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Influence of Air Movement Preference on Thermal Comfort in Naturally Ventilated Classrooms of India

Nagaraju Kaja* and Dr. Ramesh Srikonda

Department of Architecture, School of Planning and Architecture, Vijayawada 520008, India;
nagaraju.kaja@spav.ac.in, ramesh.srikonda@spav.ac.in

Abstract

Background and objectives: Thermal comfort is very essential for a comfortable stay in any indoor space. Comfort conditions of indoor spaces are influenced by parameters like air movement, humidity, air temperature, etc. The aim of this research is to assess the air movement preferences by the occupants in classrooms of the selected higher education institutes in hot humid climate of India. **Methods/statistical analysis**: Surveys were conducted in all the three seasons of the year as per ASHRAE standard procedures. Environmental variables were measured in classrooms while questionnaires were distributed to the occupants simultaneously. A total of 361 students were surveyed with 1444 data sets for the whole year. **Findings**: Outdoor (T_{out}) temperatures were recorded and regression analysis has been done to find the relationship between the mean outdoor temperatures with the indoor operative temperatures (T_{op}) recorded. The acceptance of air movement in classrooms during summer is 10–15.4%, in moderate season it is 5.6–30% and during winter it is up to 58%. **Improvements/application**: This study enables to understand the influence of air movement preference on occupant's thermal comfort in classrooms of hot and humid climate of India. This will help in creating a comfortable environment in classrooms of higher education through placement and designing of openings for increased air movement thereby improving the thermal comfort conditions. This research assessed the movement of air in the classrooms of higher education and the occupants air movement preference for thermal comfort. This study is a starting point for the adaptive thermal comfort research in hot and humid climate of Vijayawada region.

Keywords: Thermal Comfort, Air Movement Preference, Naturally Ventilated Classrooms, Environmental Factors

1. Introduction

Buildings are designed for human activity and are as per user's requirements, needs, and aspirations. A good thermal environment is essential for human wellness and comfort.[1] Increasingly, more building research has been done considering people's participation, behaviour adjustment, and their subjective psychological specifics.[2] The condition of the mind that expresses satisfaction with the thermal environment.[3] A happy thermal environment around keeps people healthy both physically and psychologically. Comfortable environment is a situation where an individual shall not feel too cold or hot in the surrounding thermal environment having adequate air movement and lighting.[4] Subjective parameters like climate, age, sex, health and objective parameters like air temperature and speed, relative humidity, radiant temperature of the bodies which are in proximity shall also impact the thermal comfort.[5] Researchers like Mendell and Heath, Wyon proved through research that the higher air temperatures in the learning atmosphere can impact the performance of the occupant's negatively.[6,7] Same time low ventilation rates can cause respiratory symptoms and reducing concentration levels in indoors.[8] The interactions between occupant and immediate environment in a naturally ventilated building are much more dynamic and the occupant's behavioural, physiological, and psychological adaptations are wider compared to conditioned buildings[9] Air movement is one of the most important environmental variables which can impact the thermal comfort conditions in a space.[10–17]

**Author for correspondence*

Naturally ventilated buildings can provide comfortable living in all the seasons yet still uses less energy when compared to air-conditioned buildings.[18,19] Indian building stock consists of naturally ventilated buildings or partially air-conditioned buildings mostly. From time, immemorial, naturally ventilated buildings are considered comfortable by common people in India. But designing naturally ventilated buildings with good thermal conditions is all the more difficult task than similar but air-conditioned building owing to stringent requirement of meeting thermal comfort for minimum of 80% of occupants for 90% of occupied hours and narrow thermal comfort band as per the international standards ASHRAE 55.[20] Design and use of naturally ventilated buildings, if propagated can provide comfortable thermal environment for better occupant wellbeing and also for reduced carbon footprint. But in the context of no available comfort standards for buildings in India, people are adopting to easy solution of converting the spaces to conditioning increasing the energy consumption and carbon footprint. As per the standards ASHRAE,[21] the permissible air speed for warm climate is 0.2–1.50 m/s and this air velocity range do not unequivocally address the acceptability of air movement, but focuses mainly on the thermal comfort conditions of the space as a whole. Heat tolerance levels of students are higher and there are no specific standards for classrooms in India.[22] Recently, it has widely seen that people are using air conditioning systems widely, increasing energy consumption and thereby carbon footprint. The results of thermal comfort studies help in the formulation of thermal comfort standards enhancing the existing Indian building codes[23] as shown in Figure 1.

