

Experimental evaluation of a novel combined Wind catcher - indirect evaporative cooling System for cooling application in buildings

Elzaidabi*, A. A.; Omer, S. A. and Riffat, S. B.

Institute of Sustainable Energy Technology, School of the Built Environment, the University of Nottingham, University Park, Nottingham NG7 2RD, UK.

*Tel: (44)1158467874, Fax: (44) 115 9513159, Email: laxael@nottingham.ac.uk.

ABSTRACT: This paper presents results of an experiment conducted to investigate the performance of a newly developed air cooling system comprising a Psychrometric Energy Core (PEC), cooling unit assisted wind catcher technology. A laboratory unit of the combined system was designed and constructed using a wind catcher and a PEC unit. The purpose of the wind catcher is to assist air flow in and out of the PEC unit. This is achieved using a double concentric hollow ducting system; an outer large circular duct for fresh air supply and a smaller central duct to allow exhaust air from the PEC to exit the system. A series of tests were conducted using a wind tunnel, in order to assess the performance of the system under varying wind speed and ambient temperature. Results of the tests show that, the system has a potential of operation passively without a support of a fan under certain wind speeds. A fan would be required at very low wind speed to overcome the pressure drop through the PEC core channels.

Key words: Psychrometric Energy Core, wind catcher, indirect evaporative cooling.

1.0 INTRODUCTION

Historical uses of evaporation for cooling of interior spaces are well known by the traditional Middle Eastern wind scoop ('malqaf' or 'badgir'), which had been used to channel air passing a wetted mat or pool of water [1]. They were constructed, traditionally from wood-reinforced masonry with opening at height above the building roof ranging from 2 to 20 meter, with taller tower capturing winds at higher speeds. They are used in the hot arid region of the Middle East to provide natural ventilation and hence thermal comfort [2].

These traditional systems have been produced in a modern design known as "wind catcher" where the two ventilation principles of wind tower and passive stack are combined in one design around a stack that is divided into two halves or four

quadrants running the full length of the stack [3, 4]. This paper presents a combination of both concepts using a wind catcher and a PEC media to form a system that can be used to provide both cooling and ventilation.

The cooling process using a heat exchanger involves sensible heat exchange, and when applied to evaporation the process is known as indirect evaporative cooling. Indirect evaporative cooling enables the ambient air to be cooled without increasing its relative humidity considerably. The performance of such a system depends on the type and performance of the heat exchanger. To obtain a highly efficient indirect evaporative cooling system, a highly effective heat exchanger should be used. It must be noted that, since the air

temperature drops during cooling process its relative humidity will increase, but at a lower rate compared with the direct evaporative cooling process. This process is presented in the psychrometric chart by a displacement along a constant humidity ratio line, CD, shown in Figure 1.

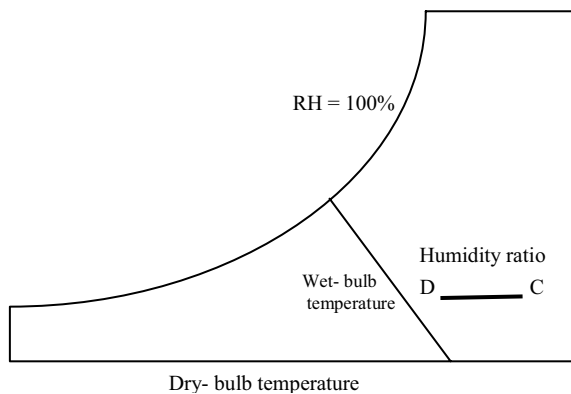


Figure 1 Indirect evaporative cooling process

The performance of both direct and indirect evaporative cooling systems is based on the concept of the saturation efficiency, defined as

$$\text{Saturation Efficiency} = \frac{T_{db,in} - T_{db,out}}{T_{db,in} - T_{wb,in}}$$

Where $T_{db,in}$ and $T_{db,out}$ are the dry bulb temperatures of the air at the inlet and outlet of the system respectively and $T_{wb,in}$ is the wet bulb temperature of the air at the inlet of the system.

