ICMIEE22-215

Experimental Investigation on Heat Transfer through the Roof of Air-Conditioned and Non Air-Conditioned Rooms

Md. Jahangir Hossain[1,*], *Mohammad Ariful Islam*[2]
[1]Department of Energy Science and Engineering, Khulna University of Engineering & Technology, Khulna-9203, BANGLADESH
[2]Department of Mechanical Engineering, Khulna University of Engineering & Technology, Khulna-9203, BANGLADESH

ABSTRACT
Building energy consumption in Bangladesh is increasing day-by-day as a result of the increased use of air conditioners. To reduce air conditioning energy consumption, it is required to use energy-efficient building envelopes and properly sized air conditioners. In this respect, it is required to know about the time at which indoor and outdoor air temperatures, and roof surface temperature become peak and heat transfer through building envelopes, especially roofs. The peak indoor air temperature and thermal condition of the roof vary with the indoor air temperature of a room. These data are not available for the Khulna district of Bangladesh. So, the present work has focused on the investigation of such data for air-conditioned room maintained at 25ºC and non air-conditioned room for a typical day in June 2022. From the research work, it is found that the indoor air temperature of the non air-conditioned room reaches peak value at the evening which is higher than that of the outdoor air temperature. As the temperature of indoor air becomes high enough, severe discomfort is felt in rooms on the top floor of the building. For both air-conditioned and non air-conditioned rooms, the outside surface temperature of the roof becomes maximum at noon. In case of the non air-conditioned room, this maximum outside surface temperature is found to be higher than that of the air-conditioned room. On the other hand, the peak value of the inside surface temperature of the roof is found in the evening and this value for the air-conditioned room is higher than that of the non air-conditioned room. Due to maintaining a lower temperature by air conditioners, the peak roof heat gain for the air-conditioned room becomes more than 3 times higher relative to the peak roof heat gain of the non air-conditioned room.

Keywords: Heat transfer, roof, air-conditioned room, non air-conditioned room.

1. Introduction

A building is composed of a number of envelopes such as windows, doors, walls and roofs. Though all the building envelopes are exposed to solar radiation, the roof is exposed to solar radiation for a longer period of time [1]. Due to longer exposure time, the roof heat gain is a major contributor to the building cooling load [2, 3]. The roof absorbs heat from solar radiation and its surface temperature increases. The inside surface of the roof remains at the highest temperature in the indoor of a room [4]. This increased inside surface temperature is largely responsible for high indoor air temperature and human discomfort in buildings. To obtain thermal comfort inside a room, air conditioners are installed in buildings that remove excess heat from buildings and bring buildings to thermal comfort condition [5]. If building envelopes are selected on the basis of energy efficiency, the heat gain of the building will significantly reduce which will reduce the cooling load of the building. Also, the energy-efficient and appropriate size air conditioners can reduce the energy consumption of buildings. The selection of energy-efficient building envelopes and air conditioners highly depends on the nature of the climate. Khulna is a district of Bangladesh in the southern part of the country having 22°49′N latitude and 89°33′E longitude [6]. The climate of Khulna is hot and humid. Throughout the year, the temperature in Khulna varies from 14ºC to 34.5ºC but it may fall below 11ºC or rise above 38ºC [7].

* Corresponding author. Cell: +880 1771 965258
E-mail address: jahangir.hossain@ese.kuet.ac.bd

Vijaykumar et al. [8] numerically analyzed the thermal performance of reinforced cement concrete (RCC) roof at Coimbatore city, Tamil Nadu state, India for the month of May and found that the outdoor air temperature was maximum at 1:00 PM but the inside surface temperature of the roof of an air-conditioned room maintained at 25ºC was maximum at 5:00 PM. Mahmoodzadeha and Fatehi [9] numerically investigated the thermal performance of concrete block roof with polyurethane insulation in a hot dry climate for constant inside surface temperature. They found that the outdoor surface temperature of the roof was maximum at approximately 2:00 PM.

Although the roof is a major concern for the cooling load of the air-conditioner, sufficient information is not available about the occurrence of peak indoor air temperature, roof surface temperature and peak roof heat gain in the context of building in Bangladesh. In this investigation, the heat gain through the roof of a building in Khulna region was analyzed for air-conditioned and non air-conditioned rooms.

2. Experimental procedure

To investigate the heat gain through the roof, two rooms under the same roof of a building have been selected. The rooms are situated on the top floor (4^{th} floor) of an academic building (New Academic Building, Block-C) of Khulna University of Engineering &

Technology (KUET) campus. One room is air-conditioned using four air-conditioners each having a capacity of 2 tons and the other room is non air-conditioned. The roof is constructed using 127 mm reinforced cement concrete with 38 mm patent stone on the outside surface and 6 mm plaster on the inside surface. The layout of the rooms are shown in **Fig.1**.

