

Direct evaporative cooling with porous ceramics

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Abstract: A traditional clay ceramic was tested under open atmospheric conditions to investigate its cooling effect as a direct evaporative cooler. A porous ceramic prototype was then manufactured and tested in purpose built laboratory test rig to examine the influence of the physical parameters of the ceramic including porosity and atmospheric conditions such as temperature, humidity, air velocity and solar radiation.

Keywords: evaporative cooling, porous ceramic

1. Introduction

Passive cooling is achieved without consumption of fossil fuels, and the related emission of CO₂ to the atmosphere, and so offers a means to provide a comfortable indoor environment without compromising the quality of life for future generations [1]. The most common methods are evaporative cooling, radiant cooling, earth coupling, ventilation cooling and nocturnal ventilation with thermal mass. Evaporative cooling involves the transfer of sensible heat to latent heat without changing the total heat balance, and as the heat required for this process is extracted from the surroundings, they become cooler.

Traditionally in the hot-arid climates of the Middle East, a wind catcher is used to draw the air into a room through a shaft [2]. The incoming air passes over a number of clay ceramics filled with water. The ceramics are located on the base of the wind catcher shaft. Due to the porosity of the ceramic material, water is drawn to the external surface of the containers and the passing air stream causes evaporation of the surface water. This process reduces temperature of the incoming air to a value closer to its wet bulb temperature. This paper describes the evaluation of passive evaporative cooling system based upon the traditional cooling ceramic technique. The system could be used in a wind catcher and/or a chilled ceiling.

2. Investigation of the cooling effect in traditional porous clay ceramics

A traditional porous clay ceramic originating from the Middle East region was chosen for this simplified test (see Fig. 1).

The porous clay ceramic was filled with water and

placed on a flat roof. The clay ceramic was exposed to atmospheric weather conditions for a period of 24 hours. Temperatures at three locations were monitored using thermocouples and a data logger to store the data recorded at 5s time intervals. Two thermocouples were attached to the ceramic surface while the third thermocouple was immersed in the water inside the ceramic. Weather conditions such as air temperature and relative humidity were obtained from the weather monitoring station at the School of Built Environment, which was located in the proximity of the test rig.

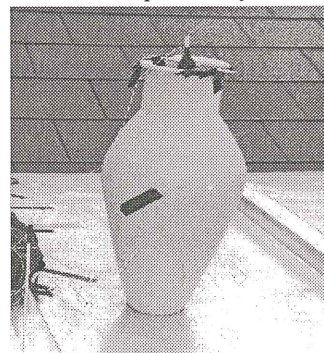


Fig. 1 Testing of traditional porous clay ceramic under atmospheric conditions

A sample of the test results obtained from monitoring the clay ceramic temperatures is shown in Fig. 2.

The temperatures recorded on the clay ceramic surface were obtained by placing two thermocouples on opposite surfaces. Hence when one surface was directly exposed to the solar radiation the other one was shaded. It can be seen that the surface temperature of the shaded side was lower than the temperature of the ambient air. The temperature of the clay ceramic surface exposed to solar radiation was higher than the ambient air temperature. This indicates that solar radiation has a negative effect on the cooling process. It can also be seen that the clay ceramic surface

temperature was approximately equal to the air temperature during periods of high relative humidity. This was observed mainly in wet conditions and at nighttime when relative humidity was as high as 90%. Furthermore the recorded temperature of the water inside the clay ceramic remained at a temperature lower than the surrounding air temperature when the relative humidity was below 80%. These results indicate the cooling effect of porous clay ceramic under conditions of low relative humidity.

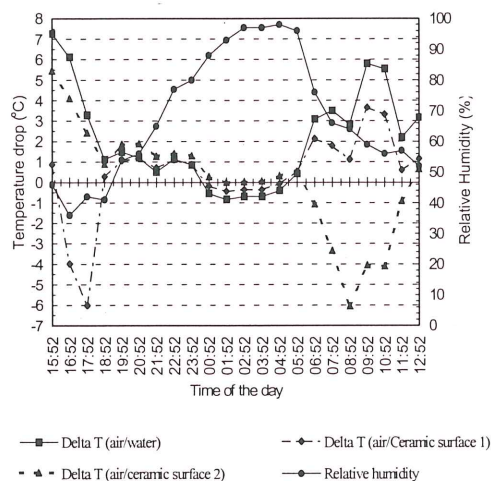


Fig.2 Evaporative cooling obtained from the clay ceramic testing

3. Design of the direct evaporative cooler

The direct evaporative cooler described here was manufactured from clay composite. The chemical composition of the clay material was predominantly silica and alumina as shown in Table 1.

Table 1 Ceramic main chemical content %

SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	TiO ₂	MgO	CaO	K ₂ O	Na ₂ O	LOI
69.39	19.23	0.47	0.26	0.18	0.84	1.62	0.36	6.91

The manufacturing process of the ceramic containers allowed various porosities to be achieved by controlling the firing temperature and baking time in the oven. Prototype ceramic containers with three values of porosity were produced. For high porosity ceramic coolers the firing temperature was around 1000°C and for low porosity prototypes the baking temperature was even higher. All the porous ceramic prototypes were made in a cylindrical shape.

