Electrical Energy Saving in a Household Water Heater by Heat Recovery from a Room A/C Condenser Using a Compact Plate Heat Exchanger

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Abstract

While electric water heater is usually required for showering in some households, heat dissipation from a condenser in the outdoor unit of a small room air conditioner (A/C) is conventionally considered as a waste heat. Utilizing the waste heat in warm water system could save electricity in water heater, and performance of the A/C could also be enhanced. This study performed a system design, installation and testing of by using a compact heat exchanger (HE) to trap the waste heat from superheated refrigerant transferred to a water circulation system. Hourly system testing was performed under actual Chonburi weather condition in May 2013. It was found that the water temperature could meet 40^{o}C within 2-2.5 hours after the A/C was turned on. Longer period is required for higher water temperature setting. During the water circulation mode, performance of the A/C was enhanced by 15.28%. Annual electricity consumption could be saved by 1415 kWh with 4.46 years payback period. High investment was partially top up by a backup electric heater required for warm water in some winter hours where the outside air temperatures were below the room air setting temperature.

Keywords: Air Conditioning, Water Heater, Heat Recovery, Heat Exchanger.

1. Introduction

Heat removal by an air cooled condenser of a small, split-type, room air conditioner (A/C) in a hot climate is usually considered as waste. While, the heat is rejected from the refrigeration cycle, a same apartment is usually using an electric warm water heater for showering. Utilizing the waste heat in warm water system could save electricity in water heater, and a higher coefficient of performance could also be found. [1-2]

In refrigeration cycle, a system performance of an A/C could be increased by an increasing in heat transfer from the condenser, and the heat is possible to be recovered by transferring to water for energy saving. The A/C performance could be met due to increasing the condenser heat transfer and, finally, additional energy saving from the refrigeration system could be expected [1-6]. Suksuntornsiri et al. 2007 [1] has studied on a waste heat recovery from a 9000 btu/h A/C for the required 40^{o}-43^{o}C 300-L warm water stored in a warm water tank. The system was designed for 3 residences that turned on the A/C during night time and showering twice a day, after and before going for daily work. The systems was installed by trapping the superheat refrigerant pipe that required additional refrigerant connecting and another 3.67 meter refrigerant pipe submerged in a 423 L water tank located near the existing air-cooled condenser. After the superheat refrigerant was cooled by water, it was further cooled by conventional air cooled condenser. With 28°C outside air temperature and 1” rubber insulation, the warm water temperature was 36°C in the morning, and dropped to 34°C in the evening. Under low outside air temperature in some winter hours, the A/C was turned off and could not provide warm water.

Since an apartment conventionally using a small split-type 9000 btu/h A/C was normally resided by 1-2 people that required less water volume, but higher temperature warm water, more suitable tank should be redesigned. Suksuntornsiri et al 2009 [2] has improved the study on the 9000 btu/h A/C by an installing a submerged refrigerant pipe in a smaller water tank. It could be hided above the bathroom ceiling (0.8m x 0.8 m x 0.4m). Under 30°C outside air temperature, the warm water temperature could reach 46°C in the next morning.

Generally, the submersed piping installation requires long refrigerant pipe and it needs to be pre-charged with higher refrigerant mass than a normal A/C system. More compact design could be applied to provide a better appearance and reduce some extra installation task. The A/C size should be studied on a highest market preference. Therefore, this study performs a study on a heat recovery from heat rejection of 12,000 btu/h split-type room A/C for providing energy saving in a warm showering water to be used by 2 persons residing in a one bedroom apartment with one bathroom. The amount of refrigerant charging and travelling distance could be reduced by using a plate heat exchanger. It also provides minimum installation task.

