A NON-WASTE-HEAT AIR CONDITIONING SYSTEM USING WATER EVAPORATION AND DECOMPRESSED SOLAR PANEL

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1. Introduction

About 40% of the annual global energy demand has been consumed in buildings; meanwhile more than a half of the building-energy-demand is consumed for air-conditioning (Omer, 2008a). In industrial nations, from 35 % to 40 % of total national primary use of energy is consumed in buildings, the figure which approaches 50 % by including the energy for manufacturing building materials and for the infrastructure to serve buildings (Aitken, 2003).

Combining space cooling and heating in one vapor compression cycle system is a common way in countries with mild climate like Japan. Air-conditioning system is commonly used in houses and buildings due to its simplicity in the operating and maintenance. By using sensible heat from the ambient air, outdoor-heat-exchanger temperature is higher than the ambient air in cooling mode and lower in heating mode. The average temperature difference is assumed to be about 7 °C. In summer, this system releases higher temperature thermal load to the environment; hence, outdoor space is not comfortable for people, which causes "heat island" problem in cities. When condenser temperature of outdoor unit of air-conditioning system could be lower than that of existing system, it also makes the performance of air conditioning system to be higher in vapor compression cycle because the smaller temperature difference between condenser and evaporator causes higher performance in heat pump systems.

Besides, geothermal heat pump system is also favorable by utilizing the stable temperature of the earth. In geothermal system, outdoor-heat-exchanger unit is buried underground. To avoid the destruction due to oxidization, the heat exchanger material is selected and the installation cost makes the higher price. Harada et al. (Y. Harada, 2010) have studied with multi-source and multiple-use heat pump system, in which outdoor-heat-exchanger unit was built underground. From summer experiment results, they have found out that ground temperature increase day by day, so it can make the performance decrease day by day as well. Consequently, they have to use an additional heat pump as artificial recovery to keep the ground temperature to be constant.

In this paper, development of a non-waste-heat air conditioning system using water evaporation and decompressed solar panel will be introduced by a prototype experiment for cooling in summer mode and a new idea of heating in winter mode. Outdoor space at the place of outdoor unit is compared with that of the conventional system. In order to understand how the new system improves compared to the conventional heat pump system, Coefficients of Performance (COP) of this system in both cooling and heating modes will be introduced. Finally, amount of energy saving is roughly calculated by using decompressed solar thermal panel.

2. System development and description

2. 1. System development

The system of a new air conditioning system was modified from an existing commercial air-conditioning system using R410A as the refrigerant and the nominal cooling capacity of original system was 2.5 kW, as shown in Fig. 1. An air-heat-exchanger (AHEX) of the existing outdoor-unit was replaced by a helical water-heat-exchanger (WHEX), as shown in Fig. 2. The WHEX can make it possible to use cooled water from a cooling tower in cooling mode and warmed water from solar thermal panels in heating mode. The cooling tower in this experiment has a 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 in Japan.

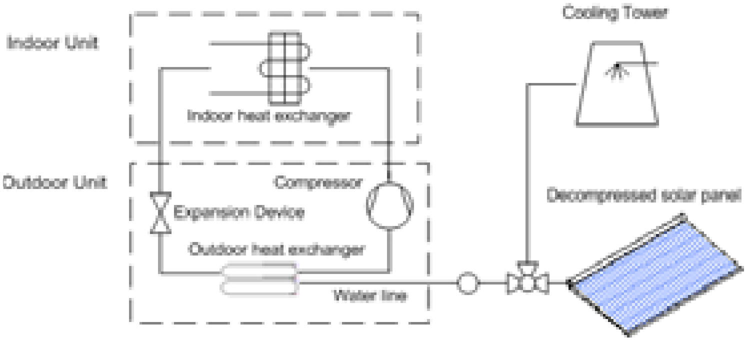

Fig. 1: Rough sketch of the proposed air-conditioning system

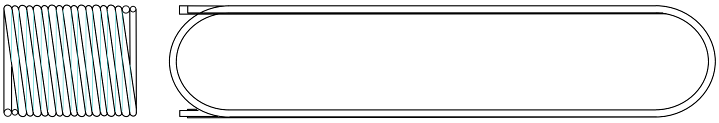

Fig. 2: Water-heat-exchanger (WHEX)

