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Study passive evaporative cooling technique on the water-retaining roof brick

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Abstract

This paper introduces a new method water-retaining roof brick to reduce the energy cooling load in meeting people’s comfort demands in hot seasons. An experimental model of passive evaporation is designed in order to explore a complete heat transfer process law of water-retaining brick in hot summer and cold winter region. The result of using a flat roof with water-retaining brick shows a drop of 1.9℃ in the indoor temperature in summer compared to the base case of the conventional flat roof in residential buildings. In addition, the results indicate the cooling load required for the building will decrease after using water-retaining bricks on roof and also using the radiation shield on roof. The best solution to increase the indoor thermal comfort is water-retaining brick rather than roof with shield, because the evaporation process plays a supporting role to ease the city heat island effect. Thus, it’s the most optimal scheme.

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Keywords: passive evaporative cooling; building roof cooling; water-retaining brick; radiation shield roof

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1. Introduction

Over-consumption of conventional fossil fuel resources, economic and environmental problems associated with the global warming, and climate variation have emphasized the urgency of transiting to renewable energy resources[1]. There is a need for energy conservation and transformation through improving existing buildings' roofs. A great number of buildings are involved. Therefore, this will be significant in energy conservation. The roof

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receives the strongest direct radiation from the sun for the longest time compared with other parts of a building, about 40% of the heat gain in top floor rooms comes through the roof [2]. In addition, controlling the increase of urban surface temperatures is one of the most important strategies for relieving the urban heat island effect. From the aspect of saving energy, as a passive cooling method, positive application of materials with evaporative cooling effect to the urban surface has become a great concern in the urban environmental design[3]. Therefore, using the principles of evaporation cooling, heat preservation and heat insulation in roof renovations will not only improve the quality of the indoor environment, but also effectively relieve the urban heat island effect.

As for different elements of building envelope, roof is believed to be the most important in developing passive measures [4]. Ineffective roofing insulation usually leads to bad thermal environment in top floor apartment. Accordingly, building heating and air-conditioning load is significantly higher than level required in the design standard. Indoor heat loss from the roof in winter is the main factor influencing the room air conditioning or heating system energy consumption, and induces obvious impact on indoor thermal comfort of the top-floor room[5-8]. Using water as an ideal thermal mass (because of its large volumetric heat capacity and low-cost and nontoxic[9]), roof ponds can provide passive heating and cooling. Harold Hay and his colleagues put forward the idea of creating roof pond system in late 1960s [10,11], a vast body of work has been published on design and performance of different types of roof ponds. Literatures show that Hay and Yellott [12] developed Sky-therm (insulation panels opened during daytime to absorb solar heat and closed at night to prevent heat loss) as a system to be used in the arid conditions. Results achieved from their experiments showed that the system can provide comfort conditions for non-freezing conditions. and Raeissi and Taheri [13]compared winter performances of a bare roof and two types of Sky-therm (metal and concrete deck) under the arid climatic conditions Both variants can significantly reduce heating load in winter. Roof-integrated water solar collector system has a structure similar to that of Skytherm and was developed by Juanico [14]. Although not completely passive, roof-integrated water solar collector can work better than Skytherm. Walkable pond with water spraying system which water is sprayed over the tiles in the daylight time to absorb heat, which is then stored in the water pond below the insulation layer. The stored heat is then transferred to the indoor environment[15]. Experimental study by Kaushik showed that roof pond is always exposed to the environment and can provide limited heating benefits[16].

This study will cover the use of water-retaining bricks on the roof and the controlled unit without any handling and their comparative performance has been studied and described in this paper. The purpose of this study is to reduce heat load from the roof by identifying suitable passive techniques for cooling of buildings with water-retaining brick.

2.Experimental method

In this paper, the research team developed a water-retaining brick, through which rainwater is stored to provide cooling capability in summer and provide heat preservation in winter. At the same time, the evaporation of the water in brick can relieve the heat island effect in urban district[17-18]. Water-retaining roof brick dimension:300mmX300mmX240mm; the height of the air layer between the brick bottom and the roof is 20mm; maximum water depth: 120mm; roof brick thickness is 20mm; the hole area ratio is 20%. The brick structure and mass transfer mechanism is shown as Fig.1.

