

# Performance Evaluations and Comparison of Selected Addis Ababa Sub-city Administration Buildings in Terms of Thermal Comfort

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**Abstract** The office building thermal comfort is very important for occupant performance. This study investigates the thermal comfort performance of the naturally ventilated buildings of five selected Addis Ababa sub-city administration offices in different orientations. The objective of the study is to evaluate and compare the office building thermal performance in different orientations with the same thermal insulation materials. This research study is based on building users survey, field measurements, and secondary data review and analysis. The field study and survey were carried in the warmest month of the city May 2019 for a selected room of the case buildings. The field study and survey assessed the indoor air temperatures and relative humidity levels of selected five office building rooms, as the occupants completed questionnaires covering their thermal sensations and thermal preferences. The data obtained from the survey was analysed by SPSS and excel software and secondary data was analysed in a practical part through measurement from survey data collection. Results of field studies have shown that most of the occupants prefer a cooler environment and found their thermal environment not comfortable. The indoor temperature fluctuation of the buildings and the humidity level are within the allowable limits. But, sometimes the temperature levels overpass the acceptable range. The result also revealed that there is a difference in thermal performance between the buildings in different orientations. At the time of measurements building 'III' oriented towards North West perform better to occupants thermal environment compared to other buildings. Consequently, to improve the internal environment, additional appropriate passive design strategies are recommended.

**Keywords:** thermal performance, thermal comfort, natural ventilation, passive design

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## 1. Introduction

The sustainable building performance basic principle is to provide residents with a comfortable working and living environment while avoiding high energy consumption [1]. In buildings where people are staying the thermal comfort issue is very important [2]. The office building is one of the most known involving people occupancy especially the workers stay there for a lot of time.

The indoor thermal environment of buildings is strongly influenced by the design of enclosures and building orientation, especially for buildings with natural ventilation [3,4]. The effect of orientation is also one of the most important design variables upon the indoor temperature [5,6]. However, most conventional office concepts depend on a mechanical operation as the external design has poor connections to the indoor environment [7].

Now days there is incredible development of office building construction in Ethiopia, especially in the country's capital, Addis Ababa. And the building construction industry is expected to continue with large scale as the needs of it are high in the city and other part of the country. Those building developed in the city currently in large scale majorly use glass façade in their most parts, especially in the front side without consideration of the building orientation. However, as stated on the most research paper the glazed curtain walls, large windows on building façade and building orientations has the potential to increase the risks of overheating. The phenomenon of temperature rise probably questions the performance of existing and upcoming buildings in terms of occupants thermal comfort. So, it is necessary to evaluate the comfort level of those buildings to shape the future development.

The comfort range for most people (80%) as on ASHARE 55 standard to maintain thermal comfort the room temperature between 20°C to 26°C and humidity

level below 80% and no lower humidity limit while outdoor temperature 18°C [8]. According to ISO 7730 the allowable temperature ranges are 20°C-23°C and 24°C-26°C in winter and summer time respectively, and relative humidity is set between 70% and 30% both in summer and wintertime [9]. Temperature fluctuations in room temperature with time also can affect the thermal comfort of the occupants. So, the permissible limit values for temperature fluctuations of the cyclic operating temperature are 1.1°C and for drifts and ramps up to 3.3°C based on time [8].

The main objective of this study is to investigate the performance of selected Addis Ababa sub city office buildings in different orientation on occupants thermal comfort. This is helpful to recommend possible solutions for detected limitations and to suggest policy directives suitable for thermal comfort in the city.

## 2. Method of Study

### 2.1. The Case Building Description

The study were conducted on five selected typical office building in different orientation existed in Addis Ababa city, Ethiopia. The buildings are serving as

administrative building with seven floors in major part and eleven stories at central part of it. The building have a basement and typical floor plan (ground to G+7) with a central circulation area with open down goes up to G+11. And the finishing material is double glazed window, partition and door; block tiled for other parts of the wall (see Table 1). DSF has the ability to mitigate internal thermal conditions and reduce energy consumption [10]. From those building one room having the same direction and function were selected for study from first floor as on Figure 2.

### 2.2. Study Design (Type of Study)

This is a descriptive study where quantitative data are used to get an understanding of the thermal comfort performance of selected case building with different orientation of the same façade design and room space. The methods that are used as part of this descriptive research are surveys, comparison studies, observational studies, and case studies. Hence the research focuses on thermal comfort performance the buildings in different orientation.

