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Analysis of Thermal Comfort and Indoor Air Quality (IAQ) In Free Running (FR) Office Buildings during Summer Season: A Case Study of Kathmandu Valley

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Abstract

Due mostly to adult work requirements, youngsters spend 75% of their time indoors, and adults have spent up to 90% of their time indoors within the past fifty years. In office buildings, indoor environmental quality (thermal comfort and indoor air quality) significantly influences occupants' comfort and productivity; hence, for occupants to work effectively, a productive and comfortable working environment is a crucial and fundamental requirement. The scientific and technical community concerned with building analysis has been increasingly interested in thermal comfort and indoor air quality issues, as seen by the most recent revision to Directive 2023/2413/EU on the energy performance of buildings. This study reports on the thermal environment and perception of office employees in free-running (FR) office buildings in Kathmandu Valley, focusing on thermal comfort and indoor air quality (IAQ). The field study was conducted through physical parameter monitoring and survey questionnaires during the summer season (June-July, 2023). Comfort temperature is determined using Griffiths' method and found to be 27.21 °C during the summer season in free-running buildings inside Kathmandu valley. In this field survey, the indoor thermal comfort temperature ranges from 21 °C to 32.8 °C. The findings show that office employees considered temperature ranges their comfort zone validating the findings of previous studies and regression analysis confirms that thermal sensation votes are correlated with thermal preference of office employee. Furthermore, in free-running mode, CO_2 concentration limitations were significantly within the limit as per the ASHRAE 62 guideline indicating, good indoor air quality, sufficient ventilation and the well-being of the occupants.

Keywords

Thermal Comfort survey, Comfort temperature, free running (FR), Indoor air quality (IAQ), CO_2 concentration level

1. Introduction

In recent years, the study of indoor environmental comfort during the warm season has been one of the most attractive and hard tasks for architects and energy designers [?].Thermal comfort in many types of buildings has become a focus of contemporary research. Besides thermal comfort, the Indoor Air Quality (IAQ) is also important for the sensation of humans in indoor environments, as well as for their health [1].Indeed, thermal comfort and indoor air quality (IAQ) are crucial aspects of indoor environmental quality that receive significant attention from building designers, architects, and environmental engineers to achieve building efficiency [2] as the prominent strategy to mitigate climate change. Both factors play a vital role in the overall well-being, health, productivity of building occupants as well.

[3]Thermal comfort is described as a "state of mind which expresses satisfaction with the thermal environment". In addition to being the definition of a person's awareness of the thermal atmosphere, thermal comfort is also the state in which a person feels neutrally heated or cooled, without perspiring [4].Nicol and Humphreys [5]discovered a strong association between the comfort operative temperature and the running mean outdoor temperature observed over the previous days by examining a large number of surveys on free-running buildings that were done all over the world. As a result, they claimed that thermal comfort in free-running structures can be evaluated just as a function of the interior operating temperature, ignoring all other parameters taken into account in Fanger's model that would be of secondary value [?].A free-running mode office building is one that has an HVAC(Heating, Ventilation, and Air Conditioning) system or is naturally ventilated, but all of its heating and cooling systems were turned off throughout the study period [6].This approach is sometimes called "natural ventilation" or "passive cooling" and is intended to reduce energy consumption and promote sustainability. Field thermal comfort research serves as the foundation for the adaptive approach to thermal comfort [7].Several studies have embraced the Griffiths' Method as an alternative approach for determining the comfortable temperature. Numerous field studies on adaptive thermal comfort in office buildings have been carried out in several countries, including China, Japan, India, the United States, and Australia [8]. The results demonstrated that people may adapt to their surroundings since they showed that comfort temperatures in tropical areas were higher than those in cold climate zones and that in the same location, comfort temperatures in winter were lower than those in summer [7].

According to ANSI/ASHRAE 62 [9], acceptable air quality is defined as "air in which there are no known contaminants at harmful concentrations as determined by cognizant authorities and with which a substantial majority (80% or more) of the people exposed do not express dissatisfaction". Indoor carbon dioxide concentrations have been referred to as an indicator of indoor air quality, often without describing a specific association between carbon dioxide and indoor air quality [2]. The indoor air quality procedure contains a guidelines for indoor carbon dioxide concentrations of 1,800 mg/m3 (1000 ppm). Continuous monitoring of indoor carbon dioxide concentrations using a data logger device can be useful in investigating Indoor Air Quality [10].

