

Experimental studies of a passive cooling roof in hot arid areas

H. Ben Cheikh¹ and A. Bouchair²

¹ Département d'Architecture, Amar Tiliidji University, Laghouat, Algeria

² Laboratoire de Recherche Cadre Bâti et Environnement, 'LRBCE'
Département d'Architecture, Faculté des Sciences de l'Ingénieur,
Abdelhak Benhamouda University, Jijel, Algeria

(reçu le 20 Novembre 2008 – accepté le 25 Décembre 2008)

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.*

Résumé – *Une étude expérimentale a été faite sur un système de refroidissement passif utilisant une toiture réflective-évaporative pour une journée d'été en Juin dans la région de Laghouat en Algérie. Le système étudié est composé d'une enceinte métallique étanche dans laquelle sont déposés des galets insérés dans une mare d'eau, la face supérieure de l'enceinte est recouverte par une tôle en aluminium peinte blanche pour augmenter la réflexion des rayons solaires au maximum, un vide d'air sépare la surface supérieure des galets et le couvercle. Plusieurs combinaisons de ce système passif ont été expérimentées dans l'ordre de diminution de la température intérieure dans les climats arides. Des investigations expérimentales sur le système ont été étudiées. Les résultats montrent que la température de l'air intérieur peut être réduite de l'ordre de 6 à 10 °C. Cette réduction peut être augmentée par 2 à 3 °C en utilisant la ventilation naturelle nocturne.*

Keywords: Evaporative cooling – Evaporative 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 [1]. 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, ie, 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 [2-4].

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 figure 1. In many studies [1, 5, 6, 7] the heat gain through the roof present 50 % of the total heat gain in buildings.

In recent years, several investigations were performed and showed that there can be multiple solutions to the excessive heat problem through the roof [3, 8, 10]. The use of low emissivity material in the attic of a building reduced the underside ceiling surface temperature, which lowered the room air temperature [8].

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 [9, 10].

The reduction of heat gain through the roofs using evaporative cooling systems was extensively investigated with open roof ponds [11, 12], on water spraying over the roof, moving water layer over the roof, thin water film and roofs with wetted gunny bags [13, 14].

Chandra and Chandra [13] 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.



Fig. 1: Roofs exposed to solar radiations

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 figure 2.

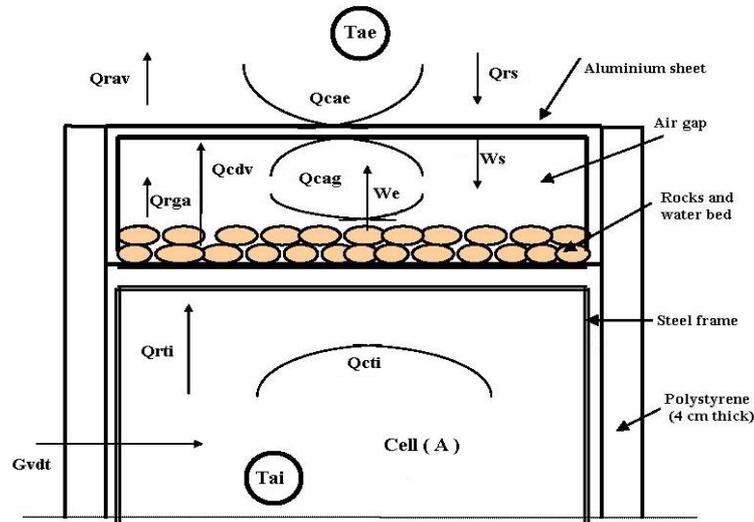


Fig. 2: A schematic diagram of the model design

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 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 [1]. The rocks water volume was 6.5 litres. The weight of the rocks was 65 kg. The width of the air gap was variable from 17 cm to 27 cm.

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 x 0.7 x 0.90) m³. Figure 3 shows the configuration of tested cells.

The experimental cell (A), is made of metal frame of (0.70 x 0.7 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 figure 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).



