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Heat Recovery System from Air-Cooled Chillers in Iranian Hospitals

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Abstract**—**Few people would dispute the fact that one of the most common applications of energy is creating comfort in buildings, so it is probably true to say that management of energy consumption is required due to the environmental issues and increasing the efficiency of mechanical systems. From the geographical point of view, Iran is located in a warm and semi-arid region; therefore, air-cooled chillers are usually used for cooling residential buildings, commercial buildings, medical buildings, etc. In this study, a heat exchanger was designed for providing laundry hot water by utilizing condenser heat lost base on analytical results of a 540-bed hospital in the city of Mashhad in Iran. In this paper, by using the analytical method, energy consumption reduces about 13%, and coefficient of performance increases a bit. Results show that this method can help in the management of energy consumption a lot.

Keywords**—**Energy management, air-cooled chiller, heat exchanger, hospital laundry system.

I. Introduction

ENERGY consumption has a huge impact on climate change and the destruction of the global environment in addition to imposing high costs. As Iran is located in the arid and semi-arid world waistband, lack of water resources has always been a constraint for various activities across the country. Thus, using equipment with low water and energy consumption is a top priority for engineers. The world today is facing a lot of difficulties in energy management and energy-saving technologies are the need of the hour [1]. The literature has conducted a lot of innovative technologies and research studies to solve the energy consumption issues as fossil energy is still playing a major role as a source of fuel after the oil crises in the 1970s [2]. The high consequent costs of global management stimulate the users, and therefore the technical managers involved, to find new plant and management solutions which are able to permit significant savings [3]. Refrigeration systems have become an integral part of every house [4]. Generally, the purpose of the air-conditioning system is to maintain the indoor air quality and to provide thermal comfort inside the conditioned space [5]. When designing a refrigeration installation, it should be remembered that the heat recovery system must not harm the energy efficiency of the refrigeration unit, and the main function of the modernized device still has to be to provide a cooling effect with unchanged parameters [6]. The data obviously indicate that energy-saving methods that can reduce energy consumption for air conditioning would be extremely valuable [7]. Recovery of waste heat is a hefty research area among the majority of scientists [8]. Heat energy, once degraded to lower temperature, will not be of any use [9]. Many energy-saving processes and techniques have been proposed for residential building applications, including recovering the waste energy of buildings, which is also referred to as a heat recovery system [10]. Waste heat which is rejected from a process at a temperature enough high above the ambient temperature permits the recovery of energy for some useful purposes in an economic manner [11]. The use of recovered heat from chillers can be an efficient and cost-effective means of providing heating hot water or domestic hot water to buildings [12].

In hospitals, a high level of hygiene is expected. Because of this, installing healthy laundry equipment is of great importance to avoid any setback caused by an infection passed through the hospital clothing or linens. A hospital laundry room requires a great selection of machinery, which can optimize the washing quality and saving both power and water.

In this paper, we designed a heat exchanger for providing laundry hot water by heat recovered from the condenser.

II. System Description and Design

The proposed system is the mechanical system of a 540-bed hospital in Mashhad city with three air-cooled chiller as shown in Fig. 1.

Fig. 1 Chillers under study

Each chillier contains three screw compressor and one condenser with 24 fans with variable speed setting.

As shown in Fig. 2, we have mounted a shell and tube converter for preheating laundry hot water between compressor and condenser for transferring a part of refrigerant heat to water. For that reason, some calculations are made for

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determining the length of the heat exchanger.