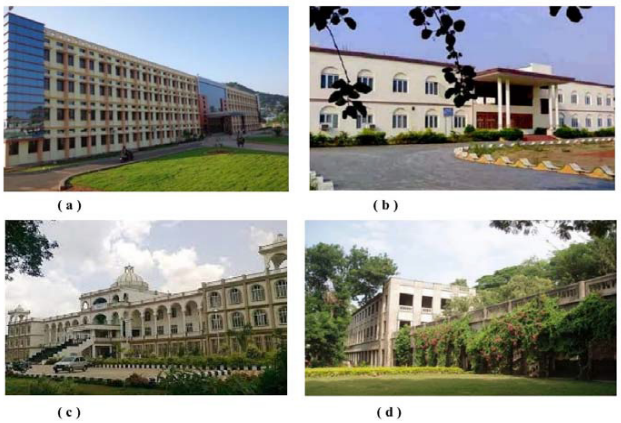


Figure 1. Investigated institute buildings (a) ALIET (b) SIHM&CT (c) VSRCE, and (d) ALC-PG (Source: author).

2. Environmental Factors Affecting Thermal Comfort

As listed by[24] in his research works, the below environmental variables influence thermal comfort:

2.1. Air Temperature

It is the temperature of the air surrounding a body.[4] It is usually given in degrees Celsius (°C). It is an important environmental variable which affects thermal comfort. Air freshness and suitable temperature are the most important variables required for built environment.[25]

2.2. Radiant Temperature

The temperature around an occupant, including the thermal radiation emitted from any equipment, sky and surrounding surfaces around it. Mean radiant temperature (MRT) is measured by globe thermometer. MRT may be calculated by using air temperature (T_a) with the following equation: $MRT = 0.99T_a\text{-}0.01$ ($R^2 = 0.99$).[26]

2.3. Air Velocity

An average of the instantaneous air velocity over an interval of time.[2] It is the speed of air moving across the occupants of an area and may help cool them if the air is cooler than the environment. Air velocity is an important factor influencing the thermal comfort. More the air, the occupants may feel comfortable.

2.4. Relative Humidity

As per ASHRAE, it is "the ratio of the partial pressure (or density) of the water vapor in the air to the saturation pressure (or density) of water vapor at the same temperature and the same total pressure."[2] Other than the environmental factors, personal factors like clothing insulation, metabolic rate will also influence the thermal comfort of a space.

2.5. Operative Temperature (T_{op})

Operative temperature is an important factor influencing thermal comfort which is used by researchers in their researches. Operative temperature combines the impact of both air temperature and radiant temperature without air movement and relative humidity. The operative temperature can be considered by taking the average

of air temperature and mean radiant temperature if the occupants' metabolic rates are between 1.0 and 1.3 met, no direct sunlight into the space, average air velocity less than 0.2 m/s and the difference of average air temperature and MRT is not more than 4°C.[4,27] As per ASHRAE, 2013, average of air temperature may be considered as operative temperature when there are no radiant heating systems in the space and the weighted average U value of the external wall or window (U_w), satisfies the equation

$U_w < 50\ (t_{d,}I - t_{d,}e)$, where U_w = weighted average U value of the external wall or window (W/m^2 K),

$t_{d,}i$ = internal design temperature in °C

$t_{d,}e$ = external design temperature in °C and SHGC of window glass is not more than 0.48.