2. 2. Proposal of an improved system

- Cooling mode

In order to save energy of cooling-tower pump in cooling mode, we developed a heat exchanger in the outdoor-unit, as in Fig. 3. The fin of the existing air-cooled compact heat exchanger was taken out, and the straight tube covered with porous ceramics was replaced. The length of copper tubing covered with porous ceramics is about 11 m, which is about a half of the total length in the existing air-heat-exchanger. The residual copper tubing was insulated.

Since porous ceramics is hydrophilic material, it can automatically transfer water through. Hence, in order to have wet surface for water evaporation, pumping power can be neglected. From our prototype design for cooling mode, tap water is supplied from the top tank to one edge on the top row of copper tubing. While airflow enhances water evaporation on the surface of ceramics, water continues supplying to keep ceramics surface always to be wet.

- Heating mode

In actual manufacturing, a sophisticated heat exchanger is required to be developed for combining water-evaporation cooling mode and heating mode. For the helical WHEX, it is difficult to set porous ceramics around copper tubing. Therefore, we are going to use the commercial multi-petal double copper tubing, which is manufactured by Nishiyama company, Japan, as shown in Fig. 4. In this design, hot water from solar panel flows in the inner tube, refrigerant flows in the “annulus” cross-section space, and outer copper tubing is covered with porous ceramics. In cooling mode, solar panel is not used in this system but it can be used for other purpose, i.e., hot water supply.

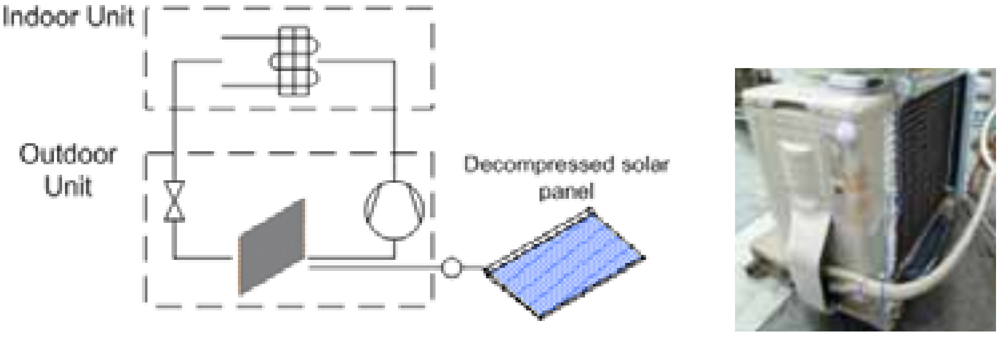

Fig. 3: Sketch of an improved system and a picture of outdoor unit

Fig. 4: Cross-section of copper tubing (Nishiyama)

