ABSTRACT

The energy demand for cooling is continuously increasing due to population growth and improvement of the average lifestyle, which has prompted experts to consider the cooling method that can help to minimize the rising energy consumption and carbon emissions. Currently dominated vapor compression cycle consumes high energy leading to negative environmental effects and hence an alternative long-term solution is needed. Evaporative cooling is a green solution that uses substantially less energy to provide cooling. Direct evaporative cooling is effective in the dry months; whereas, regenerative evaporative cooling is effective in the humid months. Hence, seasonal change of the cooling device is needed for effective cooling in varied climatic conditions. A dual-mode evaporative cooler (a two-in-one device) is realized in this situation, which is a unique concept that can operate in direct evaporating mode during the dry months and regenerative evaporating mode during the humid months.

The performances of all the feasible configurations (four parallel/counter-flow and four cross-flow configurations) of the regenerative evaporative cooler while keeping the water flow in a natural (gravity-driven) downward direction are examined and compared. All the configurations are numerically simulated using a single set of generalized governing equations and configuration-specific boundary conditions. The cooling capacity, dew point effectiveness, and coefficient of performance of various configurations are compared. The effects of geometrical (wet or dry channel gap) and operational factors (air intake temperature, humidity, extraction ratio, inlet velocity, water inlet condition) are explored. The exergetic, economic, environmental and sustainability aspects of a regenerative evaporative cooler are simulated on the basis of exergy destruction, exergy efficiency, specific total cost, CO_2 emission, and sustainability index.

The analysis concluded that the lower channel gap, extraction ratio, and airflow rate improve the energetic efficiency and the sustainability index and reduce CO_2 emission. Two configurations (A and H) yield the highest exergy efficiency, lowest specific total cost, and highest sustainability index among the considered designs.

The impacts of employing hybrid nanofluids (fluid with better thermophysical characteristics) as coolant and various cooling plate surface modifications for the regenerative evaporative cooler are examined in this work. The effect of the influencing variables on the performance of the heat and mass exchanger is explored using numerical modeling of the four heat-transmitting surfaces (flat plate, capsule embossed, finned, and corrugated). The results reveal that using hybrid nanofluid as a coolant in a regenerative evaporative cooler on its own is ineffective, but combining it with plate surface modification results in a considerable improvement in all performance metrics. Among the plate surfaces studied, the capsule embossed surface is shown to be the most effective (in terms of dew point effectiveness, coefficient of performance, and exergy efficiency.

A novel dual-mode evaporative cooler is developed and experimental energy, exergy, economic and sustainability assessments are conducted to determine its acceptability. The impact of changing the essential operational parameters (extraction ratio, inlet air temperature, inlet air velocity, inlet air specific humidity, water flow rate, and water inlet temperature) on the performance parameters (dew-point effectiveness, cooling capacity, specific cost, COP, exergy efficiency, sustainability index, and specific total cost) is investigated. Water entry temperature has a greater impact on regenerative mode. In all modes, a high water flow rate reduces the COP dramatically. The comparison reveals that direct mode has a larger cooling capacity and COP than regenerative mode, while regenerative mode has a higher dew point effectiveness and exergy efficiency. This dual-mode device is found more economical in both modes as compared to conventional vapor compression-based cooling device

The month-wise cooling performance of the dual-mode cooler is evaluated for five Indian cities (Bhopal, Lucknow, and Varanasi of composite climate; Ahmedabad of hot-dry climate; Kolkata of hot-humid climate). A psychrometric chart is used to assess the suitability of the modes and devices for the various months (April to September). The suggested gadget can be employed successfully and affordably for composite climatic zones. Both (direct and regenerative) modes of operation are examined for dew-point effectiveness, coefficient of performance, exergy efficiency, operating cost, and specific total cost. The month-wise performances of this device are also assessed for five cities of International climate zones. The operating cost of both modes is compared by considering respective electricity charges. The dual-mode device is compared with the single-mode device as well. The specific total cost is more for climate zone 4 and, variation is similar for both modes in most of the ASHRAE climatic zones. The present study reveals that significant energy and cost savings are possible by using the dual-mode evaporative cooler. The performance in both modes of a dual-mode evaporative cooler is finally forecasted in future weather scenarios. The exponential smoothing approach is used to anticipate temperature and humidity for four cities of major climatic zones. A psychrometric chart is used to forecast the acceptability of the modes of a dual-mode evaporative cooler based on current and future thermal comfort conditions. The current analysis demonstrates the usability analysis of the individual modes (of the dual-mode cooler) for composite and hot-dry climatic conditions in the futuristic (2030) scenario.