

# A PASSIVE COOLING SYSTEM OF RESIDENTIAL AND COMMERCIAL BUILDINGS IN SUMMER OR HOT SEASON

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*Abstract:* -The demand of ventilation appliances in the residential and commercial buildings in the tropical region is increasing very rapidly due to the population increase as well as climate change. The increasing number of high rise buildings may result in the lack of natural ventilation in modern buildings. Generally, fan and air conditioning are used in the modern building for cooling as well as for air ventilation. In the tropical regions most of the energy is consumed by the heating, cooling and ventilation appliances. Therefore, solar power appliance for cooling, heating and ventilation will be a suitable and valid option for the saving of energy from the household sector. A modified-structure building is designed and constructed with solar chimney to enhance ventilation rate that increases cooling performance as well as ensuring thermal comfort. An evaporative cooler is introduced with newly designed room to enhance the temperature reduction capacity. The room temperature is compared with a non-modified room as well as with ambient temperature. The results show that passive cooling system with evaporative cooler was able to reduce temperature by 5°C compared to the ambient temperature and about 2°C to 3°C below the reference room temperature.

*Key-words:* - Passive cooling; thermal comfort; solar chimney

## 1.0 Introduction

The demand of electrical energy in a developing country depends on the economic development as well as the standard living of the people that makes electricity a key indicator of the economic development of the country. The generation of electricity depends on the natural resources of that country. Subject to availability of natural resources of the country, commercially electricity is generated mainly from natural gas and hydropower [1] but the reserve of the natural gas in Bangladesh is likely to be depleted by the year 2020 [2].

In Bangladesh, about 40 per cent of the total energy used in the urban areas is consumed by the residential and commercial building and about 50-60 per cent of this energy is used for cooling, heating, ventilating and space conditioning in residential and commercial

buildings [3]. Therefore, during hot climate or in summer when the outside temperature is high, effective passive cooling system for commercial and residential building will be a viable option. It can reduce the electricity consumption as well as extending the availability of natural resources. Bangladesh is situated between 20.30° and 26.38° north latitude and 88.04° and 92.44° east of GMT which provides this country with abundant solar energy for utilization. The average daylight or sunlight hour throughout the year is more than 10 hours and average solar radiation varies from 4 to 6.5 kWh/m<sup>2</sup>-day. It indicates a good prospect for solar power ventilation system or passive cooling system for commercial and residential building in Bangladesh [1 - 2]. In this study the space cooling is defined as the rate of energy removed from the air space in order to maintain a set lower temperature than the surrounding

atmospheric temperature. During summer or hot climate when the ambient temperature is high, poor ventilation and cooling system can change the environment of the residential and the commercial building in the cities and causes thermal discomfort. In addition, electricity blackout is very common in the cities of Bangladesh that worsens the situation [1-4]. At present all the modern commercial and residential buildings are furnished with electrical appliances mainly used for cooling and ventilation, resulting in excessive energy consumption during summer. Therefore, an efficient passive cooling system coupled with a solar chimney system can minimize this energy used for the commercial and residential buildings in urban areas of Bangladesh. There are some well-established methods available for space heating by using solar energy which are direct radiation, trombe wall, transparent insulation etc.[5]. On the other hand very limited number of studies is available on space cooling by using solar energy. This is due to the skepticism on the use of night ventilation, shading, evaporative cooling etc. The earliest methods of space cooling during dry season was discussed by Bahadori in 1978 [6] and the summary of the state-of-the-art of passive cooling systems was provided by Givoni in 1991[7]. Study also shows that in India larger parts of the central and northern regions including New Delhi experience mixed climates such as hot – humid, hot – dry and cold climate systems. Attempt to implement passive cooling in the city buildings in New Delhi was made in 1990's but limited literature is found related to this study [8]. Ventilation by using natural draft system is one of the passive cooling techniques used for space cooling initially [9 - 10]. Introduction of modern science and technology has significant changes in the controlling of indoor environment of commercial and residential buildings. Passive cooling system is also closely related to thermal comfort of occupants of the building. Although some of the passive cooling techniques do not help to remove the cooling load significantly it does extend the tolerance of humans to achieve thermal comfort in a given space. Thermal comfort for the building can also be achieved by controlling the climate of the building, changing the site design, introducing thermal insulation, changing the behavior of the occupant, preventing the heat