Decompressed solar-thermal panel

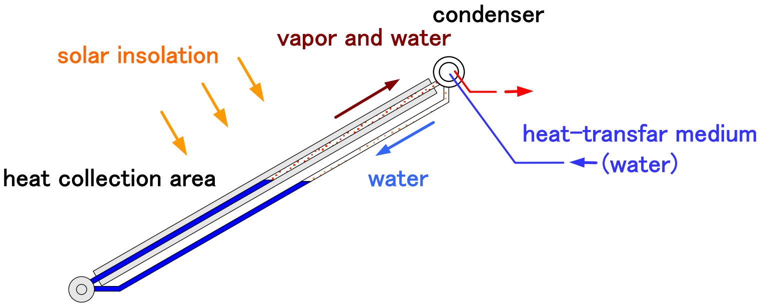

Fig. 5: Sketch of a decompressed solar-thermal panel

Fig. 5 shows a sketch and principle of a decompressed solar-thermal panel, which was developed by one of our group members for high efficiency solar desalination system. This system could transfer more than 80 % of solar thermal energy collected as latent heat at about ambient temperature, depending on the temperature of heat transfer medium. This kind of solar panel could reduce the heat island problem on the roof of building, and can reduce the cooling load for house in summer. The decompressed solar-thermal panel can provide heat at any temperature plus about five Kelvin from the temperature of heat-transfer medium, which can be used as a evaporator of air-conditioning system.

3. Outdoor space and system performances

3.1. *Outdoor space in summer*

Outdoor-unit of existing air conditioning system provides hot air with velocity about 0-3 m/s in cooling mode. The exhaust air temperature is much higher than the ambient temperature due to absorbing heat from refrigerant in the condenser. It causes the space near the outdoor unit to be uncomfortable. On the other hand, proposed system can provide the exhaust air with the temperature near the ambient, it can make the surrounding space of outdoor unit to be more comfortable.

As study of Omer (Omer, 2008b), he did mentioned that, in warm humid conditions, like in summer, airflow can conduct heat from human skin. In steady airflow, human cooling sensation (CS), of airflow can be estimated in degrees Celsius using equation:

$$\mathrm{CS} = 3.67(V-0.2)-(V-0.2)^2\ {}^\circ\mathrm{C} \qquad (1)$$

where average airflow, V , is in m·s^{-1}.

3.2. *System performance*

As in **Error! Reference source not found.**, when a difference between condensation and evaporation temperature is reduced, work required by compressor can reduce. By using a simple and practical estimation of Coefficient of Performance (COP) was proposed by Koga (Koga, 2005), in which COP is estimated mainly by condenser and evaporator temperatures with their relation.

The COP and enthalpies are obtained from the following simple practical correlations with the points indicated in **Error! Reference source not found.**:

- Cooling mode

$$\mathrm{COP}_{\mathrm{cooling}} = \eta_{sys} \cdot \frac{h_1 - h_4}{h_2 - h_1} \qquad (2)$$

$$h_1 = -0.0043T_{evap}^2 + 0.3196T_{evap} + 278.264 \qquad (3)$$

$$h_2 = 0.0009\Delta T^2 + 0.5791\Delta T + 284.11 \qquad (4)$$

$$h_3 = 0.0073T_{cond}^2 + 1.2633T_{cond} + 60.84 \qquad (5)$$

$$h_4 = h_3 \qquad (6)$$

where $\Delta T = T_{cond} - T_{evap}$

- Heating mode

$$\mathrm{COP}_{\mathrm{heating}} = \eta_{sys} \cdot \frac{h_2 - h_3}{h_2 - h_1} \qquad (7)$$

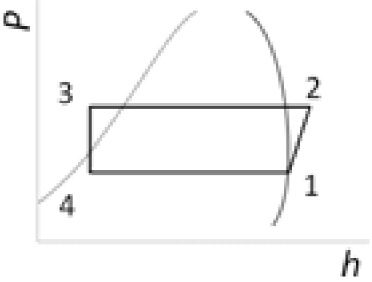

Fig. 6: Indication of the states in P-h diagram

$$h_1 = -0.0028T_{evap}^2 + 0.3133T_{evap} + 278.25 \qquad (8)$$

$$h_2 = 0.0024\varDelta T^2 + 0.4625\varDelta T + 285.17 \qquad (9)$$

$$h_3 = 0.0083T_{cond}^2 + 1.225T_{cond} + 61.05 \qquad (10)$$

$$h_4 = h_3 \qquad (11)$$

where η_{sys} is system coefficient, which is calculated by:

$$\eta_{sys} = \frac{\mathrm{COP_{cata}}}{\mathrm{COP_{theo\_n}}} \qquad (12)$$

and $\mathrm{COP_{theo\_n}}$ is the theoretical COP at nominal condition and $\mathrm{COP_{cata}}$ is the COP in manufacturer’s catalogue. Nominal condition is defined as an outdoor temperature of 35 ˚C, indoor setting temperature of 27 ˚C, and wet bulb temperature of 19 ˚C where dew point temperature is 13.52 ˚C for cooling mode; and outdoor temperature of 7 ˚C, indoor setting temperature of 20 ˚C for heating mode.