The study focused on occupancy time and the worst orientation performances of the case building using Double Skin Façade (DSF) were identified by comparative analysis. The overall methods used for this study is as on Figure 1 below.

Table 1. Location of the case buildings and orientation

Building	Location	Orientation	Façade design material
I	It is located in Akaki kality sub city which is located in the Southern Part of Addis Ababa city at latitude of 8°53'50.43"N and longitude of 38°46'17.97"E	It oriented toward south west at an angel of 49° from horizontal(south) axis	Double glazed window and door and HCB wall with cement plaster as internal and Porcelain tile for external covering
II	It is located in Bole sub city which is in the Eastern Part of Addis Ababa city at latitude of 9° 1'6.20"N and longitude of 38°48'10.06"E	It oriented toward south west at an angel of 75° from horizontal(south) axis	Double glazed window and door and HCB wall with cement plaster as internal and Porcelain tile for external covering
III	It is located in Gulale sub city which is located in the Northern Part of Addis Ababa city at latitude of 9° 3'32.65"N and longitude of 38°44'8.44"E	It oriented toward north west at an angel of 140° from horizontal(south) axis	Double glazed window and door and HCB wall with cement plaster as internal and Porcelain tile for external covering
IV	It is located in Kirkos sub city which is located in the central part of Addis Ababa city at latitude of 9° 0'37.53"N and longitude of 38°45'57.30"E	It oriented toward north west at an angel of 175° from horizontal (south) axis	Double glazed window and door and HCB wall with cement plaster as internal and Porcelain tile for external covering
V	It is located in Yeka sub city which is located in the North east Part of Addis Ababa city at latitude of 9° 1'22.17"N and latitude of 38°48'2.15"E	It oriented toward south west at an angel of 31° from horizontal(south) axis	Double glazed window and door and HCB wall with cement plaster as internal and Porcelain tile for external covering

Source: extracted from Google earth map and site observation.

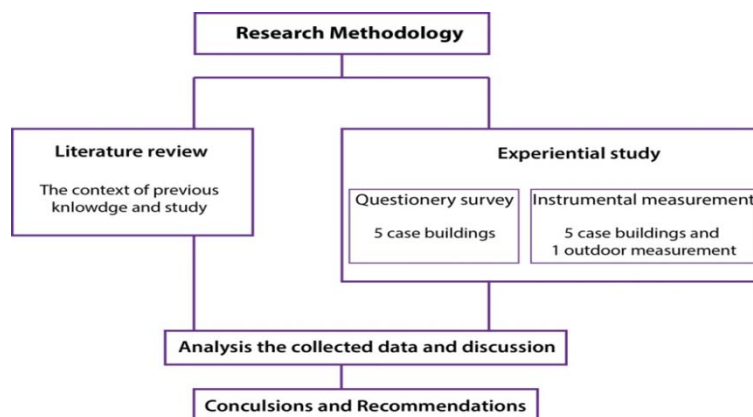


Figure 1. Research Methodology

For this study the researcher used several assumptions were formed based on the pilot study of the case building and literature. The personal factor affect thermal comfort (clothing and activity) assumed relatively the same or constant as all of the building occupants engage in similar activity and wear similar clothing factor. The main radiant temperature is also assumed to be very similar with air temperature as the building is well insulated buildings and the occupants in sedentary physical activity below or equal 1.1 met [11,12]. And this study conducted while the personal factor, building orientation and façade design and window state is a controlled factor.

### 2.3. Study Population and Sampling

The study population in this research is the occupant on the selected case building room for investigation. The case building room is selected based on the perimeter of equal size room and height, same function, same façade design and material in all building. To select the building rooms for the case study from the sampling frame the stratified random sampling method preferred. Based on the selection methods stated the rooms in first floor in one side of the front part of the building were selected for study as shown in Figure 2 below. The sampling was conducted from the selected case building room for occupant surveys is simple random sampling as each member of a population stands on a chosen room for case study has a chance to be selected.

The monitored offices were expected to be occupied during normal working hours as occupants were department secretary or administrative staff. To confirm this, occupants were observed for the first week of the measurement. This observation revealed that they typically stayed in their offices actively during normal working hours from 9:00 am- 12:00 am and 2:00 pm to 5:00 pm.