gains from internal sources. A hybrid system, by a combination of natural convection cooling and cooling system with evaporative cooler can prevent heating of the building as well as enhance the cooling efficiency to improve thermal comfort conditions in buildings [11-15]. In this paper a solar chimney-driven passive cooling system capable of enhancing ventilation above normal natural draft system is discussed for providing thermal comfort conditions inside a building throughout the summer season in hot and humid climates.

## 2.0 Methodology

Fig.1 shows the model of the passive solar ventilation and cooling system consisting of a solar chimney or solar air heater or simply a mechanical ventilator system. The model is developed in the laboratory of the Mechanical Engineering Department at Khulna University of Engineering and Technology (KUET) Bangladesh. In the solar passive cooling model (Figure 1), solar air heater with chimney is used to enhance the suction of the hot air from the space during day time. At bottom, a water tank is used as evaporative cooler. A circular copper tube is used as inlet duct which is completely immersed in the water tank. The whole system worked as a heat exchanger. Thermal energy was transferred from the hot air to the cold water. The evaporative cooler was insulated to protect heat transfer from ambient air and was shaded to protect radiation absorption.

## 3.0 Design

### 3.1 Modification of Room for Thermal Load Reduction:

The physical dimension (*long × wide × high*) of the existing single room was approximately  $150\text{ cm} \times 120\text{ cm} \times 90\text{ cm}$ .

The longer side of the room was aligned to the east-west direction. Thirteen centimeter wide bricks were used to build surrounding walls with a reinforced concrete slab of 10 cm thickness. A wooden door of about  $60\text{ cm}^2$  face area was used in the north facing wall. After completing the construction of the room, ambient and room temperatures were measured and found to differ by  $5^{\circ}\text{C}$ .

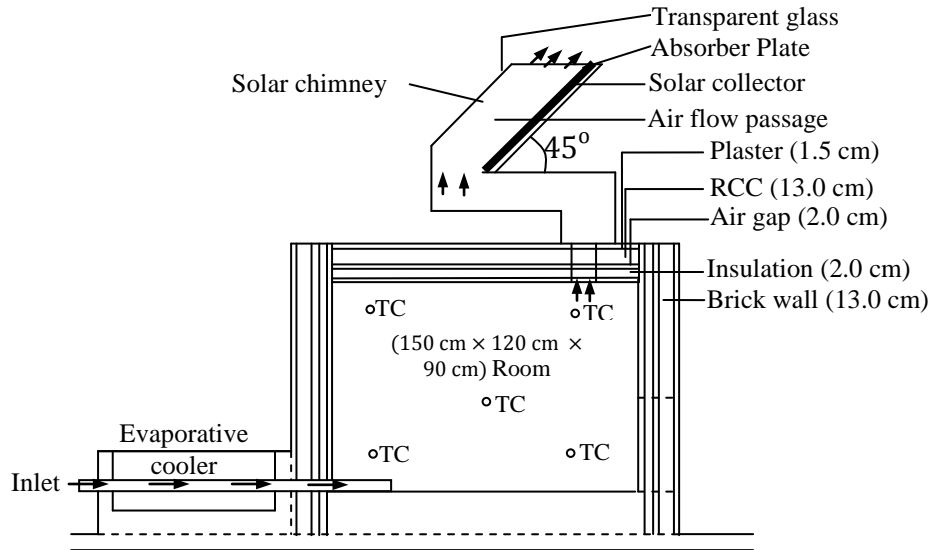


Fig. 1: Cross-sectional View of Solar Passive Model

The above mentioned passive cooling system used a natural draft solar chimney which had a solar heat collector and a transparent glass. In the solar chimney, the solar energy was absorbed by the solar collector and transferred to the adjacent air. The stack effect caused air flow through the solar chimney. Air flow rate in a normal solar chimney may reduce due to cross wind and flow reversal [16]. To overcome this problem, the chimney was installed on a base opposite to the air flow direction. Solar chimney was also placed at  $45^\circ$  to the horizontal axis, to receive maximum sunlight during day time.

