Experimental Studies of a Passive Cooling Roof in Hot Arid Areas

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Abstract

An experimental study of passive cooling roof was carried out for a typical summer day of June for Laghouat in Algeria. The proposed roof design is composed of a metal plate ceiling over which lies a bed of rocks in a water pool. Over this bed is an air gap separated from the external environment by an aluminium plate. The upper surface of this plate is painted with a white titanium-based pigment to increase the radiation reflection process during daytime. Several passive modifications have been introduced to the roof in order to reduce indoor air temperature in hot climates. An experimental investigation, employing passive procedure, has been carried out to study the possibility of reducing air temperature in buildings. The results show that the air temperature can decrease with a range from 6 to 10°C. This decrease can further be lowered by 2 to 3°C if night natural ventilation of buildings is allowed.

Keywords: Evaporative cooling; Evapo-reflective; Roof; Hot dry climate; Night ventilation.
1 Introduction

In regions with arid climates such as Laghouat in southern Algeria, excessive heat is the major problem that causes human thermal discomfort, as concluded Bencheikh & Bouchair (2004). Cooling is then the basic requirement of building occupants. In modern buildings, this can be provided by mechanical and electrical instruments. Traditional architecture in hot climate had many passive aspects which contributed to thermal comfort in dwellings, such as, compact urban heavy building structure, white painted external surfaces, blind facades, open courtyards, etc. The presence of trees, vegetation and water around the building in modifying the thermal microclimate was well appreciated. With the advent of energy crisis there has been a renewed interest in those aspects of architecture which contributed to thermal comfort in a building without or with minimum energy consumption, Bouchair (1989, 2003, 2004). Unlike rural areas, where the building is most exposed to external environment via its facades and roof, in urban area the most exposed part of the building to radiation and winds is the roof as shown in Fig. 1 In many studies such as Runsheng, Etzion, and Erell (2003), Jain (2006) and Amer (2006) show that the heat gain through the roof present 50% of the total heat gain in buildings.

In recent years, several investigations done by Verma, Bansal, and Garg (1986) were performed and showed that there can be multiple solutions to the excessive heat problem through the roof. The use of low emissivity material in the attic of a building reduced the underside ceiling surface temperature, which lowered the room air temperature, Nahar, Sharma, Purohit (2003). The evaporative cooling approach for passive cooling of buildings in hot arid climates has also become an attractive subject of investigation for many researchers. The relative advantages of evaporative cooling in relation to many other approaches (cavity wall, insulation, whitewash and large exposure orientations, vegetable pergola shading, roof with removable canvas, water film, soil humid grass and roof with white pots as cover) were demonstrated in R. Lambert (1988). The reduction of heat gain through the roofs using evaporative cooling systems was extensively investigated with open roof ponds by Nayak, Srivastava, Singh, Sodha (1982), Sodha, Singh, Tiwari (1980), on water spraying over the roof, moving water layer over the roof, thin water film and roofs with wetted gunny bags Sodha, Srivastava, Kumar, Tiwari (1980) . Chandra and Chandra (1983) have developed a periodic heat transfer model to study the effects of evaporative cooling using water spray and variable ventilation on the temperature control of a non-air-conditioned building.
The present study suggests an improved roof design by combining the advantages of the previously described cooling techniques (water ponds, low emissivity surfaces) and inserted rocks of high thermal capacity. The resulting design can be more advantageous and effective than other systems for reducing heat during daytime and storing coolness at night. High thermal capacity materials (rock bed) will delay the entry of daytime heat into the building by such a period that it reaches the interior during the evening, when it is least bothersome and often welcome. The roof is composed of steel plate ceiling and a flat aluminium plate separated by an air space partially filled with high thermal capacity rocks placed in a small quantity of water. The system is properly closed to prevent water vapour escaping outside. A schematic diagram of the model design is shown in Fig. 2.

The choice of the roof for our investigation comes from the fact that 50% heat load passes through it. The reduction of heat transmission via the roof was investigated for a typical summer day of June for Laghouat in Algeria (Latitude 33.43°N, Longitude 2.56 E). Theoretical results presented Ben Cheikh H. Bouchair A (2003) shows that the most significant factors affecting the cooling power of the passive cooling roof were the rocks, water volume, aluminium roof thickness and roof air space width. The rocks water volume was 6.5 litres. The weight of the rocks was 65kg. The width of the air gap was variable from 17cm to 27cm.
Figure 2: A schematic diagram of the model design.