The study month selected based on the climate of the city. May is selected for this study as it is the most hottest and transitional month of the city. The studies were conducted from Monday May 13 to Friday May 17, 2019.

A total of 90 occupants from the total 117 occupants in the selected rooms were examined in five buildings.

### 2.4. Data Collection Methods and Instruments

To carefully investigate how the different orientation affects the thermal comfort in internal spaces, one typical office rooms were used in all five buildings to conduct measurements and user survey. The numerical results of actual measurement by tools called temperature-humidity meter (digital thermo hygrometer) to record the temperature and humidity variation during occupancy time at the same over the room selected were used. And the questionnaire surveys were also used to identify the occupants overall evaluation of indoor environmental conditions over the room. As in POE studies questionnaires are the most important part of any building evaluation study [13]. The secondary data was collected to cover the areas such as theoretical part and policy directives regarding the specific topic.

The survey aimed to record occupants perceived thermal comfort while there is no state change in clothing, activity and window state. The indoor thermal conditions were assessed by voting the thermal sensation, using the evaluation scale (ASHARE thermal sensation scale).

Thermal indoor environment variables were measured in order to assess compliance with ASHRAE Standard 55 requirements (2017), in particular temperatures and humidity. The same digital thermo hygrometer instruments were used for the measurement of temperature and humidity in the five buildings. The measurement were conducted during active working hour in controlled room (no window state change whereas all closed and without any curtain). The instruments temperature measurement accuracy is within ( $\pm 1^{\circ}\text{C}$ ) margin of error and humidity accuracy is within ( $\pm 5\%$ ) margin of error. The instruments were installed at heights (1.10 m) over a table in the center of room selected for study in each of five building, where it may be expected that the room average temperature. And the measurements were registered within 15 minute interval in active working hour whereas the outdoor temperature and humidity is also within 15 minute interval from nearest meteorology station.

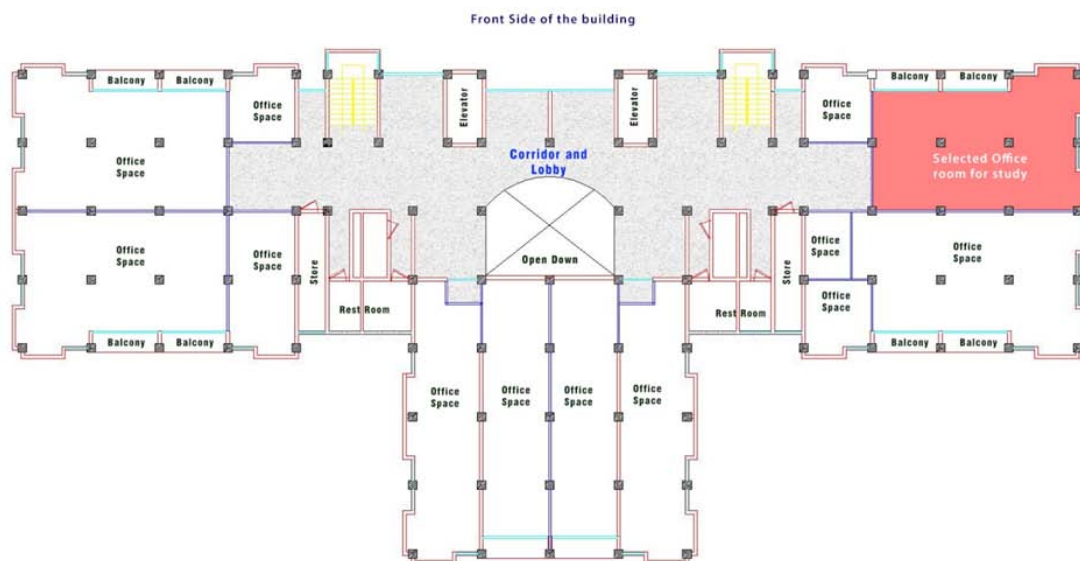


Figure 2. The typical first floor plan of the buildings and the office room selected for study

### 2.5. Data Analysis and Interpretation

The field measurements are analyzed through, indoor temperatures and humidity were averaged over each interval were used for data analysis. And the data collected from questionnaires are analyzed by SPSS and Excel software to investigate the relationship with measurement and thermal comfort sensation of occupants. Obtained data from the theoretical part was then analyzed in the practical part through measurements and observations. Indoor thermal environment parameters found in the building (air temperature and relative humidity) were compared with the comfort zone defined in ASHARE 55 Standard.

