Comparative Study of Residential Split Air Conditioner as Water Heater (RSACWH) Using R-22 and HCR-22 Refrigerant

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ABSTRACT

Experimental studies on Residential Split AC Water Heater (RSACWH) by replacing refrigerant R-22 with HCR-22 (hydrocarbon refrigerants) as a drop-in substitute has been carried out. The dummy condenser (trombone type coil) as heat recovery system was used for heating water and installed in the water tank with 50 L capacity. The use of HCR-22 save electrical energy due to decrease in compressor power about 16.31% - 21.64% of the R-22, because HCR-22 refrigerant mass charge in the refrigeration system 40% less than the charge of R-22. The cooling capacity and heat rejection capacity is relatively the same for R-22 and HCR-22. The COP_R increases around 11.89% - 18.69% and COP_{R+HP} also increases around 4.26%-11.41% for HCR-22 compared to R-22. The room temperature with HCR-22 is relatively the same compared to R-22, while the hot water temperature using HCR-22 and R-22 are about 46.58˚C-48.81˚C and 59.50˚C-63.40˚C respectively. The use of the HCR-22 provides electrical energy savings for compressor power and better performance (COP) at similar room temperature compared to R-22.

KEY WORDS: *water heater, hydrocarbon refrigerant, trombone coil, dummy condenser, heat recovery*

1.0 INTRODUCTION

The Montreal Protocol, an international treaty on the environment, first set the R-22 on the list of substances that are harmful to the environment in 1987 [1]. Indonesia as a country that participate in the Montreal Protocol already has government regulations on the elimination of Ozone Depletion Substance (ODS) and Global Warming Potential (GWP). Among others of the regulation are Presidential Decree No. 23/1992 (protection of the ozone layer), Law of The Republic of Indonesia No. 17/2004 (Global Warming), Regulation of Minister of Trade No. 24/2006 about imports of ODS regulations, Regulation of the Minister of Industry and Trade No. 33/2007 (prohibition on the production of goods using ODS and BPO, Regulation of Minister of Environment No.2 / 2007 (for technician of Air Conditioner/AC) [2].

The latest regulations [3, 4] which was started earlier this year is the Regulation of the Minister of Industry of the Republic of Indonesia no. 41/2014 on the prohibition use of hydrochlorofluorocarbon (HCFC) in the field of Industry contained in article 3: At the beginning of January 1, 2015 HCFC type of HCFC-22 and HCFC-141B is prohibited for use on:

a. Charging in the process of production of air conditioner (AC), air conditioning machines, and equipment / refrigeration machine ;
b. Process and production of rigid foam for freezer goods, domestic refrigerator, boardstock / laminate, refrigerated truck.
c. The production process of integral skin for use in the automotive and furniture sectors.

Recovery of waste heat energy in the condenser can be used for heating water, so that the modification of RSACWH for cooling and heating simultaneously will affect RSACWH performance. Some researchers have been conducted a study utilization of waste heat in the condenser as water heater and the use of hydrocarbon refrigerants, that produce energy savings for hot water needs [5-9]. Yu and Teng [10] reported retrofit assessment of refrigerator using hydrocarbon refrigerants (HCs). The results shows that the HCs charged ratios were 30–60% based on the charged mass of R134a. Konrad et al [11] studied the usage of waste heat energy from air conditioning as water heater for bathing. The study shows that the compressor power increase from 1,357 kW to 1,447 kW where the hot water temperature reaches 60^{o}C after heating for 120 minutes in 20 L water tank capacity.

Some studies shows that the use of hydrocarbon refrigerants can increase the COP of the air conditioning system (AC) [12-14]. Khalid A. Joudi and Qusay R. Al-Amir [15] reported the performance of residential air conditioning systems using R22 and alternatives R290 (Hydrocarbon refrigerant), R407C, R410A. The study showed that R290 is the better candidate to replace R22 It has lower Total Equivalent Warming Impact (TEWI) values and a better coefficient of performance than the other refrigerants tested.

The research objective was to compare the performance of HCR-22 and R-22 in the hybrid refrigeration system (combined cooling and heating) on Residential Split Air Conditioner Water Heater (RSACWH). The RSACWH system performance parameters such as pressure, temperature, compressor power, energy saving, cooling capacity, room temperature, heat rejection, and COP also observed in this study.

2.0 METHODOLOGY

Schematic diagram of the test apparatus is shown in Figure 1. This test apparatus is original Split AC modified with the addition of dummy condenser (trombone coil type), so the AC operates as an air conditioner and water heater simultaneously or called as Residential Split Air Conditioning Water Heater (RSACWH). The test apparatus is equipped with 3 pieces of the valve (valve 2, 2a and 2b), so that the system can operate as RSAC standard (without dummy condenser) or as RSACWH (with dummy condenser). The dimension of test room is 2,26m x 1,75m x 2m (length x width x height) and equipped with 30 pieces of 100 Watt incandescent lamp. The variation of cooling load in the test room as actual load simulation are 0W, 1000W, 2000W, and 3000W depend on the usage number of incandescent lamp. While the dummy condenser is placed in a water heater tank with water capacity of 50 L, without water circulation.

The research method was experimental method by comparing performance R-22 refrigerant in RSACWH system or hybrid refrigeration system with hydrocarbon refrigerants HCR-22 as drop-in substitute (without change in the components of RSAC system). The original RSAC system used R-22 refrigerant (before modification) as the working fluid with the compressor power 680 Watts. The performance comparison in RSACWH system are the power compressors, cooling capacity, heating capacity, the capacity of waste heat recovery, and the COP.