The Psychrometric energy is the energy produced during a specific process of interaction between air and a hygroscopic solution such as water, and utilizes the basic characteristics of air and water to produce a significant temperature drop. In general, indirect evaporative cooling performance is influenced by the same factors that affect direct evaporative cooling, although an additional factor affects indirect evaporative cooling due to the use of heat exchangers in the process.

The rate of evaporation increases with the increase of the evaporation surface area. The PEC media used in this system is designed to give maximum contact surface between air and water.

The rate of evaporation could be improved by introducing a moving air, either through natural circulation or by using an electric fan. Air movements provide a constant supply of drier air to the evaporation surface, therefore lowering the relative humidity which has a significant effect on increasing the evaporation rate.

In the proposed system a wind catcher has been made to provide air movement through wind catcher mechanism. The paper examines the ability of the wind catcher to overcome the pressure drop due to presence of the PEC unit.

2.0 SYSTEM DESCRIPTION AND OPERATION

A laboratory unit of the combined system was designed and constructed using a wind catcher and the PEC unit (Figure 2a). A wind catcher obtained from Monodraught has been modified and used to assist air flow in and out of the PEC unit. This is achieved using a double concentric hollow ducting system; an outer large circular duct for fresh air supply and a smaller central duct to allow exhaust air from the PEC to exit the system. The PEC used in this system (Figure 2a) has a diamond shape which allow cross flow arrangement. The PEC media is manufactured from a special cellulose paper (pads) that absorb and hold moisture and these are separated by thin plastic sheets to give structural strength and prevent moisture exchange. These sheets are impregnated and treated to resist biological and mechanical degradation. This provides media longevity and high adsorption rates.

The cross fluted design of the PEC media results in two important effects. First, it optimizes the surface area

available to hold sufficient amount of water for evaporation, and secondly the way it is aligned causes the air to change direction in a way that ensures that all the air will pass over the wetted media surface before leaving the pad. As a result the air leaves the pad with the greatest amount of cooling and/or humidification possible. The pads are arranged in a special way, using horizontal and vertical channels through the core [5].

PEC pads also act as a natural filter that purifies the inlet air. A carefully designed flute angle directs water towards both the air inlet and outlet side. The water then intrinsically flushes away dust, algae, and mineral build up on the evaporation surfaces.

Two fans have been used to distribute air through the PEC and the exhaust duct. The first is an exhaust fan which pulls the air and blows it out of the system through the central duct. The second fan is the supply fan which pulls the air coming through the wind catcher vents into the room. The purpose of this fan is to ensure that there is a sufficient airflow through the PEC unit, by overcoming the pressure loss due to friction in the core channels.

The water is sprayed over the pads along vertical channels using a circulating pump allocated in the supply water tank. Water droplets passing through the vertical channels soak the pads and trickles through them to be collected at bottom of the core in the return water tank (Figure 2.b). The intakes air (supply air) passes through the wind catcher inlets vents, and is drawn by the supply fan through the Psychrometric Energy Core and split into two streams. One stream flows through the wet channels in the PEC to enhance evaporation of the water sucked in the PEC and thus produces cooling effect. The second air stream passes through the dry channels of the PEC. The cooled air stream then flows into the room while the warm exhaust air rises through

the PEC exhaust channel to leave the wind catcher through the central exhaust air duct. This warm humid air stream is extracted through the exhaust duct out of the system.