## 3. Analysis and Result

### 3.1. Thermal Preference

The thermal preference of the majority of occupants are cooler temperature by covering 70% and the warmer temperature shares low percentage by covering 11% of preference as shown in Figure 3 below.

### 3.2. Thermally Discomforted Time

The problem of thermal comfort is significant in afternoon session especially from 2:00 pm to 4:00 pm in all buildings by sharing 81% (refer Figure 4 and Table 2 below).

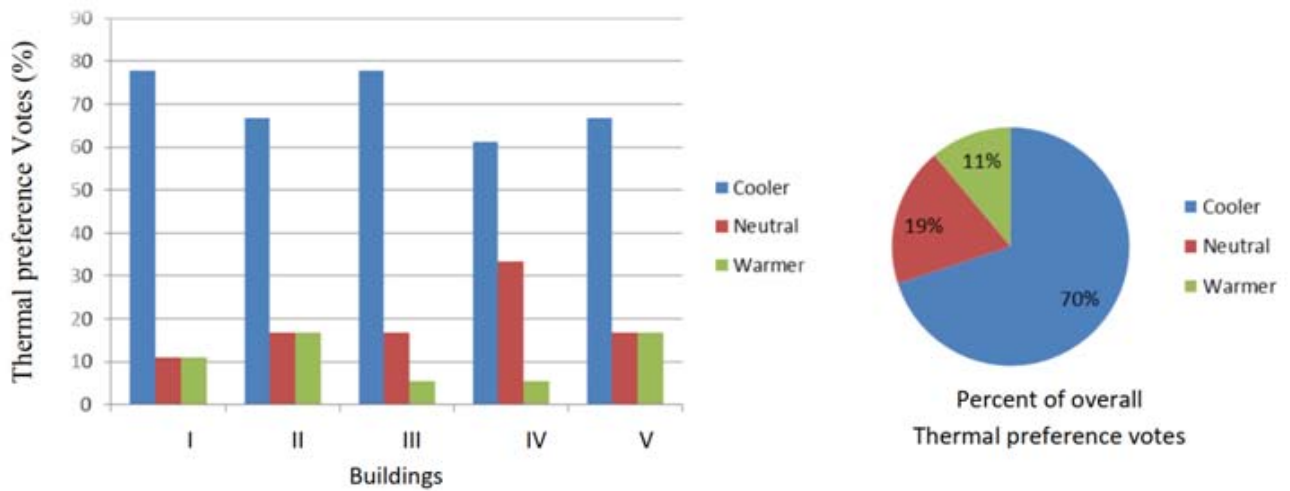


Figure 3. Thermal preference votes of the buildings

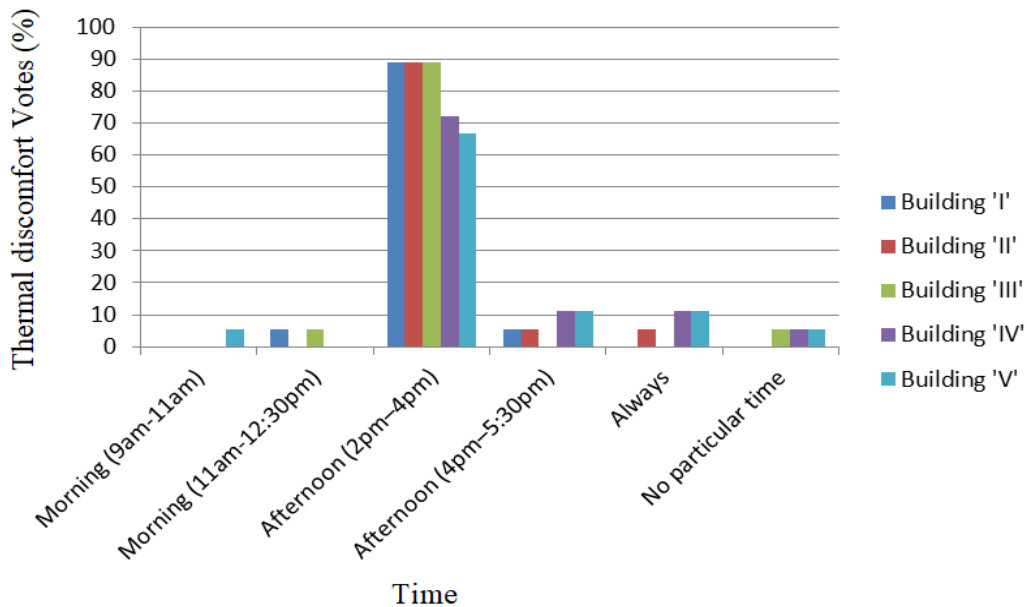


Figure 4. The problem of thermal comfort occurrence time frequency

Table 2. Overall thermally discomfort time of the day of all building

Time	Morning (9am-11:00am)	Morning (11:00am-12:30pm)	Afternoon (2pm-4:00pm)	Afternoon (4:00pm-5:30pm)	Always	No particular time
Percent	1.12 %	2.24 %	81.12 %	6.68%	5.56%	3.36%



### 3.3. Thermal Comfort Analysis

The thermal comfort response over all building shows about 33%, 28%, 12%, 12%, 11% and 4% of respondent where feel warm (+2), slightly warm (+1), hot (+3), neutral, slightly cool (-1) and cool (-3) respectively (see Table 3 below). The thermal comfort response on building II, V, & I respectively shows the worst performance descending. But, building III and IV performed better than others as building III accounts only 16.67% vote not comfortable and for building IV 38.89% voted not comfortable. Thus, more than 50% of the respondents are not comfortable which implies less performance as on ASHRAE Standard 55. When we look at those buildings performance based on occupants response on thermal comfort the building III performed better than other and the building II relatively very uncomfortable than others as shown on Figure 5 and Table 3 below.