3. Methodology

Data were collected in the surveyed classrooms by using Testo 480 of size of 81 mm × 235 mm × 39 mm, 1.8 GB internal memory with humidity probe and a globe thermometer constructed by the researcher using a 110 mm plastic ball painted with matt black and by inserting mercury in glass thermometer inside. The equipment used for the survey is presented in Figure 2 and the ranges and other technical detail of the instrument below is described in Table 1. Air velocity, air temperature, and relative humidity were recorded by placing the instrument at a height of 1.1 m from the finished floor level. A questionnaire based on ASHRAE 55[3] adaptive comfort guidelines was used to get the responses from the students in each class.

3.1. Climate

Vijayawada is located on the banks of river Krishna in the state of Andhra Pradesh in southern part of India. The new capital of Andhra Pradesh "Amaravathi" is located 30 km from Vijayawada. It is located at 16.5193°N 80.6305°E and has an altitude of 11 m (36 ft.). The climate of Vijayawada city is warm-humid with hotter summer seasons and monsoons with a higher percentage of humidity. Temperatures can go up to 48 °C (118 °F) during May–June and winter temperatures from 18.8 to 25 °C. The average humidity is 78%, and it will cross 80% during moderate (monsoon) seasons. The average annual rainfall is 977.9 millimetres (36 inches) and Southwest and Northeast monsoon gets the rainfall. Climate data[28] of Vijayawada are presented in Table 2.

Table 1. Different parameters of the instrument

S. no	Parameter	Temp	Humidity	Velocity
1	Measurement range	−100 to +400 °C	0 to 100% RH	0 to +20 m/s
2	Accuracy	± (0.5 °F + 0.1% of mv)		
3	Resolution	0.01 °F/0.01 °C	0.1% RH	1.97 fpm/0.01 m/s

Testo 480 & Temp with Humidity Probe & Globe thermometer

Figure 2. Instruments used for the survey.

Table 2. Climate data of study area (Vijayawada)

Month	Temperature in °C			RH (%)	Air velocity in m/s	Precipitation in mm
	Min	Max	Average			
January	18.9	30.1	24.5	76	1.39	1
February	20.1	32.8	26.4	76	1.67	4
March	22.6	35.4	29	75	1.94	5
April	25.8	37.5	31.6	73	2.5	15
May	27.9	39.6	33.7	67	2.78	71
June	27.4	37.5	32.4	67	2.78	136
July	25.4	32.9	29.1	74	2.5	250
August	25.2	32.4	28.8	77	2.22	197
September	25.2	32.6	28.9	79	1.67	164
October	24.2	31.8	28	81	1.67	169
November	20.9	30.4	25.6	78	1.94	45
December	18.8	29.5	24.1	75	1.67	10

Climate data table made based on the data accessed at http://www.Climate-data.org/asia/india/andhra-pradesh/vijayawada-715084/#temperature-graph, Data accessed: 30/09/19.

3.2. Case Study Areas

The classrooms of four higher education institutes were selected from the city and surroundings were representing the wider cross-section of the graduate students studying in these institutions of the region. The field studies include subjective surveys of the occupants and recording the physical measurements and the environmental variables like air temperature and humidity, etc. in the classrooms. The surveys were conducted for the period of a year during 2017–18.

The **Andhra Loyola institute of Engineering and Technology (ALIET)** is an old institution offering various courses at Bachelors and master's level in Engineering. Siddhartha Institute of Hotel Management and catering Technology **(SIHM&CT)** offers courses in hotel Management and situated as part of a 33-acre campus in a prime locality of Vijayawada. College of Architecture and Planning (**ANU CAP)** is located inside the Acharya Nagarjuna University campus and 25 km from Vijayawada on National highway. **Andhra Loyola college for Post Graduate studies (ALC-PG)** is a part of Andhra Loyola Campus which is one of the premier institutions in Vijayawada and runs various departments with at UG and PG level.