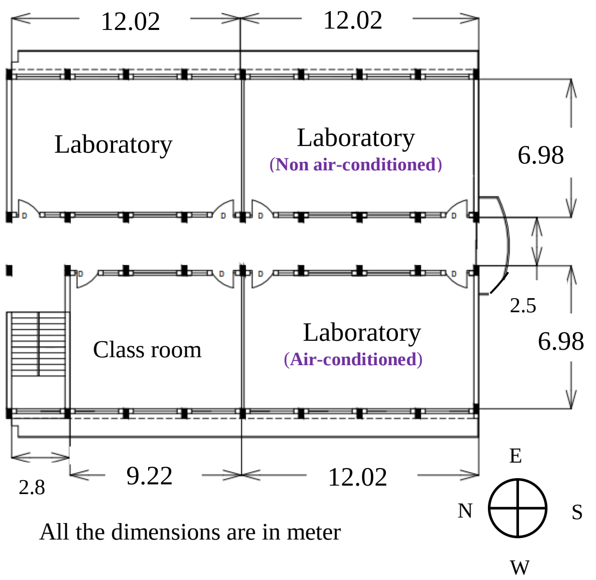

Fig.1 Layout of southern part of Block-C (4th Floor), New Academic Building, KUET.

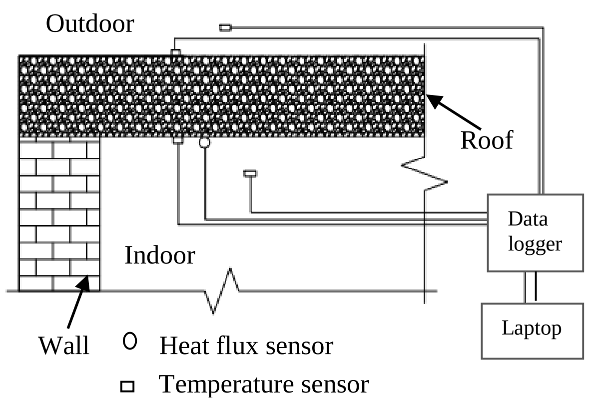

Fig.2 Schematic diagram of experimental set up.

Fig.3 Heat flux sensors in the air-conditioned room.

Fig.4 Heat flux sensors in the non air-conditioned room.

Fig.5 Measurement of global solar radiation by a pyranometer.

To record temperature and heat flux data a thermal resistance measuring apparatus (TRSYS01) is used. It has both temperature and heat flux sensors. The heat flux sensor is a thermopile which is manufactured by Hukseflux. It has a ceramics-plastic composite body. Firstly, the thermopile measures the temperature difference across the composite body. Then, a small voltage is generated which is proportional to the temperature difference. The heat flux measured by the sensor is proportional to the temperature difference and average thermal conductivity of the composite body of the sensor. The sensors are installed on the roof of the building as shown in **Fig.2 to Fig.4**. The data has been taken for a typical day of June (10 June, 2022). The indoor air temperature of the air-conditioned room is maintained at approximately 25ºC using air-conditioners. In each room, a heat flux sensor is installed on the inside surface of the roof, temperature sensors are installed on both the inside and outside surfaces of the roof as well as to record indoor and outdoor air temperature. The temperature and heat flux data are obtained through a data logger. A laptop is connected to the data logger to access and monitor the data. A pyranometer (SR11-T1) is used to record global solar radiation on the roof of the particular day as shown in **Fig.5**.

3. Results and discussion

The sun has risen before 06:00 and sat after 18:00 for the particular day and the change of solar radiation with the time of day is shown in **Fig.6**. With the rise of the sun, solar radiation increases and becomes maximum at 12:00 and then begins to fall. As the day was cloudy, frequent rise and fall in solar radiation has been noticed.

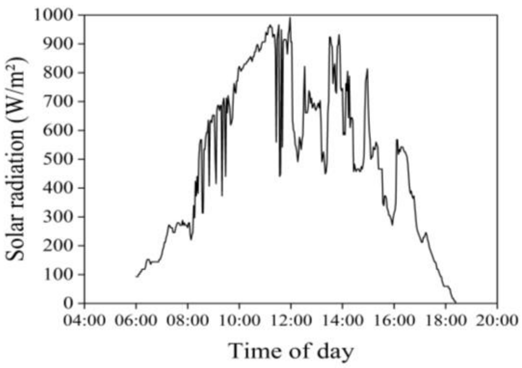

Fig.6 Variation of solar radiation with time.

