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Increasing effectiveness of evaporative cooling by pre-cooling using nocturnally stored water

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ABSTRACT

In this paper, a multi-step system of nocturnal radiative cooling and two-stage evaporative cooling is studied. The feasibility and potential of this system is investigated for four cities which have different climatic conditions. During the night time in summer, water is circulated from a storage tank to two radiative panels. The temperature of the water from the radiative panels decreases because of radiative heat transfer between the water in panels and night sky. During the next day, the stored cold water in the storage tank is used as coolant for a cooling coil unit. Hot outdoor air is passed through the cooling coil unit and a two-stage evaporative cooler. The results obtained demonstrate that first, the multi-step system can be considered as an alternative cooling system in some hot regions that evaporative cooling cannot be used. Second, the multi-step system has higher effectiveness than conventional two-stage evaporative coolers. Third, an energy saving of the multi-step system is between 75 and 79% compared to mechanical vapor compression systems. Consequently, this environmentally-friendly and highly-efficient system can replace the mechanical vapor compression systems.

1. Introduction

Among the heating, ventilation, and air conditioning (HVAC) systems, cooling systems consume the largest amount of electrical energy. Cooling is an essential issue in air conditioning in warm climates. The issues of global warming, the natural resources depletion, and demand for environmentally-friendly systems have led to a growth in use of natural green resources instead of conventional systems. The usage of passive cooling system has been considered to derive heat absorbing cycles to provide thermal comfort [1–3].

Heat dissipation techniques are based on the transfer of excess heat to lower temperature natural sinks. Regarding the sky, heat dissipation is carried out by long-wave radiation from a building to the sky that is called radiative cooling. The sky equivalent temperature is usually lower than the temperature of most bodies on the earth; therefore, any ordinary surface that interacts with the sky has radiant loss [2,3].

Direct evaporative cooling (DEC) is the oldest, and the most widespread form of cooling systems. The underlying principle of DEC is the conversion of sensible heat to latent heat. Through a direct evaporative cooling system, hot outside air passes a porous wetted medium. Heat is absorbed by the water as it evaporates from the porous wetting medium, so the air leaves the system at a lower temperature. The minimum temperature that can be obtained is the Wet-Bulb Temperature (WBT) of the entering air. Indirect evaporative cooling (IEC) has high potential for providing air conditioning demands at low energy costs. An indirect evaporative cooling system consists of two impervious separate air passages, primary and secondary air passages which are dry and wet, respectively. In the primary passages, outdoor air flow is sensibly cooled without adding water, while the secondary air and water flow in the secondary passages. The surface of the secondary passages is wetted by spray water, so that water film evaporates into the secondary air and it decreases the temperature of the wall. As a result, the cold wall removes the heat from the outdoor air. Consequently, the leaving air from the primary passages has a lower wet-bulb temperature than the entering air. In a two-stage Indirect–Direct Evaporative Cooling (IDEC) cold air enters to DEC unit after IEC causes further temperature drop, as a result, effectiveness of the systems increases.

Several research papers are dedicated to explore issues about nocturnal cooling including, Erell and Etzion [4,5], Meir et al. [3], Bagioras and Mihalakakou [2], and Farmahini-Farahani et al. [6]. Aforementioned research studied experimental and theoretical investigations of long-wave radiance, nocturnal radiative cooling

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