### 3.4. Morning Temperature and Humidity

The morning average indoor temperatures of the buildings have great difference with the outdoor and the

building I have high temperature relative to others. The indoor relative humidity was high in building I and IV relative to other building in the morning (refer Figure 6). Whereas, the whole building indoor temperature fluctuation was within allowable limit and the humidity range in all building was within allowable limit as on ASHARE 55. The average indoor temperature was within acceptable limit of ISO 7730 and ASHARE 55 except in building I and II.

### 3.5. Afternoon Temperature and Humidity

The average afternoon indoor temperature building 'I', 'II', 'V', 'IV' and 'III' respectively high to low and the performance level was from worst to good respectively (refer Figure 7). But, there is no significant difference in relative humidity. The outdoor humidity in day three and day five high because of the air condition of this two day was humid and light rainy but, the effect was not significant in indoor temperature. Except building 'IV' and 'III' the others was not within allowable limit of indoor temperature as on ISO 7730.

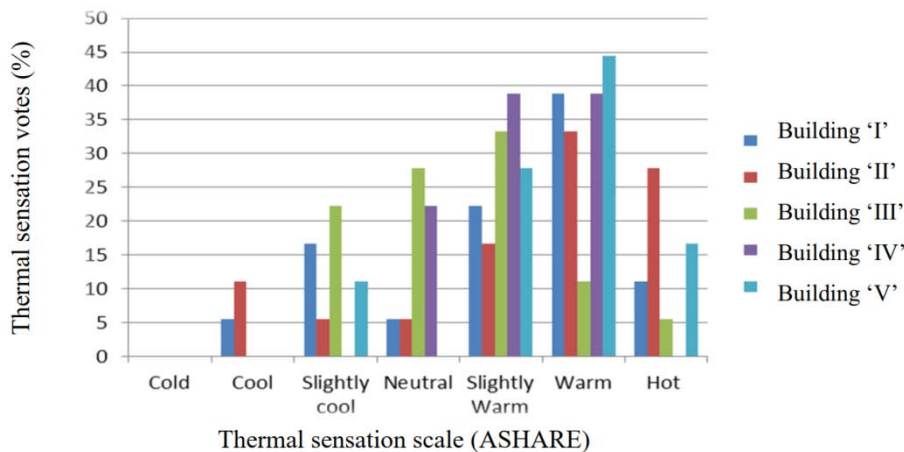


Figure 5. Overall Thermal sensation votes of occupants

Table 3. Overall percent of thermal comfort level of all buildings

Building	Cool (-2)	Slightly cool (-1)	Neutral (0)	Slightly warm (+1)	Warm (+2)	Hot (+3)
Building 'I'	5.56 %	16.67 %	5.56 %	22.22 %	38.89 %	11.11 %
Building 'II'	11.11 %	5.56 %	5.56 %	16.67 %	33.33 %	27.78 %
Building 'III'	0	22.22 %	27.78 %	33.33 %	11.11 %	5.56 %
Building 'IV'	0	0	22.22 %	38.89 %	38.89 %	0
Building 'V'	0	11.11 %	0	27.78 %	44.44 %	16.67 %
Average	3.34 %	11.12 %	12.24 %	27.78 %	33.32 %	12.24 %

