DEVELOPMENT AND EVALUATION OF SOLAR POWERED EVAPORATIVE COOLING SYSTEM

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Abstract: *The demand for cooling system is high during summer as it is most widely used for human comfort. Hence, different methods of cooling systems are developed and among all the systems, evaporative cooling is preferred as its one of the cheapest cooling system and do not affect the ozone layer. In an evaporative cooling system, the room air temperature is reduced by the addition of water vapour into air, which causes a lowering of the temperature of the air. The energy needed to evaporate the water is taken from the air and hence the room air is cooled. In this work, an evaporative cooling system was developed and the effect of evaporative pad thickness, fan speed and water flowrate were studied. This system was fully powered by electrical energy developed by the solar PV system.*

Keywords: *Cooling, Evaporative pads, Evaporative system, Solar energy, Performance*

1. INTRODUCTION

In summer, cooling system is most widely used for human comfort. Among the available cooling system, an evaporative cooling system is most widely used in rural and urban areas of India, as it is one of the cheapest cooling systems and does not need much electrical power. An evaporative cooler is a device that cools the air through the evaporation of water. The evaporative cooling differs from typical air conditioning systems which use vapor-compression or absorption refrigeration cycle to produce the cooling. The evaporative cooling works by employing water's large enthalpy of vaporization. The temperature of dry air can be dropped significantly through the phase transition of liquid water to water vapor during, which can cool air using much less energy than refrigeration. In extremely dry climates, evaporative cooling of air has the added benefit of conditioning the air with more moisture for the comfort of building occupants.

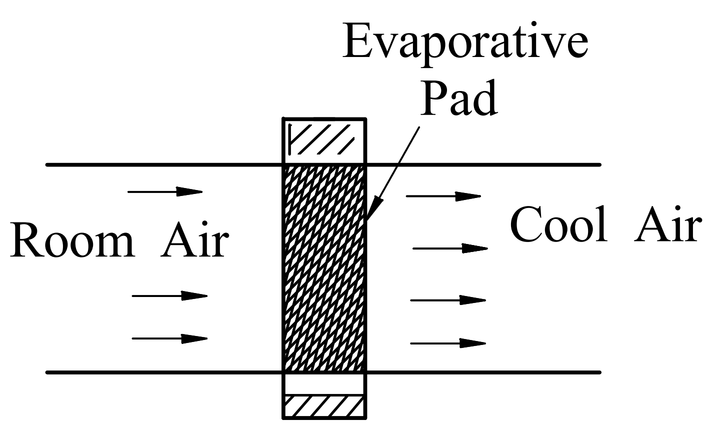

Figure-1: Principle of evaporative cooler

The cooling potential for evaporative cooling is dependent on the wet bulb depression, the difference between dry-bulb temperature and wet-bulb temperature. In arid climates, evaporative cooling can reduce energy consumption and total equipment for conditioning as an alternative to compressor-based cooling. In climates not considered arid, indirect evaporative cooling can still take advantage of the evaporative cooling process without increasing humidity. The passive evaporative cooling strategies offer the same benefits of mechanical evaporative cooling systems without the complexity of equipment and ductwork.

From the literature review, it is observed that in dry and humid regions, evaporative coolers can be available in most of the building for cooling utilizing one-fourth energy of conventional equipment. Figure-1 shows the working principle of evaporative cooling system. In an evaporative cooling system, dry unsaturated air is pulled through a cooling pad which is wetted by water spray; the water is evaporated and is absorbed into air as water vapour. The process takes place by increasing the humidity in the air and decreasing the indoor dry bulb temperature and makes indoor system cool. In India, energy consumption is increasing day-by-day, so there is a need to conserve energy for future generation, in order to conserve we need to utilize renewable energy sources. The evaporative cooling system is most widely used in summer and hence it is a better option to use solar energy to drive the evaporative system.