2. Objectives

The general objective is to determine a comprehensive understanding of the occupant's thermal perception in free-running office buildings during the summer season. Specific objectives are:

1. To study thermal perception of office employee in free-running office buildings
2. To predict the comfort temperature using Griffths' method in free-running office buildings .
3. To analyze the CO_2 concentration level in free-running office buildings.

3. Limitations

Due to the three-month time limit, this research will solely focus on thermal comfort and indoor air quality inside the free-running and mixed-mode office buildings during June-July 2023. A questionnaire survey will be used to gather data on the office employee's thermal perception using a 7-point ASHRAE scale. During the site visit, field measurements and temperature data will be gathered. No conventional or Traditional typology of office buildings is included in the analysis. Additionally, no other types of buildings other than free - running offices would be included in the investigation.

4. Research Methodology

Identification of the study site and four free-running mode office buildings has been selected. Quantitative method has been used for the investigation. Field questionnaires survey were carried out to find the thermal perception with the help of the ASHRAE 7-point scale and air quality preference. Thermal measurement (air temperature) and Indoor air quality (CO_2 concentration) have been measured using digital instruments (TR-76i, Thermo Recorder-(TR-52i)). The comfort temperature is often determined using two methods. In this study, Griffiths' approach and regression method were used to predict the comfort temperature. The linear regression equation of the thermal feeling and indoor air temperature is substituted with "4 neutral" to estimate the comfort temperature using the regression approach. Nevertheless, the adaptive comfort temperature is examined using the Griffiths' approach because the regression method's forecast of the temperature may not be appropriate for the field survey [8].

4.1 Investigated Area

Kathmandu Valley is indeed a significant urban and cultural hub in Nepal, and it is located in the central part of the country. It encompasses Kathmandu, Lalitpur , and Bhaktapur cities.The valley is surrounded by hills where the elevation is more than 2000 m, with the central part consisting of flat land and small hills with an elevation of 1300 to 1400 m. Pre-monsoon (March–May), monsoon (June–September), post-monsoon (October–November), and winter (December–February) are the four distinct seasons in the valley's sub-tropical and temperate environment [11].

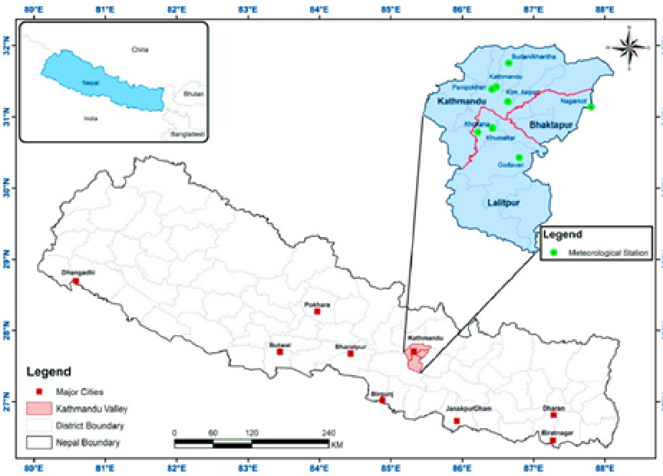

Figure 1: Location of investigated area

4.2 Investigated office buildings

The field survey was carried out in four different free running office buildings located inside Kathmandu valley from June to July, 2023. Context of each RCC framed free-running office buildings was building's HVAC system operating without mechanical heating or cooling, relying instead on natural environmental conditions to maintain a comfortable indoor climate. Table 1 shows the detail descriptions of investigated buildings.

Figure 2: Investigated buildings

Table 1: Detail description of investigated office buildings

S.N	Office Name	Office building Code	Orientation of the building	Location	No. of surveyed employees	Investigated floors
1	AKG Associates Chartered Accountants	AKG	South	Kupondole	18	FF and SF
2	HECAF 360	HCAF	South	Maharajgunj	10	GF
3	Informative Solutions	IS	East	Pulchowk	12	GF
4	Civil Informatics and Solutions (CIS)	CIS	East	Patan Dhoka	15	GF and FF

*GF:Ground Floor, FF:First Floor, SF:Second Floor

4.3 Thermal comfort scale

The thermal comfort survey utilized in this study was taken from earlier research on the topic, which was conducted by numerous researchers through fieldwork [7, 12, 13] .In this survey, occupants were provided with forms to assess their thermal comfort and were requested to return these forms at the end of the measurements on the day they were carried out. This allowed for the collection of records that captured the occupants' immediate perceptions of their thermal environment at that specific moment.