4. Test rig

A test rig was constructed and set up in the laboratory to monitor the influence of different parameters (e.g. temperature, air velocity, relative humidity, etc.) on the performance of the ceramic as a

direct evaporative cooler. As shown in Fig. 3, the rig consists of a thermally insulated rectangular duct with a glazed upper section containing porous ceramic containers. The inlet of the duct was connected through a flexible duct to an environmental chamber, which allowed the temperature and relative humidity to be set to desired levels. Each porous ceramic container was connected by a flexible pipe to a water tank feed to keep the containers fully filled with water. To simulate solar insolation, 16 250 Watt halogen lamps were used to irradiate the glazed section of the duct and different intensities were achieved by changing the height of the lamps.

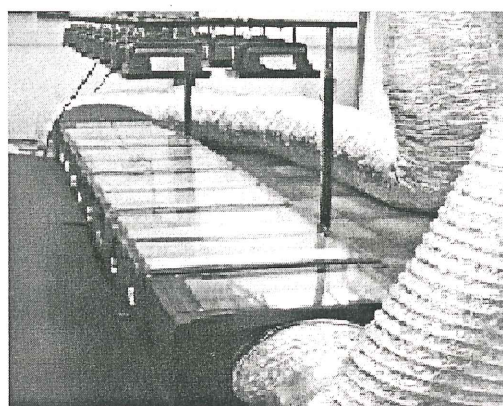


Fig. 3 Direct evaporative cooling test rig

The test rig was fully equipped with a data acquisition system and the following measurement sensors and transducers were used to monitor the operating parameters.

- 1) Thermocouples: T type thermocouples were used to measure the temperature of the air inlet and outlet, the ambient temperature and the temperatures of the environmental chamber and the water supply.
- 2) Relative Humidity Sensors: The relative humidity sensor was a ROTRONIC type, which had a range of 0 to 100% with corresponding voltage signal reading of 0 to 1 volt and accuracy of $\pm 1.5\%$ relative humidity at 23°C.
- 3) Air Velocity sensor: The sensor had a range of 0.125 to 25 m/s with very high accuracy of ± 0.08 m/s.
- 4) Pyranometer: A pyranometer was used to measure the solar irradiation level. It had an accuracy level of $\pm 3\%$.

5. Experimental procedure

The effect of a number of factors on direct evaporative cooling was investigated by carrying out sets of controlled experiments.

5.1 Relative humidity

These tests were carried out by changing the inlet air relative humidity. Other parameters, e.g., air velocity, inlet temperature, and irradiation levels were kept constant. The relative humidity levels were measured using two humidity sensors, one installed at the inlet of the air stream duct and the other installed at the outlet.

5.2 Air temperature

The tests were carried out by changing the inlet air stream temperatures, while keeping the other parameters constant. The temperatures were measured by using two thermocouples, one installed at the inlet of the air stream duct and the other at the outlet.

5.3 Air velocity

The air velocity was changed by adjusting fan rotation speed, while keeping the other parameters constant. The air velocity sensor was located at the air stream duct inlet, downstream of a honeycomb flow straightener. The purpose of the honeycomb flow straightener is to create a constant air stream velocity before passing over the air velocity sensor.

5.4 Solar radiation

The lamp irradiation influenced the evaporation process at the ceramic surface and its effect was measured under steady conditions. The irradiation level was measured at the porous ceramic surface using a pyronometer.

5.5 Ceramic porosity

Containers of three different porosity levels were tested under similar environmental testing conditions. The air velocity, relative humidity and temperature were kept constant.

6. Results and discussion

The direct evaporation cooling power per unit area of the evaporation surface of porous ceramic can be expressed as follows:

$$P_c = \frac{VS\rho C_p(T_1 - T_2)}{S_c}$$

where V air velocity (m/s); S cross sectional area of the duct (m^2); ρ : air density (kg/m^3); C_p air specific heat capacity ($J \cdot kg^{-1} \cdot K^{-1}$); T_1 and T_2 : inlet and outlet air temperatures of the air stream; and S_c : total evaporation surface area of the ceramic containers.

Equally the cooling efficiency of the direct evaporative cooler can be defined as a ratio of the temperature drop through the air duct by the evaporative cooling process to the wet bulb depression.

$$\eta_c = \frac{(T_1 - T_2)}{DBT - WBT}$$

where DBT and WBT are the air inlet dry bulb and wet bulb temperatures, respectively.

6.1 Effect of relative Humidity

Tests of the effect of relative humidity show that the lower the relative humidity level of the inlet air, the higher the cooling power obtained from cooler system, as lower air relative humidity produces a higher evaporation rate. Experimental data of the effect of relative humidity are shown in Figure 4. It can be seen that the cooling power decreases almost proportionally as the relative humidity increase. Cooling efficiency on the other hand remains approximately constant.

