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Experimental Analysis of the Dew Point Indirect Evaporative Cooler Operating with Solar Panels †

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Abstract: Indirect evaporative cooling can meaningfully improve the natural environment. It involves low operating costs for air cooling systems. The dew point indirect evaporative cooler (DP-IEC) is energy-efficient, ecological, and economical. The current study reports on an experimental analysis of a DP-IEC working under a wide range of operating conditions and integrated with a solar panel system. The electricity consumption of the DP-IEC can be met by utilizing renewable energy technology (solar panels). The system is designed for a cooling capacity of up to 3 kW, with an energy efficiency ratio of about 20. The experimental setup is investigated here in terms of velocity, water temperature, ambient air temperature, and air humidity. The temperature is dropped from 43 °C to 23 °C (i.e., 20 °C temperature drop) at 20% humidity and from 49 °C to 24 °C (i.e., 25 °C temperature drop) at 13% humidity at a fixed air velocity and water temperature. The cooling capacity, coefficient of performance, and energy efficiency ratio values vary across the ranges of 1612–3215 W, 2.93–5.85, and 9.21–18.37, respectively. The DP-IEC is integrated with solar panels to offset the electricity consumption. This research work also shows that the DP-IEC, when integrated with renewable energy technology (i.e., solar panels), provides energy savings as compared with air conditioners. As such, it is suitable for use in several areas around the world.

Keywords: evaporative cooler; Maisotsenko cycle; thermal effectiveness; cooling technology; solar panel

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1. Introduction

Energy is a primary commodity that is needed for comfortable living. Advanced countries around the world have plentiful energy resources, which signifies the quality of life of their citizens. As the population is increasing, energy demands are on the rise throughout the world. The air handling process meets the necessary requirements for cooling by regulating the temperature, cleanliness, humidity, and circulation in the air conditioning system [1]. The ultimate objective of HVAC systems is to provide human comfort, and numerous studies were found in the literature showing that comfort under steady-state conditions in terms of ambient temperature is in the range of 12–48 °C [2].

M-cycle cooling is becoming popular around the world, as it is an electrically efficient technique. This type of system does require refrigerants, which generate chlorofluorocarbons, so this system is environmentally friendly. The technique is utilized to decrease the temperature of the incoming air, which is considered as the ambient air in proximity to the incoming dew point temperature [3]. It saves 80% more energy than other conventional systems. The process involves the pre-cooling of air using the indirect evaporator, which then causes cooling [4].

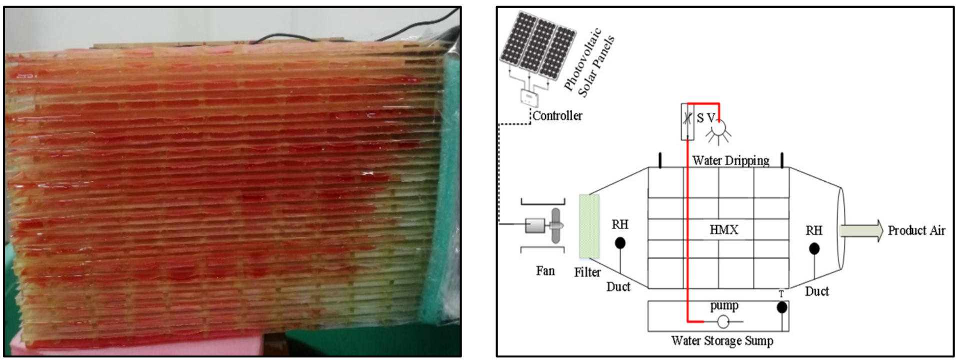
Muzaffar Ali et al. performed an experimental study on a crossflow DP-IEC using fins in dry channels, finding that it was more effective than a standard IEC. The results showed a wet bulb effectiveness value of 1.43 and dew point effectiveness value of 0.93 [5]. Duan et al. performed a novel simulation study on a counter-flow M-cycle heat exchanger and found that it was more efficient than indirect evaporative cooling. The results showed that the heat exchanger achieved wet bulb effectiveness of 1.4 [6]. Previously, Dove et al. studied the effectiveness and energy-saving potential of an M-cycle evaporative cooler and showed that M-cycle-based evaporative cooling reduces energy use by up to 80% [7]. Hassan studied four dissimilar configurations for an indirect evaporative cooler, namely counterflow, parallel flow, combined flow, and one regenerative flow. He found the wet bulb effectiveness values of 1.26, 1.09, 1.31, and 1.16, respectively, for each system [8]. Kashif et al. studied the application of an M-cycle-based evaporative cooler in Pakistan. This study was also conducted to compare the M-cycle evaporative cooler with other types of evaporative coolers [9].