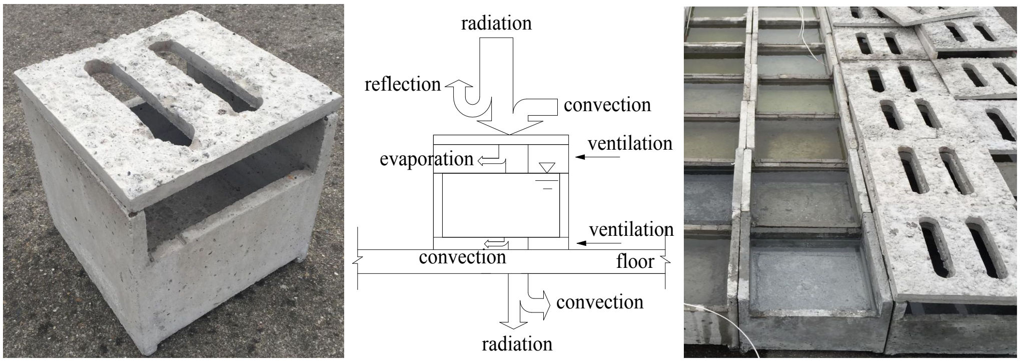
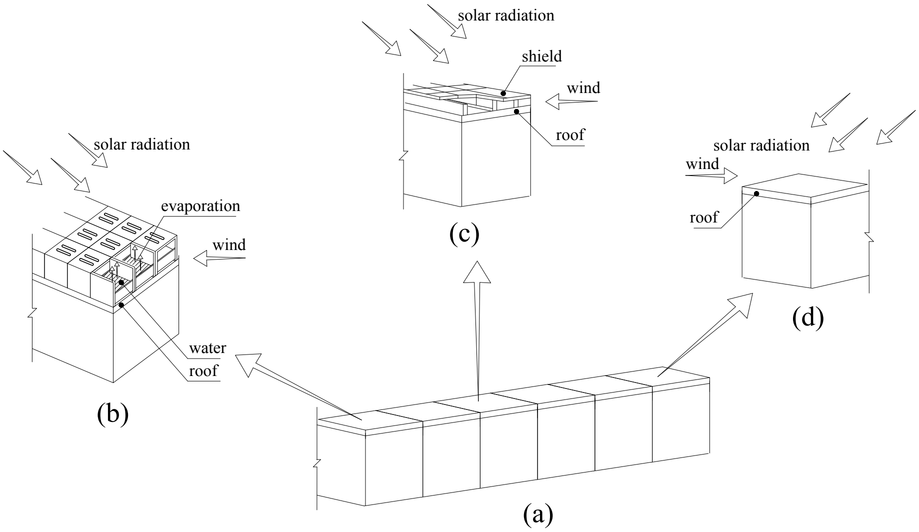
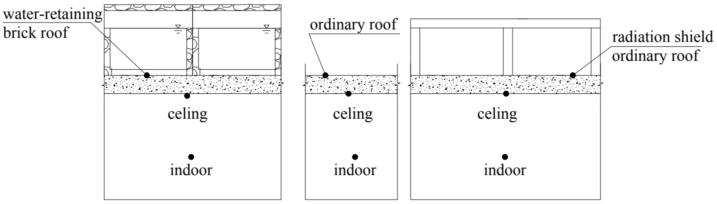


Fig. 1. The brick structure and mass transfer mechanism.