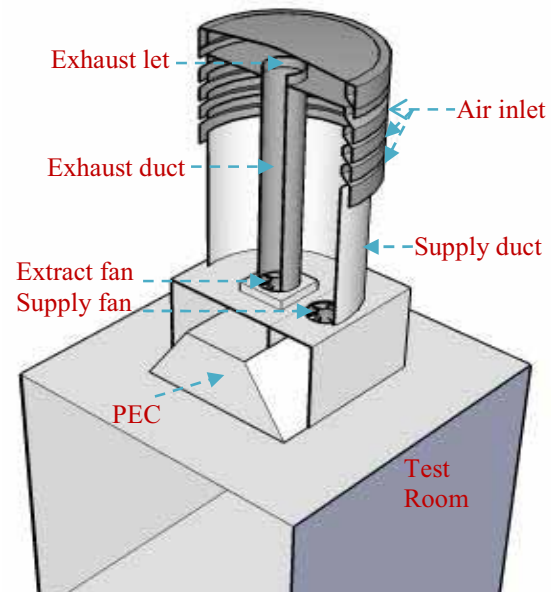


Figure 2a system description and operation

3.0 EXPERIMENTAL RIG SETUP

Figure 3 presents description of the test rig including the wind tunnel which is used to simulate wind at different speeds. A variable flow DC pump is used to maintain the water flow through the PEC core. The test room is well insulated using a 15mm thick insulation made of mineral wool. Air leakage test has been performed to ensure that there is no air leakage. Two DC fans were used to assist air flow into and out of the PEC. A number of measuring transducers are used for measurement of the humidity, temperature and air velocity. An electrical heater is used to provide heat load at 30 and 38 degree C in the vicinity of the wind tunnel outlet. A wind tunnel has been used to simulate the ambient wind by directing the air towards the wind catcher inlets.

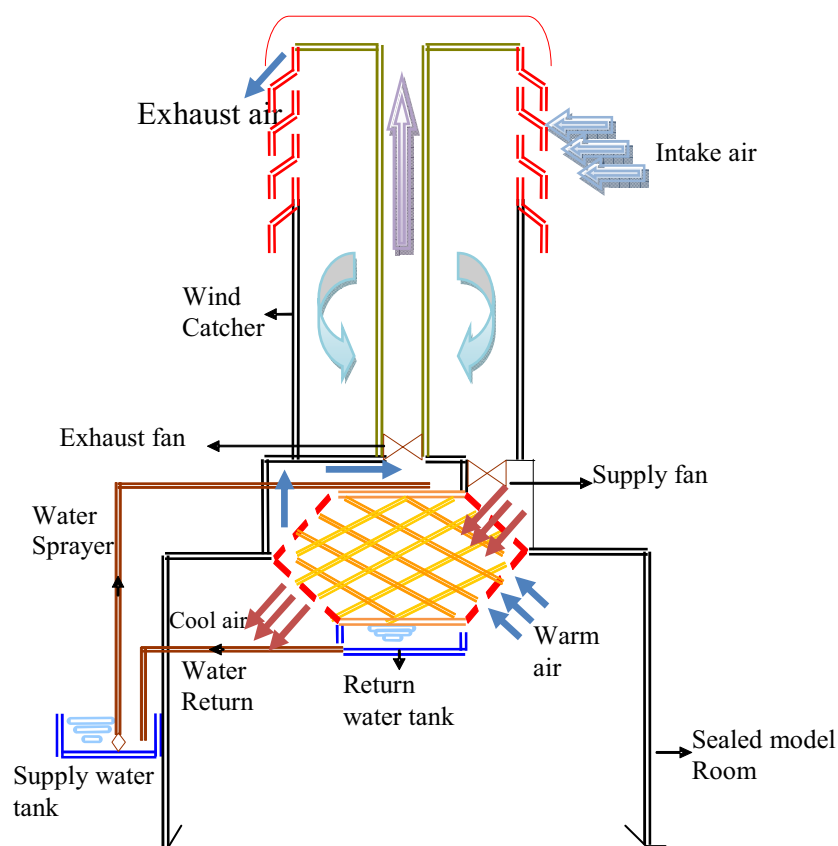


Figure 2b system description and operation

The parameters that have been studied include the temperature and relative humidity and the air flow rate through the system. The tests were carried out under different wind speeds and different water flow rates. Figure 3 shows the setup of the experimental rig.



Figure 3: A photo showing the experimental rig setup

4.0 RESULTS AND DISCUSSION

The effect of the ambient temperature, air flow rate and water flow rate on the cooling effect of the system was assessed. These were conducted by running the tests at different ambient i.e., 23 °C, 30 °C and 38 °C.

Figure 4 shows the variation of the room temperature and the ambient temperatures. Temperature difference between the room and the ambient of 5.5°C, 6.86°C and 9.6°C respectively have been achieved in the test.

