Study, Design and realization of an evaporative cooling system using solar energy

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Abstract

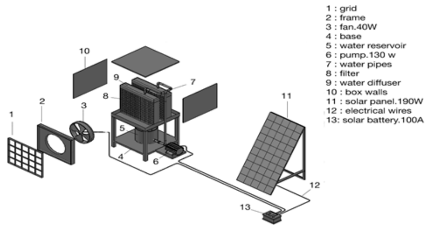
The analysis of an evaporative cooler under different input climate conditions carried out on a digital psychrometric chart and using code developed and implemented in Matlab, demonstrated that a rise in the dry bulb temperature affect essentially the wet bulb temperature, the wet bulb depression and affects strongly the vapor pressure deficit. The rise in the relative humidity has a great effect on the wet bulb depression and on the vapor pressure deficit.

Project Objectives

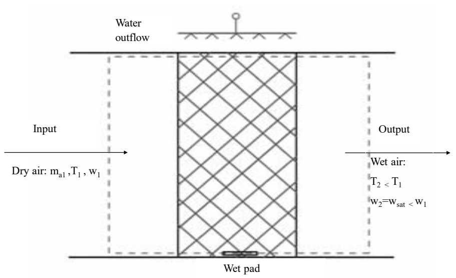
The main objective of this study is to develop an experimental-like numerical predictive model of an evaporative cooling system. This model aims to predict the influence of the input air and the water characteristics on the system performance.

Design of the system

The system design contains a water reservoir , a fan motor and a pump for water recirculation . The fan and the pump supplied by a PV cell as a source of energy. The solar energy delivered by the PV panel is stored in a solar battery. The housing is louvered on three sides and each of these sides is fitted with a thick of excelsior pad. A PVC tube water distribution system keeps these pads saturated with water when the cooler is operating. They may be roof or window mounted. One of the affecting parameters of the adiabatic efficiency of this system is the nature of the wetted pad. The figure bellow shows a description of our system.



MATHEMATICAL MODELING OF AN EVAPORATIVE COOLING SYSTEM



In this model, we will consider an air conditioning process: state 1 is the input, state 2 is the output and a water spray system.

Mass balance

The conservation of dry air gives:

$$\dot{m}_{a1} = \dot{m}_{a2}$$

The conservation of the mass water is written:

$$\dot{m}_{a1} . w_1 + \dot{m}_{liq} - \dot{m}_{a2} . w_{sat} = 0$$

Where $\dot{m}_{liq}$: is the liquid flow rate and w_{sat} : is the specific humidity corresponding to the saturating vapor :

$$\dot{m}_{liq} = \dot{m}_{a1} . (w_{sat} - w_1)$$

Energy balance

We assume that the system does not exchange heat or mechanical work with the external environment, the conservation of energy is reduced to a conservation of enthalpy. The enthalpy at the inlet is the sum of the enthalpy of the incoming air and the enthalpy of liquid water. At the outlet it is only the enthalpy of the outgoing air:

$$\dot{m}_{a1} . h_{a1} + \dot{m}_{liq} . h_{liq} - \dot{m}_{a2} . h_{a2} = 0$$

Given the previous equations, the energy conservation equation can be written:

$$\dot{m}_{a1} \left[(C_{pa1} + w_1 . C_{pv}) . T_1 + w_{1sat} . L_v\right] + m_{a1} . (\dot{w}_{sat} - w_1) C_{pliq} . T_1 - \dot{m}_{a1} \left[(C_{pa1} + w_{sat} . C_{pv}) . T_2 + w_{sat} . L_v\right] = 0$$

By dividing this equation by $\mathbf{m_{a1}}$, moving the term to $\mathbf{T_2}$ in the second member, and grouping all the terms into $\mathbf{T_1}$, we get:

$$(C_{pa1} + w_{sat} . C_{pv}) . T_2 = \left[C_{pa1} + w_1 . C_{pv} + (w_{sat} - w_1) . C_{pliq}\right] . T_1 + (w_1 - w_{sat}) . L_v$$

$$T_2 = \frac{[C_{pa1} + w_{sat} . C_{pv} + (w_{sat} - w_1) . (C_{pliq} - C_{pv})] T_1 - (w_{sat} - w_1) . L_v}{(C_{pa1} + w_{sat} . C_{pv})}$$

$\mathbf{T_2}$: represents the humid temperature of dry air at temperature T_1 and humidity w_1

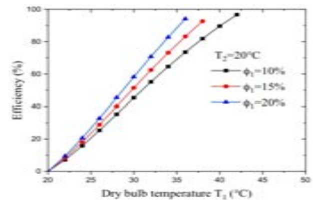
$$T_2 = T_1 + \frac{(w_{sat} - w_1) . [(C_{pliq} - C_{pv}) T_1 - L_v]}{(C_{pa1} + w_{sat} . C_{pv})}$$

NUMERICAL RESULTS: Effect of the dry bulb temperature on the evaporative cooler’s efficiency

at a constant dry-bulb temperature and desired wet-bulb temperature, an increase in the dry air’s relative humidity leads to an increase in the evaporative cooler’s efficiency.

It is generally accepted that evaporative cooling is satisfactory only when dry-bulb temperatures in excess of 32°C coincide with wet-bulb temperatures below 24°C.

iii. For a desired wet-bulb temperature, the evaporative cooler reaches its maximum efficiency (about 94%) when the dry air’s relative humidity is low and the dry-bulb temperature is maximal, while it reaches its minimum efficiency (about 90%) when the dry air’s relative humidity is high and the dry-bulb temperature is low.



i. At constant relative humidity for the dry air, a rise in the dry-bulb temperature leads to an increase in the evaporative cooler’s efficiency.

ii. With the dry-bulb temperature and the dry air’s relative humidity kept constant, a rise in the wet-bulb temperature leads to a decrease in the evaporative cooler’s efficiency.

EXPERIMENTAL RESULTS AND DISCUSSION

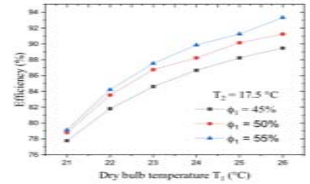
Experimentally, it was shown that:

(i) An increase of the dry bulb temperature leads to an increase of the evaporative cooler efficiency.

(ii) For constant dry bulb and wet bulb temperature, the evaporative cooler efficiency increase by increasing the relative humidity of the dry air.

(iii) The evaporative cooler reaches its maximum (around 93%) for maximum dry bulb temperature and maximum humidity

Experimental results of the evaporative cooler efficiency variation with dry bulb temperature were in good agreement with theoretical results obtained by numerical simulation.



Conclusions

A numerical and an experimental model was developed to investigate the performance of an evaporative cooling system powered by solar energy under different climate conditions. Evaporative cooling systems are essentially useful in environments where a high dry-bulb temperature (more than 32°C) simultaneously coincides with a low wet-bulb temperature (less than 24°C) for extended periods. Under different input dry-air conditions, the obtained results show that evaporative cooling systems can provide substantial relief from the high dry-bulb temperatures found in desert-type climates. This present study found that the dry- and wet-bulb temperatures are determining factors for an evaporative cooler’s efficiency. For a desired wet-bulb temperature, the evaporative cooler reaches its maximum efficiency at a high wet-bulb depression (WBD = T1 – T2), and it achieves its minimum efficiency for a low wet-bulb depression. Preliminary experiments showed that Aspen material is more suitable than Celdek one. Further studies should be developed to experimentally investigate the efficiency of the evaporative cooler under real and appropriate conditions.

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