The indoor and outdoor air temperature changes with time and this is represented in **Fig.7**. The outdoor air temperature begins to increase after sunrise due to solar radiation and becomes a maximum of 39.47ºC at 13:50, then the temperature starts to decrease. The indoor air temperature of the air-conditioned room is maintained at approximately 25ºC by air conditioners. In the non air-conditioned room, the indoor air temperature begins to increase after sunrise and reaches a peak value of 40.13ºC at 18:00 and then begins to decrease. This higher temperature is the main reason for the discomfort in the non air-conditioned room. Also, after 15:00, the indoor air temperature is found to be higher than the outdoor air temperature and it is continued up to the morning of the next. Therefore, natural or mechanical ventilation in this period can provide comfort in the non air-conditioned room. For the non air-conditioned room, from **Fig.7** it can be noticed that the maximum indoor air temperature is greater than the maximum outdoor air temperature as a result of releasing absorbed heat of the roof.

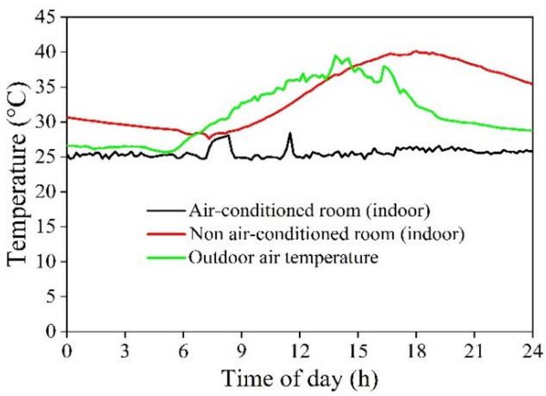

Fig.7 Variation of indoor and outdoor air temperature with time.

As the roof is directly exposed to solar radiation, it absorbs heat from incident solar radiation. Also, the roof absorbs heat from hot outdoor air and its temperature increases. As the solar radiation and outdoor air temperature change with the passage of time, the outside surface temperature of the roof also varies with time and this is given in **Fig.8**. Near 6:00 the outside surface temperature of the roof in both air-conditioned and the non air-conditioned room begins to rise and reaches a peak value of 40.73ºC at 14:40 for air-conditioned room and 44.71ºC at 14:20 for the non air-conditioned room. For the non air-conditioned room, the outside surface of the roof remains warmer than that of the air-conditioned room for most of the time.

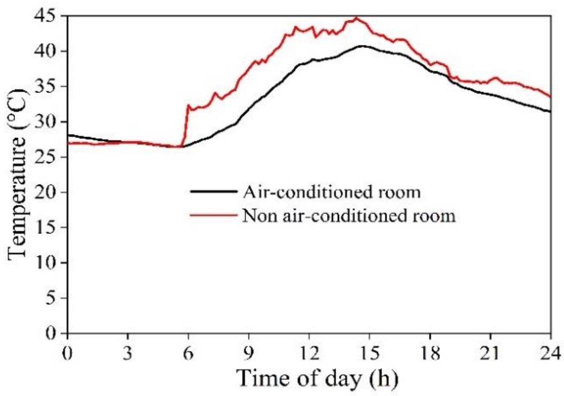

Fig.8 Variation of outside surface temperature of roof with time.

The selected building has a reinforced cement concrete (RCC) roof. Heat transfers through the roof from the outside surface to the inside surface by conduction. For this reason, the inside surface temperature of the roof starts to increase after 6:00 for the air-conditioned room and before 6:00 for the non air-conditioned room as given in **Fig.9**.

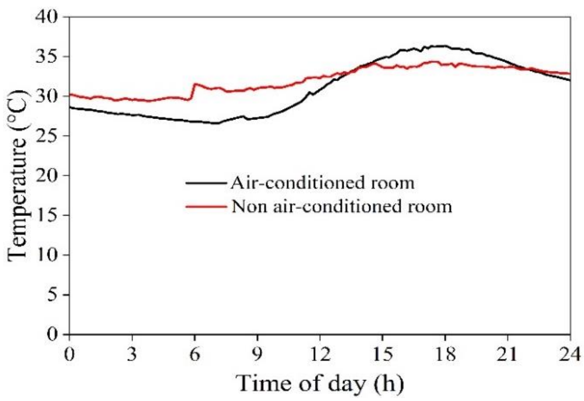

Fig.9 Variation of inside surface temperature of roof with time.

From **Fig.9** it can be seen that the inside surface temperature reaches peak value at 18:00 for the air-conditioned room and at 17:20 for the non air-conditioned room. From 13:20 to 21:50 the inside surface temperature of the roof in air-conditioned room is found to be higher than that of non air-conditioned room due to large roof heat gain during this time period. Except for this time, the temperature of inside surface of the roof of the non air-conditioned room remains higher than that of the air-conditioned room.