### 3.2 Solar Chimney

In the solar passive cooling system, the solar chimney was fabricated with mild steel sheet. The dimensions of the solar chimney were  $130 \text{ cm} \times 120 \text{ cm}$  (length  $\times$  width). Glass wool insulation was used at the bottom and at the sides. The solar chimney was installed to face north, where the open loop system was set with a tilt of  $45^\circ$  from the horizontal, having an air flow passage above the absorber plate.

### 3.3 Evaporative Cooler

An insulated water tank was used as evaporative cooler. A 7.5 cm diameter copper pipe was immersed in the water and was used as the inlet of the solar passive model room. Water of the tank exposed to the ambient air evaporated and cooled. Warm fresh air passing through the copper tube transferred heat to the water and air and water became cool compared to ambient air, subsequently this cooled air would reduce the room temperature.

### 4.0 Performance Analysis

An ordinary room with the same physical dimensions as the solar passive model room and without solar chimney is selected as the reference room. The room temperature was collected from 21<sup>st</sup> to 25<sup>th</sup> May, 2014 and presented in the Figure 2. It was found that, the solar chimney passive cooling model room was able to maintain the temperature at about  $4^\circ \text{C}$  to  $5^\circ \text{C}$  below the outside ambient temperature and at about  $2^\circ \text{C}$  to  $3^\circ \text{C}$  below the reference room temperature.