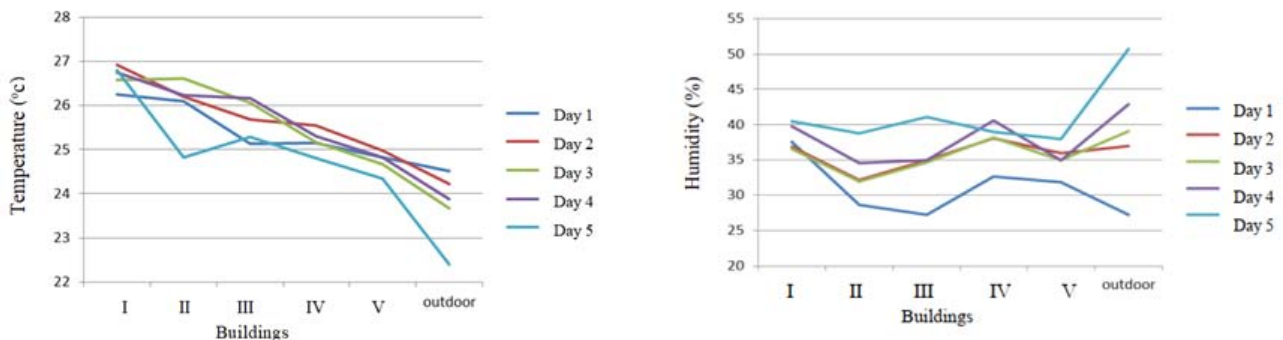


Figure 6. Indoor and outdoor morning temperature and humidity

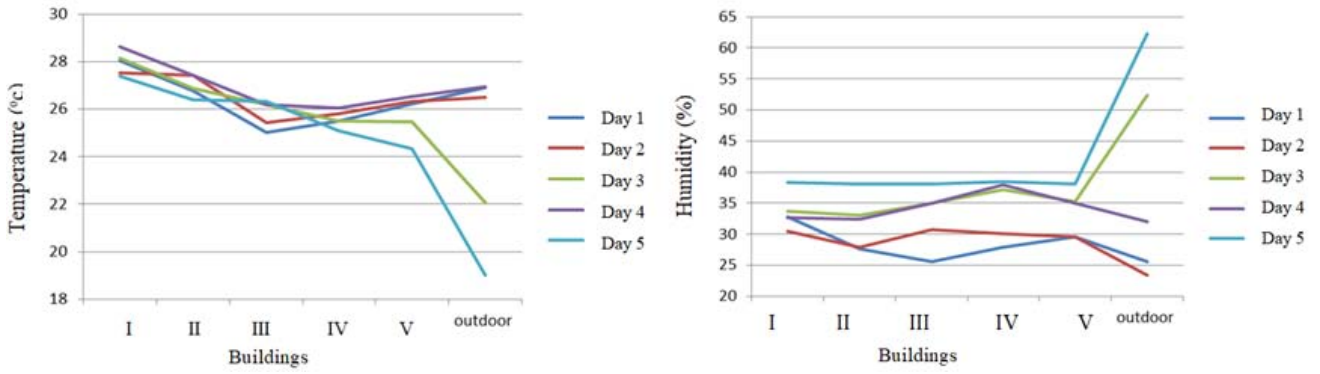


Figure 7. Indoor and outdoor afternoon temperature and humidity analysis

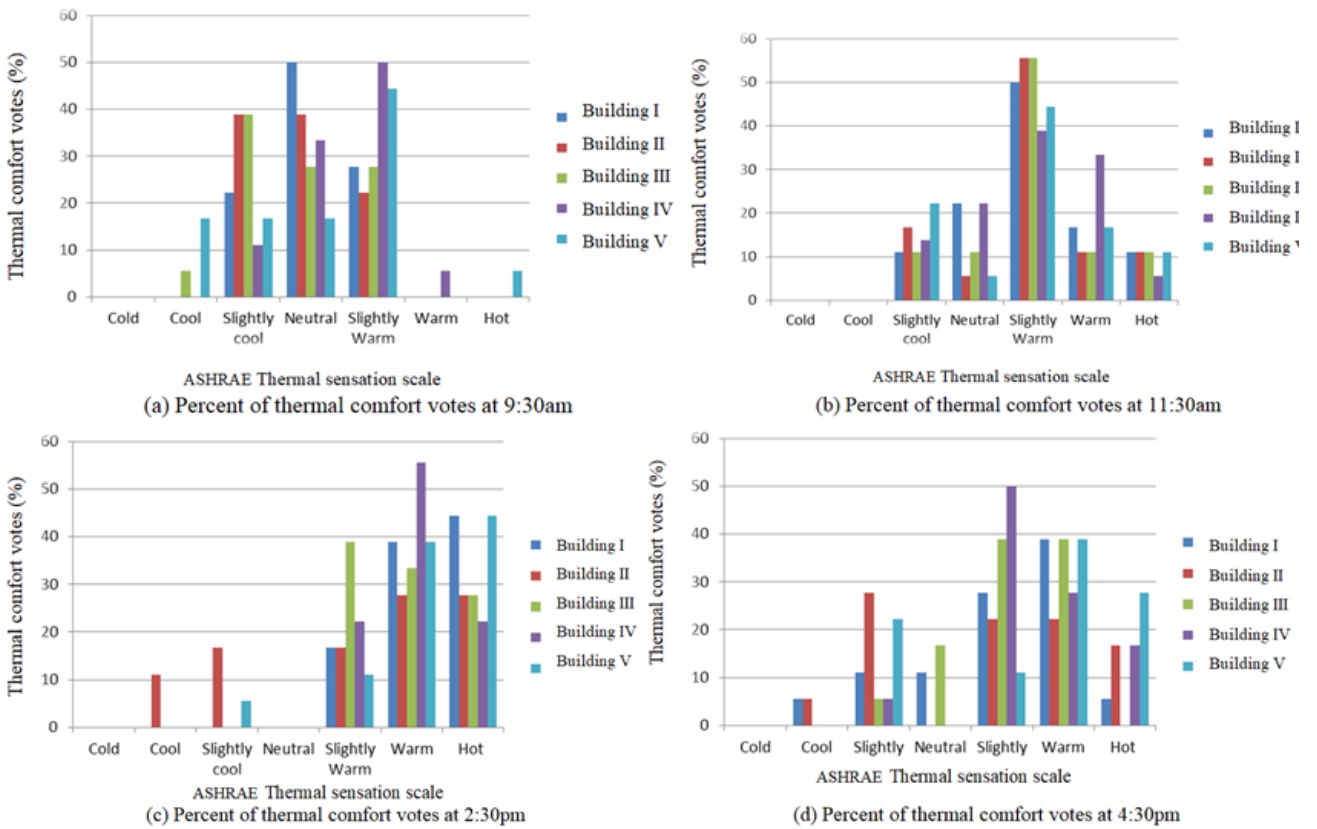


Figure 8. Temporal performance of the buildings in terms of thermal comfort

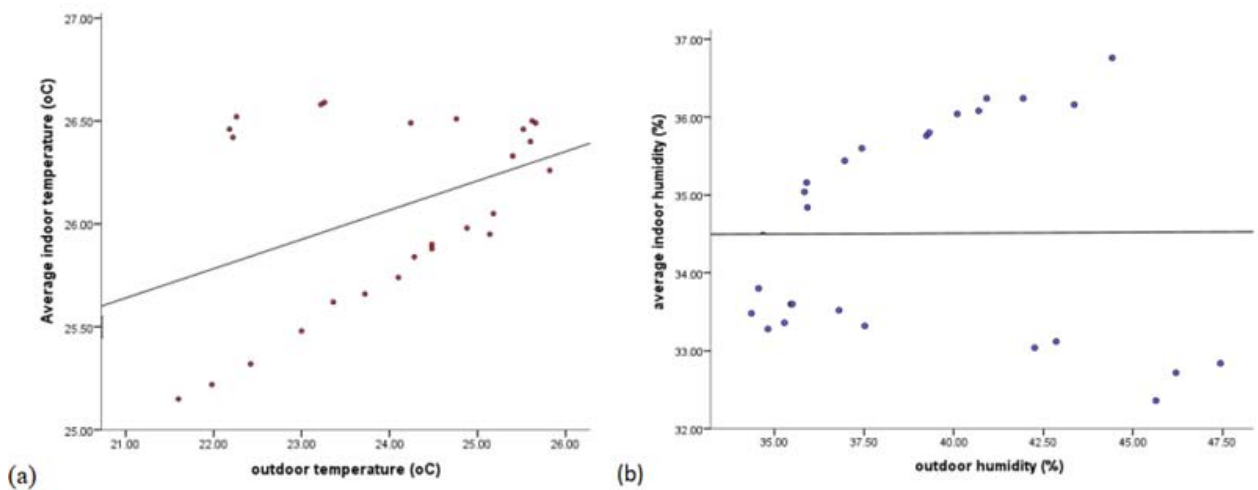


Figure 9. (a) Scatter plot of indoor and outdoor temperature and (b) Scatter plot of indoor and outdoor humidity

### 3.6. Temporarily Response of Thermal Comfort of the Building Occupant

The thermal sensation of the occupants in the all building was within comfort limit according ASHARE 55 at 9:30am in the morning. The degree of thermal discomfort increased with the time as that of temperature both indoor and outdoor in the morning. The most thermally uncomforted time in all building is afternoon at 2:30pm as shown on [Figure 8](#) and relatively decreased at 4:30pm. Based on the thermal sensation of occupants building 'III' performs better and building 'II' was the worst performed. In afternoon 2:30pm all building occupants complain the thermal environment.

### 3.7. Correlation between the Indoor and Outdoor Temperature and Humidity

There is no correlation between indoor and outdoor humidity level as the correlation coefficient obtained is nearest to zero (refer [Figure 9](#)). The correlation between indoor temperature and outdoor temperature in overall study building is low with correlation coefficient ( $\approx 0.42$ ). These low correlations are due to in well thermally insulated naturally ventilated buildings indoor thermal environment was not largely affected by varying outdoor conditions.