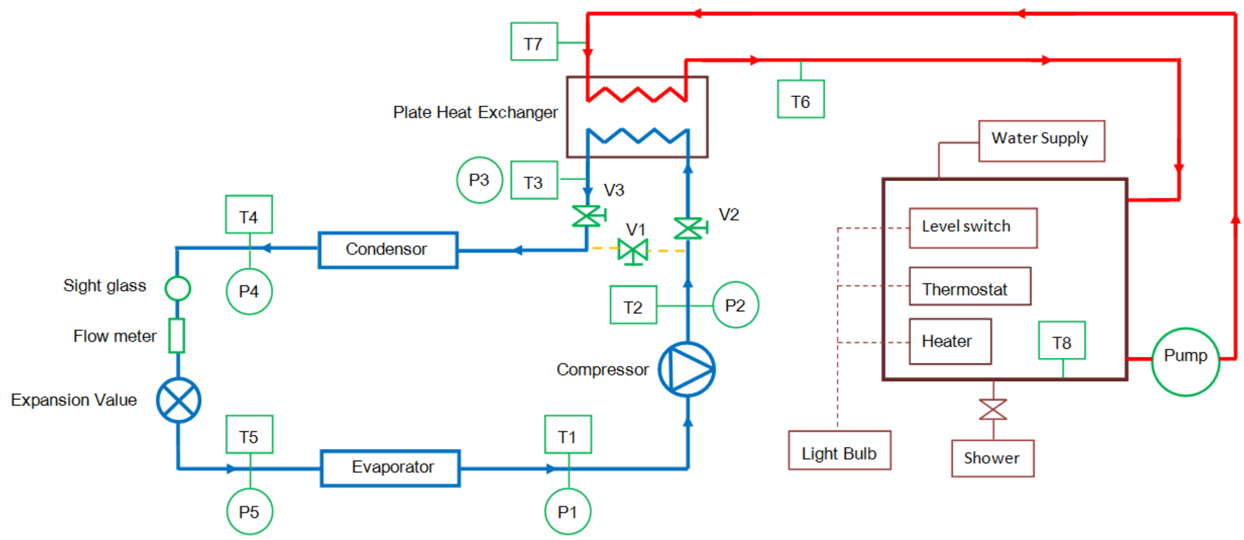


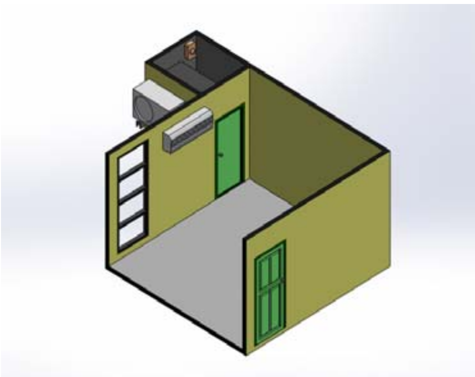
Fig. 1 Design and installation of a Plate Heat Exchanger and water circulation system with a room A/C system

2. System Design and Installation

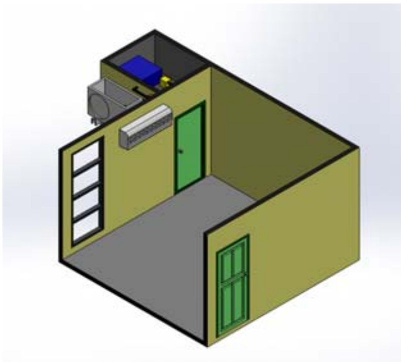
The proposed system was designed to be applied with a 1-bedroom and 1 bathroom apartment that installed with 1 TR A/C and required daily warm water for showering for 2 persons. The proposed additional system is designed to make a smallest disturbance to the existing room appearance and require small installation time and cost.

The additional condenser heat dissipation by the water system is designed to decrease the temperature of the superheat refrigerant before flowing to the existing air cooled condenser by using a plate heat exchanger. It was designed to trap the superheated refrigerant before flowing to the existing air-cooled condenser as seen in Fig.1. One side is a water system that could reduce the temperature of the superheated refrigerant in another side, before it was flown to the existing air cooled condenser.

The heat would be dissipated by the flow of the water system circulated by a 0.5 hp pump. After the water received the heat from the plate heat exchanger, it was flown into the water tank. Proper warm water for showering could be set at required warm water temperature (40°-43 °C [7]). Water temperature would be increase to reach the setting temperature and the circulating pump would be turned off. The system appearances before and after installation are shown in Fig.2.



(a) Before



(b) After

Fig. 2 Appearances of a room air conditioning system before and after installed with a Plate Heat Exchanger and the water system.