A typical dormitory was selected in Mianyang, China and tested in three different configurations including roof with water-retaining brick, roof with a radiation shield and an ordinary roof. Mianyang is located in southwest part of China (latitude 103°45′~105°43 and longitude 30°42′~33°03′). The summer ambient temperature in Mianyang reaches up to 36.1~39.5℃. A schematic of the dormitories and the passive cooling approaches of the experimental arrangement are shown in Fig.2(a-d) and the experiment measuring point distribution is show in Fig.2(e). Test equipment and operating methods are as follows:

For total solar radiation intensity, outdoor wind velocity, outdoor air temperature, and relative humidity of outdoor air testing, we used the products of Mianzhou Sunshine Meteorological Science and Technology Inc., that is PC-4 type of environment monitoring system, to monitor the sensitivity of ±0.2% ℃, recorded once per hour. Each measuring point temperature was tested with Shanghai ZhaoJie paperless recorder C6108A, accuracy ±0.2% FS, and recorded once every 4 minutes. This paper uses the hourly data to draw the chart of the trend of temperature changes. And The experiment started on November 5th 2014 and finished on February 28th 2016. We selected test data obtained in consecutive sunny days: in summer: test from July 28th 2015 to August 26th; In Winter： test from January 20th 2016 to February 23th; and from January 16th 2015 to January 18th 2015.





(e)

Fig. 2. Schematic representation of (a) the experimental layout, (b) a roof with water-retaining brick, (c) a roof with a radiation shield, (d) an ordinary roof without any passive cooling. (e) experiment measuring point distribution.

3.Results and discussion

3.1 Performance of roof with water-retaining

The ambient temperatures inside test dormitories were measured in a whole day and the diurnal variation is shown in Fig.3 for a sunny summer day. The different meteorological parameters are shown in Table 1. From Fig.3, it is clear that the drop in roof and ambient temperature inside test structures handled with water-retaining bricks over the roof. Table.1 shows already roof of dormitory has been provided with water-retaining bricks and average 9.94 ℃ fall in roof temperature has been observed as compared to a regular roof without any treatment. Thus, water-retaining bricks over the roof can reduce heat load from the roof and cool the temperature inside the building.

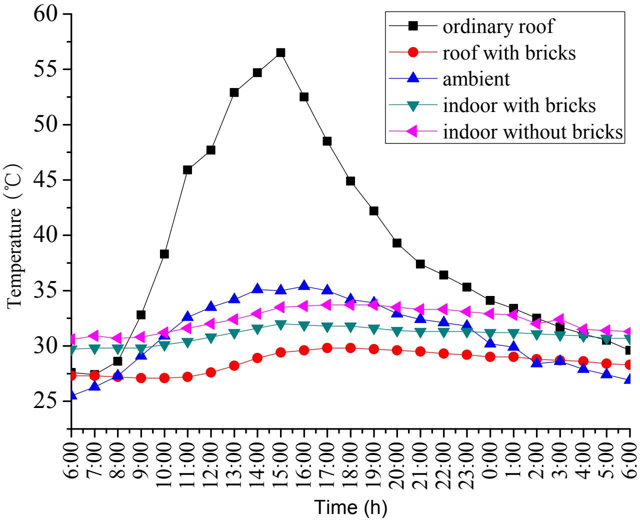


Fig. 3. Diurnal variations in temperatures

Table 1.The different meteorological parameters.

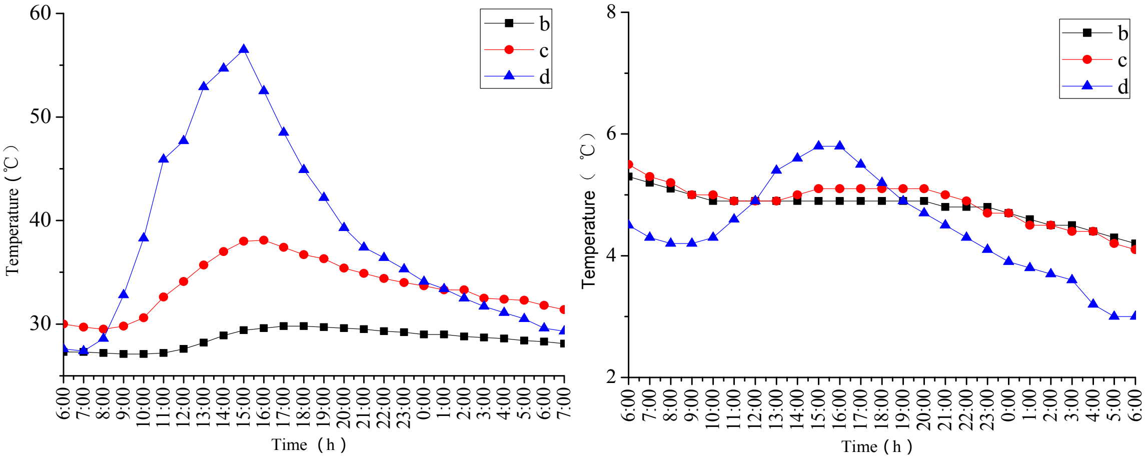
Item	average	Min	Max
Ambient Temperature (℃)	31.06	25.5	35.4
Relative humidity(%)	62.40	41.0	86.4
Ordinary roof temperature (℃)	38.50	27.4	56.5
Roof temperature with bricks (℃)	28.56	27.1	29.8
Indoor temperature with bricks（℃）	30.95	29.7	32
Indoor temperature without bricks（℃）	32.30	30.6	33.7