2. LITERATURE REVIEW

Demis et al., 2016 carried out a numerical analysis of a three desiccant air-conditioning systems equipped with different indirect evaporative air coolers, cross-flow Maisotsenko cycle heat and mass exchanger, regenerative counter-flow Maisotsenko cycle heat and mass exchanger and standard cross-flow evaporative air cooler. They carried out the simulations under the assumption that the desiccant wheel is regenerated with air heated to relatively low temperature values, which can be produced with solar panels in typical moderate climatic conditions. They suggested that this system can provide comfort conditions even with less effective dehumidification. Few researchers considered three configurations for two-stage indirect/indirect evaporative cooling systems for their work (Type A, Type B and Type C) so as to determine what configuration produces better wet-bulb effectiveness. They considered six cities with a variety of hot weather conditions with the dry-bulb in range of 31.9 –46.66 °C. Their results show that under these three configuration, the wet-bulb effectiveness of Type A, Type B and Type C varies over ranges of 62–68%, 76–81% and 85–91% respectively, whereas the effectiveness of a one stage indirect evaporative cooler varies over a range of 54 – 60.

Shahab et al., 2016 carried out the numerical simulations of Cross- and Counter-Flow Regenerative Evaporative Coolers (REC) and a Cross-Flow Indirect Evaporative Cooler (IEC) using one set of the governing equations. The Numerical simulation shows contour plots of two-dimensional temperature across the exchanger for Cross-Flow REC with two directions of air flows in wet channel. They studied the impacts of the working air to total air ratio on Counter-Flow REC which show that product air temperature decreases as the working air to total inlet air ratio increases. Alklaibi’s, 2015 results show that the efficiency of the internal two-stage evaporative cooler is higher than that of direct evaporative cooler but it cannot be raised over 100%. It was also shown that the efficiency of the internal evaporative cooler type is less sensitive to air speed than direct type. Also, their results show that the supply air of the internal evaporative cooler has higher humidity content than the direct evaporative cooler which makes it a good humidifier in cold storages.

Other researchers, such as, Elgendy & Mostafa, 2015 proposed three novel desiccant evaporative cooling system and carried out simulation and compared their results with the conventional system under a wide range of ambient air temperature and humidity ratio. In configuration - I, a direct/indirect evaporative cooling is inserted before the rotating heat exchanger and in the configuration - II, it was inserted after the rotating heat exchanger. In configuration-III, an extra direct/indirect evaporative cooling is added in an opposite manner. Their energetic analysis revealed that configuration-I has the highest cooling capacity while configuration - III has the highest thermal COP and air handling COP.

Elmetenani et al., 2011 carried out the theory and design of the direct evaporative air cooler (DEAC). They carried out their simulation for an evaporative air cooler for three successive months June, July and August under TRNSYS environment. Their result showed that the maximum depression of the dry bulb temperature reached is about 18.86 °C and the evaporative cooling equipments work well in the hot and arid southern regions. They reported that the energy consumption of the DEAC is much less than in classical air conditioning units and it can be powered by solar photovoltaic panels. Few researchers, such as MetinDagtekin et al., 2011 reported that the air velocity affects the performance of evaporative cooling system.

3. METHODOLOGY

The objectives of the present work were as follows:

1) To measure the solar radiation intensity
2) To measure the solar power produced by the solar PV system
3) To study the performance of the solar powered evaporative cooling system

The pyranometer with data logger used for measuring solar radiation of flux and is shown in the Figure 2. It consists of thermopile sensor with black coating which absorbs the solar radiations and converts the thermal energy into electrical energy.

Figure-2: Pyranometer with data logger

Figure-3: Sunshine Recorder

Figure-4: Solar PV panels with inverter

A 1 KVA solar PV system was used in this work. A solar inverter was used to convert the variable Direct Current (DC) output from the PV panels to alternating current (AC) and then supplied to OFF-grid for the utilization and to supply power to the evaporative cooling system. Figure 4 shows the solar PV system and the solar inverter.

3.1 Experimental Setup

The schematic of the evaporative cooling system is shown in the Figure 5. The experimental set up of consists of a direct evaporative cooling system which consists of a rectangular wind tunnel, an axial fan fixed at inlet of tunnel, an evaporative pad is kept close to the inlet of the tunnel where air should strike the evaporative pad.