The variation of roof heat flux with time is illustrated in **Fig.10**. With the increase of solar radiation, the roof heat gain increases for both the rooms. The air-conditioned room has peak roof heat gain at 16:40 while non air-conditioned room has peak roof heat gain at 17:30. The heat gain through the roof in air-conditioned room is always higher than that of the non air-conditioned room due to maintaining indoor air temperature 25ºC in the air-conditioned room. Due to load shedding, there has been a sudden change in roof heat transfer from 7:10 to 8:20 in air-conditioned room as air conditioners have been off during this time and the indoor air temperature in the conditioned room has risen above 25ºC. Though no roof heat loss is found for air-conditioned room except load shedding, roof heat loss is noticed for non air-conditioned room from 00:00 to 10:30 due to higher inside surface temperature of roof than outside surface temperature and release of stored heat of roof materials which can be seen from **Fig.8** and **Fig.9**. For the typical day, the average roof heat gain for the air-conditioned room is found to be 38.37 W/m^2 which is more than 3 times higher than that of non air-conditioned room (11.49 W/m^2). The roof heat gain and air-conditioning energy consumption can be significantly reduced by installing appropriate roof insulation.

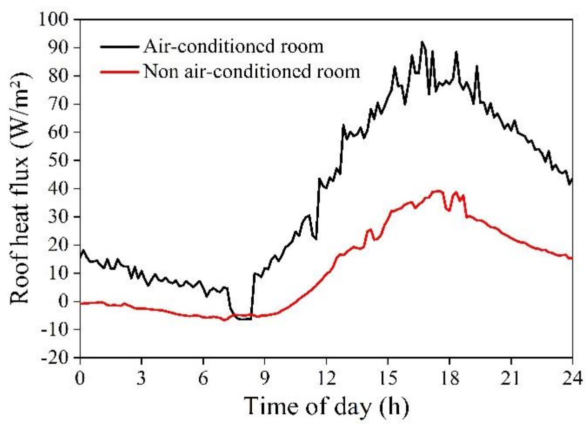

Fig.10 Variation of heat transfer through roof with time.

4. Conclusion

The temperature of indoor air, outdoor air and roof's thermal condition have been monitored for air-conditioned and non air-conditioned rooms in a typical day of summer season in Bangladesh. From the research work, the following conclusions can be made:

(i) The indoor air temperature in non air-conditioned room remains higher than outdoor air temperature from afternoon to next morning. For non air-conditioned room, the maximum indoor air temperature is found to be higher than the maximum outdoor air temperature for which extreme discomfort is felt in the evening.

(ii) As relatively lower indoor air temperature is maintained in air-conditioned room, heat gain through the roof increases significantly with the increase of outdoor air temperature.

(iii) The heat gain through the roof in air-conditioned room is always higher than that of non air-conditioned room. The average roof heat gain of air-conditioned room is more than 3 times higher than that of non air-conditioned room.

5. References

[1] Tong, S., Li, H., Zingre, K. T., Wan, M. P., Victor, W. C. Chang, V. W. C., Wong, S. K., Toh, W. B. T., Lee, I. Y. L., Thermal performance of concrete-based roofs in tropical climate, *Energy and Buildings*, vol. 76, pp. 392-401, 2014.

[2] Setyawan, A., Effect of room temperature setting on the cooling load, supply air quantity, and apparatus dew point, *Journal of Engineering Science and Technology*, vol. 15 (3), pp. 1799-1814, 2020.

[3] Lubis, I. H., Koerniawan, M. D., Reducing heat gains and cooling loads through roof structure configurations of a house in Medan, *Earth and Environmental Science*, vol. 152, 2018.

[4] Arminda, W., Kamaruddin, M., Heat transfer through building envelope materials and their effect on indoor air temperatures in tropics, *Journal of Science and Applicative Technology*, vol. 5 (2), pp. 403-410, 2021.

[5] Wang, N., Zhang, J., Xia, X., Energy consumption of air conditioners at different temperature set points, *Energy and Buildings*, vol. 65, pp. 412–418, 2013.

[6] https://en.wikipedia.org/wiki/Khulna#Climate (22 Oct. 2022).

[7] https://weatherspark.com/y/111687/Average-Weather-in-Khulna-Bangladesh-Year-Round (22. Oct. 2022).

[8] Vijaykumar, K. C. K., Srinivasan, P. S. S., Dhandapani, S., A performance of hollow clay tile (HCT) laid reinforced cement concrete (RCC) roof for tropical summer climates, *Energy and Buildings*, vol. 39, pp. 886–892, 2007.

[9] Mahmoodzadeha, M., Fatehib, R., Numerical investigation of roofing materials effect on solar heat gain in different external conditions, *Journal of Heat and Mass Transfer Research*, vol. 6, pp. 41-53, 2019.