4. Results and discussions

4.1. Better outdoor space in summer

From the experiment done in summer with the AHEX air conditioning system, temperature of exhaust air from fan is higher than outdoor temperature more than 5 °C, as in Fig. 7. On the other hand, in case of using the proposed system for cooling mode, exhaust air temperature is nearly as the outdoor temperature.

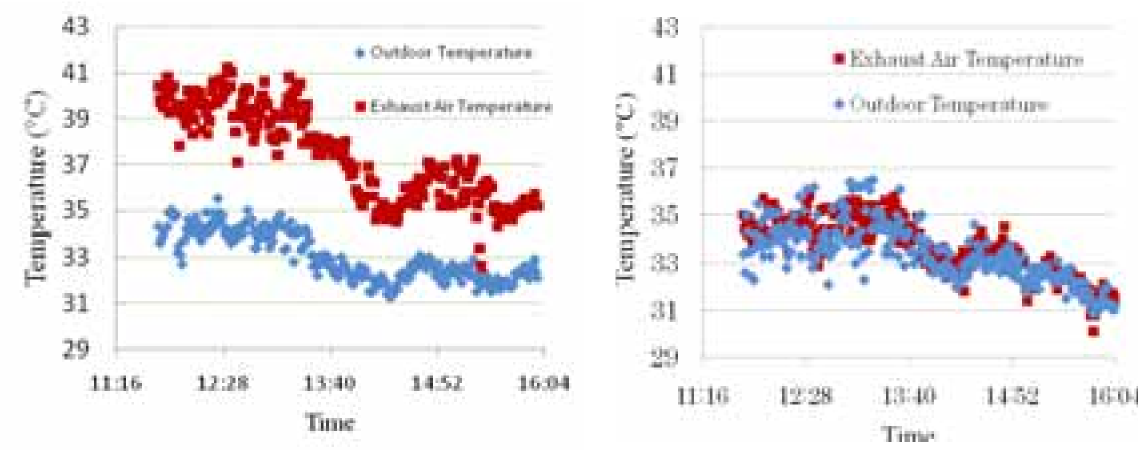

Fig. 7: Temperatures of exhaust air of AHEX system on Aug 7th 2009 (L) and the proposed heat exchanger on Aug 6th 2011 (R)

In addition, as existing fan in outdoor unit has velocity of 0 to 3 m·s^{-1}, the sensation cooling of the fan is shown in Fig. 8. Consequently, although it might be careful that the sensation cooling will strongly depending on the relative humidity of the air, people who stay in front of the outdoor unit possibly feel some degrees cooler than the surrounding.