3.3. Data Collection

3.3.1. Physical Measurements of the Study Areas

Case study surveys were conducted by taking physical measurements in the classrooms of the selected institutions and the perceptions of the occupants through questionnaire survey. Both the surveys were conducted simultaneously during the field visits. The floor plans of the surveyed classrooms are presented in Figure 3.

Measured environmental variables of all the case studies are presented in Table 3. The mean air velocity across all the study areas during summer is 0.31 m/s, for moderate season it is 0.18 and during winter it is 0.23 m/s. The mean outdoor temperatures recorded during the surveys are 32.9 °C during summer, 28.9 °C during moderate season, and 26.1 °C during winter. Recorded mean relative humidity (RH) in the classrooms are 56% during summer, 58.6% during moderate season, and 63.9% during winter.

3.3.2. Subjective Survey of the Occupants

A questionnaire was prepared as per ASHRAE 55 standard[28] and issued to students for giving their input about the questions which is divided in two sections (i) Personal information like gender, age, height and weight, etc and (ii) Questions about occupants' perceptions about the indoor environment. Subjects are all of the graduate

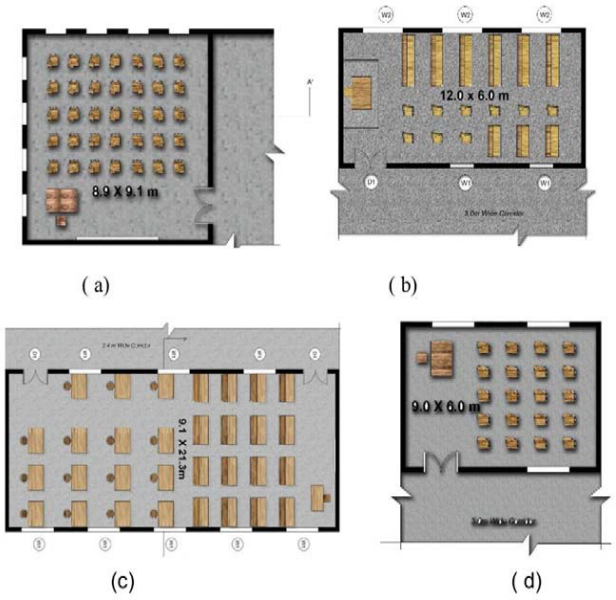


Figure 3. Acceptability of air movement in classrooms of study areas on ASHRAE scale.

Table 3. Measured environmntal variables of the study areas

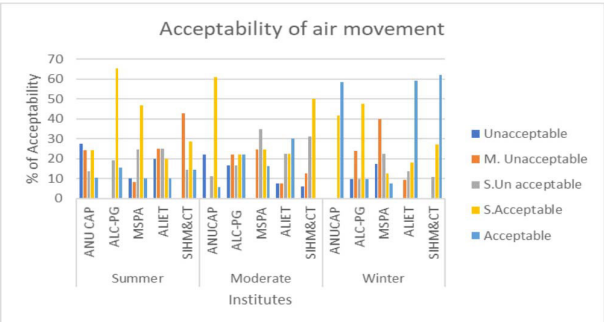
Season	Institute	T_{op}	RH	Air speed	T_a	T_{out}
Summer	ANU CAP	33.4	56.4	0.32	32.3	33.9
	ALIET	33.5	61.3	0.48	32.5	33.3
	MSPA	34.4	55.6	0.14	34	32.2
	ALC-PG	35	51.2	0.18	34.3	35.2
	SIHM&CT	34.3	55.5	0.42	33.2	30
Moderate	ANU CAP	31.2	57	0.24	30.8	28.3
	ALIET	30.8	54	0.21	30.5	31.2
	MSPA	31.75	71.3	0.11	31	27.8
	ALC-PG	30.42	55	0.18	30.2	28.3
	SIHM&CT	30.7	55.9	0.15	29.8	28.9
Winter	ANU CAP	27.12	61	0.28	26.8	24.4
	ALIET	26.56	63.5	0.19	26.2	30.1
	MSPA	26.95	68	0.28	25.3	23.9
	ALC-PG	28.45	65	0.22	28.3	25.6
	SIHM&CT	27.6	62	0.2	28.3	26.7