TABLE I
SPECIFICATION OF CHILLERS

Chillers specification	Unit	Quantity
Cooling capacity	Kw	1597.2
Compressor power	Kw	499.6
Condenser capacity	Kw	1097.6
Fan power	Kw	1.85
Air temperature	^{o}C	35

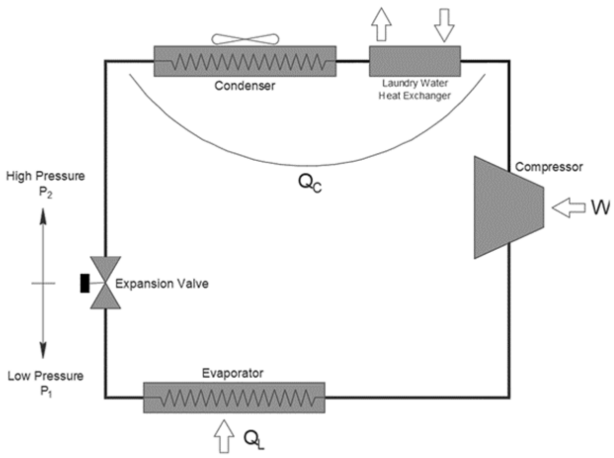

Fig. 2 Diagram of chiller cycle with heat converter

TABLE II
INITIAL DESIGN DATA OF HEAT EXCHANGER

Converter specification	Unit	Quantity
Length	m	unknown
Internal diameter	m	0.074
Outer diameter	m	0.086
water pipe diameter	m	0.02

TABLE III
R-134A PROPERTIES

properties	unit	Quantity
c_p	$j.kg^{-1}.K^{-1}$	1.066×10^{3}
ϑ	$m^{3}.kg^{-1}$	0.0175
μ	$pa.s$	0.012×10^{-3}
k	$w.m^{-1}.{}^{\circ}K^{-1}$	0.074

TABLE IV
WATER PROPERTIES

properties	unit	Quantity
c_p	$j.kg^{-1}.K^{-1}$	4.2×10^{3}
Pr	-	0.0175
μ	$pa.s$	695×10^{-6}
k	$w.m^{-1}.{}^{\circ}K^{-1}$	628×10^{-3}

III. THEORETICAL BACKGROUND

A. Thermal Capacity of Heat Exchanger

The amount of heat recovered in the heat exchanger could be achieved by:

$$q_{\max} = \dot{m}_R \times c_p \times \left(T_{R,o} - T_{R,i}\right) \tag{1}$$

The maximum refrigerant outlet temperature of the compressor is 80 ^{o}C and the maximum refrigerant outlet temperature of the condenser is about 50 ^{o}C. As shown in Fig. 2, we put the heat exchanger before the condenser, so we transfer refrigerant heat to the water until the refrigerant temperature becomes lower than the superheat temperature range that it is 65 ^{o}C.

Mass flow rate of refrigerant can be achieved by compressor power consumption relation:

$$w_c = \dot{m}_R \times \left(h_2 - h_1\right) \rightarrow \dot{m}_R = \frac{w_c}{\left(h_2 - h_1\right)} \tag{2}$$

According to Fig. 3, the outlet enthalpy of the compressor is $450\left(\frac{kj}{kg}\right)$ and the inlet enthalpy is $400\left(\frac{kj}{kg}\right)$.

By using (1) and (2), thermal capacity of heat exchanger is determined as:

$$\dot{m}_R = \frac{135}{\left(450 - 400\right)} = 2.7\left(\frac{kg}{s}\right)$$

$$q_{\max} = 2.7 \times 1.066 \times \left(80 - 65\right) = 43.17\left(kw\right)$$

Because we have three compressors in each unit, the maximum amount of energy exchange in the heat exchanger is 129.5 Kw.

