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Performance improvement of vapor compression cooling systems using evaporative condenser: An overview

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ABSTRACT

Reduction of energy consumption is a major concern in vapor compression cooling systems, especially in areas with very hot weather conditions. In hot weather conditions, performance of these systems decrease sharply and electrical power consumption increases considerably. Evaporative condensers enhance the heat rejection process by using the cooling effect of evaporation and therefore improve energy-usage efficiency. This paper presents an extensive review of the state of the art of evaporative condensers used in residential cooling systems: refrigeration, air-conditioning, and heat pump systems. The paper primarily concentrates on the energy consumption of residential cooling systems worldwide and its related problems. In addition, the paper covers the operation principles of evaporative-condensers, theory of heat rejection, and water evaporation rate. Finally, comparison between different types of condensers is presented. It is found that by using evaporative-cooled condenser instead of air-cooled condenser, the power consumption can be reduced up to 58% and the coefficient of performance can be improved by about 113.4% with systems of different cooling capacities ranging from 3 to 3000 kW.

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Contents

1. Introduction

Energy is a very important factor in driving strong economic development and growth of any country. With the increasing demand on energy, the research on conservation of energy and its efficient use is turning out to be one of the important topics. Reduction of energy consumption through efficient energy use or by reducing the consumption of energy services is a goal in all engineering fields [1–3]. Saving energy will decrease the dependence on fossil fuel, and this is an essential contributor in the measure and gross of the economy in any country due to the high

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Nomenclature

A	coil surface area, m^2
C	specific heat capacity, kJ/(kg K)
G	rate of water spray, kg/s
H	Enthalpy, kJ/kg
H	condenser water basin height, m
L	air flow rate, kg/s
M	Working fluid charge mass, kg
COP	Coefficient of Performance
EACC	Evaporative Air Cooled Condenser
h_{fg}	latent heat of vaporization, kJ/kg
m	mass flow rate, kg/s
P	power consumption, kW
Q	heat transferred, kJ/s
Q	volumetric flow rate, m^3/s
T	temperature, °C
U	overall heat transfer coefficient, kW/m^2 K
V	velocity, m/s
PLRs	part load ratios
RH	relative humidity, %
SCT	saturated condensing temperature, °C

Greek symbols

ρ	density, kg/m^3

Subscripts

a	air
c	condensing
cond	condenser
comp	compressor
ch	chiller
d	discharge
d_b	dry bulb
in	inlet
out	outlet
r	refrigerant
s	suction
w	water
w_b	wet bulb
w_{eva}	evaporated water
w_s	water film surface

prices of fossil fuel [4–6]. This saving and reduction in energy consumption, in addition, helps in decreasing global warming.

Increasing living standards and demand for human comfort has caused an increase in energy consumption. The amount of energy consumed by air conditioners, refrigerators, and water heaters is increasing rapidly, and occupies about 30% of the total power consumption [7]. Electricity consumption for air conditioning systems has been estimated around 45% for residential and commercial buildings [8]. Because of the rapid growth in world population and economy, the total world energy consumption is projected to increase by about 71% from 2003 to 2030 [9]. Therefore, any attempt to decrease the energy consumption of cooling systems as a whole will contribute to large-scale energy savings at the international level. Reduction of energy consumption of cooling units can be achieved by improving the performance. This can be done by lowering the compressor power consumption, increasing the condenser heat rejection capacity, or reducing the difference between condenser and evaporator pressures.

Higher condensing temperature causes an increase in the pressure ratio across the compressor, thus increasing compressor work and thereby decreasing the compressor lifetime and coefficient of performance. High outdoor air temperatures above 35 °C in summer is one of the reasons, leading to a drop in coefficient of performance of most air cooled units to the range of 2.2–2.4 [10]. In addition, if this temperature remained above 45 °C for an extended period, the air conditioner would trip because of the excessive condenser working pressure. Chow and Cengel [11,12] mentioned that the coefficient of performance of an air conditioner decreases about 2–4% for each 1 °C increase in the condenser temperature.

In many Middle East countries, the atmospheric temperature during summer approaches 40–45 °C or sometimes higher. During these prevailing conditions, the air conditioner compressor continuously works and consumes more electrical power and the COP deteriorates [13]. Therefore, it is required to decrease the ambient air temperature before it passes over the condenser coil, in order to decrease the temperature and pressure of the condenser. This can be achieved by using evaporative condensers, which reduces the temperature of the condensing environment from the outdoor dry bulb temperature to close to the outdoor wet bulb temperature [14]. Efficiency of evaporative condensers is essentially unaffected by high ambient temperatures in dry climates. The merit of evaporative condensers is most significant during utility peak periods when the difference between dry and wet bulb temperatures is often greatest [15].

Evaporative cooled condensers can have a smaller heat transfer area and lower airflow rate for the same overall heat transfer coefficient as compared with air-cooled counterpart [16]. This could result in overall significant savings in energy and demand since any small reduction in power consumption in the residential sector could save huge amount of energy [17,18]. The problem of evaporative cooled condenser has activated the research programs in order to improve the performance of the cooling systems by enhancing heat transfer rate in the condenser [19].

In this paper, a comprehensive review and subsequent analysis into the evaporative condenser technology is carried out. In addition, the paper addresses the energy consumption by residential cooling systems and covers the basic concept, operational principles, and theory of heat rejection by evaporative condensers.

2. Condensers used in cooling systems

Condensers in all cooling systems are used to reject the heat gained during evaporation and gas compression processes of the refrigerant to the ambient air. A change in the refrigerant state from superheated vapor to liquid occurs as energy is removed from the hot refrigerant to the ambient. Depending on the type of the cooling medium, there are three main types of condensers used named air-cooled, water-cooled, and a combination of the both types known as the evaporative cooled condenser.

Condensers used in conventional small and medium-sized refrigeration cooling systems (up to 20 TR) are mainly; air-cooled [20–22], and it represent the first type. The air-cooled condensers depend on the heat transfer between the condenser coils and the ambient airflow. Their energy performances are governed by the thermodynamic properties and heat transfer with air. Therefore, the thermodynamic performances of the cooling systems coupled with an air-cooled condenser will depend on climatic conditions, which prevent it from giving a constant