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Study on comfort temperature in autumn season of naturally ventilated office building in Kathmandu

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Abstract

Due to the direct connection between thermal comfort and worker productivity, the thermal environment quality of office buildings is important. Considering the impact of climate, geography, and surroundings, it is essential to establish thermal comfort guidelines to aid building designers to create a comfortable indoor thermal environment. As one of the metropolitan agglomerations in South East Asia with the quickest rate of growth, Kathmandu has seen significant changes in its land use and land cover, particularly in the commercial sector. In this context, the present study examines the comfort temperature in the autumn season of naturally ventilated office buildings of Kathmandu. For this, two naturally ventilated building has been selected. The questionnaire survey method has been used to measure thermal sensation with the help of slightly modified ASHRAE 7 point scale.. At the same time, the thermal environment (air temperature and relative humidity) has been measured. And then comfort temperature has been calculated from regression analysis and Griffiths' method. Regression analysis is also done to analyze the relation between thermal sensation vote and thermal preference. It has been found that thermal sensation vote is related to thermal preference. The comfort temperature of 25.7℃ and 25.4℃ has been identified from regression analysis and Griffith's method respectively for autumn season in naturally ventilated office building of Kathmandu.

Keywords

Comfort temperature, naturally ventilated, office building

1. Introduction

There has been a significant surge in study on indoor thermal comfort as people spends most of their time indoor. Thermal comfort is subjective, as indicated by the definition, "a condition of mind that expresses satisfaction with the thermal environment" [1]. The most frequent approach for creating thermal comfort conditions is subjective evaluation, which involves analyzing each occupant's thermal sensations, preferences, and physical and personal comfort features across a group of people in a field or a lab [1]. And this thermal environment is dependent upon the climate, geographical location, and built environment [2-5]. In order to help building designers to create a thermally suitable indoor environment for building occupants, there is a need for climate-specific thermal comfort guidelines [6-8]. Thermal comfort is directly related to human productivity [9-11]. As a result, thermal sensitivity is important in office building.

Thermal comfort research conducted in the field served as the foundation for the adaptive method [6]. Typically, two approaches are used to calculate the comfort temperature. Several studies have previously used the first approach linear regression method to calculate comfort temperatures. The regression equation analyzes the relationship between the indoor temperature and the thermal sensation votes (TSV).

The Griffiths' Method, which has been adopted by numerous studies [12-18], is the second way of estimating the comfort temperature. Several field studies have been conducted on adaptive thermal comfort in office buildings across the globe, such as in India, Japan, United States, Australia, and China. The findings proved that people might adapt to the environment since the comfort temperatures in hot climate zones were greater than those in cold climate zones and that in the same place, the comfort temperature in winter was lower than in summer [15, 17, 19-22]. In naturally ventilated buildings, a comfortable temperature ranges from 17.6°C to 31.2°C [8]. In 1978, Humphreys [23] also found the 17°C to 30°C comfort range. This suggests that naturally ventilated buildings have a greater variation in comfort temperature in different season.

The urban population of Nepal has increased at a 4.7 percent annual rate [24]. As one of the metropolitan agglomerations in South East Asia with the quickest rate of growth [25], Kathmandu has seen significant changes in its land use and land cover, particularly in the commercial sector. The Kathmandu Valley's built-up area increased by 211percent, from 38 square kilometers in 1990 to 119 square kilometers in 2012, while the percentage of mixed residential cum commercial building increased by 524 percent [26].

Several research in Japan, India, Singapore, Malaysia, Indonesia, and Singapore [12, 27-28] have looked at the comfort temperatures in office buildings. Thus yet, a few relevant research have been carried out in Nepal, but solely in the residential sector [29-30]. Various researcher has found that, Kathmandu being the temperate climate there is a need of active heating only in few months [31-32]. But nowadays, modern office buildings are fully equipped with HVAC load. So there is need of thermal comfort standards to optimize the HVAC load. In Nepal, building codes are only in terms of their safety which is first basic priority but not in terms of energy use. The stringent ASHRAE standard is followed by designers in the absence of regulation when creating fully air-conditioned (AC) buildings, which is leading over design and enormous energy use. Not a single research has been carried out on comfort temperature in office building of Kathmandu. Therefore, it is imperative to carry out the thermal comfort survey of office occupants and examine the thermal environment in order to provide the thermal comfort standard for office building. The main objective of this study is to find the actual comfort temperature in autumn season for office building in Kathmandu.