2.1 A/C and Plate Heat Exchanger specification

The conventional A/C system in this study is the FTE12NV2S Daikin with 12,300 btu/hr cooling capacity. It is industrial specified with 1043 W power input and 11.77 EER [8]. The BL14-12D Ranotec plate heat exchanger (HE) [9] was installed to trap the heat from superheated refrigerant to the water system. Hourly energy balance in the HE and warm water tank was continuously estimated until the water temperature in the tank reach the design point; (see Fig.3)

Heat removal from refrigerant side:

$$\dot{Q} = \dot{m}_R (h_2 - h_3)$$

Heat received by water side:

$$\dot{Q} = \dot{m}_w c_p (\mathrm{T}_6 - \mathrm{T}_7)$$

Increasing internal energy of the water tank was estimated by;

$$E_{in} - E_{out} = \Delta E_{systems}$$

$$\dot{m}_{w,i}(h_a + \frac{V_a^2}{2} + gz_a)\Delta t - \dot{m}_{w,o}(h_b + \frac{V_b^2}{2} + gz_b)\Delta t$$

$$= m_t (u_2 - u_1)$$

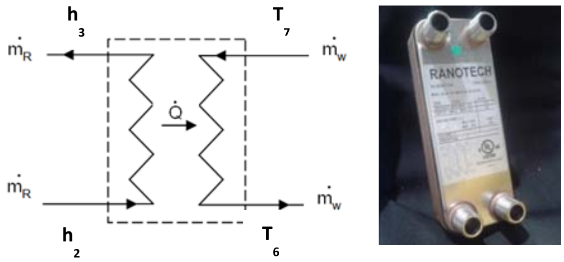


Fig.3 Plate Heat Exchanger [9]

On the heat transferring period, the heat exchanger efficiency could be estimated by dividing the heat receiving rate by the water with the heat rejection rate from the refrigerant.

$$\eta_{HE} = \frac{\dot{m}_w c_{p,w}(T_6 - T_7)}{\dot{m}_R (h_2 - h_3)}$$

2.2 Warm water system

The water system majorly comprised of a warm water tank, the plate heat exchanger (HE), and the circulating pump. Level switch and solenoid valve and thermostat were installed in the tank to control daily water refilling and to swtich between the HE and water circulation on or off from the A/C system.

Water tank volume was estimated for showering for 2 persons that each person requires to shower twice a day.

Therefore, minimum water (V) should be

$$\mathrm{V} = (2\ \mathrm{person})[(5\ \frac{\mathrm{liter}}{\mathrm{min}})(5\ \frac{\mathrm{min}}{\mathrm{rev}})](2\ \frac{\mathrm{rev}}{\mathrm{person}}) = 100\mathrm{liter}$$

Then the tank was designed to be installed inside a maximum of 40-cm height of bathroom ceiling chamber with 169 liter capacity with the size of 0.65m x 0.65 m x 0.40 m as seen in Fig.4.

2.3 Measuring Equipment

The refrigerating system performance was test on normal weather operation during 6th – 19th May 2013. The data includes

- 2 data sets of nighttime operations (18.00-06.00) on A/C operation without trapping the heat to the warm water system by the plate heat exchanger (A/C only)
- 2 data sets of daytime operations (8.00-20.00) on A/C operation without trapping the heat to the warm water system by the plate heat exchanger (A/C only)
- 2 data sets of nighttime operations (18.00-06.00) on A/C operation with trapping the heat to the warm water system by the plate heat exchanger (A/C with HE)
- 2 data sets of daytime operations (8.00-20.00) on A/C operation with trapping the heat to the warm water system by the plate heat exchanger (A/C with HE)

Hourly cooling, heating, input powers, and coefficient of performance (COP_R) of the refrigerating system was assessed by measuring temperatures (T_1, T_2, T_3, T_4, and T_5) and pressures (P_1, P_2, P_3, P_4, and P_5) by thermocouple type K and pressure gauge in five connecting points between condenser, capillary tube, evaporator, and compressor, and the heat exchanger as shown in Fig.1. Refrigerant mass flow rate ($\dot{m}_R$) was measured hourly by using ABB armored purge meter. Water temperature located inside the water tank (T_8), temperatures before and after the HE (T_7, and T_6) were measured by thermocouple type K. Water circulation flow rate ($\dot{m}_w$) was also measured. Electrical Power inputs for A/C system, water system were measured by power and energy meters.