Fig. 3: The experimental cell



Fig. 4: The evapo- reflective roof

3. TEMPERATURE MEASUREMENTS

Air temperatures outside the room were measured using a mythological station installed near the laboratory, far from the test cell by 150 m.

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 figure 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 17 cm 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.

Figure 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.

Figure 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 figure 8.

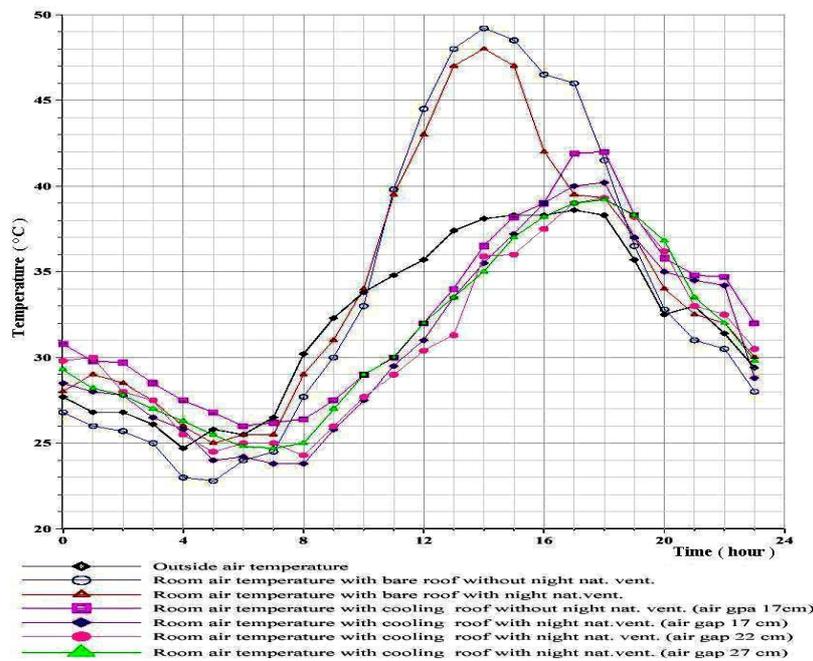


Fig. 5: Comparison of measured room air temperature when roof system is functioning and when the roof is bare (for ventilated and non ventilated cases for variable air gap dimensions)

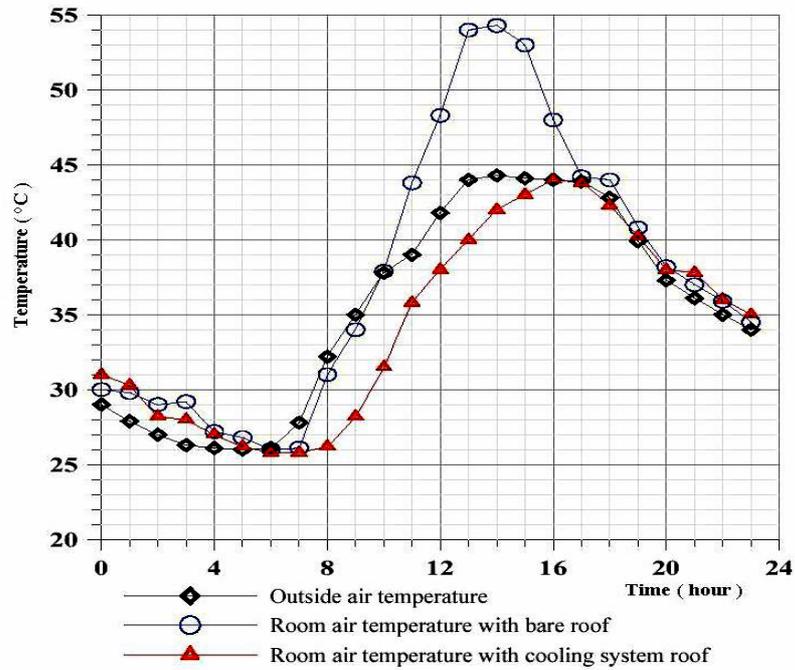


Fig. 6: Comparison of room air temperature when roof system is functioning and with bare roof (without ventilate)