students in the age group of 20–24 old and the metabolic value is considered as 1.2 since all the occupants are engaged in sedentary activities like writing, listening, etc. in the classrooms. Surveys were conducted four times in a day between 9 AM and 5 PM during the field visits. In total, 1444 questionnaires were collected from 361 students through the surveys conducted in summer, moderate season, and winter across the classrooms of selected institutes of higher learning. Questions were asked on a seven-point scale about the acceptance of air movement in classrooms described as "unacceptable", "moderately unacceptable", "slightly unacceptable", "slightly acceptable", "moderately acceptable", and "acceptable". Preference of air movement was asked on a three-point scale as described as "more", "less", and "no change". Subjective questionnaires were distributed to the participants well before the start of the survey and occupants were explained about the purpose and objectives of the research study.

4. Results and Discussion

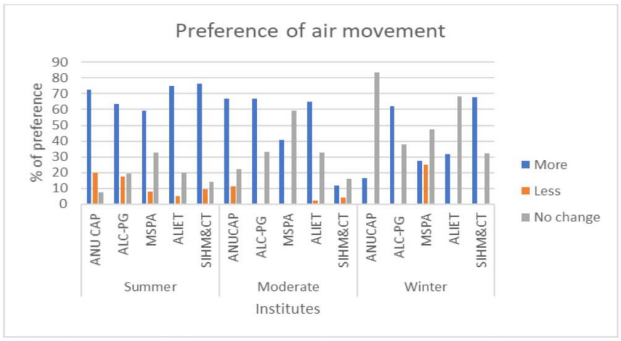
Surveys conducted for a year during summer, moderate season, and winter during 2017–18 and the results are presented in Figures 4 and 5. Figure 4 presents the percentage of the acceptability of the occupants about the environmental conditions in the classroom on a five-point scale, and Figure 5 presents the percentage of occupants' preference about the prevailing air movement in the classrooms.

During summer in ANU CAP, 27.6% not accepted the air movement and 10.4% only accepted it. In ALC PG, 15.4% accepted it and 65.4% slightly accepted it. In MSPA, 10.2% not accepted and 10.2% accepted the air movement. In ALIET, acceptance of air movement is 10% and 20% of the occupants have not accepted the same. In SIHM&CT, acceptance of air movement is 14.3% and 42.8% of the occupants mostly unaccepted the air movement in the classroom. During moderate season, in ANU CAP, acceptance of air movement is 5.6% and 22.2% of the occupants have not accepted it. In ALC PG, 16.7% not accepted it and 22.2% accepted it. In MSPA, 16.3% of occupants accepted air movement. In ALIET, 30% accepted it and 7.5% not accepted the air movement. In SIHM&CT, 50.0% of the occupants slightly accepted the air movement and 6.2% not accepted it in the classroom. During winter months in ANU CAP, acceptance of air movement is 58.3%. In ALC PG, acceptance of air movement is 9.6% and 9.5% not accepted it. In MSPA, acceptance of air movement is 7.5% and 17.5% of the occupants have not accepted it. In ALIET, acceptance of air movement is 59% and in SIHM&CT it is 62.2%. During the survey, it was observed that even though the mean air velocity is 0.31 m/s during summer, mean of percentage of not accepting the air movement is 37.8% across all the institutes. We can understand with this that students were voting based on their perceptions than the actual physical measurement of the air velocity. In Figure 4, in ANU CAP, during summer 72.4% of the occupants preferred more air movement, in moderate season, 66.7% and during winter it is 16.7%. In ALC-PG, during summer 63.5% of the occupants preferred more air movement, in moderate season, 66.7% and during winter it is 61.9%. In MSPA, during summer 59.2% of



% of occupant's acceptability of Air movement in class rooms of surveyed Institutional Buildings

Figure 4. Acceptability of air movement in classrooms of study areas on ASHRAE scale.



