THE DECREASE OF COOLING LOAD IN THE VAPOR COMPRESSION SYSTEM BY THE EARTH-TO-AIR HEAT EXCHANGER SYSTEM

Weerawoot Arunwattana

Abstract

The purpose of this research is to decrease the cooling load of a vapor compression system by using an earth-to-air heat exchanger system. Only during rainy season in Thailand this earth-to-air heat exchanger system could cool the air in a building for almost the entire period of the experiment. In contrast, in summer and winter seasons, it worked as a heating mode. It could save sufficient energy in the vapor compression system. However, the total energy used in this combined air-conditioning system with the earth-to-air heat exchanger system and the vapor compression system is slightly more than the compression system alone with the thermostat set at low temperatures for comfortable levels; but it is less than the vapor compression system alone at the peak temperature for comfortable levels.

Keywords: Cooling load, air-conditioning, comfortable level

Introduction

Since Thailand is a tropical country, the weather is hot and humid for most of the time. The air in residential buildings must be cooled by air conditioners in order to keep the condition in the room to be comfortable. A large number of air conditioners in Thailand use the vapor compression system, which consumes lots of energy. Through the reports gathered, it was realized that most residential buildings used more than 50% of their total electrical energy in the air-conditioning system (Yiemwattana, 2002). For this reason, the most efficient means of saving energy in a residential building is through management in the air-conditioning system. However, good energy management requires improvement of the vapor compression system or substituting it with another system.

Arunwattana (2000) improved the cooling capacity of the vapor compression system (12,000 BTU/h capacity) using the evaporative cooling system to decrease the air temperature before entering the condenser. This could increase the coefficient of performance by 8.5% and save energy by 8.2%. This system was then improved by using the condensate water after evaporation in the evaporative cooling system (Arunwattanana *et al.*, 2004). It was pumped into the cooling wall to extract heat gain in the wall and was then returned to the evaporative cooling system. This system

*Department of Physics, Faculty of Science, Mahasarakham University, Mahasarakham 44150, Thailand.
  E-mail: we_thermal@hotmail.com*

could increase the coefficient of performance by 41% and save energy by 22%.

However, earth-to-air heat exchangers, also called ground tube heat exchangers, are an interesting technique to reduce energy consumption in a building. They can cool or heat the ventilation air using cold or heat accumulated in the soil. In Europe, many buildings are conditioned by an earth-to-air heat exchanger for air-conditioning in most heating modes (Pfafferott, 2003). In contrast, Arunwattana *et al.* (2005) designed and constructed an earth-to-air heat exchanger system for cooling air in buildings during summer in Thailand. It only decreased the air temperature in a building by about 1 - 8 degrees Celsius when compared with the ambient temperature. Unfortunately, it was unable to cool the air temperature to a comfortable level although it was improved slightly by the use of fan. Because this system cannot cool the air temperature sufficiently, it was decided to experiment with the vapor compression system to save energy. This paper describes the experiment.

Materials and Methods

Installation

In this research, two identical buildings were each installed with a 12,000 BTU/h cooling capacity of the vapor compression system, as shown in Figure 1. Building no.1 was then complemented with an earth-to-air heat exchanger system, which was designed by Arunwattana *et al.* (2005) (Figure 2).

Evaluations

The air conditioning system with the combination of the earth-to-air heat exchanger system and the vapor compression system was installed in building no. 1. Building no. 2 was installed with the vapor compression system. The system in both buildings had been evaluated by the coefficient of performance and the consumption of electrical energy in the summer, rainy, and winter seasons. The equation of the coefficient of performance of the combined air conditioning system is shown in Eqn. 1 and the

vapor compression system is shown in Eqn. 2.

$$(COP)_{combined} = \frac{\rho_a c_a \dot{V}(T_{in} - T_{out}) + \dot{m}_r (h_1 - h_4)}{\Delta P \dot{V} + \dot{m}_r (h_2 - h_1)}$$