The questionnaire used a slightly altered seven-point scale aligned with the ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) [14] standard for assessing thermal sensation as shown in Table 2. Additionally, it utilized a five-point scale for evaluating thermal preference, as detailed in Table 2 of the study. This allowed for the assessment of how occupants perceived their comfort level in terms of thermal sensation and their preferences regarding the temperature conditions at the time of the survey. A total of 55 office employee participated and responded to the questionnaire. Respondents did not apply any adaptive thermal adjustments during the course of the investigation.

Table 2: Detail descriptions of investigated office building

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 warm	Much cooler
6	Warm	
7	Hot	

Figure 3: Field questionnaire survey

4.4 Digital instruments

Digital instruments were used to measure the physical parameters, including air temperature, and CO_2 concentration (Figure 3). The specifics (range, accuracy) of the digital devices used in the field investigation to monitor the ambient conditions are shown in Table 4. The parameters were recorded at a height of around 1.1m above the floor level and measured three times at the interval of 15 -20 minutes during office hours. The data was monitored for only occupational hours.TR-76Ui is set to record CO_2 concentration level at an interval of one hour for a week (1st-7th July, 2023) in each investigated buildings by connecting to the electric plug. Data was then retrieved by connecting the logger to a PC via USB cable and running the software "CO_2 Recorder for Windows." Data is downloaded to a PC and then examined and analyzed using compatible software such as "T&D Graph" and excel.

Figure 4: Digital instrument setup

Table 3: Detail descriptions of investigated office buildings

Parameter measured	Range	Accuracy	Instruments
Air temperature	0-55ºC	±0.5ºC	TR-74Ui
Carbon dioxide	0 to 9,999 ppm	±50 ppm	TR-76Ui

5. Results and Discussion

5.1 Analysis of Thermal Sensation and Thermal Preference

Thermal sensation: The thermal sensation vote of office employee in free-running office buildings were collected through questionnaire. The result of the thermal sensation vote are shown in figure below. As depict in the figure 5, regarding thermal sensation vote, 44% of respondents voted for slightly warm, while 31% voted for neutral, 9% for slightly cool, 15% voted for warm and 2% voted for hot. In simple terms, most people prefer that their surroundings maintain a constant temperature or fluctuate just slightly.

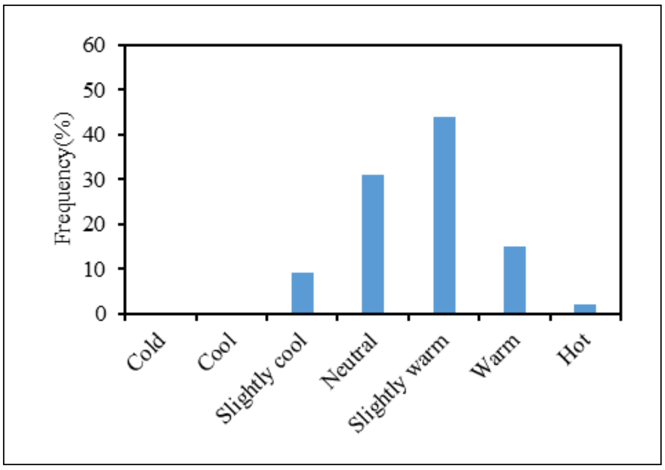

Figure 5: Distribution of Thermal Sensation Vote

Thermal perception: For free running mode office buildings, 55% of respondents prefer a bit cooler , while 40% said they would prefer no change and remaining 7% voted for much cooler. The data suggests that during the summer season, the majority of respondents expressed a preference for a slightly cooler thermal perception, with 55% preferring a bit cooler environment. This aligns with the expectation for comfort during warmer weather. It's important to note that despite the preference for a bit cooler environment, 40% of the respondents prefer no change in temperature during the summer. This could indicate that these respondents find the current thermal conditions during summer acceptable or only undergo minor fluctuations.

