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Experimental Investigation of False Ceiling Height on The Thermal Comfort of Building

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ABSTRACT

Sustainable building design and passive cooling strategies are highly prominent areas of research. This investigation assesses the thermal performance of polystyrene as a false-ceiling material for hot climate of Khulna, Bangladesh. Experiments were conducted to measure temperature of two similar, same-sized rooms (Rooms 504 and 505, Block C, Academic Building-1, KUET, Khulna) were monitored simultaneously to ensure comparable thermal conditions. Polystyrene boards were installed in Room 504 with varying clearance gaps of 25 mm, 76 mm, 152 mm, and 228 mm, while the other room was kept in its normal condition. The temperatures at different points inside and outside the rooms were measured using thermocouples, and a data logger was used to store the data. The results showed that the maximum temperature reduction of 2.675 °C occurred in the room with polystyrene as false ceiling with a 76 mm clearance. The minimum reduction, 0.6875 °C, was observed with a 25 mm clearance. For 152 mm and 228 mm clearances, the reductions were 1.475 °C and 1.9 °C, respectively. The findings suggest that low-conductivity false ceilings with appropriate air gaps between roof and false-ceiling can effectively reduce heat gains and lower indoor temperatures, offering a practical solution for energy demand reduction in residential buildings in the hot climatic condition.

Keywords: Thermal comfort, False Ceiling, Polystyrene, Clearance optimization, Building energy consumption.

1. Introduction

Energy is a significant driver of global progress, powering industries, transportation, and daily life. Its importance lies in sustaining economic growth, improving living standards, and fostering technological advancements. However, the world faces the challenges of energy scarcity due to growing demand, population expansion, and environmental concerns [1]. The residential sector consumes a significant amount of energy that consists of a diverse range of energy-intensive activities, including space and water heating, lighting, and the operation of numerous electric appliances in households worldwide [2]. With the continuous growth of the global population, there is a subsequent rise in the number of residential units, leading to increased energy requirements to fulfill basic living needs [3]. The residential sector is responsible for about 21% of global energy use [4], contributing to 17% of global CO2 emissions that contribute to climate change [5]. The trend suggests that the global building energy demand is expected to double by 2050 [6]. Above 40% of the total electricity consumption in Bangladesh is due to residential sectors, which is rising due to enhanced lifestyle and household income [7]. Industrialization, urbanization, and improved living standards in various regions contribute to higher energy consumption per household [8].

Thus, holistic and comprehensive strategies are required to reduce the building energy consumption as well as to reduce the environmental impact. These strategies include the incorporation of modern technologies such as heat pump systems [9], photovoltaic cells [10], and innovative system integration. Another effective way is the supportive local and national policies that promote green and energy-efficient appliances for sustainable building practices. On the other hand, green roofs, shading, and thermal insulation are all passive ways to cut down on the amount of energy a building use. Green roofs are unique in that they also allow food to be grown on site [9]. A numerical analysis was conducted to examine the impact of a rooftop garden on a four-storied industrial building that revealed an average energy saving ranging from 1/100th to 1/10th of the total yearly energy consumption [12]. According to a study, passive strategies like wall or roof insulation can improve building's thermal performance without adding further operational power demand [13]. Energy savings are concentrated in the building envelope, especially walls, roofs, and windows. Experiment conducted to measure the thermal performance of laminated plywood with a RCC roof with four reflective coatings. It has been observed that the indoor temperature decreased by 2.1°C to 3.2°C, and the thermal performance enhanced by 16.10% to 27.94% compared to a regular RCC roof [14]. The effect of passive cooling techniques such as roof insulation and white reflective coating on the roof has been investigated. Findings indicate that the roof coated with a white reflective coating demonstrated a more significant cooling load reduction than the roofs with insulation only or with a combination of insulation and reflective coating [15]. Shading techniques are another potential passive technique in which a false ceiling and strategic orientation of the building can reduce the total energy consumption significantly [10]. Another major concern is the clearance between the ceiling and insulation, which has a substantial impact on the consumption of energy.