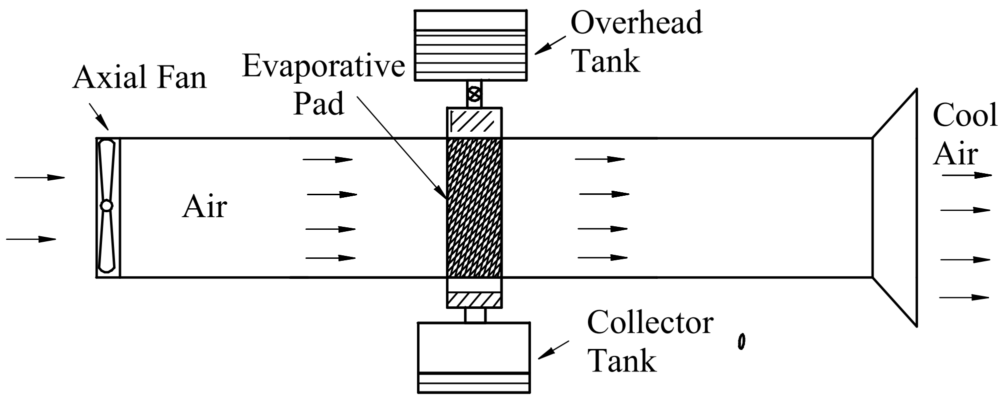

Figure-5: Schematic of Evaporative cooling system

Figure-6: Experimental setup

A non-contacting tachometer was used to measure the speed of the fan. The fan is the variable speed fan. Thermometers were used to measure the wet bulb and dry bulb temperatures of the inlet and outlet air which passes through the wind tunnel. A digital anemometer was used for the measurement of the air velocity. An energy meter was used for the measurement of the power consumed by the evaporative cooling system. The cooling pads used in this work are made of cellulose materials. A small overhead tank was placed above the evaporative tank to supply the water to the evaporative cooling system. A series of nozzles were arranged to spray the water into the evaporative pads. A U-Tube water manometer was used in this work to measure the pressure drop across the evaporative pads. The green stripe evaporative pad consists of specially impregnated and corrugated cellulose paper sheets with different flute angles. This design gives higher evaporation efficiency with low pressure drop across the pad. In addition scaling is kept to a minimum and no water carry-over occurs due to the fact that the water is directed to the air inlet side of the pad. The impregnation procedure for the cellulose paper ensures a strong self-supporting product, with high absorbance, which is protected against decomposition and rotting and therefore increasing longevity.

When the fan was switched on, the room air is supplied to the evaporative cooler tunnel. The water is supplied from the overhead tank to the cooling pad through the nozzle arranged on the top of the pads. When the water flows down the corrugated surface of the evaporative cooling pad, part of the water is evaporated by the warm and dry air that passes through the pad. Due to the evaporation, the temperature of the air is reduced and simultaneously its humidity increases. The rest of the water assists in washing the pad and collected in the collector tank as shown in the figure 6.

4. RESULTS AND DISCUSSION

4.1 Analysis of solar radiation and power production

The study of solar radiation was carried out from 9.10 AM to 3.10 PM using the sunshine recorder, pyranometer and compared with the power produced by the 8 PV panels each of 230 W capacity. The card burnt length shows the hours of the sunshine at respective time on the card and solar radiation flux (W/m2) recorded with the pyranometer is plotted against time and compared with the sunshine recorded card, correspondingly the power generated from the PV Panels are noted from the solar inverter.

Figure 7 shows the results of the reading recorded by the sunshine recorder and the solar radiation flux on the Equinox card. The card is placed at 9:10 AM and the sunshine is observed from 9:15 AM to 3:10 PM. There was cloud formation during the daytime and hence there is a slight variation in the solar radiation flux. The radiation flux was high during afternoon and was appeared to be constant. The average solar radiation flux was 926.34W/m^2 and power generation from 9:00 to 3:30 was about 3.8 kW.