## 4. Conclusion

From the current study, using a series of field studies, including the assessments of thermal comfort and in situ measurement was carried out for one week in May 2019 to analyze the performance of the building, in terms of indoor thermal environments, as well as the thermal comfort of the occupants. The field studies and survey result showed that most of the inhabitants of the building found their thermal environment not to be comfortable especially during the afternoon season and the occupants favored to be in a cooler environment. Sometimes even when the indoor temperature was within the comfort band ( $<26^{\circ}\text{C}$ ) in some building the occupants was not feeling comfortable. This indicated that the occupants comfort temperature was different from the other world office building occupants and that the maximum comfort temperature band was lesser than the maximum range in ISO 7730 and ASHARE 55. Additionally, the thermal sensation survey result of occupants in all buildings shown that about 51% of the occupants replies fell into the three central classes of ASHARE scale (slightly cool to slightly warm) but, according to ASHARE 55 standard more than 80% should be in these categories to consider the indoor environment comfortable. Whereas, around 44%, 28%, 83%, 61% and 39% of the occupants in building I, II, III, IV, and V respectively thermal sensation fell into the central three categories ASHARE scale. The result reveals only building 'III' oriented towards North West indoor environment are comfortable as on ASHARE 55 acceptability limit for naturally ventilated building. In addition, around 77.78%, 66.67%, 77.8%, 61.11% and 66.67% of the occupants in building I, II, III, IV, and V respectively preferred a cooler indoor environment.

Generally based on this study analyses result the following main findings can be summarized as follows:

- The relative humidity of the whole building was within the acceptable limit as on ASHARE 55
- The temperature fluctuation of the whole building in both afternoon and morning season was within the allowable limit of ASHARE 55
- The thermal preference of the majority occupants were cooler (70%) and has a statistically significant effect on thermal sensation and thermal acceptability
- In the afternoon at 2:00-3:30 pm the thermal sensation of occupants in all buildings has a statistically significant effect on thermal comfort as it shows the thermal uncomfortable time which needs a remedial solution.
- The relationship between room temperature and thermal performance has a positive correlation. In other words, when there is an increase in the temperature values, the thermal discomfort values also increase and vice versa.
- Building III performs well than others in terms of thermal comfort and indoor thermal environment. So, the location and orientation of the building have an impact on thermal performance as many studies revealed.
- The study observed a weak correlation between indoor and outdoor temperatures in the collected data.

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