2. Methodology

This study lies within the post-positivist paradigm and hence uses the quantitative methods for the investigation. After literature review, two naturally ventilated buildings have been selected. From the occupants of that building, different variables have been collected. Questionnaire survey method has been used to measure the thermal sensation with the help of ASHRAE 7 point scale. At the same time the thermal environment (air temperature and relative humidity) has been measured. Then, by analyzing the data comfort temperature has been identified for the autumn season in Kathmandu.

2.1 Investigated buildings

The research was carried out in two naturally ventilated office buildings in Bishalnagar and Lazimpat, as illustrated in Figures 1 and 2, during the autumn season from 11 to 14th October 2022. Table 1 summarizes general information about the buildings. Both buildings were loadbearing with 350 mm thick wall and the study was done at the ground floor of the building.

Figure 1: Picture of investigated buildings and thermal comfort survey

Table 1: General information about the building

Building	Location	Main orientation	No. of votes
Office 1	Bishalnagar	North	30
Office 2	Lazimpat	South	21

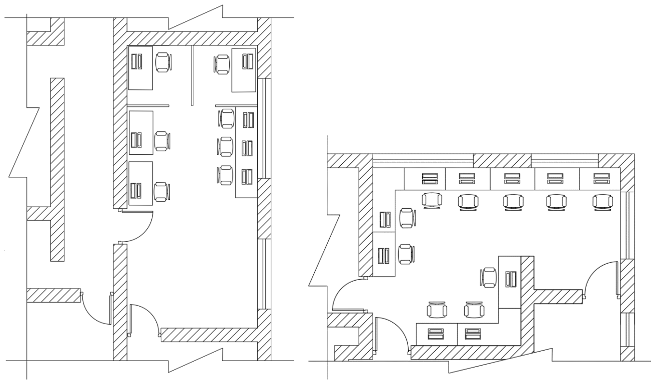

Figure 2: Floor plan of office 1 and 2

The HOBO data logger was used to measure the site's indoor air temperature and relative humidity. The equipment was positioned 1.1 meters above the ground. The data logger's air temperature and relative humidity accuracy are ±0.25ºC and ±5 percent respectively.

2.2 thermal comfort survey

The survey on thermal comfort employed here was adopted from earlier thermal comfort studies done through field studies by many researchers [4, 15, 33]. The thermal comfort survey questionnaires were given to the occupants on the day of the field measurements, and they were requested to fill them out and return them at the end of the measurements. As a result, occupant perceptions of their thermal environment on a 'right here-right-now' basis were collected. The slightly modified seven-point scale of ASHRAE standard [1], was used for the thermal sensation and five point scale was used for thermal preference in questionnaire survey as shown in Table 2 which was also used by many researchers [14, 15, 27] to get more accurate data.

Table 2: Scale used in survey

Scale	Thermal sensation	Thermal preference
1	Very cold	Much warmer
2	Cold	A bit warmer
3	Slightly cold	No change
4	Neutral	A bit cooler
5	Slightly hot	Much cooler
6	Hot	
7	Very hot	

3. Results and discussion

3.1 Indoor and outdoor thermal environment

In autumn season, the range of outdoor air temperature of Kathmandu is 7.8-27.5 degree centigrade [34, 36]. But in our study period, the mean outdoor temperature was 26.0 degree centigrade. Whereas, the mean indoor temperature was 25.5 degree centigrade and mean relative humidity was 64 percent.