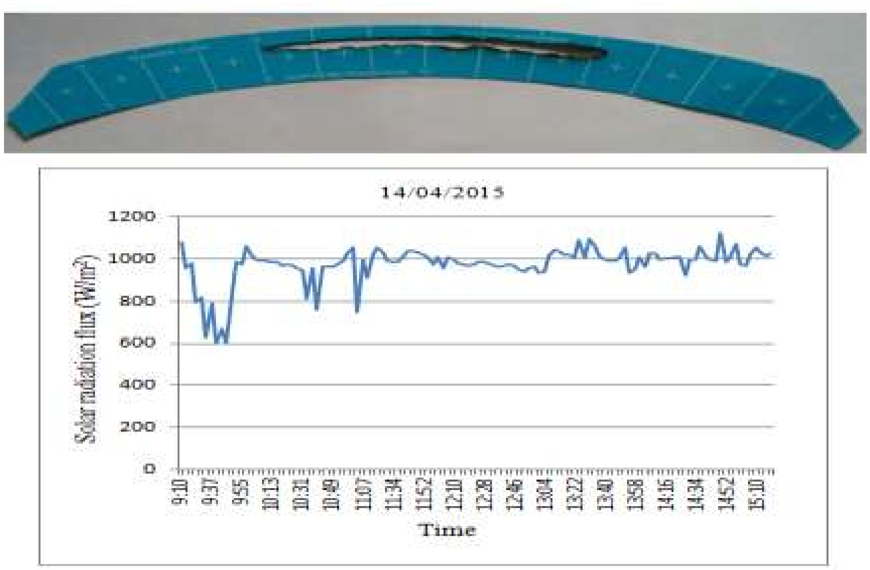

Figure-7: Sun shine hours and solar radiation of Equinox card

4.2 Analysis of performance of evaporative cooling system

Figure 8 shows the effect of fan speed on the saturation efficiency of the solar powered evaporative cooling system at water discharge rate of 215 lt/hr. From the figure, we observe that the 20 cm thick evaporative pad gives better performance than the 10 cm thick pad. Also, it is observed that as the speed of the fan increases, the saturation efficiency of the evaporative cooling system also increases. At higher speed, both the evaporative pads gives higher efficiency. However, the variation in the saturation efficiency is small at higher speeds. The performance of the evaporative cooling system is higher at the speed range of 1000 – 1100 rpm.