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These strategies are effective, but they cost a lot and take a long payback period. After looking at all the options, expanded polystyrene panels are the best and cheapest way to passively improve the thermal efficiency of a building [16]. Due to the high temperature and humidity in the Khulna region of Bangladesh during the summer, the transfer of heat from the outside to the inside of buildings can be significantly reduced with the use of cost-effective, available, and convenient materials as ceiling materials under the roof, like polystyrene, PVC, Styrofoam, etc.

However, the previous studies lack the ability to illustrate the effect of cost-effective and available ceiling materials that possess both low thermal conductivity and minimal impact on the environment, such as polystyrene, plastic sheets, Styrofoam, fiberboard, cork sheets, cellulose fiber, foam glass, and stone wool, among others. Furthermore, prior work did not accurately depict the mechanism and the gap between the roof and false ceiling. A comparative analysis of using polystyrene in the context of Khulna, Bangladesh, has yet to be conducted, and this could have a substantial impact on the design of energy-efficient buildings.

The present study will focus on experimental approaches to determine the thermal performance of cost-effective, available, and convenient ceiling materials such as polystyrene, used at the ceiling under the roof. Additionally, the impact of clearance between the ceiling materials and roof are analyzed to evaluate thermal performance. To ensure thorough evaluation, the chosen technique has been implemented in two similar sized rooms located on the same floor, ensuring uniform heat distribution. Through this organized approach, the investigation aims to contribute valuable insights into effective strategy for reducing residential building energy consumption.

2. Methodology

The investigation is conducted on the fourth floor of the academic building-1 at KUET, Khulna, Bangladesh, in rooms 504 and 505 of Block C. The orientation of the test rooms is shown in Fig 1, and room dimensions, ceiling material thickness, and clearance thickness are provided in Table 1. The tests are being performed simultaneously in both rooms to ensure similar external conditions, facilitating accurate data comparison. Ceiling materials with low thermal conductivity offer higher thermal resistance, leading to reduced cooling during heat. In addition to thermal conductivity, factors such as cost, density, environmental impact, and material availability considered for material selection.

To measure temperatures, the probe of thermocouples is connected to the outside and inside of the roof at several positions. The temperature is measured with the help of K-type and T-type thermocouples, which are recorded by using a data logger. Thus, the obtained temperature data are used in the following Eq. (1) to determine thermal resistance.
Thermal resistance,

$$R_{th} = \frac{T_1 - T_2}{q}\ m^2.K/W \qquad (1)$$

Where, q, T_1, T_2 are the heat flux (W/m^2), hot surface temperature (K) and cold surface temperature (K), respectively.

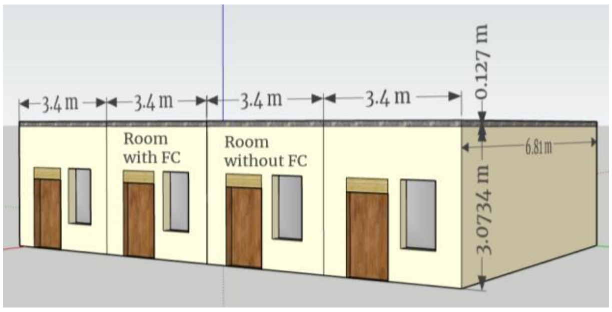

Fig. 1 Orientation representation of Room No: 504 and 505

Table 1 Dimensions of rooms, insulation materials and clearance

Name	Dimension
Length of each room (m)	6.81
Width of each room (m)	3.40
Height of each room (m)	3.07
Roof thickness (m)	0.127
Ceiling materials thickness (mm)	20
Clearance (mm)	25, 76, 152, 228

Three different stages were ensured to determine the effect of the false ceiling. Firstly, a typical roof thermal performance is measured for both rooms to ensure the thermal difference between the rooms. Secondly, a roof with an inner false ceiling using polystyrene and a typical roof is considered. Thus, the clearance between the roof and ceiling materials is varied by 25 mm, 76 mm, 152 mm, and 228 mm to observe the effect of air resistance. Additionally, to determine the room temperature distribution, six thermocouple probes are placed at different heights for both rooms, which is illustrated in Fig 2. Additionally, the actual setup of room 504 with polystyrene as false ceiling is depicted in Fig 3.