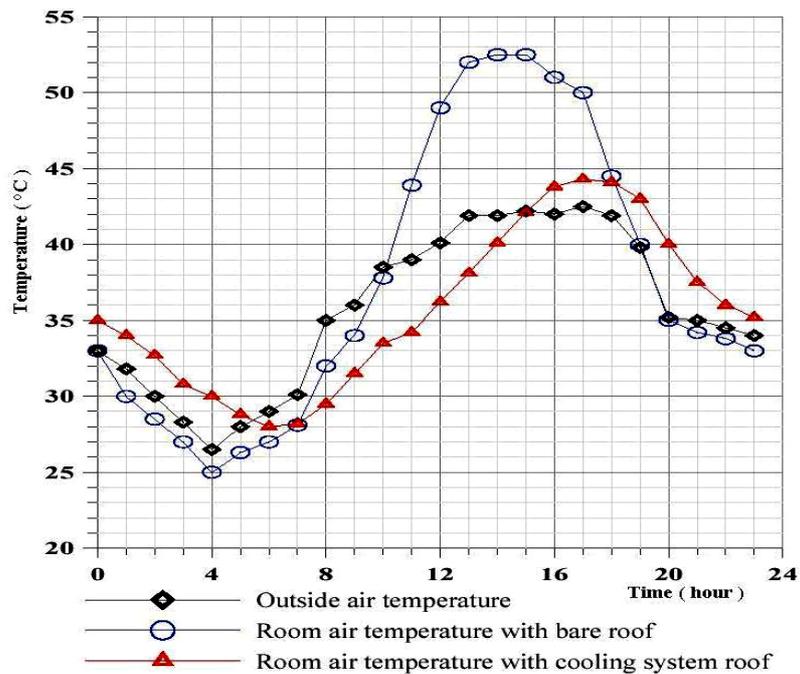


Fig . 7: Comparison of room air temperature when roof system is functioning and with bare roof (with ventilate)

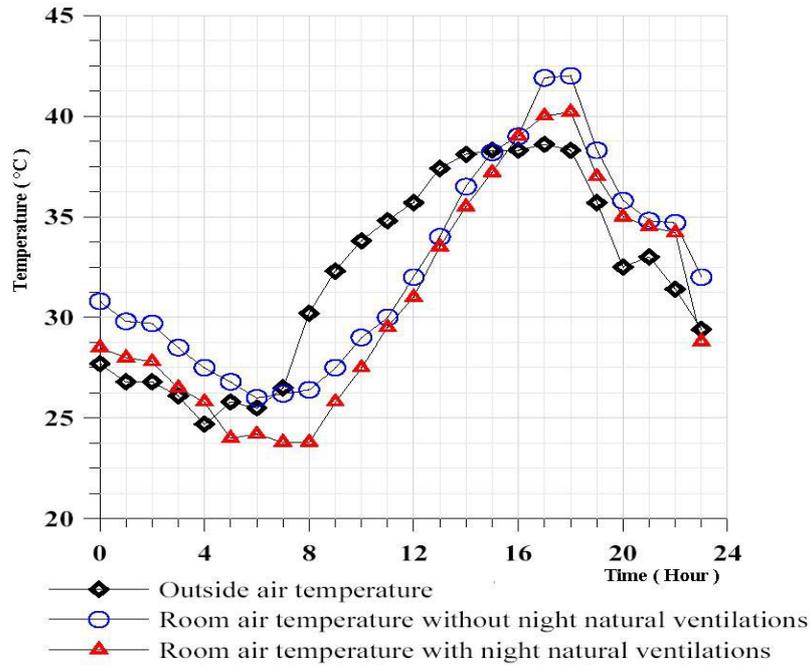


Fig. 8: Comparison of room air temperature when roof system is functioning for ventilated and non ventilated cases

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.