3.2.Comparison of performance between roof with a radiation shield and water-retaining bricks

The studies have been carried out under the same condition. The diurnal variations of the temperatures tested inside and outside of the dormitories equipped with on-roof water-retaining bricks, an on-roof radiation shield and ordinary roof are shown in Figs.4-6. As can be seen, the ordinary roof temperature increases gradually from morning to afternoon, because both increases in ambient and the solar irradiance received through the roof. It is clear that the most fall in roof temperature is treated with water-retaining bricks over the roof in summer.

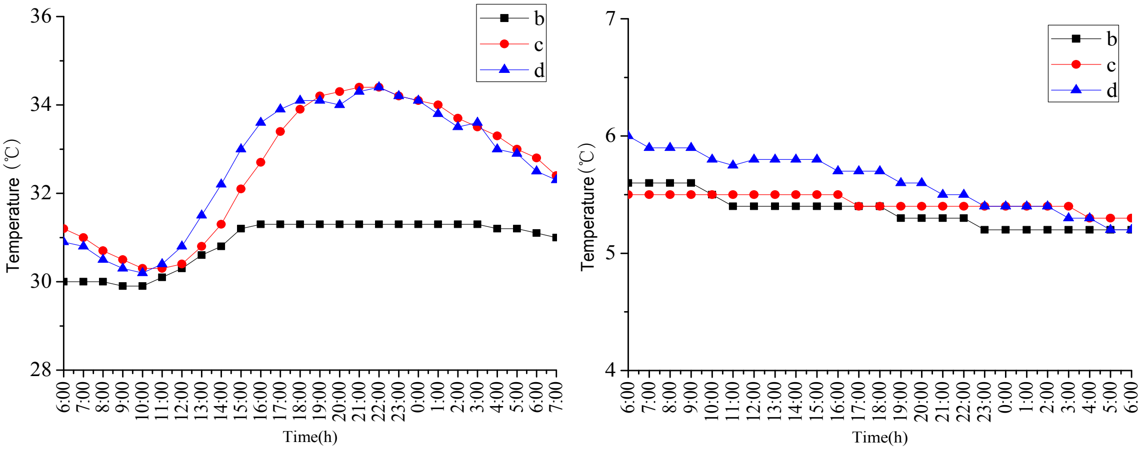
Fig.6 compares the variations of the temperatures inside the dormitories using the same ambient conditions under various types of passive cooling approaches in the same day, with those of the ordinary roof. As expected, the application of the passive cooling methods lowers the temperature inside the dormitories in summer when compared to that of the dormitories with an ordinary roof, which is consistent with the results of previous works[19]. For instance, the indoor temperature with an ordinary roof is 33.7℃ at 16:00, but it is 31.8℃ and 31.7℃ for the house with water-retaining bricks on roof and a radiation shield, at the same time. The test results also show that application of water-retaining bricks on roof is less effective in the morning than in the afternoon. For example, the temperature inside the dormitory decreases by about 3.5% at 9:00 while it just reduces by approximately 5.6% at 17:00, when using water-retaining bricks on roof. This is because of the roof's higher thermal mass, due to the presence of water-retaining bricks on it and more water evaporate in the early afternoon than the rest of the day. The results also show that the performance of the over-roof water-retaining bricks and on-root radiation shield are relatively the same in terms of the temperature inside the building, while, the application of the water-retaining over roof results in lower temperatures inside the building. For example, the temperature inside the building rises from 31.6℃with water-retaining bricks to 32 ℃ with radiation shield. This is because the water-retaining bricks intercept solar radiation and dissipate part of it through evaporation, convection and nocturnal radiation.This shows that in general the best cooling performance within the dormitories can be obtained through using the water-retaining bricks on roof. Note that this would be achieved at the cost of using more water, but the water can come from rainwater. Thus,it recommends that the best solution to increase the indoor thermal comfort is water-retaining bricks rather than roof with shield, because the evaporation process plays a supporting role to ease the city heat island effect. Note: b-roof has water-retaining bricks, c-roof has radiation shield, d-ordinary roof.