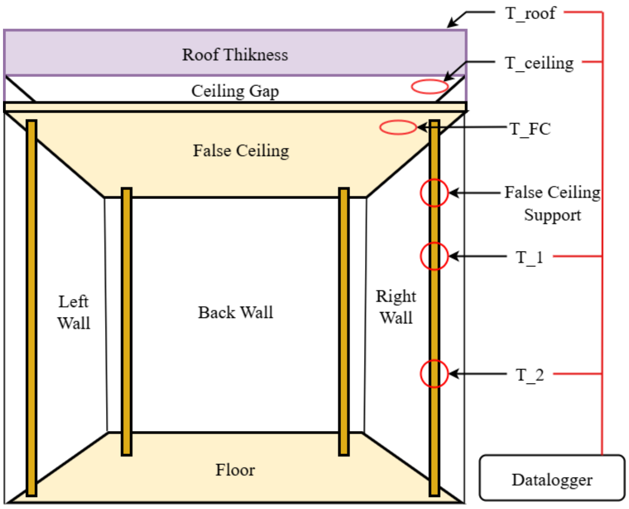

Fig. 2 Simplified view of experimental setup and data points

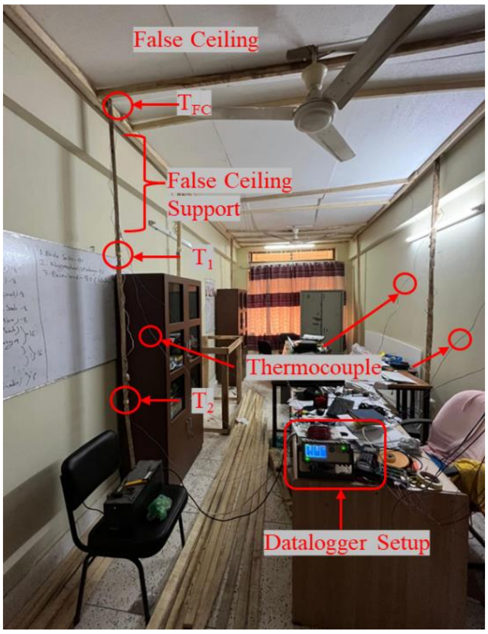

Fig. 3 Actual experimental setup of room 504 with polystyrene as false ceiling

4. Results and Analysis

Data was collected from September to November 2024, with various combinations of clearance gaps with polystyrene as ceiling material. However, selective data that represents the thermal performance trends are analyzed here for this investigation.

4.1 Effects of Polystyrene with 25 mm clearance

Fig. 4 shows the vertical temperature distribution of various selected temperature points in room 504 and 505 on September 25, 2024. Room 504 was equipped with polystyrene as ceiling material under the ceiling with a 25 mm clearance gap. But room 505 did not have any artificial ceiling material.

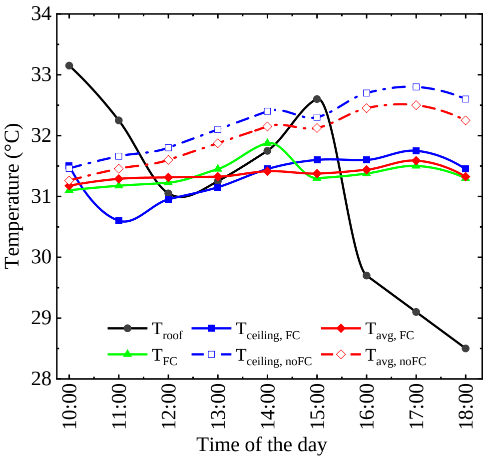

Fig. 4 Vertical temperature distribution comparison of room 504 using polystyrene and 25 mm clearance with room 505 without false ceiling

Fig. 4 shows that during the use of 25 mm clearance between false ceiling material - polystyrene and ceiling in room 504, roof temperature ranged between 28.50°C and 33.15°C for both room 504 and 505. The effects of polystyrene were accessed using the temperature difference of ceiling and room. For room 504, the ceiling temperature was between 30.60°C and 31.75°C, which was lowered down to 31.15°C. But for room 505, the maximum ceiling temperature of 31.80°C was only lowered to 31.75°C which is non-significant. The effects of 25 mm clearance were present but not too drastic as observed from Fig 4.