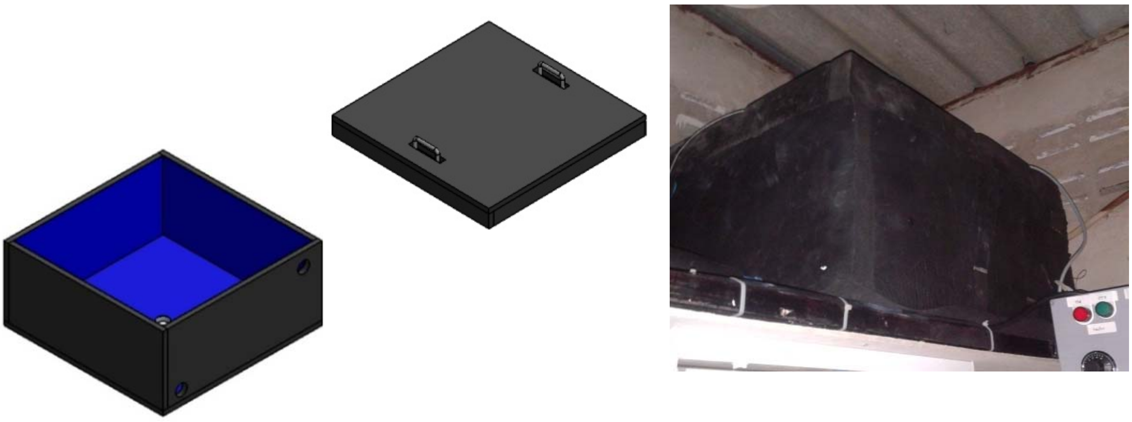


Fig.4 Warm water tank

In refrigeration side, the cooling rate ($\dot{Q}_L$), heat rejection rate (to the ambient), and the power input ($\dot{W}_{in,R}$) were calculated from the measured refrigeration mass flow rate ($\dot{m}_R$) and the different enthalpies (h) assessed from measured temperatures and pressures. The electrical power input ($\dot{W}_{in,elec}$) was measured by an electrical energy meter.

$$\dot{Q}_L = \dot{m}_R(h_1 - h_5)$$

$$\dot{Q}_{H,reject} = \dot{m}_R(h_3 - h_4)$$

$$\dot{W}_{in,R} = \dot{m}_R(h_2 - h_1)$$

The refrigeration COP_R was calculated from

$$COP_R = \frac{(h_1 - h_5)}{(h_2 - h_4)}$$

The system *COP* was assessed from

$$COP = \frac{\dot{Q}_L}{\dot{W}_{in,elec}}$$

By a conversion factor, 1 kW = 3,412 btu/h, the EER is 3.412 *COP*.

The experiment assumed that the A/C user set the room air temperature at 25°C. Considering Chonburi outdoor air temperature in 2011 [10] (see Fig.5) where most of the outdoor temperatures were higher than 25°C, the A/C system was mostly turned on. The data reminded that on the lower outdoor temperature hours the A/C system was turned off and the system should be supported with a back-up electric heater.

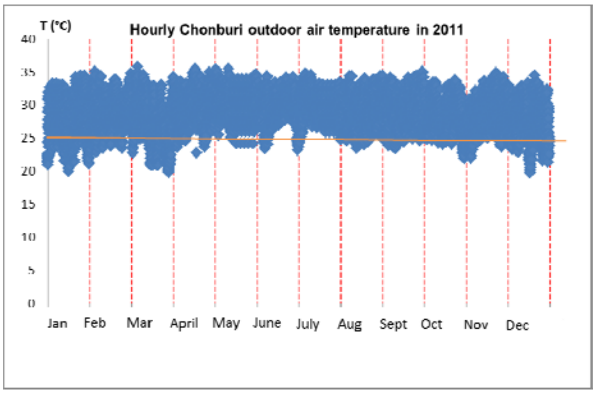


Fig.5 Hourly Chonburi outdoor air temperature in 2011 [10]