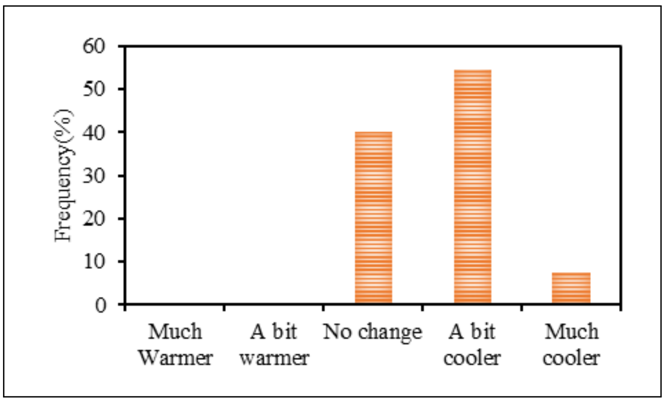

Figure 6: Distribution of Thermal Preferences

Notably, there is a consistency between the thermal sensation and perception data during the summer. Many people feel slightly warm, and a majority of them prefer a bit cooler surroundings, indicating that their perception aligns with their sensation as shown in table 4.

Table 4: Detail descriptions of investigated office buildings

Scale	Thermal Sensation		Thermal Preference	
	N	P (%)	N	P (%)
1	0	0	0	0
2	0	0	0	0
3	5	9	22	40
4	17	31	30	55
5	24	44	4	7
6	8	15	-	-
7	1	2	-	-
Total	55	100	55	100

5.2 Prediction of Comfort temperature

The key finding of thermal comfort data survey analysis is comfort temperature [7]. With the linear relationship between thermal sensation vote and indoor air temperature the comfort temperature is determined. Following is the linear regression equation that we obtained:

$$TSV = 0.138T_i + 0.7039 \qquad (N = 55, R^2 = 0.05) \qquad (1)$$

Where,
TSV = Thermal sensation vote,
T_i = Indoor air temperature (°C),
N = Number of votes,
R^2 = Coefficient of determination.

If we substitute "4. Neutral" in equation (1) the comfort temperature would be 23.88 °C .In equation (1) the regression coefficient is 0.13 i.e. 7.6°C (1/0.13) is needed to shift one thermal sensation vote. More than 5°C to shift one thermal sensation vote is impractical. Sometimes when the TSV is situated away from the neutral point, the linear regression method often leads to an extraneous value as identified by [14]. Hence Griffiths' method is used to avoid extraneous value from the regression analysis.

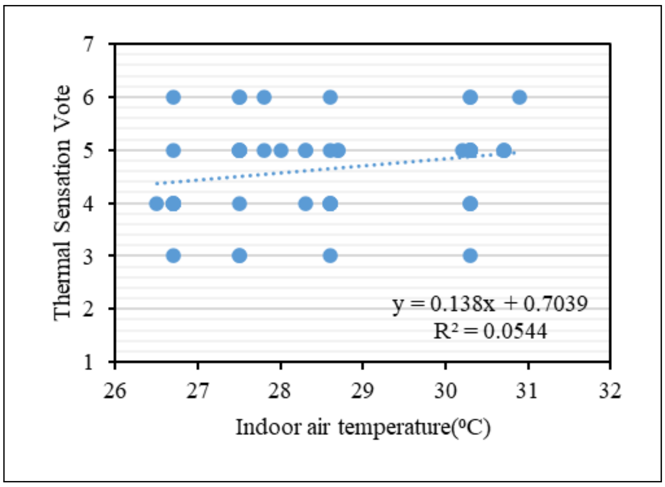

Figure 7: Relationship between Thermal Sensation Vote and Indoor air temperature

Table 5: Comfort temperature found in various studies for autumn season in office buildings

Country/City	References	Mode	season	Variable for Tc	T_0 (°C)	Tg,Ta (°C)	Tc (°C)
This study	-	FR	Summer	Ta	26.2	28	27.21
India/ Chennai, Hyderabad	[15]	NV	Autumn	Tg	31.3	29	27
Japan /Yokohama, Tokyo	[13]	FR	Autumn	Tg	17.9	24.8	24.9

Griffiths' comfort temperature (Tc) is estimated using the equation;

$$T_c = T_i + (4 - TSV)/a \quad (2)$$

Where,
T_c = Comfort temperature
a = Griffiths' constant,
T_i = Indoor air temperature,
TSV = Thermal sensation vote.