Test results also show that application of on-roof water-retaining bricks and an on-roof radiation shield are less effective in winter. For example, the average temperature inside the dormitories decreases from 5.65 ℃ to 5.36℃ with water-retaining bricks and 5.48 ℃ with radiation shield. This shows that the best thermal insulation performance within the dormitories can not be obtained through the application of the water-retaining bricks on roof in winter.



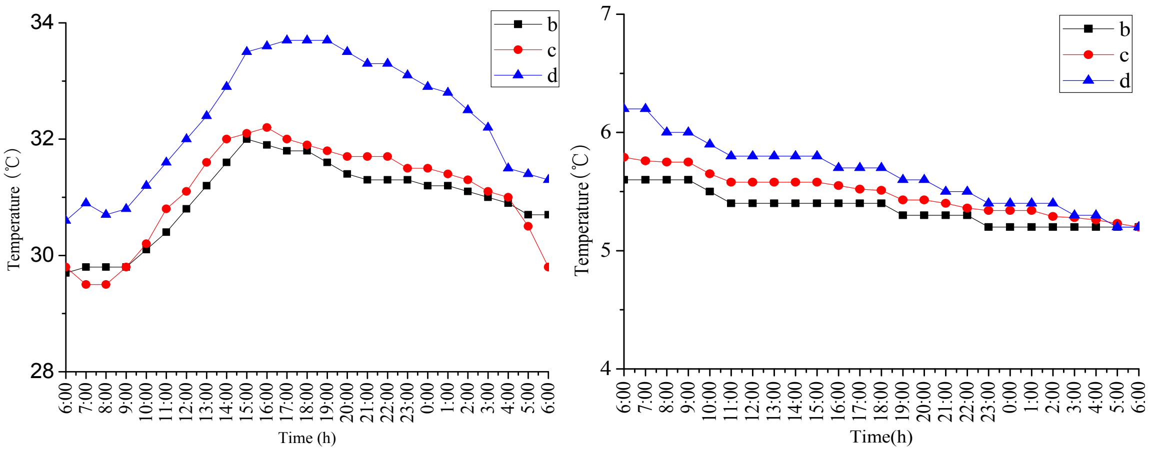
summer winter

Fig. 4. Diurnal variations in roof temperatures



summer winter

Fig. 5. Diurnal variations in ceiling temperatures



summer

winter

Fig. 6. Diurnal variations in indoor temperatures

4. Summary

The effect of two passive cooling systems, water-retaining bricks on roof and radiation shield on roof, as well as a building equipped with ordinary roof are evaluated in Mianyang, China by doing experiment research. The results show that all of the considered passive cooling systems decrease the cooling load required for the building in summer, the maximum cooling capability can be achieved through on-roof water-retaining bricks added with the radiation shield, respectively. The test results also show that best thermal insulation capability in the dormitories can not be obtained through the on-roof water-retaining bricks in winter, even though the on-roof water-retaining bricks is much more effective in the evening than in other period.

Acknowledgements

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