Available online at www.sciencedirect.com
SciVerse ScienceDirect
journal homepage: www.elsevier.com/locate/ijrefrig

Proposal of an eco-friendly high-performance air-conditioning system. Part 1. Possibility of improving existing air-conditioning system by an evapo-transpiration condenser

Huynh Thi Minh Thu [a], *Haruki Sato* [b,*]

[a] *Graduate School of Science and Technology, Keio University, 3-14-1 Hiyoshi, Kohoku-ku, Yokohama 223-8522, Japan*
[b] *Department of System Design Engineering, Faculty of Science and Technology, Keio University, 3-14-1 Hiyoshi, Kohoku-ku, Yokohama 223-8522, Japan*

ARTICLE INFO

Article history:
Received 27 January 2012
Received in revised form
28 March 2013
Accepted 6 April 2013
Available online 15 April 2013

Keywords:
Air-conditioning
Energy saving
Heat island
Condenser
Evapo-transpiration
Exergy

ABSTRACT

Air-conditioning (AC) system consumes high energy and releases waste-heat. In the present study, we propose a method to improve its performance and minimize waste-heat by replacing existing air-cooled condenser by an evaporation and transpiration, evapo-transpiration, condenser. The improvement is confirmed by performing experiment for a conventional air-cooled AC system and a water-cooled AC system. Condenser temperature in the air-cooled system is higher than outdoor-temperature by 5–10 °C, while it is −5 to 5 °C in case of the testing system. From simulation results, saving energy consumption is expected to reach up to 30% in summer with the testing system. Based on these results, an evapo-transpiration heat-exchanger was developed as a new condenser. Heat-transfer coefficient of the testing heat-exchanger is at least 4 times higher than that of air-cooled condenser. Even hot fluid is used inside copper-tubing, its outlet-air temperature is as nearly as outdoor temperature.

Proposition de système de conditionnement d’air hautement performant et écologique. Partie 1. Possibilité d’améliorer un système de conditionnement d’air existant à l’aide d’un condenseur à évapotranspiration

Mots clés : conditionnement d’air ; économies d’énergie ; îlot de chaleur ; condenseur ; évapotranspiration ; exergie

* *Corresponding author*. Tel.: +81 45 563 1141x43045; fax: +81 45 566 1729.
E-mail address: hsato@sd.keio.ac.jp (H. Sato).

0140-7007/$ – see front matter
http://dx.doi.org/10.1016/j.ijrefrig.2013.04.004

Nomenclature

Air-conditioning system

T_o outdoor temperature [K]
T_{cond} condenser temperature [K]
$\Delta T = T_{cond} - T_o$ temperature difference between condenser and outdoor [K]
T_{ao} outlet-air temperature from outdoor unit [K]
P power consumption rate [W]
$\dot{Q}_{cond}$ condenser heat-transfer rate [W]
$\dot{E}$ exergy [W]

Heat exchanger

T_{fi}, T_{fo} temperatures at inlet and outlet of fan [K]
T_{hwi}, T_{hwo} temperatures at inlet and outlet of hot water [K]
U_o overall heat-transfer coefficient [W m^{-2} K^{-1}]
q_{hw} heat-transfer rate releases from hot water [W]
A_o outside surface area [m^2]

1. Introduction

Annual global average temperature trend continues increasing. One-degree Celsius increase in summer has been correlated with 3.8% increase in peak demand load for air-conditioning (Peck and Richie, 2009).

Air-cooled condensers have contributed large amount of small-scale air-conditioning due to its advantages of easy maintenance with convenient size. However, cooling by sensible heat from air is only expected to get low heat-transfer performance that makes high condensing temperature, i.e. 15–20 °C above that of the ambient air in some cases (Hosoz and Kilicarslan, 2004). In studies of Chow et al. (2002) and Hajidavalloo (2007), they mentioned that the coefficient of performance (COP) of an air-conditioner decreases about 2–4% by increasing each degree Celsius in condenser temperature. In addition, by releasing waste-heat to the surroundings, it further increases temperatures outside, which contributes to heat island problem in urban area. Moreover, hot-air flow of the waste-heat contains exergy, which is available energy that can transfer to work, generally it is not re-used.

Other types of condensers that commonly used in air-conditioning system are water-cooled and evaporative condensers (Hosoz and Kilicarslan, 2004). Most of water-cooled condensers reject heat by connected with cooling tower, while evaporative condenser is compact by combining functions of an air-cooled condenser with a water-cooled condenser and a cooling tower. Cooling by water evaporation has much higher performance compared to air-cooled condenser. In evaporative condenser, fin combined with packing material have been used (Ettouney et al., 2001). Cellulose is a common material for evaporative packing (Hajidavalloo, 2007; Hu and Huang, 2005), but it requires large space for evaporation. However, size of these condensers is large and recently they are applied for medium- and large-scale cooling system, in which, additional pump is required to operate.

We propose a new air-conditioning system using an evapo-transpiration heat-exchanger for higher performance condenser to reduce its temperature with convenient size and creating comfortable space at the outdoor unit. The possibility for developing a new air-conditioning system will be discussed in this paper.

- By experiments, we examine the relationship of power consumption of conventional air-conditioning system and average condense-temperature for every hour. Effect of condenser-temperature to the system performance is also demonstrated by simulation. Besides, waste-heat and its exergy from air-cooled outdoor-unit are also evaluated.
- Temperatures of condenser and compressor of a water-cooled system are measured to confirm the possibility of reducing those temperatures in the new system. Performance of new system is also expected based on this result.
- An evapo-transpiration heat-exchanger, which is proposed for new condenser, will be explained by its heat-transfer coefficient and possibility to minimizing environmental effect of the new outdoor-unit.

2. Experiment description

2.1. Air-conditioning systems

An existing commercial air-conditioning system using R410A as refrigerant, nominal cooling capacity of 2.5 kW and catalogue COP of 5.68 is used as a baseline system. This conventional system has an air-cooled condenser, which is copper-tubing of 22.3 m length and 8 mm outside diameter. A water-cooled air-conditioning system, which was modified from conventional system by using a water-cooled condenser that connected with cooling tower, as shown in Fig. 1, is used as a testing system. Water-cooled condenser is a double copper-tubing adjacent to each other, with total length of 21 m, refrigerant outside diameter of 6.35 mm and water outside diameter of 8 mm. The cooling tower used in the testing system has nominal cooling capacity of 13.6 kW with a 0.25-kW pump and a 0.05-kW fan being commercially available as the minimum capacity.

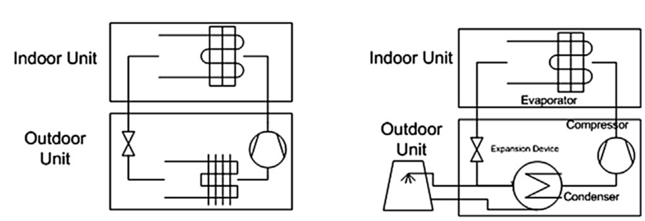

Fig. 1 – Sketch of conventional AC (left) and testing AC systems (right).