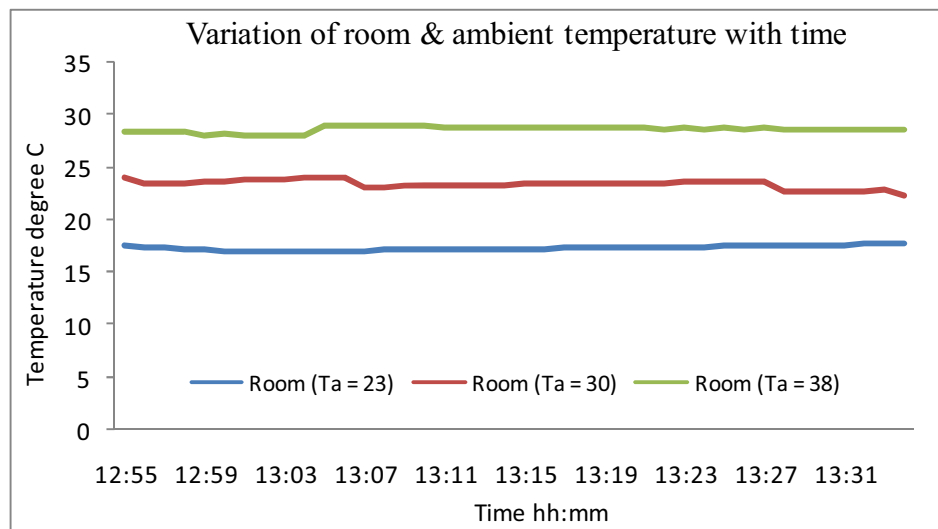


Figure 4: Variation of Room and ambient temperature with water flow rate

The relative humidity of the ambient air has also been varied to assess its effect on the cooling effect of the system. Figure 5 shows the variation in the relative humidity of the air inside the room when ambient relative humidity was set to 30%,

35% and 40%. It can be seen that, the room relative humidity of the room have increased by 22%, 21% and 20 % respectively.

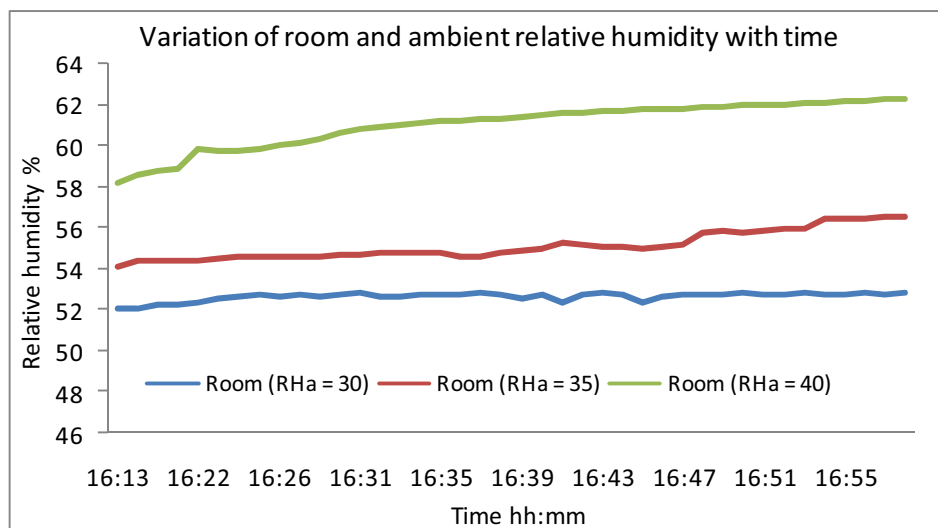


Figure 5: Variation of room arelative humidity with realtive humidity of the ambient air

Figure 6 and Figure 7 show the variation of the room temperature and the room relative humidity with the evaporative cooling water flow rate. The water flow was varied as 0.6 l/s, 0.9 l/s and 1.2 l/s. The results indicate that the variation in

water flow rate have a very little effect on the cooling effect of the system, however it does affect the room relative humidity, as shown in Figure 7.