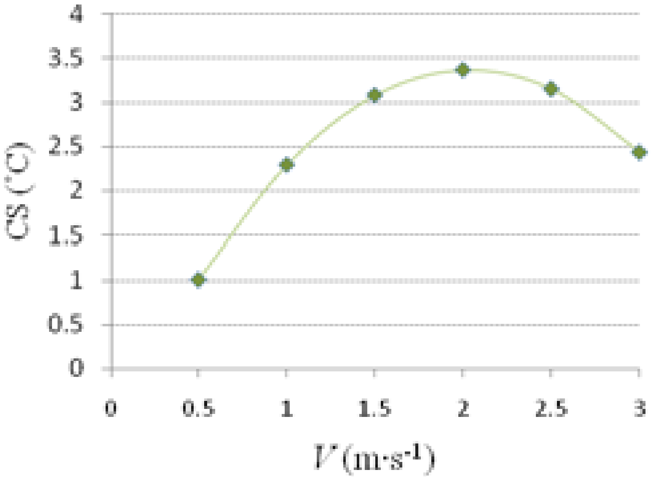

Fig. 8: Cooling sensation vs. air velocity

4.2. System performance

For the WHEX system which is connected with a cooling tower, average condenser temperature and compressor outlet temperature at every outdoor temperature are shown in Fig. 9. From the figure, it can conclude that by getting lower condenser temperature, compressor temperature is also getting lower. For the same outdoor temperature, indoor setting temperature and cooling space, with lower compressor outlet temperature, it is expected that pressure ratio, which is the ratio between condenser and evaporator pressures, can be reduced. Then, working power requirement can decrease. However, since power consumption in cooling tower was not possible to be measured for, power consumption cannot be compared here.

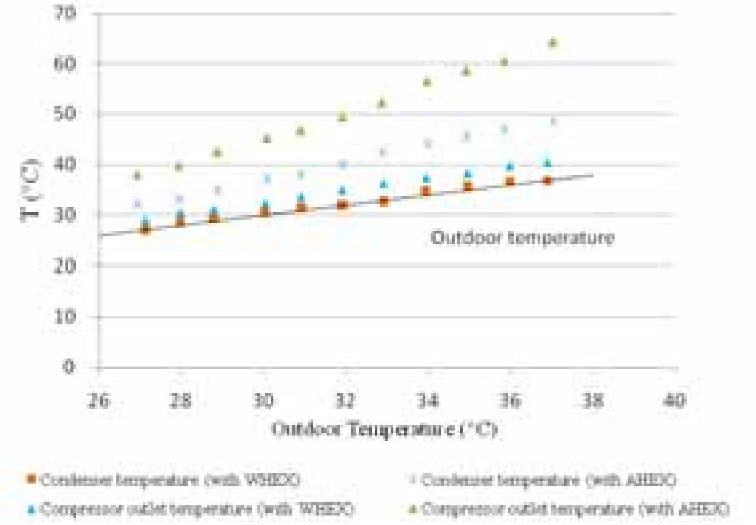

Fig. 9: Comparison of average temperatures of condenser and compressor of WHEX and AHEX air-conditioning systems

The results of COP estimating in cooling and heating modes are shown in Fig. 10. In these figures, $\triangle T$ is temperature difference between condenser and evaporator in air conditioning system. From the results, it can be seen that $\triangle T$ plays an important role to the performance. In cooling mode, with the same cooling load required, if condenser temperature decreases 1 °C, COP could increase about 4 %. Meanwhile, in heating mode, with the same heating load required, if evaporator temperature increases 1 °C, COP could increase about 3 %.