NOMENCLATURE

T_{ae} : Outside air temperature (°C)

T_{ai} : Inside air temperature (°C)

Q_{rav} : Heat change by radiations between the roof and the sky

Q_{cae} : Heat change by convections between the roof and the outside air temperature

Q_{rs} : Heat gain from solar radiations

W_s : Heat change by condensation

W_e : Heat change by evaporation

Q_{rga} : Heat change by radiations between the roof and rocks water upper surface

Q_{cdv} : Heat change by conduction between rocks

Q_{cga} : Heat change by convection between the air and rocks water upper surface

Qrti : Heat change by radiations between the inside wall surfaces and the roof inside surface
 Qcti : Heat change by convection between the inside air and the roof inside surface
 Gvdt : Heat change between Tai and Tae , through exterior walls and by natural ventilation.

REFERENCES

- [1] H. Ben Cheikh and A. Bouchair, '*Passive Cooling by Evapo-Reflective Roof for Hot Dry Climates*', Renewable Energy, Vol. 29, pp. 1877 – 1886, 2003.
- [2] A. Bouchair, '*Solar Induced Ventilation in the Algerian and Similar Climates*', PhD thesis, University of Leeds, UK, 1989.
- [3] A. Bouchair, '*Decline of Urban Ecosystem of Mzab Valley*', Building and Environment, Vol. 36, N°4, pp. 719 – 732, 2004.
- [4] A. Bouchair and A. Dupagne, '*Building Traditions of Mzab Facing the Challenges of Reshaping of its Built Form and Society*', Building and Environment, Vol. 38, N°11, pp. 1345 – 1364, 2003.
- [5] T. Runsheng, Y. Etzion and E. Erell, '*Experimental Studies on a Novel Roof Pond Configuration for the Cooling of Buildings*', Building and Environment, Vol. 28, pp. 1513 – 1522, 2003.
- [6] D. Jain, '*Modelling of Solar Passive Techniques for Roof Cooling in Arid Regions*', Building and Environment, Vol. 41, pp. 277 – 287, 2006.
- [7] E.H. Amer, '*Passive Options for Solar Cooling of Buildings in Arid Areas*', Energy, Vol. 31, pp. 1332 – 1344, 2006.
- [8] N.M. Nahar, P. Sharma and M.M. Purohit, '*Performance of Different Passive Techniques for Cooling of Buildings in Arid Regions*', Building and Environment, Vol. 38, pp. 109 – 116, 2003.
- [9] R. Lambert, '*Heat Transfer Through Roofs of Low Cost Brazilian Houses*'. PhD Thesis. UK, University of Leeds, 1988.
- [10] R. Verma, N.K. Bansal and H.P. Garg, '*The Comparative Performance of Different Approaches to Passive Cooling*', Building and Environment, Vol. 21, N°2, pp. 65 – 69, 1986.
- [11] J.K. Nayak, A. Srivastava, U. Singh and M.S. Sodha, '*The Relative Performance of Different Approaches to Passive Cooling of Roofs*', Building and Environment, Vol. 17, N°2, pp. 145 – 161, 1982.
- [12] M.S. Sodha, U. Singh and G.N. Tiwari, '*Periodic Theory of an Open Roof Pond*', Applied Energy, Vol. 7, N°4, p. 307, 1980.
- [13] S. Chandra and S. Chandra, '*Temperature Control in a Building with Evaporative Cooling and Variable Ventilation*', Solar Energy, Vol. 30, N°4, pp. 381 – 387, 1983.
- [14] M.S. Sodha, A. Srivastava, A. Kumar and G.N. Tiwari, '*Heating and Cooling of a Building by Flow of Water over the Roof*', Applied Energy, Vol. 7, N°1, p. 229, 1980.