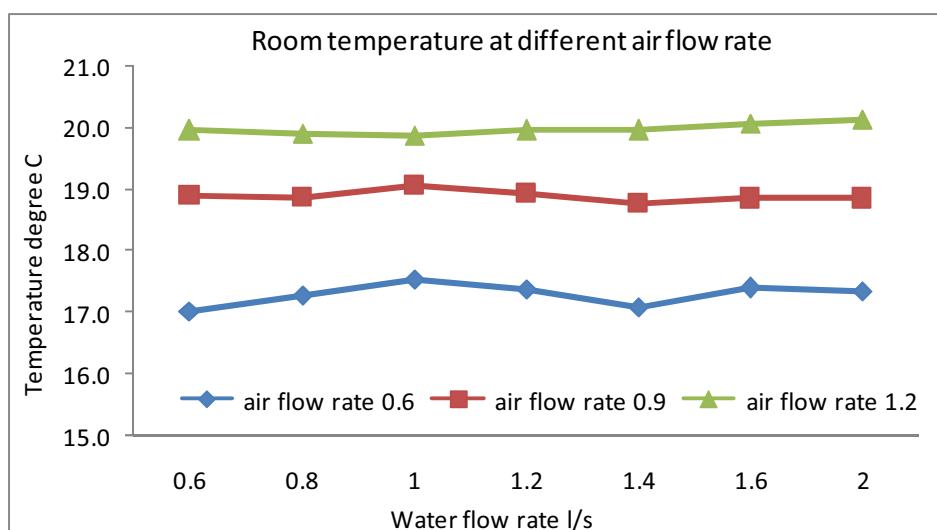


Figure 6: Variation of room temperature with air flow rate

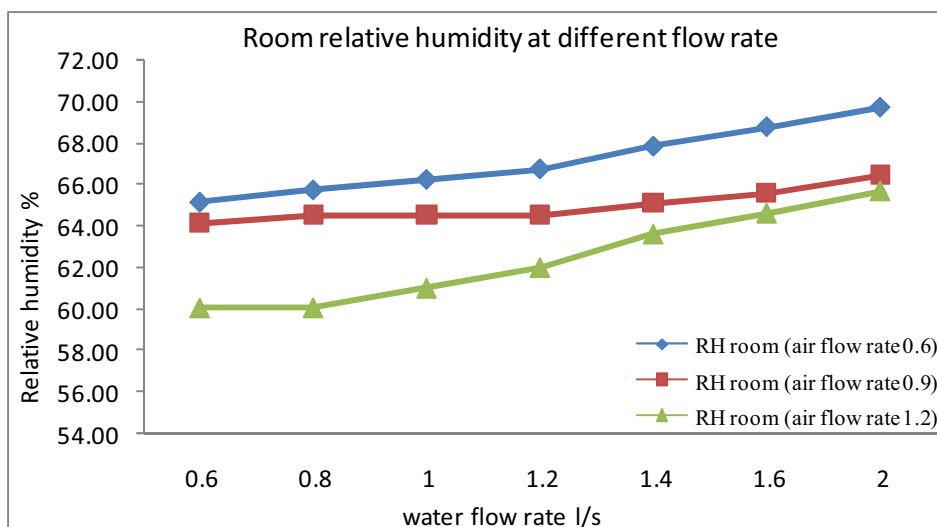


Figure 7: Variation of room humidity with water flow rate

System cooling load has been calculated at different temperature and relative humidity, using EES software. Cooling load of 1.75 kW has been achieved. The system power consumption is 24 watt (fans) + 15 watt (pump) = 39 watt. Table 1 presents the System cooling load and COP.

Table 1: System cooling loads and COP.

RH1	T1	RH2	T2	$Q=\dot{m}(h_{in}-h_{out})$	COP
30	23	52.7	17.7	9.54	24.4
35	30	56.0	23.14	11.15	28.5
40	38	60.5	28.4	17.53	44.9

5.0 CONCLUSIONS

Results of the tests show that, the system has a potential of operation passively without a support of fan under certain wind speeds condition. However a fan would be required to overcome the pressure drop inside the PEC core channels at low wind flow rates. The tests results also show that, the system has ability to provide cooling effectively even at relative high humid air conditions.

The system has no compressor, no refrigerant and water is the only cooling

media used, therefore, it is environmental friendly. The system consumed only the necessary electrical energy for the operation of air fans and the small water pumps, this is far less than the electricity required for the operation of conventional air conditioners; and so could be operated using solar energy.

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