% of occupant's preference of Air movement in classrooms of surveyed Institutional Buildings

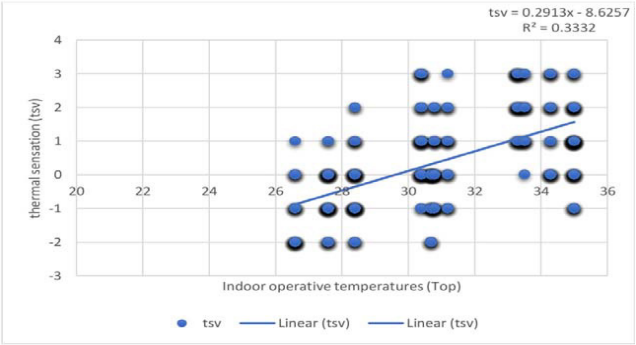
Figure 5. Preference of air movement in classrooms of study areas on ASHRAE scale.

the occupants preferred more air movement, in moderate season, 40.8% and during winter it is 27.5%. In ALIET, during summer 75% of the occupants preferred more air movement, in moderate season, 65% and during winter it is 31.8%. In SIHM&CT, during summer 76.2% of the occupants preferred more air movement, in moderate season, 12% and during winter it is 67.6%.

4.1. Relation Between Recorded Operative Temperatures (T_{op}) and Thermal Sensation of the Occupants (tsv)

Indoor operative temperatures were recorded during the field studies in all the study areas. The cross-tabulation of indoor operative temperature (T_{op}) and thermal sensation votes (tsv) obtained through questionnaire are presented in Table 4.

To calculate the relation between the measured thermal sensation of the occupants and the recorded indoor operative temperatures (T_{op}), linear regression analysis has been done. The results of the regression analysis are presented in Figure 6. Through the regression analysis between thermal sensation of the occupants and the recorded indoor operative temperatures, the correlation found is **tsv = 0.2913 T_{op} – 8.6257 (correlation coefficient R^2 = 0.3332, $p < 0.01$)**



Regression analysis between recorded thermal sensation of occupants and operative temperatures recorded (T_{op}) of classrooms

Figure 6. Regression between thermal sensation of occupants and top of classrooms.

It shows that there is a correlation exists between the indoor operative temperature and thermal sensation of the occupants in the studied population.

4.2. Relation Between Air Movement Preference and Thermal Comfort

From the analysis presented in Figure 7, it is observed that 100% of the occupants who have voted thermal sensation as hot (+3), 98% of the occupants who voted for

Table 4. Cross-tabulation of indoor operative temperature (Top) and thermal sensation votes (tsv)

Institute	T_{op}	Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot
Summer								
ANU CAP	33.36	0	0	0	0	24.1	34.5	41.4
ALC-PG	35	0	0	9.6	15.4	42.3	25	7.7
ALIET	33.54	0	0	0	5	40	40	15
SIHM&CT	34.31	0	0	0	38	14.4	23.8	23.8
SPAV	31.5	0	0	0	16.4	23.3	23.3	37
Moderate season								
ANUCAP	31.2	0	0	22.2	22.2	33.3	16.7	5.6
ALC-PG	30.42	0	0	27.8	27.8	16.7	11	16.7
ALIET	30.8	0	0	28.6	32.1	25	14.3	0
SIHM&CT	30.7	0	0	25	62.5	12.5	0	0
VRSEC	30.6	0	12.5	12.5	50	25	0	0
Winter								
ANUCAP	28.12	0	20.8	41.7	37.5	0	0	0
ALC-PG	28.45	0	0	14.3	47.6	23.8	10.5	0
ALIET	26.56	0	50	27.3	18.2	4.5	0	0
SIHM&CT	27.6	0	13.5	40.5	40.5	5.5	0	0