B. Convection Heat Transfer Coefficient

Water

Nusselt number of water is calculated by:

$$\bar{N}u_w = \frac{h_w \times D_H}{k_w} \rightarrow \bar{N}u_w = 0.023 \times \mathrm{Re}^{0.8} \times \mathrm{Pr}^{0.4} \tag{3}$$

$$h_w = \frac{\bar{N}u_w \times k_w}{D_H} \tag{4}$$

Hydraulic diameter is:

$$D_H = D_o - D_i \tag{5}$$

Reynolds and Prandtl number is calculated by:

$$\mathrm{Re} = \frac{\rho_w \times u_w \times D_H}{\gamma_w} \tag{6}$$

$$\mathrm{Pr} = \frac{\gamma_w \times c_p}{k_w} \tag{7}$$

In (6), water velocity of water is calculated by:

$$q_{\max} = \dot{m} \times c_p \times \left(T_{w,o} - T_{w,i}\right)$$

$$129.5 = \dot{m} \times 4.2 \times (48-15) \rightarrow \dot{m} = 0.93\left(\frac{kg}{s}\right)$$

$$\dot{m} = \rho \times u_w \times A_o$$

$$0.93 = 1000 \times u_w \times \frac{\pi \times 0.086^2}{4} \rightarrow u_w = 0.16\left(\frac{m}{s}\right)$$

By using (3)-(6), convection heat transfer coefficient of water is determined as:

$$D_H = 0.086 - 0.074 = 0.012\,(m)$$

$$\mathrm{Re}_w = \frac{1000 \times 0.16 \times 0.012}{695 \times 10^{-6}} = 2762.5$$

$$\bar{N}u_w = 0.023 \times 2762.5^{0.8} \times 4.62^{0.4} = 24.02$$

$$h_w = \frac{24.02 \times 628 \times 10^{-3}}{0.012} = 1257\left(\frac{w}{w^{2}\,{}^\circ c}\right)$$

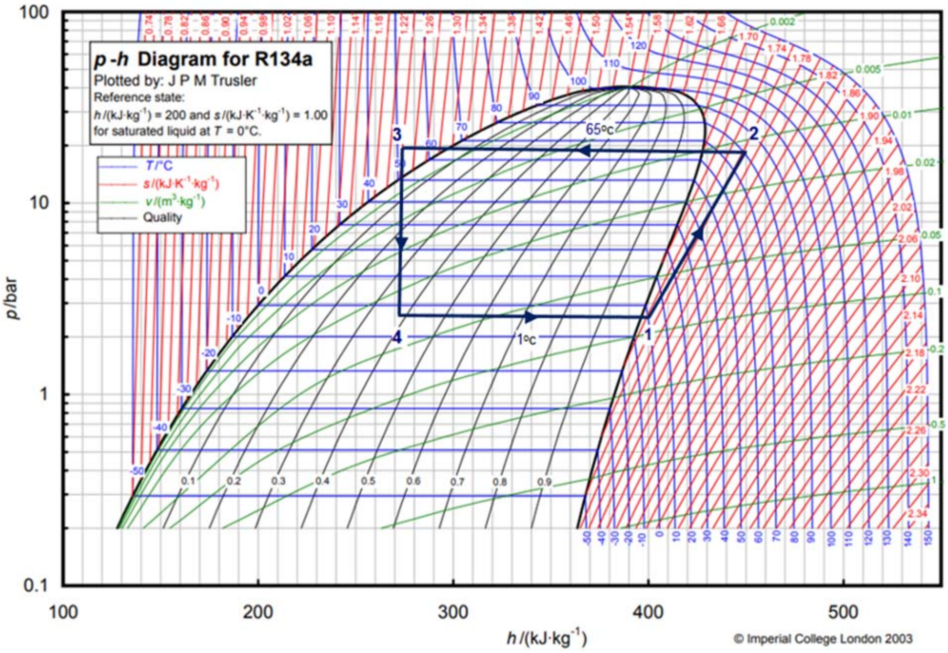

Fig. 3 p-h diagram of refrigerant R-134a

Refrigerant

Nusselt number of refrigerant is calculated by:

$$\bar{N}u_R = \frac{h_R \times D_i}{k_R} \rightarrow \bar{N}u_w = 0.023 \times \mathrm{Re}_R^{0.8} \times \mathrm{Pr}_R^{0.3} \tag{8}$$

$$h_R = \frac{\bar{N}u_R \times k_R}{D_i} \tag{9}$$

In (6), refrigerant velocity of refrigerant is calculated by:

$$\dot{m}_R = \rho \times u_R \times A_i$$

$$2.7 = \frac{1}{0.0175} \times u_R \times \frac{\pi \times 0.074^2}{4} \rightarrow u_R = 10.99\left(\frac{m}{s}\right)$$