(1)

$$(COP)_{vapor} = \frac{h_1 - h_4}{h_2 - h_1}$$

(2)

where

$(COP)_{combined}$ = coefficient of performance of the combined air-conditioning system

$(COP)_{vapor}$ = coefficient of performance of the vapor compression system

$\dot{m}_r$ = mass flow rate of refrigerant-22, kg/s

h_1 = enthalpy of refrigerant-22 before entering the compressor, kJ/kg

h_2 = enthalpy of refrigerant-22 after leaving the compressor, kJ/kg

h_4 = enthalpy of refrigerant-22 before entering the evaporator, kJ/kg

ΔP = air-pressure losses in the earth-to-air heat exchanger system, kN/m²

$\dot{V}$ = volume flow rate of supply air, m³/s

ρ_a = density of *air*, kg/m³

C_a = specific heat of air at constant pressure, kJ/kg.°C

T_{in} = air temperature before entering the earth-to-air heat exchanger system, °C

T_{out} = air temperature after learing the earth-to-air heat exchanger system, °C

The Position of Measurement and Instruments

In the research, the coefficient of performance of the combined air-conditioning system and the vapor compression system were evaluated by using the measured thermodynamic properties of working fluids. In the combined air-conditioning system composes of the earth-to-air heat exchanger system and the vapor compression system. The temperatures of air

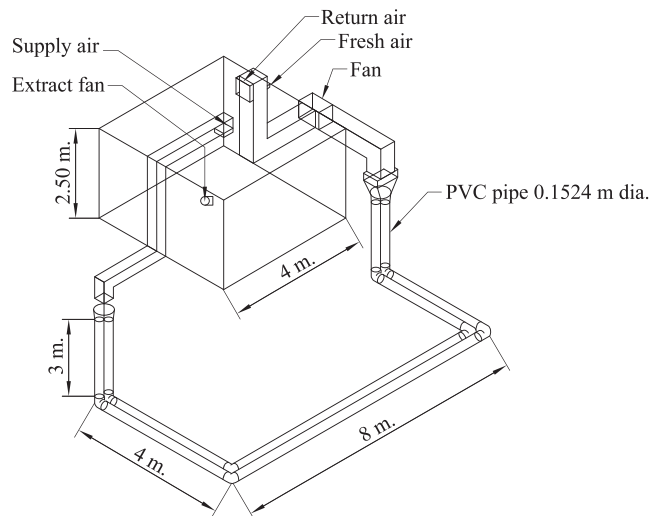**Figure 1. Two identical buildings for the experiment**

Figure 2. The earth-to-air heat exchanger system (Arunwattana _et al.,_ 2005)

flowing through into the heat exchanger pipes of the earth-to-air heat exchanger system were measured at 2 points-before entering and after leaving the heat exchanger pipes. Furthermore, the pressure loss in the system and the supply air velocity were also measured. In addition to measuring the properties of the air in the earth-to-air heat exchanger system, the properties of refrigerant in the vapor compression system were also measured in the terms of the temperatures and pressures at before entering and after leaving the compressor and the condenser, and the mass flow rate was also measured. The properties of the refrigerant of the vapor compression system, which operated alone, were measured at the same position as in the vapor compression system of the combined air-conditioning system. Furthermore, the positions of measurement of thermodynamic properties are shown in Figure 3 and details of the instruments are shown in Table 1.