3.2 Thermal sensation and preference vote

Using the information gathered from the survey, we have examined the thermal sensation vote (TSV) and thermal preference vote (TP). Out of total number of thermal sensation, 64 percent of vote was for neutral for given temperature while 18 percent vote was for slightly warm and slightly cold. For the same given thermal environment the percentage of no change has changed to 51 percent for thermal preferences. Which has been expressed as given Table 3 and Figures 3 and 4. The relation between thermal preference and thermal sensation vote is shown in Figure 5. We have obtained the following equation (1) for the relation between thermal preference and thermal sensation vote. Here we have found that thermal preference is related to thermal sensation vote, but some people preferred to shift from neutral to much warmer. It indicates that a neutral thermal sense does not ensure the occupant's thermal comfort, as the person may choose feelings different than neutral (e.g. while feeling neutral, the occupant yet likes a change). Various researchers [35, 36] said that thermal preference, rather than thermal sensation, is a more accurate indicator of thermal comfort.

$$\mathrm{TP} = 0.67\mathrm{TSV} + 0.4 (N = 51, R^2 = 0.33, S.E. = 0.137, p < 0.001) \quad (1)$$

Where,
TP = Thermal preference,
TSV = Thermal sensation vote,
N = Number of vote,
R^2 = Coefficient of determination,
S.E = Standard error of regression coefficient,
p = Significant level of regression coefficient

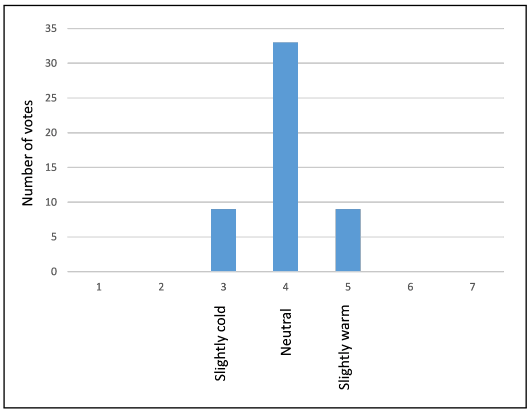

Figure 3: Distribution of number of votes for thermal sensation

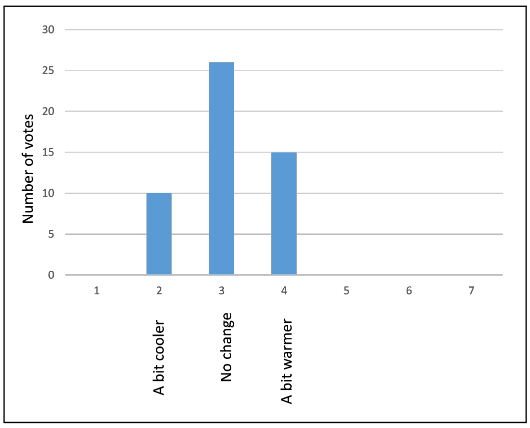

Figure 4: Distribution of number of votes for thermal preference

Table 3: Distribution of number of votes for thermal preference

Scale	Thermal sensation		Thermal preference	
	N	P (%)	N	P (%)
1	-	-	-	-
2	-	-	10	20
3	9	18	26	51
4	33	64	15	29
5	9	18	-	-
6	-	-	-	-
7	-	-	-	-
Total	51	100	51	100

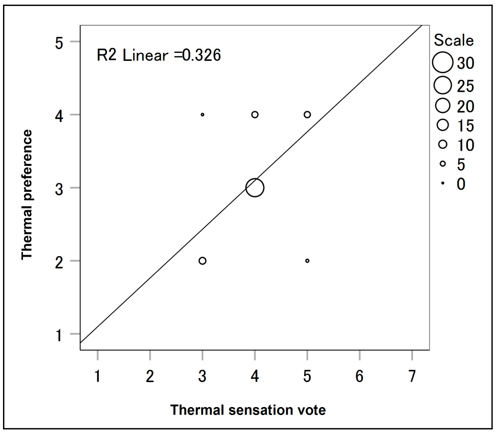

Figure 5: Relation between thermal preference and thermal sensation vote

3.3 Prediction of comfort temperature

One of the key outputs of thermal comfort field survey data analysis is comfort temperature. The comfort temperature is determined by the linear relationship between thermal sensation and the indoor temperature (Figure 6). The sensitivity of the subjects is evaluated by using the regression coefficient obtained from the regression analysis. We found the linear regression equation shown below (2).

$$\mathrm{TSV} = 0.23T_i - 1.9 (N = 51, R^2 = 0.13, S.E. = 0.086, p = 0.009) \quad (2)$$

Where,
TSV = Thermal sensation vote,
T_i = Indoor air temperature,
N = Number of vote,
R^2 = Coefficient of determination,
S.E = Standard error of regression coefficient,
p = Significant level of regression coefficient.