Though in Fig 4 it was seen that temperature curves were always between 30.5°C and 32°C for room with FC, for room without FC, the temperatures were rising with time, which is one of the results due to not using false ceiling. Maximum temperature difference between ceiling and room ambience was found to be 0.6875°C for room 504 whereas it was 0.21°C for room 505 at 11 AM. All other data points also show that the temperature difference between ceiling and room is always higher in the room with FC with 25 mm clearance gap.

4.2 Effects of Polystyrene with 76 mm clearance

Fig 5 shows the vertical temperature distribution of various selected temperature points in room 504 and 505 on October 1, 2024. Room 504 was equipped with polystyrene as ceiling material under the roof with a 76 mm clearance gap. But room 505 did not have any additional ceiling materials added. From the temperature vs time graph the changes in temperature at different points of the two experimented rooms were observed. It was observed that roof temperature was increasing till 1:00 PM on that day and then the decrease began. The room with false ceiling showed ceiling temperature between 34°C to 36°C throughout the whole data collection period but the other room had ceiling temperature ranged between 35°C to 37°C, which is higher than the overall temperature range. This was due to the FC providing resistance to transfer heat from top side of roof to the bottom side, i.e., the ceiling. This temperature difference can be seen distinctively for all setups except 228 mm clearance gap. Maximum ceiling temperature was found to be 36°C which was lowered to 33.43°C, with a 2.675°C temperature drop due to polystyrene using 76 mm clearance. At the same time without insulation, the temperature difference for room 505 was 1.37°C.

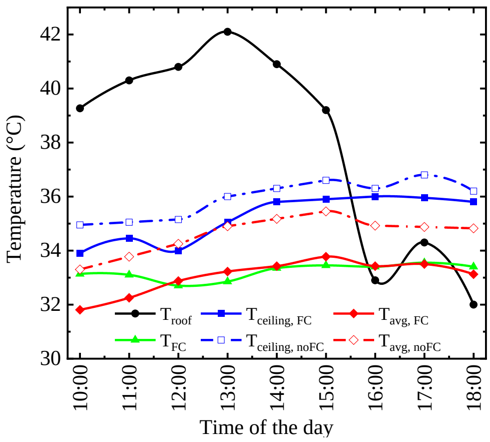

Fig. 5 Vertical temperature distribution comparison of room 504 using polystyrene and 76 mm clearance with room 505 without false ceiling

For room 504 the temperature just under the FC ranged from 32.70 °C to 33.55 °C but because of polystyrene, average room temperature was found between 31.81°C to 33.78°C. Average room temperature was found to be 33.78 °C but at the same time at room 505 the average room temperature was found to be 35.45°C, which clearly indicated the temperature drop because of FC with 76 mm clearance.

4.3 Effects of Polystyrene with 152 mm clearance

Fig. 6 shows the changes of temperature at each strategic point at different times of the day for room 504 and room 505. Both followed similar trends as before and room 504 due to polystyrene, showed greater temperature difference between ceiling and room temperature. Ceiling temperature ranged between 27.35°C and 30.05°C for room 504 and 27.90°C and 30.20°C for room 505, which is similar. However, the difference due to polystyrene with 152 mm clearance was found to be 1.48°C maximum for room 504 whereas it was 0.80°C without insulation.

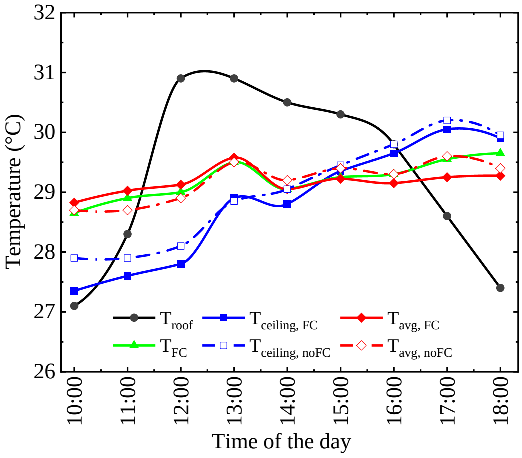

Fig. 6 Vertical temperature distribution comparison of room 504 using polystyrene and 152 mm clearance with room 505 without false ceiling

4.4 Effects of Polystyrene with 228 mm clearance

Fig 7 illustrates the changes of temperature at each strategic point at different times of the day for room 504 and room 505. Only room 504 was equipped with 228 mm clearance with polystyrene. Both followed similar trends as before and room 504 due to insulation, showed greater temperature difference between ceiling and room temperature. Ceiling temperature ranged between 28.25°C and 31.25°C for room 504 and 28.25°C and 31.10°C for room 505, which is almost similar. However, the difference due to insulation was found to be 1°C for room with polystyrene and 228 mm clearance whereas it was 1.50°C without insulation. This is due to the room without polystyrene gaining higher temperature than the room with polystyrene as there was less thermal resistance for heat gain.