Results and Discussion

The ability of cooling air by the combined air-conditioning system for saving energy was only used in rainy season because the ground temperature at 3 meters depth was lower than 27°C (Figure 4(b)), which is the comfortable peak level. This earth-to-air heat exchanger system could cool air in the building for the full time of the experiment because the ground temperature that exchanges heat with the heat exchange tubes was lower than 27°C. From the
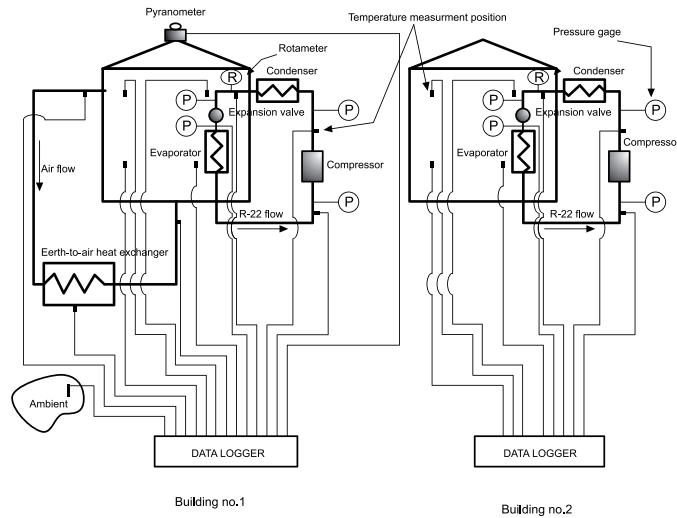

Figure 3. The details of the instrumentation used for the experiment

Table 1. Details of the instrumentation

| Measurement Variable	Instrument	Range	Uncertainty
Temperature	Type K Thermocouple	- 50 to 100°C	$\pm 0.4\%$
Pressure	Type 4 Manometer		
	No. 103483	0 to 2.5 kPa	$\pm 0.2\%$
High pressure (R-22)	Pressure gages Succo	0 to 3,400 kPa	-
Low pressure (R-22)	Pressure gages Succo	0 to 1,724 kPa	-
Velocity (Air)	DGICON Anemometer		
	Model DA-43	0.4 to 30 m/s	$\pm 0.2\%$
Flow rate (R-22)	Rotameter	0 to 3 kg/s	-
Solar radiation	Pyranometer		
	Apogee Model PYR	0 to1,000 W/m^2	$\pm 0.2\%$
kW-hr	kW-hr meter Mitsubishi	-	-
Data record (no.1)	Data logger ΔT		
	Model DL2e No. 414-1	-	-
Data record (no.2)	Data logger DaqPro		
	No. 5300	-	-
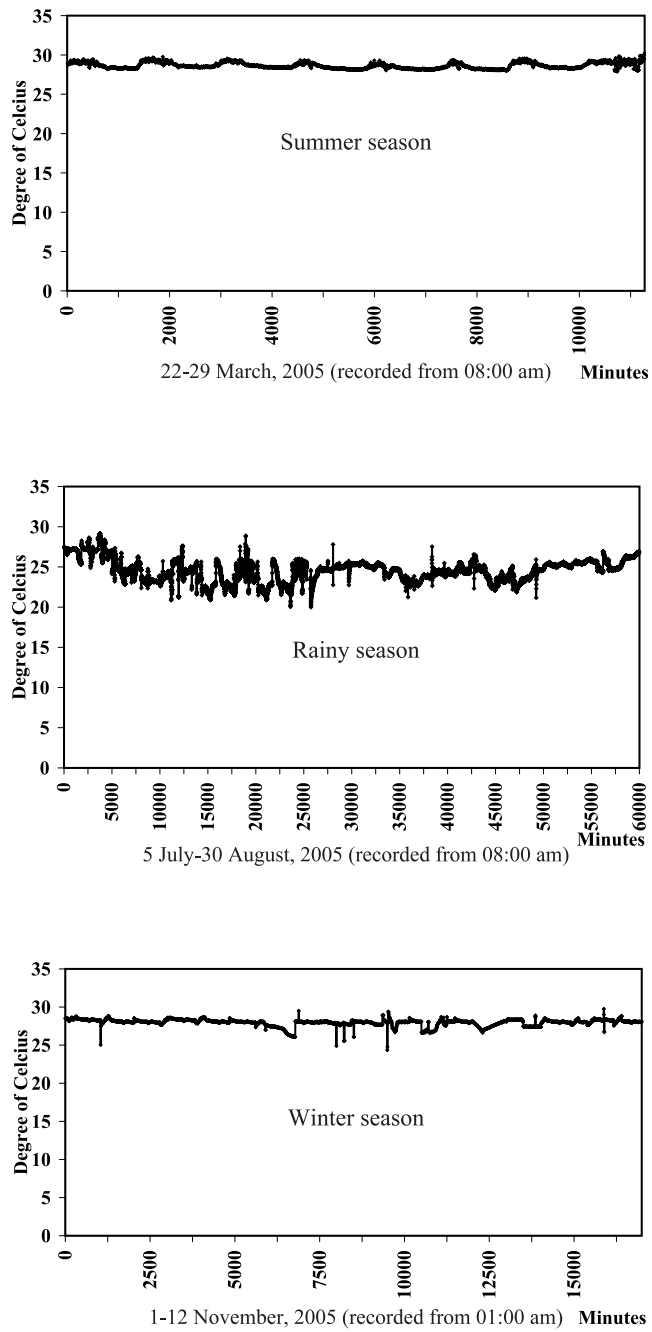
Figure 4. Ground temperature at 3 m depth during summer, rainy, and winter seasons