The regression coefficient of 0.5 was used here, as was the case with many other researchers [7]. We obtained Griffiths' comfort temperature for all comfort votes and achieve mean adaptive comfort temperature is 27.21°C. Table 4 compares the findings of this investigation with those of other studies conducted throughout the fall in naturally ventilated office buildings. In a study conducted in dwellings, [13], determined that the summer comfort temperature in temperate climates was 25.6°C. The comfort temperature in India was found to be slightly higher by [15] , which more closely aligns with the results of this investigation as shown in Table 5.

5.3 Analysis of Indoor Air Quality (IAQ)

Figure 8: Distribution of air quality satisfaction vote

Figure 8 depicts the distribution of Air quality (freshness) satisfaction votes of office employee that depicts that 47% of office employee voted slightly good,30% voted for good,12% voted slightly bad,9% voted very good and 2% voted for bad.

The ASHRAE 62.1 standard recommends a target CO_2 level of 700 parts per million (ppm) above outdoor ambient levels [9]. However, a typical indoor CO_2 level in well-ventilated spaces might range from 400 to 1,000 ppm. If the CO_2 concentration level in a given indoor environment aligns with the criteria outlined in ASHRAE 62, it indicates that the ventilation in that space is likely meeting the recommended standards for indoor air quality. Maintaining CO_2 levels within the prescribed range can help ensure a healthier indoor environment for occupants, as elevated CO_2 levels can suggest poor ventilation, potentially leading to discomfort and decreased cognitive function. The average daily concentration of CO_2 during the occupied period should not exceed 1500 ppm for naturally ventilated areas and mixed-mode systems when natural ventilation is used. The maximum concentration should not exceed 2000 ppm for longer than 20 minutes each day [16].

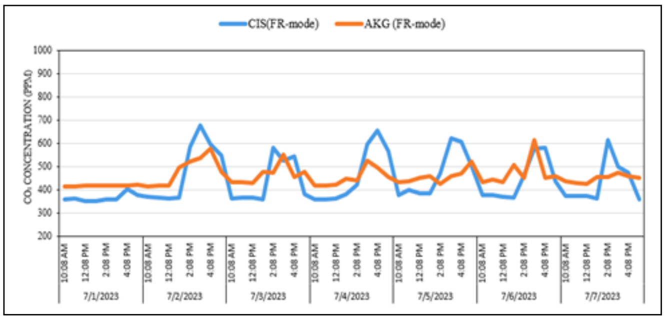

Figure 9: Indoor CO2 concentration data from 1st-7th, 2023

Figure 9 shows, the indoor CO_2 concentration rates for AKG (FR-mode) and CIS (FR-mode) were investigated during office hours from 1st July to 7th July 2023. The recorded hourly data shows that the average CO_2 concentration for AKG was 460 ppm, and for CIS, it was 414 ppm. CO_2 thresholds remain the primary indicator for IAQ in buildings [16], both of the values fall within the suggested ASHRAE 62.1 standard. This means that the indoor CO_2 concentration in both buildings is at a level that is considered acceptable for maintaining good indoor air quality and the well-being of the occupants.

6. Conclusion and Recommendation

The analysis of the thermal comfort and indoor air quality (IAQ) in four free-running office building during summer season were done and following conclusions are obtained:

1. With regard to the total, 84% office occupants voted that the thermal sensation in their office is neutral zone, this suggests that a majority of the occupants are comfortable with the current thermal conditions, which is generally a positive outcome in terms of indoor comfort. Neutral thermal sensation means that they neither feel too hot nor too cold, which is often the desired state in indoor environments to maintain occupant satisfaction and productivity.

2. Comfort temperature is determined by using Griffths' method and found to be 27.21°C in free-running office buildings during summer season. An average indoor

temperature was higher than the 28°C standard in 50% of the situations. This indicates running the buildings in FR mode presented difficulties because they were intended to operate in AC mode. This study recommends need of conducting extensive field research in office in Kathmandu to develop specific norms for adaptable comfort.

3. By following ASHRAE 62 guidelines, it guarantees that the air inside investigated free-running office buildings (AKG and CIS) is clean and fresh, also has sufficient ventilation as CO_2 concentration level ranges from 400 to 1000 ppm, which can enhance the productivity of occupants. This suggests that one of the most essential design criteria for achieving thermal comfort is to use free running mode.

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