If we substitute "4. Neutral" in equation (2), the comfort temperature would be 25.7 degree centigrade. The regression coefficient in equation 2 is 0.23, meaning that 4.4 degree centigrade (=1/0.23) is required to change one thermal sensation vote. Few field studies [15, 17, 21] have regression coefficients below 0.2, meaning that a temperature change of more than 5 degree centigrade is required to change one thermal sensation vote. It appears unrealistic to use more than 5 degree centigrade to change one thermal sensation vote. According to Nicol et al. [38] and several studies [8, 18, 29], the linear regression approach can sometimes provide an extraneous value when the TSV is located far from the neutral point.

Table 4: Comfort temperature found in various studies for autumn season in naturally ventilated office building

Country/City	References	Mode	Period	Variable for Tc	To (°C)	Tg,Ta (°C)	Tc (°C)
This study	-	NV	Autumn	Ta	26.0	25.5	25.4
Japan /Yokohama, Tokyo	Damiati et al. [23]	FR	Autumn	Top	23.4	26.5	25.8
	Rijal et al. [15]		Autumn	Tg	17.9	24.8	24.9
India/ Chennai, Hyderabad	Indraganti et al. [28]	NV	Autumn	Tg	31.3	29.0	27.0
India/ Tezpur, Shillong	Singh et al. [37]	NV	Autumn	Tg	20.9	27.9	27.3

FR: Free Running, NV: Naturally ventilated, Tg: Globe temperature, Top: Operative temperature, Ta: Indoor air temperature

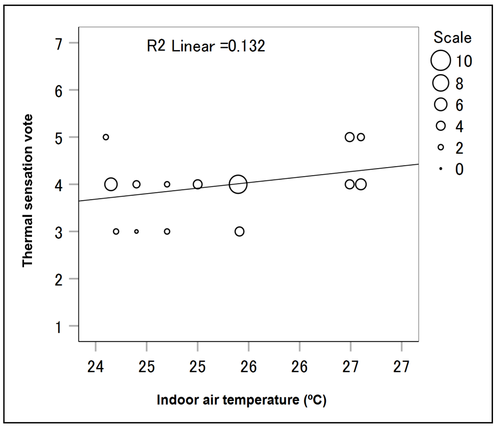

Figure 6: Relation between thermal sensation and indoor air temperature

We have also calculated the comfort temperature by using Griffiths' method [41]. Recently many researchers are using Griffiths' method to avoid the extraneous value from the regression analysis. Griffiths' approach can be very helpful when there is little temperature variation during the field survey and not enough data to do a successful regression to estimate the comfort temperature. Griffiths' comfort temperature (Tc) is estimated using the equation;

$$T_c = T_i + (4 - \text{TSV})/a \quad (3)$$

Where,
T_c = Comfort temperature,
a = Griffiths' constant,
T_i = Indoor air temperature,
TSV = Thermal sensation vote,
a = regression coefficient (0.50).

The regression coefficient 0.5 was adopted here, which was adopted by many researchers [15, 33, 42]. For each comfort vote, we calculated the Griffiths' comfort temperature. We found a mean comfort temperature of 25.4 degree centigrade. The regression approach closely approximates the mean Griffiths' comfortable temperature in this study. It is also proximity with the results obtained in Japan [12]. The result of this study has compared with different studies for the autumn season in naturally ventilated office building in the Table 3.

Indraganti et al. [28] and Singh et al. [37] found slightly higher value of comfort temperature in India. Rijal et al. [29] found 25.6 degree centigrade as summer comfort temperature in temperate climate while doing the study in dwellings, which is more similar as found in this study.

4. conclusion

- Out of total votes, 64 percent office occupants voted on neutral scale of thermal sensation. The result shows that the present thermal environment is suitable for the office occupants.
- Out of total votes, only 51 percent office occupants voted on no change scale of thermal preference. This result shows that people preference is different than their sensation.
- The comfort temperature for autumn season is found as 25.7 degree centigrade from regression analysis and 25.4 degree centigrade from Griffiths' method.

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