By using (6)-(9), convection heat transfer coefficient of refrigerant is determined as:

$$\mathrm{Re}_R = \frac{57.14 \times 10.99 \times 0.074}{0.012 \times 10^{-3}} = 3872473$$

$$\mathrm{Pr}_R = \frac{0.012 \times 10^{-3} \times 1.066 \times 10^3}{0.074} = 0.17$$

$$\bar{N}u_R = 0.023 \times 3872473^{0.8} \times 0.17^{0.3} = 2519.14$$

$$h_R = \frac{2519.14 \times 0.074}{0.074} = 2519.14\left(\frac{w}{w^{2}\,{}^\circ c}\right)$$

C. Heat Exchanger Length

Thermal resistance can be written as:

$$R = \frac{1}{U \times A} = \frac{1}{h_R \times A_i} + \frac{1}{h_w \times A_o}$$
$$\rightarrow \frac{1}{U \times A} = \frac{1}{\pi \times L}\left(\frac{1}{h_R \times D_i} + \frac{1}{h_w \times D_o}\right) \tag{10}$$

With regarding to (1) U×A can be written as:

$$q = U \times A \times \Delta T_{LMTD} \rightarrow U \times A = \frac{q}{\Delta T_{LMTD}} \tag{11}$$

By using (10) and (11), converter length is determined as:

$$q = U \times A \times \Delta T_{LMTD}$$

$$43.17 = U \times A \times \frac{32-50}{\ln\left(\frac{80-48}{65-15}\right)} \rightarrow U \times A = 1.07\left(\frac{w}{m^2 \circ k}\right)$$

$$\frac{1}{U \times A} = \frac{1}{\pi \times L}\left(\frac{1}{h_R \times D_i} + \frac{1}{h_w \times D_o}\right)$$

$$\frac{1}{1.07} = \frac{1}{\pi \times L}\left(\frac{1}{2519.14 \times 0.074} + \frac{1}{1257 \times 0.086}\right) \rightarrow L = 4.98(m)$$

IV. Results

According to the system specification table, actual COP of chiller without laundry hot water heat exchanger is:

$$COP = \frac{Q_{ev}}{w_c + w_f} = \frac{1597.2}{499.6 + 44.4} = 2.93$$

The condenser capacity (Q_h) is about 1000 kW. By using a heat exchanger we transfer 129.5 kW of this energy to laundry water that causes a 13% reduction in fan work. In this case, coefficient of performance is:

$$W_f = 38.7 \text{ kW}$$

$$COP = \frac{1597.2}{499.6 + 38.7} = 2.96$$

Due to the preheating laundry water in heat exchanger, energy-saving is calculated by:

$$Q_{H.E} = 500 \times GPM \times \Delta T$$

$$= 500 \times \left(\frac{0.00093 \times 3600}{0.227}\right) \times (48-15)$$

$$= 243226.5\left(\frac{Btu}{hr}\right) = 61292.05\left(\frac{kcal}{hr}\right)$$

V. Conclusion

In conclusion, an attempt is made by this study is to recover heat lost from the condenser. The main aim is to reduce the gas consumption of the hospital installation. Following results are provided by this paper:

1. The thermal value of Mashhad gas is about 8170 ($\frac{kcal}{m^3}$). So total gas-saving per hour is equal with:

$$\frac{61292.5}{8170} = 7.5\left(\frac{m^3}{hr}\right)$$

2. Results have shown that using condenser heat has not a negative impact on chiller operation, even it increases the chiller COP about 0.03.

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