reason mentioned above, it could decrease the cooling load of the vapor compression system in the combined air-conditioning system. On the contrary, in the summer season and the winter season, the ground temperature was higher than 27°C (Figure (4a) and Figure (4c)); therefore, the earth-to-air heat exchanger system heated air in the building for almost the entire period of the experiment due to an increasing cooling load. However, it could cool air only at the beginning period of the experiment.

For the rainy season, the coefficient of performance of the vapor compression system was slightly higher than the combined air-conditioning system, as shown in Table 2, because the total electrical energy in the vapor compression system was lower than the combined air-conditioning system. However, the combined air-conditioning system could cool air to a comfortable level faster than by the vapor compression system. As a result, the compressor of the vapor compression system in the combined air-conditioning system (in building no. 1) would be turned off by the thermostat faster than the compressor of the vapor compression system (in building no. 2). It could save electrical energy in the vapor compression system by about 21% - 31% when setting the thermostat at 25°C, 26°C, and 27°C for comfortable levels, but the total electrical energy used in the combined air-conditioning system was slightly less than in the vapor compression system when setting the thermostat at 27°C (Table 3). Furthermore, the combined air-conditioning system had a high performance in the daytime with the thermostat set at below the comfortable peak level.

Table 2. The average coefficient of performance during rainy season

Set temperature in thermostat (°C)	Average coefficient of performance (COP)			
	The combined air-conditioning system		The vapor compression system	
	Daytime	Nighttime	Daytime	Nighttime
25	3.03	2.98	3.36	3.53
26	2.76	2.60	3.20	3.09
27	2.86	2.90	3.23	3.46

Table 3. Comparing the energy consumption between the combined air-conditioning and the vapor compression system during rainy season

Set temperature in thermostat (°C)	Energy consumption (kW-h/day)			VCs in building no. 2
	The combined air-conditioning system in building no.1			
	EAHEs	VCs	Total	
25	5.15	15.14	20.29	19.27
26	5.15	14.46	19.61	19.22
27	5.15	12.74	17.89	18.47

EAHEs = The earth-to-air heat exchanger system
VCs = The vapor compression system

Conclusion

The ability to decrease the cooling load in the vapor compression system by the earth-to-air heat exchanger system is functional only in the rainy season. It can save certain amount of 21% electrical energy in the vapor compression system at 25°C of comfortable levels. However, this combined air-conditioning system uses slightly more electrical energy than the vapor compression system alone when setting the thermostat at below the comfortable peak level, but it uses slightly less when it is set at the comfortable peak level. Indeed, improvement of this system for a greater saving of total energy can be done by using a small power fan in the earth-to-air heat exchanger system and also by decreasing the cooling capacity of the vapor compression system.

Acknowledgements

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