warm (+2), and 73.3% of the occupants voted for slightly warm (+1) also preferred for more air movement in the classroom. The percentage of the occupants preferred for more air movement has gradually reduced towards cooler sensation from hot sensation. 54.5% of the occupants voted for neutral (0) on thermal sensation also voted for more air movement and 42.7% voted for no change in the air movement. 36% of the occupants voted for slightly cool (−1) on thermal sensation also preferred for more air movement and 46.7% voted for slightly cool (−1) preferred no change in air movement. 20.7% of the occupants voted for cool (−2) on thermal sensation also voted for more air movement and 68.9% voted for cool (−2) preferred for no change in air movement where as 10.3% voted for voted for cool (−2) also preferred for less air movement in the room.

In Figure 8, it is interpreted that 48.2% of the occupants who voted as accepted the thermal environment indoors also preferred for more air movement, 44.5% preferred no change in the air movement. 67% of the occupants wanted more air movement and preferred that the thermal environment in classroom not acceptable.

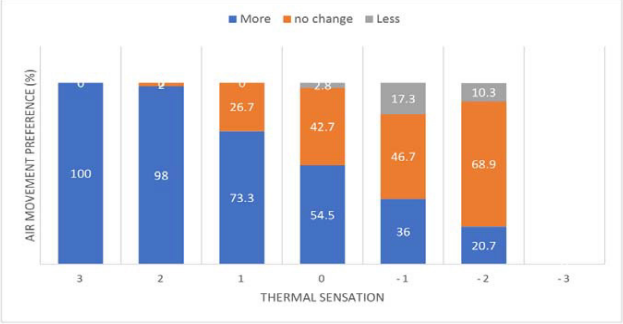


Figure 7. Distribution of air movement preference votes on thermal sensation scale.

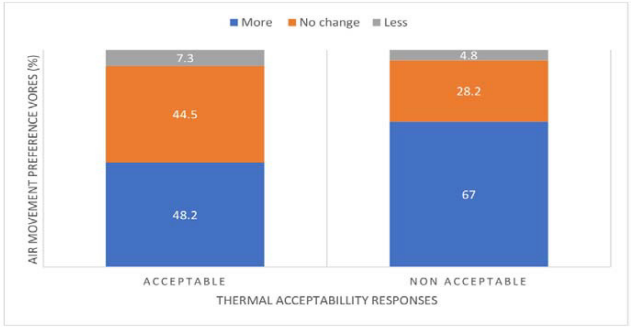


Figure 8. Distribution of air movement preference votes on thermal acceptability.

Interestingly, 28.2% of them preferred for no change in the air movement.

5. Conclusions

Subjective and objective surveys were conducted in the classrooms of the selected institutes of higher education in hot and humid climate of India to understand the air movement preferences of the occupants and the impact of air movement on the thermal comfort. The important findings are presented below:

- In the classrooms where research surveys were conducted, most of the occupants are not satisfied with the air movement in their classrooms in all the three seasons.
- The acceptance of air movement during winter season is good with 58% of acceptance and much lower in summer season with less than 16% acceptability.
- The air movement preference is not uniform in all the surveyed classrooms and this may be due to the location of the classrooms, placement of openings and its surroundings like trees, open areas, etc.
- Most of the occupants preferred more air movement in the classrooms than the prevailing conditions. Nearly 50% of the occupants who have accepted the thermal environment in classrooms have preferred for more air movement. Percentage of occupant's preferring for more air movement is 63.5–76.2% during summer, 12–66.7% during moderate season, and 16.7–67.6% during winter.
- It proves that the students in naturally ventilated classrooms of higher education in India are expecting more air movement than the prevailing conditions.
- It is important to note that this study provides a better understanding of the occupant behaviour in naturally ventilated classrooms. This will be useful in creating comfortable thermal conditions in naturally ventilated classrooms of higher education.

6. Limitations

The study is limited to assess the air movement preference and thermal comfort of the occupants. This study is focused on only on the impact of air movement preference and thermal comfort. The rest of the environmental variables and data from other questions are analysed separately.

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