0.68	1.36	2.10	3.05	+	+	+
36	1.72	2.70	+	+	+	+	+

*None
+Higher than those acceptable in practice.

Source: SP: 41 (S&T)-1987, pg 80

Inside design considerations for classroom to meet thermal comfort standardsDB-23C-26C,RH-50%-60%for summer and DB-23C-24C,RH-not less than 40%.Thermal comfort condition for non AC buildings the temperature should be less than 33C and Relative Humidity less than 70%.(GRIHA manual volume3 pg68)

Table: 4-Measurement of indoor variables

DATE	2.11.15	3.11.15	4.11.15	5.11.15	6.11.15	9.11.15	10.11.15	11.11.15	12.11.15	13.11.15
Operative temperature (OC)										
Min	28.9	29.7	27.8	28.3	29.5	24.3	24.5	27.1	28.3	28
Max	29.7	30.2	30	29.5	30	25	25.7	28	29.5	31
Mean	29.3	29.9	28.9	28.9	29.7	24.6	25.1	27.55	28.9	29.5
Relative humidity (%)										
Min	66.9	70.8	70.5	67.3	69.3	79	78	63	63.4	78
Max	69.3	71.5	72	70..2	70.5	85	86.3	64.5	65.2	84
Mean	68.1	71.1	71.2	68.7	69.9	82	82.1	63.7	64.3	81
Air speed (m/sec)										
Min	0	0	0	0	0	0	0	0	0	0
Max	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Mean	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Abs pressure										
Min	1009	1008	1007.9	1010.3	1006	1011.3	1011.3	1006.3	1007.4	1011
Max	1012.6	1008.3	1010	1012	1010.9	1012	1012	1007	1008.3	1013
Mean	1010.8	1008.1	1008.9	1011.1	1008.4	1011.6	1011.6	1006.6	1007.8	1012

According to the study above air speed required inside the class room is not according to the ASHREA and SP 41 standards. Air flow inside the room is very less. Because of this improper air change inside the class room, health problems were confronted by students. According to National Building Code (NBC) 6-8 air changes per hour should happen for an educational building. The size of the class room is 7.5mx5mx3.5m.

To find no. of air changes in the room

$$\text{Air change rate} = \frac{Qv}{V} \qquad (1)$$

Qv =Air flow rate through a space (m3/h)
V = Volume of the space m3

$$\text{Air change/hr} = \frac{0.17\text{x}3600}{3.5\text{x}7.5\text{x}5}$$
$$= 4.66$$

This is less than recommended air change so the air flow should be increased to attain more no. of air changes inside the class room. To increase the air flow in to the room in the given climatic conditions, opening area of the room has to be increased. By taking 6 air changers for the classroom to achieve better air movement, area of the opening can be calculated by using the below formula.

I.e. $A = \frac{Q}{EV}$ (source sp 41)

$$Q = EAV \qquad (2)$$

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Q = air flow in ft^3/min
A = free area of inlet openings in ft^2
V = wind velocity in ft/min
E = effectiveness of openings
= 0.5-0.6 perpendicular winds
= 0.25-0.35 diagonal winds
To find the required window size

$$A = \frac{613.22}{0.35 \times 9.8} = 178.77\text{sqft}$$

For one window 59.5 sq.ft
Existing window size is 17.8 sq.ft

5.2 Results

According to the study above, it is proven that the indoor thermal quality of the classroom is poor. Students are not satisfied with the thermal condition of the class room. The class room has poor ventilation and less air change than the recommended level. The above mentioned difficulties are creating health issues and affecting the learning capacity of the students. A thermal comfort field study in educational buildings conducted revealed the following:

(1) Higher comfort temperatures are successfully may obtain through resizing the openings.
(2) The students are comfortable at much higher indoor temperatures than those specified in the standards (NBC, 2005),
(3) The air movement preference varied with temperature, while humidity had a little effect on the air movement preference.
(4) The classroom cannot achieve proper indoor air velocity through the current position and sizing of the window.

These findings recommends some design approach to keep the class room environment in a better way and call for the development of thermal comfort standards custom-made to Indian subjects and climates.

6. CONCLUSION

According to the study above, it is proven that the indoor thermal quality of the classroom is poor. Students are not satisfied with the thermal condition of the class room. The class room has meagre ventilation and less air change than the recommended level. Also, the above mentioned difficulties are creating health issues and affecting the learning capacity of the students. Air movement can decrease the discomfort caused by thermal sources. This can be achieved through various parameters increasing the window size is one of the method used in this paper.

A thermal comfort field study in educational buildings conducted revealed the following:

(1) Higher comfort temperatures are successfully may obtain through resizing the openings.
(2) The students are comfortable at much higher indoor temperatures than those specified in the standards (NBC, 2005),
(3) The air movement preference varied with temperature, while humidity had a little effect on the air movement preference.
(4) The classroom can't achieve proper indoor air velocity through the current position and sizing of the window.

These findings recommends some design approach to keep the class room environment in a better way and call for the development of thermal comfort standards custom-made to Indian climatic regions.

The following recommendations could help to create good thermal quality inside a classroom.

1. Building location and orientation.
2. Building form and dimensions
3. Indoor partitions and layout
4. Window typologies,
5. Operation, location, and shapes
6. Other aperture types (doors)
7. Construction methods and detailing (infiltration)
8. External elements (walls, screens).

The other recommendations given by National Institute of Building Science are Maximize wind-induced ventilation by siting the ridge of a building perpendicular to the summer winds, Widths of naturally ventilated zone should be narrow (max 13.7 m [45 feet),Each room should have two separate supply and exhaust openings. Locate exhaust high above inlet to maximize stack effect. Orient windows across the room and offset from each other to maximize mixing within the room while minimizing the obstructions to airflow within the room. Window openings should be operable by the occupants. These recommendations also can be followed to achieve thermal comfort.

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