3. Results

Circulation the water passing the plate heat exchanger, temperature of the water could be reached 40°C during the testing period within 2-2.5 hours of water circulation, and it was dropped about 2°C before the 1st showering time. (see water temperature in Fig.6) The water circulation was shut down after 2 hours after the temperature in the tank reach 40°C of one represented day. The dash arrow line located at the mode switching time, from A/C operating with

HE and water circulation (A/C+HE) to the only A/C operated without water circulation. Higher water temperature at 50°C could be achieved in longer water circulation time.

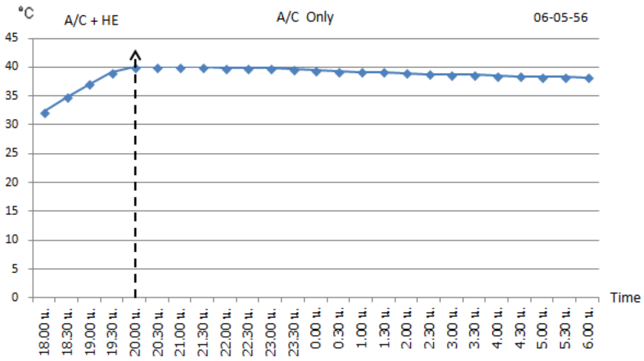


Fig.6 Water temperature

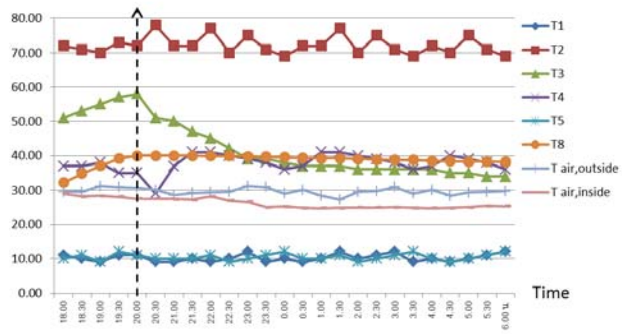


Fig. 7 System vs indoor/outdoor air temperatures

Fig.7 shows measured temperatures corresponding T1, T2, T3, T4, T5 in refrigeration cycle and T6, T7 and T8 in water cycle stated in Fig.1, of one represented operating data.

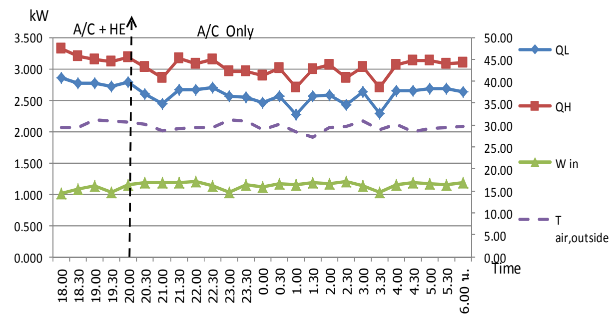


Fig.8 Cooling, heat rejection rate, and power input in a data set

Fig.8 present hourly cooling, heat rejection, and power input plotted together with the outside air temperature in 1 typical testing where the outside air temperature was about 30°C. Cooling capacity was approximately 2.6 kW. Heat rejection rate was about 3 kW. Power input was 1 kW.

Hourly Vapor compression cycle on R-22 P-h diagram on one typical daytime operation were plotted on R-22 P-h diagram as shown in Fig.9 (diagram downloaded from Gasco Nederland NV [11]. It is found that during the water circulation period (8.00-11.00 am) the refrigerant has passed through the plate heat exchanger, with 4.32 bar pressure drop (P2-P3) with 4.80 bar in total condenser pressure drop (P2-P4). . Condensing temperature were less than ones in A/C mode (12.00 and thereafter).

Pressure drop in evaporator was found 0.83 bar (P5-P1).