In view of the above literature review, it can be concluded that DP-IECs are feasible for use in hot and dry areas with significant energy savings compared to conventional vapor systems. Studies have been performed on systems integrated with photovoltaic solar panels to meet the electricity consumption requirements, as referred to in the present work. Here, a considerable experimental analysis is presented involving a wide range of operating conditions, including the ambient air temperature, relative humidity of air at a fixed velocity, and water temperature. Moreover, a thorough analysis is presented in terms of the dew point effectiveness and wet bulb effectiveness, coefficient of performance, and energy efficiency ratio.

2. System Description

The DP-IEC has a crossflow arrangement with dry channels that are covered with alternate wet channels. These channels are made of plastics sheets and fiber cloth. The plastics sheets and fiber cloth are joined with the help of an adhesive bond. Acrylic dividers are also joined with plastics sheets and fiber cloth with the help of an adhesive bond. The dividers are fixed on both sides of the sheet. The heat and mass exchanger (HMX) is made of 19 wet and 18 dry channels.

The dew point indirect evaporative cooler consists of the HMX, fan, pump, and solar panel system. The HMX consists of polypropylene-based 37 channels (19 wet and 18 dry), as shown in Figure 1a. The DP-IEC is integrated with the PV solar panel system to fulfill the electricity requirements. The power consumption of the dew point indirect evaporative cooler is 70 W, which is fulfilled using the 100 W photovoltaic solar panel system. The schematic diagram of the DP-IEC integrated with the solar panel system is shown in Figure 1b.



(**a**) (**b**)

Figure 1. (**a**) Actual heat and mass exchanger. (**b**) Schematic of the DP-IEC integrated with the solar panel system.

3. Experimental Setup

The air conditioning laboratory unit (ACLU) is used to connect to the DP-IEC. The air conditioning laboratory trainer (ACLT) is designed to validate the operation and performance of the ACLU. It is designed to create various conditions and environments. It also controls the airflow for certain processes such as cooling, pre-heating, re-heating, humidifying, and de-humidifying. It is designed to investigate primary factors that are controlled in a conventional air conditioning system. When using this system, the required temperature and humidity values must be set. This system is tested under a wide range of temperatures, which vary from 30 to 49 °C, while the other parameters such as velocity (6.1 m/s) and water temperature (20 °C) are fixed. Another parameter is the relative humidity, which varies from 13 to 20% of dry air during the experimentation. The DP-IEC is coupled at the outlet of the air conditioning laboratory unit, as shown in Figure 2a. The DP-IEC is also integrated with PV solar panels to fulfill the electricity consumption of the system. The DP-IEC consists of the HMX, water pump, and axial fan, which has a total power consumption of 0.70 kWh, as shown in Figure 2b. The required power for the axial fan and water pump is easily achieved by installing the PV solar panel setup.

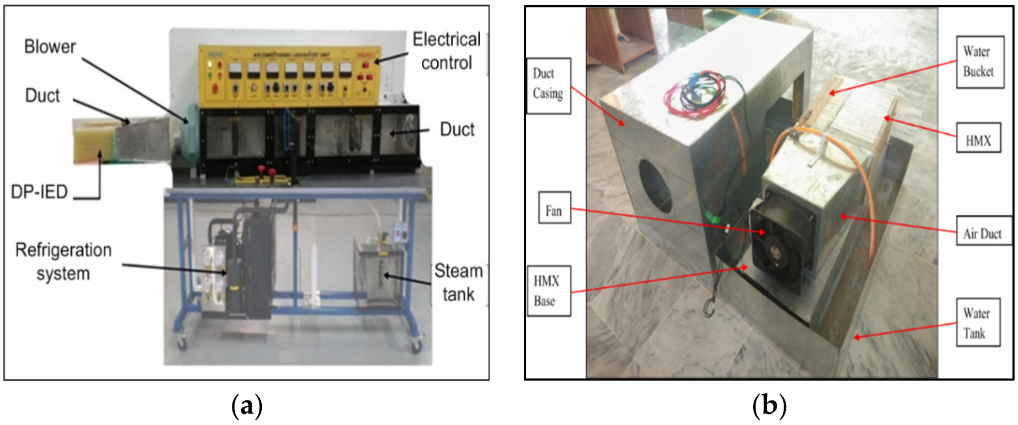


Figure 2. Experimental setup of the DP-IEC (**a**) with an air conditioning laboratory unit (**b**) integrated with PV solar panels.