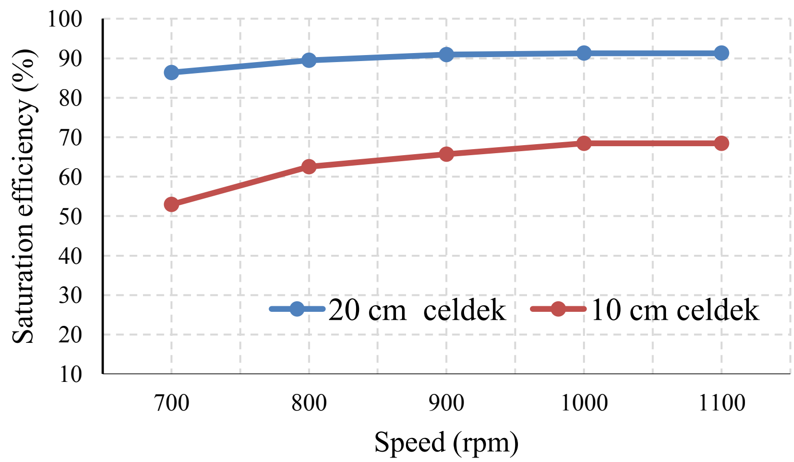

Figure-8: Variation of Saturation efficiency for different cooling pads

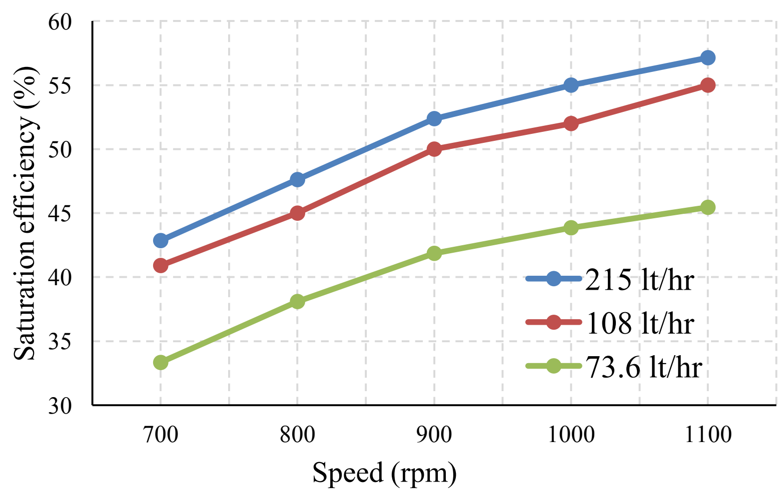

Figure-9: Variation of Saturation efficiency for different water discharge rate

The water discharge rate significantly affects the performance of the evaporative cooling system, and hence further studies were carried out to study the effect of water discharge rate on the performance of the evaporative cooling system with 20 cm thick evaporative cooling pad. Figure 9 shows the effect of water discharge rate on the saturation efficiency of the evaporative cooling system. From the figure, we observe that as the speed increases, the saturation efficiency of the evaporative cooling system also increases. The saturation efficiency of the evaporative cooling system increases as the discharge rate increases. The water discharge rate of 215 lt/hr gives higher saturation efficiency as compared to other discharge rates. for coconut coir as cooling pad material. It shows that the efficiency is high at high water discharge rate. And in desert regions the discharge rate of 108 lt/hr can be used due to lower water consumption rate and by comparing the efficiency at different discharge rate.

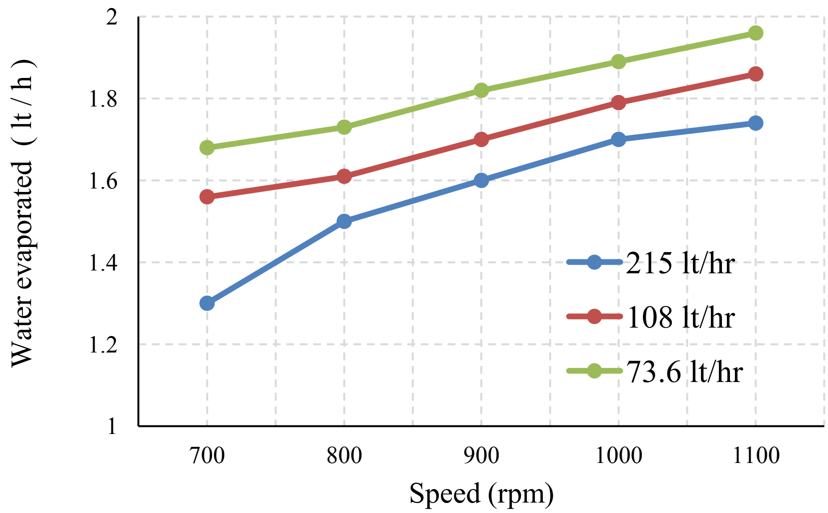

Figure-10: Variation of water evaporation rate at different water discharge

Figure 10 shows the effect of speed on the water evaporation rate of the evaporative cooling system with the evaporative cooling pad of 20 cm thickness. From the figure, it is observed that the water evaporation rate increases with the increase in water discharge rate. Also, it is observed that as the fan speed increases, the water evaporation rate also increases. This is because, as the speed increases the quantity of air supplied to the evaporative cooling system increases which results in higher evaporation rate.

5. CONCLUSION

The solar radiation is high during summer and the demand for the cooling system also in summer. Hence the power produced by the solar PV system can be used in running a solar PV based evaporative cooling system. In this work, an evaporative cooling system was developed and tested successfully. The evaporative cooling pads of 10 and 20 cm thickness were used in this work and we found that the evaporative pad of thickness 20 cm gives better performance as compared to the pad of thickness 10 cm. The fan speed significantly affects the performance of the evaporative cooling system. We found that the water flow rate also affects the performance of the evaporative cooling system and observed that the higher discharge rate results in higher saturation efficiency. From this work, we conclude that the solar PV powered evaporative cooling system will be a low cost and one of the cheapest cooling systems. Also, for the better performance of the evaporative cooling system, evaporative pad thickness, fan speed and water discharge rate has to be optimized.

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