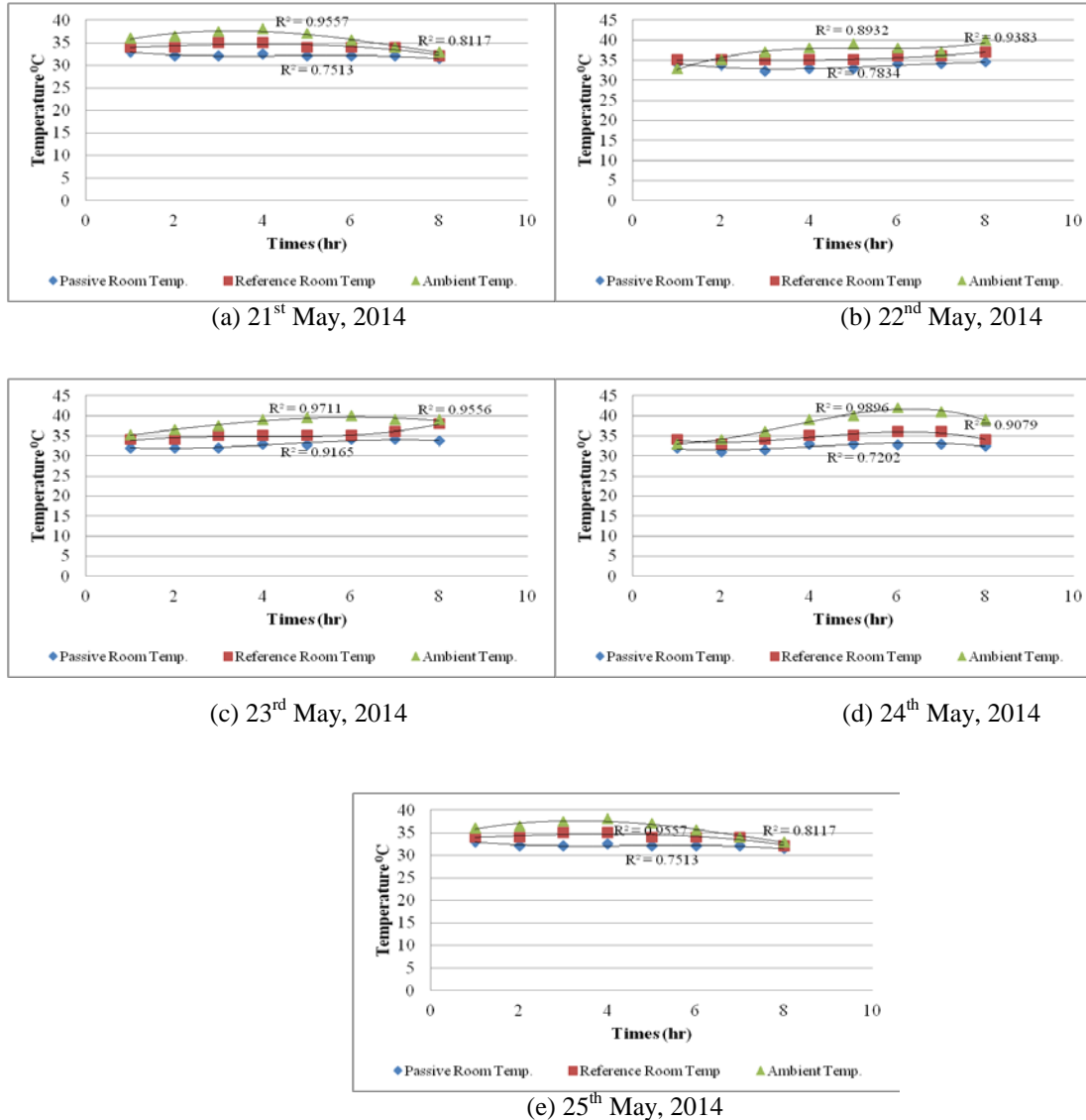


Fig.2: Variation in Temperature between Passive Room, Reference Room and Ambient Atmosphere

Cheikh and Bouchair in 2008 also developed a passive cooling system for house by introducing a passive cooling roof and were able to lower the temperature about 6°C to 10°C than ambient. The passive cooling roof was fabricated with steel structure, rocks and a water bed which was costly in comparison with brick structure [17]. Raman *et al.* in 2001 also used solar chimney with evaporative cooling system and found that during hot – dry months (April – July), the experimental room temperature was 2°C -3°C

less than the room without passive cooling system [8]. Typical ambient temperature during these times is varied from 30°C to 42°C. The comfortable room temperature was about 22°C therefore it cannot be concluded that the above described passive cooling system performances were satisfactory but that it could reduce indoor room temperature significantly. Cubic polynomial curves were obtained for the passive cooling room, reference room and ambient temperature by using least-squares

regression analysis from Microsoft Excel. All curves had good fit with data points. Among all the curves, the passive cooling room temperature curve shows weak relation with data. This is because solar chimney and evaporative cooler might have enhanced ventilation and cooling rate therefore time had very little effect on passive cooling room temperature. The data also indicate that the passive cooling room temperature was significantly below the reference room temperature.

## 5.0 Discussion

The main components of solar passive system are solar chimney, evaporative cooler and additional wall insulation described in this paper. The solar passive system showed good performance for providing thermal comfort during hot climate. It also had the ability to reduce the air conditioning load of buildings during summer and able to reduce the extensive use of electrical cooling appliances. Solar passive cooling system performance data were taken for an empty room. It must be borne in mind that human activity, appliances, metabolism etc. may alter the performance of solar passive system. In addition the performance of solar chimney may decrease due to back flow, cross wind etc. that may change also the performance of solar passive system.

## 6.0 Conclusion

A passive solar system for cooling, de-humidification and ventilation during hot environment has been tested on an experimental room with modified structure. The investigation has confirmed the effectiveness of passive cooling system in comparison to a reference room. The results show that cooling inside buildings can be enhanced by changing the design of the building to include a solar chimney for natural draft ventilation. By installing solar chimney, evaporative cooler and wall insulation, it is estimated to increase the cost by about 10 per cent of the cost of a conventional room. Therefore, the described passive cooling system with effective modified chimney seems to have

very good potential value in terms of economy and also technological point of view.

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