



Advancing evaporative rooftop packaged air conditioning: A new design and performance model development

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ARTICLE INFO

Article history:

Received 4 November 2011

Accepted 19 January 2012

Available online 28 January 2012

Keywords:

Evaporative cooling

Rooftop units

HVAC models

ABSTRACT

This paper presents a technological advancement in evaporative cooling rooftop air conditioning comprising a uniquely designed evaporative water cooler that includes a multi-stage hydronic unit and high thermal performance. In the new design, the water cooler is a counterflow air-to-air heat exchanger in which ambient air is pre-cooled in a dry path on one side of a heat transfer surface by water flowing on the other side of the surface. The water is then cooled by evaporation in a wet path by a secondary air stream flowing through the heat exchanger on the same side as the water but in the opposite direction. Outside air is cooled in the dry passages and then enters the wet passages at a lower wet bulb temperature than that of the outdoor air, potentially producing a lower sump water temperature compared to those produced by traditional evaporative condensers. We also developed a computer model to simulate the performance of the rooftop packaged unit. The model is based upon the Simulation Problem Analysis and Research Kernel (SPARK) simulation program and can be used to optimize component sizes and to perform an economic analysis. In addition, the model can be used for fault detection and diagnosis during operation. The simulation model was calibrated with experimental data obtained from the study and was then used for optimal sizing and performance tracking.

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1. Introduction

According to the US Energy Information Agency (EIA), buildings account for 39% of the primary energy use in the US and use approximately 39 Quad in 2006. Space cooling and heating collectively account for one-third of the total primary energy use in buildings [1]. Rooftop packaged air conditioners and other unitary HVAC devices are used extensively for space cooling and heating in commercial buildings in the US. They are particularly common in small commercial buildings, such as retail stores in strip malls, school buildings, and office buildings [2]. Packaged air conditioning units account for 44% of all cooling equipment and are responsible for cooling approximately half of all commercial building spaces in the US. However, rooftop packaged units are often designed and installed poorly, and they are prone to faults and malfunctions during operation and control. Unlike large built-up HVAC systems, most of which are commonly managed by dedicated building operators who are responsible for their daily operation and maintenance, rooftop packaged units are typically installed in smaller

buildings, where the owners tend to be more cost-sensitive and often capital constrained, i.e., have a tighter budget resulting in fewer resources for daily operation and lower levels of responsiveness to troubleshooting.

In typical rooftop packaged units, the direct expansion evaporator coils are usually not designed to have uncontrollable surface temperatures, which often cause unnecessary latent cooling. In addition, dust from the air can deposit onto the closely spaced fins of the coils; this dust causes condensed moisture droplets to accumulate due to latent cooling. With the help of elevated moisture or condensed water, the dust may bridge the narrow gaps between the fins, resulting in significantly lower efficiency in heat and mass transfer through the coils. While it is difficult to quantify the fraction of rooftop packaged units in the market operating with significantly lower efficiency or with degradation or faults, some studies in the literature have indicated that energy savings of 10–30% are possible from improving the operation of rooftop units [3]. Katipamula and Brambley (2004) estimated that the potential annual energy savings of improving the design and operation of rooftop packaged units on buildings in California ranged from 2 to 7 trillion BTUs ($0.58\text{--}2.1 \times 10^8$ kWh) [4]. Researches aiming at improving the performance of rooftop packaged air conditioning systems have been conducted widely. Active desiccants have been

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