COP of the refrigeration system was presented in Fig.10. System performance testing was performed to compare the performance of the conventional a/c system and the a/c system operating with a water circulation; under an actual outside air condition. Generally, due to power loss and additional power required in the fan coil unit and the condensing unit, the COP of the whole system is much lower than the COP_R that was measured in the refrigeration cycle.

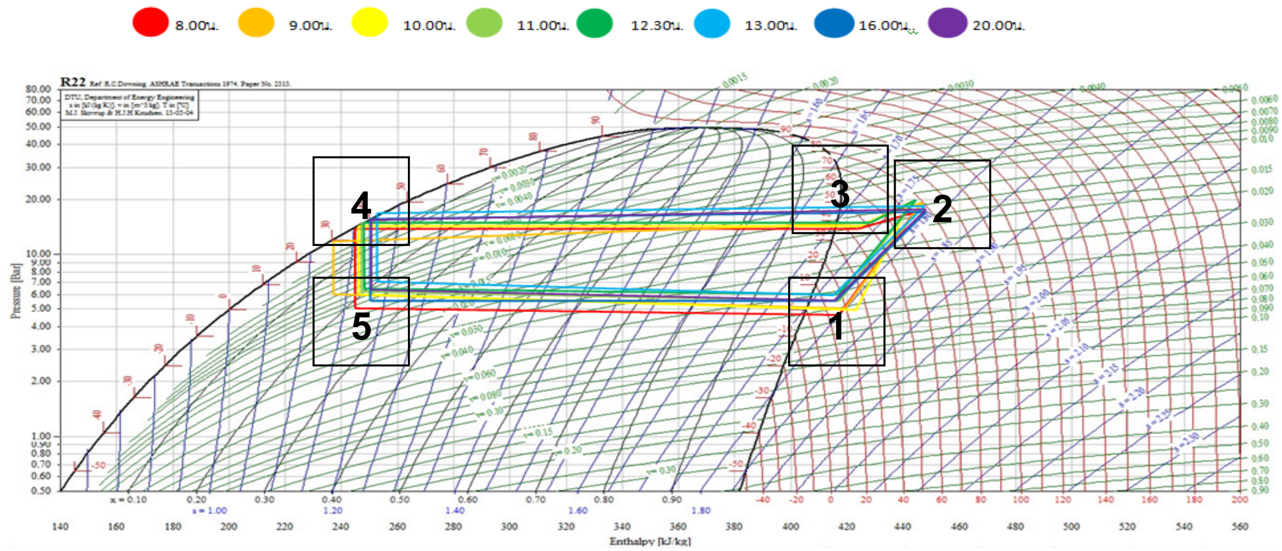


Fig.9 Hourly Vapor compression cycle on R-22 P-h diagram (P-h chart from [11])

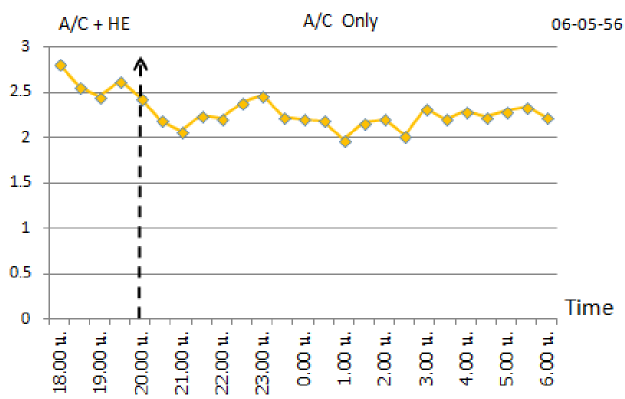


Fig.10 COP of the cooling system

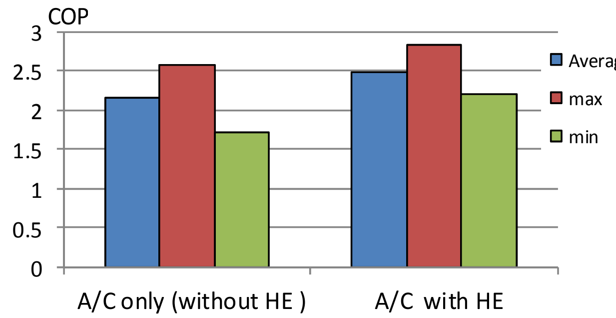


Fig. 11 Average, maximum and minimum performance of the refrigeration system

On one represented testing data, hourly operating performance of the a/c system with the additional heat removal by water circulation was presented in Fig.10. On beginning hours, the system was working on A/C with HE mode. The performance of the A/C with HE mode was found higher that The A/C mode without additional heat removal.