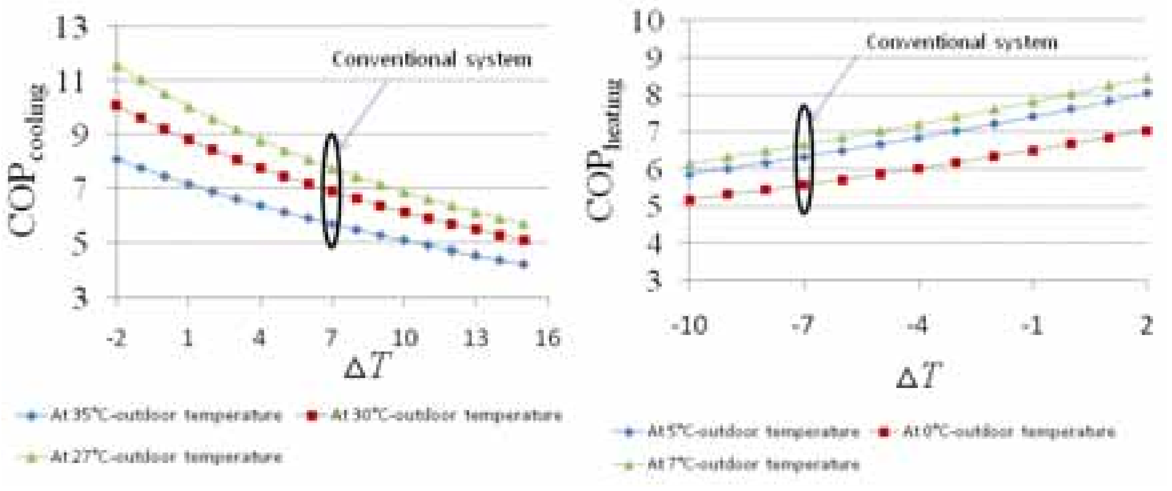

Fig. 10: COP vs. △T in cooling mode (L) and heating mode (R)

4.3. Possible of energy saving using decompressed solar-thermal panel

Tab. 1 shows the average amount of global solar radiation per day in different months, from 2001 to 2010 at Tokyo, from Japan Meteological Agency (JMA). By assuming at solar-panel efficiency being 0.7, amount of energy absorption is estimated on each m^2 panel area. In the study about energy demand of residential houses (Nagayama, 2001), monthly heating demand has simulated in Tokyo from November to April. Then, average daily heating demand in each month is estimated based on her results.

Tab. 1: Average global solar radiation and amount of absorption

Month	Nov	Dec	Jan	Feb	Mar	Apr
Average solar radiation ($MJ\cdot m^{-2}\cdot day^{-1}$)	8.53	8.22	9.31	11.12	13.8	16.13
Amount of energy absorption ($MJ\cdot m^{-2}\cdot day^{-1}$)	5.97	5.75	6.52	7.78	9.66	11.29

Monthly heating demand (GJ)	0.89	2.10	2.14	1.93	1.70	0.65
Average daily heating demand (MJ)	29.70	70.12	71.35	64.32	56.71	21.82

With an assumption that heat absorbed by solar-thermal panel can be transfered to heating demand, Tab. 2 shows the amount of solar-thermal energy with different absorbed area that can contribute to the total heating demand for 1 house in Tokyo area. If 4-m^2-solar-thermal panels are used, heating demand can reduce more than 33%. Depending on the investment cost, electricity price, and area available on the roof, the number of panels can be considered.

Tab. 2: The number of solar panels and the amount of solar energy contribution

Absorbed area (m^2)	Month	Nov	Dec	Jan	Feb	Mar	Apr
2	Amount of energy absorption (MJ/day)	11.58	5.75	6.52	7.78	9.66	11.29
	Solar energy contribution (%)	40%	8%	9%	12%	17%	52%
4	Amount of energy absorption (MJ/day)	23.17	22.33	25.29	30.20	37.48	43.81
	Solar energy contribution (%)	80%	33%	37%	48%	68%	207%
6	Amount of energy absorption (MJ/day)	34.75	33.49	37.93	45.30	56.22	65.71
	Solar energy contribution (%)	121%	49%	55%	73%	102%	310%

5. Conclusions

In developing a natural air-conditioning system which is combined with cooling and heating modes, experimental system was proposed to change from the WHEX system to the revised heat exchanger, which uses water evaporation on surface of porous ceramics in outdoor unit.

A better comfortable space in front of outdoor unit was confirmed in cooling mode with the revised heat exchanger using porous ceramics instead of aluminum fin.

By changing the temperature difference between condenser and evaporator to be smaller, higher COP was expected from a simple calculation of COP both for cooling and heating modes.

Amount of heating capacity saving by solar thermal energy was summarized in Table for giving a rough idea of designing the system.

Despite of a complicated air-conditioning system than the conventional system using AHEX in outdoor unit, it can conclude that the new proposed system is a more friendly system to the environment.

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