Abbreviations
- $T_{ae}$ = Outside air temperature ($^\circ$C), $T_{ai}$ = Inside air temperature ($^\circ$C)
- $Q_{rav}$ = Heat change by radiations between the roof and the sky (w)
- $Q_{cae}$ = Heat change by convections between the roof and the outside air temperature $T_{ae}$ (w)
- $Q_{rs}$ = Heat gain from solar radiations (w)
- $W_{s}$ = Heat change by condensation (w)
- $W_{e}$ = Heat change by evaporation (w)
- $Q_{rga}$ = Heat change by radiations between the roof and rocks water upper surface (w)
- $Q_{edy}$ = Heat change by conduction between rocks (w)
- $Q_{cga}$ = Heat change by convection between the air and rocks water upper surface (w)
- $Q_{rti}$ = Heat change by radiations between the inside wall surfaces and the roof inside surface (w)
- $Q_{eti}$ = Heat change by convection between the inside air and the roof inside surface (w)
- $G_{vdt}$ = Heat change between $T_{ai}$ and $T_{ae}$, through exterior walls and by natural ventilation (w)
2 Experimental Measurements

Field measurements were conducted at Laghouat University. The experimental set-up consisted of two identical test cells (A) and (B) fabricated of steel structure, each having dimensions (0.70 X0.7 X 0.90 m). Figure 3 shows the configuration of tested cells. The experimental cell (A), is made of metal frame of (0.70 X0.7 X 0.90 m) interior edge, all sides were strongly insulated by 4 cm thick polystyrene except the roof. The cell was elevated by 50 cm above the ground using four metal supports as shown in Fig. 3. In the North wall a steel door of 30cm x 60 cm dimensions upon which a 4 cm thick extruded polystyrene foam panel was fixed. In the south wall a window of 35 cm x 37 cm dimensions, plastic netting, of fine meshes was fixed on the window exterior face, to limits the transmission of the solar radiation Fig. 3. The door and the window are used two allow night natural ventilation. The experimental cell (B) was the basic reference unit. The roof was constructed of simple aluminium sheet painted white (Fig. 4).
3 Temperature Measurements

Air temperatures outside the room were measured using a meteorological station installed near the laboratory, far from the test cell by 150m. The temperature at different positions under the roof level has been measured by copper constant thermocouples connected to digital thermometer. Thermocouples fixed under the roof surface the end of the thermocouples were enveloped in thin aluminium paper to reflect the radiation from the surrounding interior surfaces. The readings of all thermocouples have been averaged to give the average temperature.

4 Results and Discussion

Hourly variations of the inside air temperature for typical summer day by using evaporative reflective roof measured and presented in Fig. 5, for different values of air gap width (17, 22 and 27 cm). The ambient air temperature is also given in these figures to observe the effective cooling. Roof without any treatment gives the maximum inside air temperature (48°C) when the ambient air temperature was 38.5°C during day hours. However during night hours the inside air temperature fall down to the ambient air temperature. Roof with evaporative reflective roof, when the air gap width fixed at 17cm gives higher inside air temperature (42.5°C) than 22 cm air gap by two degree (40.5°C), 27 cm air gap in the roof gives the same inside air temperature as the 22 cm air gap, that means the optimum air gap is 22 cm. Fig. 6. shows a comparison of room air temperatures with cooling roof system and with bare roof without room night natural ventilation. It can be seen from this figure that the evaporative reflective roof can reduce the internal room air temperatures during the day up to 10°C in comparison to the air temperatures for a bare roof over the room. Fig. 7. is the comparison of room air temperatures with cooling roof system and with bare roof when room night natural ventilation is allowed. The ventilation was allowed from 8 pm till 9 am, a period when the outside air temperature is relatively low. This can significantly improve cooling of room air temperatures, as shown in Fig 5.
Figure 5. Comparison of measured room air temperature when roof system is functioning and when the roof is bare (for ventilated and non-ventilated cases for variable air gap dimensions).

Figure 6. Comparison of room air temperature when roof system is functioning and with bare roof (without ventilate).
Figure 7. Comparison of room air temperature when roof system is functioning and with bare roof (with ventilate).

Fig. 8. Comparison of room air temperature when roof system is functioning for ventilated and non ventilated cases.
5 Conclusion

Under hot arid conditions a prototype model for an evaporative reflective roof used to improve space cooling in buildings has been tested. The experimental results examined the effectiveness of such a roof cooling system in comparison to a bare roof. The results showed that cooling inside buildings can be improved by the application of such a cooling design. It was also seen that combining evaporative reflective roof with night ventilation increases such cooling more significantly. From the previous graphs the cooling system had a great effect on the time lag and decrement factor, it increases the time lag so the maximum outside temperature accurs at 15pm, where the inside maximum at 18 30pm at these time the outside temperature was acceptable, which improve the inside comfort in buildings during day times and reduces the cooling load which the energy consumption.

References