4.5 Error Analysis of the Measured Data

The error analysis of the equipment by which the data has been measured is expressed in Table 2. From Table, it can be seen that the maximum error of the instruments lies below ±5%.

Table 2 Accuracy and rated output range of instruments used in this study

Name	Output range	Accuracy
Hukseflux SR11-T1 pyranometer	0 to 1600 W/m²	±5% (daily sums), ±8% (hourly sums)
K-type thermocouple	-200°C to 1260°C	+/- 2.2C
Jinko JK4000 temperature recorder	-200°C to 1800°C	± (read value×0.2%+1) °C

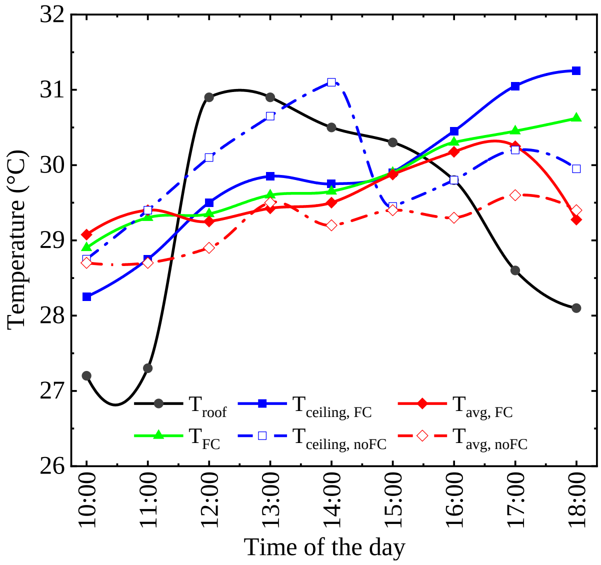

Fig. 7 Vertical temperature distribution comparison of room 504 using polystyrene and 228 mm clearance with room 505 without false ceiling

5. Conclusion

Experiments were conducted for 4 configurations with polystyrene insulation along with 4 different clearance distances for room 504 and without insulation for room 505. From the experimental data, it was observed that using a false ceiling provided better thermal comfort than without false ceiling. Among the 4 clearance distances: 25 mm, 76 mm, 152 mm and 228 mm, only 76 mm clearance provided the best result. The detailed findings from this investigation are as follows-

- Using polystyrene and with a 25 mm clearance between room ceiling and false ceiling, the maximum temperature difference between ceiling and room ambient temperature was found to be 0.6875°C at 11 AM, while at the same time in the room without false ceiling it was 0.205°C, with a maximum of 0.35°C.
- For a 76 mm clearance between the ceiling and polystyrene, the highest temperature difference observed was 2.675°C at 6 PM Meanwhile, in the other room, the difference was 1.375°C at the same time.
- Utilizing polystyrene and maintaining a 152 mm clearance between the ceiling and polystyrene, the maximum temperature difference was 1.475°C at 10 AM. Conversely, at the same time in the other room, the temperature difference was 0.8°C.
- For a 228 mm clearance between the ceiling and the false ceiling, the maximum temperature difference was found 1.9°C at 10 AM. In contrast, in the other room, it was 0.55°C.

It can be concluded that a 25 mm clearance between the ceiling and polystyrene yields the greatest impact, with a temperature difference of 2.675°C compared to other configurations. Those findings will assist the researcher to incorporate in a sustainable building design.

Ackowledgement

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8. Nomenclature

Symbol	Meaning	Unit
R_{th}	Thermal Resistance	(m^2.K/W)
q	Heat flux	(W/m^2)
FC	False ceiling	Dimention less
T_1	Hot surface temperature	(K)
T_2	Cold surface temperature	(K)