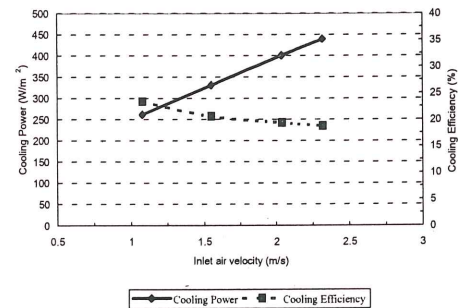


Fig. 4 Effect of relative humidity on cooling power and efficiency

6.2 Effect of air temperature

As shown in Fig. 5, the higher the air temperature, the higher the cooling power of the system. Air at higher temperatures can hold larger amounts of water, therefore larger amounts of water are evaporated from the surface of the containers, which leads to an increase in the cooling power. The cooling efficiency also increases with increasing air temperature.

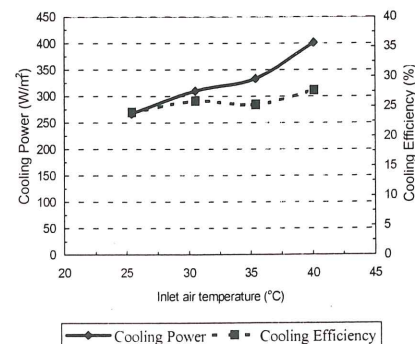


Fig. 5 Effect of air inlet temperature on cooling power and efficiency

6.3 Effect of air velocity

Fig. 6 shows that the higher the air velocity, the higher the cooling power of the system. This is a result of the increase in evaporation rate from the container surfaces. The wet bulb temperatures were obtained from the psychrometric chart using the air inlet dry bulb temperature and the air inlet relative velocity. The data collected show that the higher the air velocity, the lower the evaporation efficiency of the cooler.

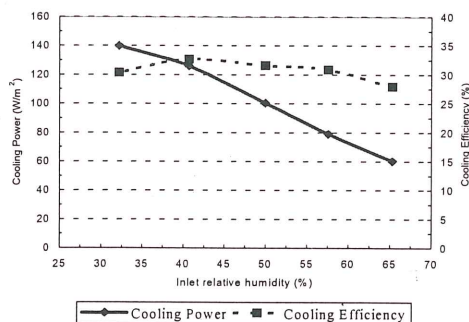


Fig. 6 The effect of air velocity on cooling power and efficiency

6.4 Effect of solar radiation

The test results of the effect of radiation are summarised in Figure 7. It is clear that cooling power and efficiency decrease rapidly as solar irradiation increases. Beyond a threshold of about 500 W/m² the system ceases to produce any cooling effect and hence the efficiency is reduced to zero. This is because when the surface is exposed to solar radiation, much of the heat required for evaporation is provided by the solar radiation rather than removed from the passing air stream.

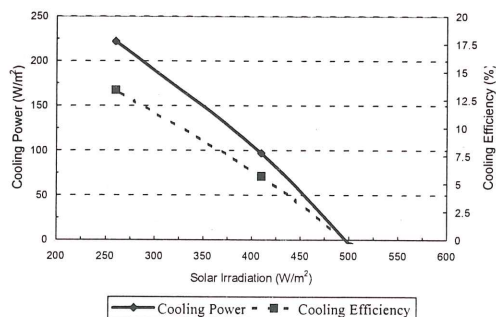


Fig.7 Effect of solar irradiation on cooling power and efficiency

6.5 Effect of porosity

To test the effect of porosity of the ceramic containers on the cooling power of the system, three structurally identical containers with porosities of 29.7%, 32.8% and 34.6% were examined. The results show that ceramic containers with higher structural porosity provide continuous moistening of the external surface and therefore provide increased evaporation rate of water, whereas less porous containers have a denser structure and therefore lower water permeability. As shown in Fig. 8, the higher the porosity of the container, the higher the cooling power of the system.

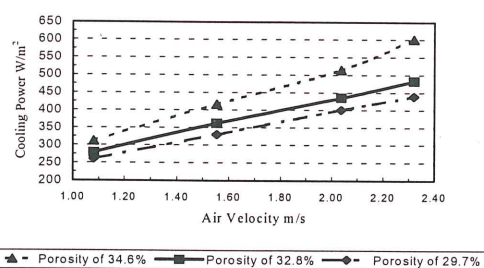


Fig. 8 Effect of porosity and air velocity on cooling power

7. Conclusions

The experimental work carried in this paper indicated that porous ceramic material could be manufactured and adapted to provide effective passive cooling in contemporary buildings. Test on the prototype ceramics under laboratory conditions showed that in general, the cooling power of a direct evaporative cooler increases with increasing air velocity, air temperature, and porosity of the ceramic container. Cooling power was found to decrease with increasing air relative humidity and solar radiation.

References

- 1 Zahra Giabaklou and John A.Bllinger; A passive evaporative cooling system by natural ventilation, Building and Environment, Vol.31, No.6, pp.503-507, 1996.
- 2 Brian Ford, Nimish Patel, Parul Zaveri and Mark Hewitt, Cooling without air conditioning, Renewable Energy, Vol.15, pp.177-182,1998.