4. Results and Discussion

In this study, the results were obtained using the ACLU by creating different temperature and humidity conditions. With this system, the temperature difference of the processed air through dry channels increases by increasing the ambient air temperature (T_a) at fixed velocity (V) and water temperature (T_w) values. The evaporation of the air increased by increasing the ambient temperature of the air, which contains more moisture before achieving the saturation point. The processed air holds more water vapor as the ambient temperature is increased. Therefore, the temperature difference and other parameters are also increased. The temperature difference (ΔT) varied from 12.95 to 26.04 °C, as shown in Figure 3a. The dew point and wet bulb effectiveness values were higher values at higher processed air temperatures as compared to lowered process air temperatures. The dew point effectiveness values varied from 0.5 to 0.75, as shown in Figure 3b. The wet bulb effectiveness varied from 0.84 to 1.07, as shown in Figure 3c. The maximum CC, COP, and EER values were measured with optimal input parameters, i.e., T_a = 49 °C, V_{in} = 6.1 m/s, RH = 13 %, and T_w = 25 °C. The cooling capacity (CC) increases when the inlet temperature is increased and decreased or when RH is increased. Here, the CC values were between 3215 and 1612 W, as shown in Figure 3d. It can be observed that increasing the CC results in higher COP and EER values. The COP and EER values varied from 2.93 to 5.85 and from 9.21 to 18.37, as shown in Figure 3e,f, respectively.

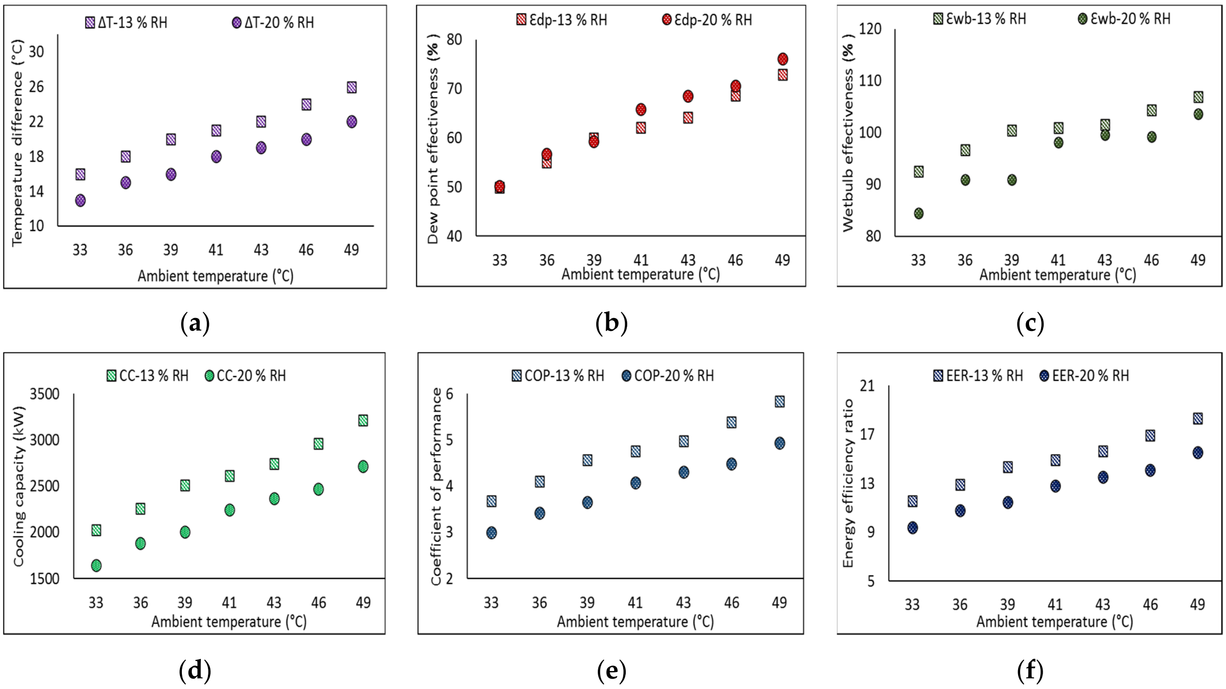


Figure 3. Experimental results: (**a**) temperature difference; (**b**) dew point effectiveness; (**c**) wet bulb effectiveness; (**d**) cooling capacity; (**e**) coefficient of performance; (**f**) EER of the system.

5. Conclusions

In this study, a thorough experimental investigation was performed. The inlet parameters were varied across wide ranges in term of the processed air temperature (33–49 °C) and relative humidity (13–20%). Comparative investigations were performed in terms of temperature differences in the produced air and the wet bulb and dry bulb effectiveness. It is worth noting that the maximum produced air temperature was achieved at T_a = 49 °C, RH = 13%, V = 6.1 m/s, and T_w = 20 °C. The higher temperature difference resulted in extreme CC, COP, and EER values in the ranges of 1612–3215 W, 2.93–5.85, and 9.21–18.37, respectively. The experimental results showed that the DP-IEC can be energy-efficient when used for cooling purposes. Another investigation was performed by integrated the DP-IEC with a PV solar panel system. It is worth noting that the electricity consumption of the DP-IEC can be easily offset by installing a PV solar system.

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