Fig. 11 presents average, maximum and minimum performance of the refrigeration system under all testing data. It was found that COP of the refrigeration system could be enhanced by A/C with HE mode from averagely 2.16 to 2.49.

5. Conclusions and discussions

The design was aimed to study another mean of heat recovery system applied on a conventional installation of 1 TR split type A/C using with warm water system. It allows the heat of the superheated refrigerant to be transferred to the water by a plate heat exchanger. The water temperature could reach the setting temperature before the showing time.

COP of the refrigerating system on the additional heat rejection mode was found increased by 15.28 %. Additional 25,000 Baht required for retrofitting. Annual energy saving of 1,415 kWh could be found, where 5,660 Baht from conventional electricity bill could be saved.

The payback period is 4.46 years. High investment was partially top up by a backup electric heater required for warm water in some winter hours where the outside air temperatures were below the room air setting temperature.

However, using the heat recovery system by mean of a plate heat exchanger faces a high pressure drop. Further study should be placed on related operation of the compressor and capillary tube that affects the refrigerant mass flow rate and the compressor power input. Additional testing on different operation should be performed to assured the increasing in the performance. Some deviation in performance from the industrial specification is found due to different testing circumstances, installation limitations and quality of measuring instruments.

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7. References

[1] Suksuntornsiri P., Jantan, T., Chotiwong, T., and Chareonwetwut, S. (2007) Small air conditioner's waste water heat recovery for household warm water system, paper presented in *the 21st Conference of Mechanical Engineering Network of Thailand*, 17-19 Oct. 2007, Chonburi, Thailand. (in Thai)

[2] Suksuntornsiri P., Ketrahong, N., Termsuk, P., and Saengthong, (2009) Development of waste heat recovery from air conditioning system for warm water showering water, paper presented in *the 23rd Conference of Mechanical Engineering Network of Thailand*, 4-7 Nov 2009, Chiangmai, Thailand. (in Thai)

[3] Hwang, Y., Radermacher, R. and Kopko, W. (2001), An experimental evaluation of a residential-sized evaporative cooled condenser, *Int.J. of Refrigeration*, 24 (2001), 238-249.

[4] Artnasaew, A. and Sripenchai, C., (2008) Saving Energy by Cooling Pad at Condenser of Water Chiller, paper presented in *The 22nd Thailand Mechanical Engineering Network*, Bangkok, Thailand. (in Thai)

[5] Wetpun, T., Borirux., T., Chamnarnmor., S., Kommeung., P., Photsri, S., and Teekasup, S. (2008) Hot water Production from Waste Heat of Portable Air Conditioning Unit (2008), paper presented in *The 22nd Thailand Mechanical Engineering Network*, Bangkok, Thailand.(in Thai)

[7] Sreatamanit, S. and Morimura, T.(2000) Engineering piping in Building: Design, Installation and Maintenance, Duangamol Publishing (2520), 5th ed., pp.117-127. (in Thai).

[8] DAIKIN Industries (Thailand) (2012) *DAIKIN Specification model FTE12NV2S*, URL: http://www.daikin.co.th/th/products/01_roomair/detail_03.html , assess on 5 Oct. 2012

[9] Ranotech, Heat Exchanger (2012), URL: http://www.ranotech.com/heat-exchanger/ , assess on 8 Dec.2012.

[10] Thai Metrological Department (2012), *Hourly Weather Temperature in 2011*, URL: http://www.aws-observation.tmd.go.th/web/reports/weather_minute.asp, assess on 25 July 2012

[11] Gasco Nederland NV (2012), *Chart R22*, URL: http://www.gasco.nl/documents/logp-h/Log(p)-h%20diagram%20R22.pdf , assess on 6 October 2012