The experiments was began with the setting of RSACWH system by closing valve 2 and open the valves 2a and 2b. First test were conducted with R-22 refrigerant as the working fluid. The amount of R-22 refrigerant charged into the system was 500 grams. Second tests were conducted by HCR-22 with removed R-22 from the system using a refrigerant recovery machine. Furthermore, system was vacuumed and oil with viscosity 4GS was added. The amount of refrigerant using HCR-22 was 300 grams and measured by refrigerant mass scales with accuracy ± 10 gram.

Data was collected every 5 minutes during the 120 minutes of the test. The composition of the hydrocarbon refrigerant cannot be displayed due to copyright issues. Enthalpy of the refrigerant was calculated using REFPROP software ver. 6 by NIST (National Institute of Standards and Technology). The calculation was carried out as ideal vapor compression refrigeration cycle.

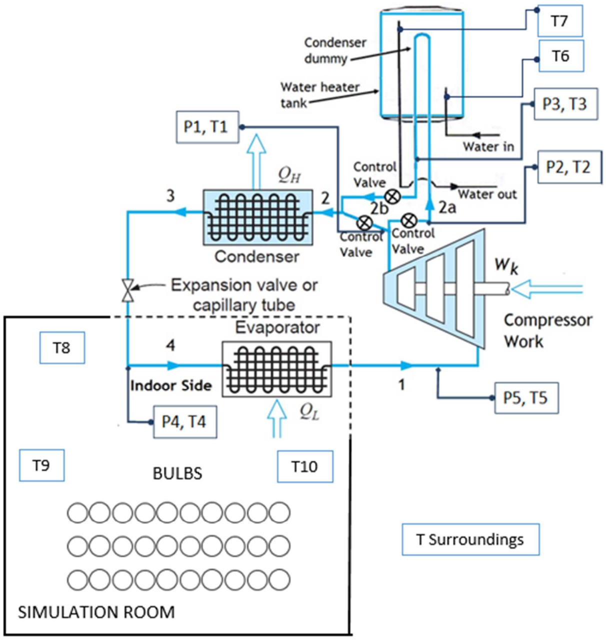

Figure 1: Schematic diagram test facility of air conditioning water heater [16, 17].

During whole the tests, test room temperature was maintained at 19°C. The data taken in each test were as follows:

1. Compressor Outlet Temperature (T_1).
2. Dummy Condenser Inlet Temperature (T_2).
3. Dummy Condenser Outlet Temperature (T_3).
4. Evaporator Inlet Temperature (T_4).
5. Evaporator Outlet Temperature (T_5).
6. Water Inlet Temperature (T_6).
7. Water Outlet Temperature (T_7).
8. Test Room Temperature (T_8).
9. Test Room Temperature (T_9).
10. Test Room Temperature (T_{10}).
11. Surrounding Temperature
12. Compressor Outlet Pressure (P_1).
13. Dummy Condenser Inlet Pressure (P_2).
14. Dummy Condenser Outlet Pressure (P_3).
15. Evaporator Inlet Pressure(P_4).
16. Evaporator Outlet Pressure(P_5).
17. Electric Current of Compressor (I)
18. Electric Voltage (V)

Temperatures of the system was measured at 8 sensor points installed on the pipe surface of installations pipe using omega TC-08 data logger with K type thermocouple (accuracy 0.2 percent ± 0.5°C and has a resolution of better than 0.1°C. The digital thermometer accuracy is ±0,1°C. Pressure of the system was measured using pressure gauges with accuracy ±5 psi (high pressure refrigerant in condenser side) and ±1 psi (low pressure refrigerant in evaporator side). The electric current and voltage of compressor were measured by ampere-meter (accuracy ± 2.0 percent) and voltmeter (accuracy ± 1.0 percent), respectively.

Figure 2 shows dummy condenser trombone coil type placed in the hot water tank to heat the water utilizing high-temperature refrigerant coming out from compressor before entering the condenser. Figure 3 shows the system of testing equipment used in this study, it appears the test room and the indoor unit (condenser) and the hot water tank (condenser dummy).

Figure 2: Dummy condenser with trombone coil type [18].

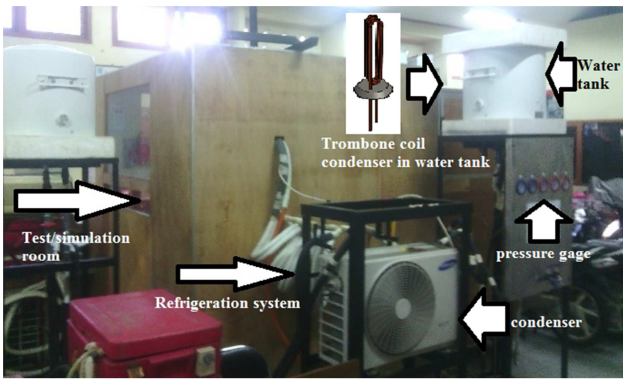

Figure 3: The test facility of experimental apparatus [18].

The calculation is done by assuming the system as ideal vapor compression cycle. The P-h diagram of vapor compression cycle is shown in Figure 4 where heat recovery (q_h coil) in 2-2'. The enthalpy of the system is calculated using Refprop software ver. 6.0.

The equations 1 - 10 are used to calculate a hybrid refrigeration system (RSACWH) performance.

- Compressor Power

$$W_{net,in} = VIcos\emptyset_{in} \quad (1)$$

where cos $\emptyset$ is 0.83

$$W_{net,in} = \dot{m}\, w_k \quad (2)$$

- Cooling Capacity

$$Q_L = \dot{m}\, q_L = \dot{m}\,(h_1 - h_4) \quad (3)$$

- Heat Rejection Capacity

$$Q_{H(condenser)} = \dot{m}\, q_{Hcondenser} = \dot{m}\,(h_{2'} - h_3) \quad (4)$$

- Heat Recovery Capacity

$$Q_{H(coil)} = \dot{m}\, q_{H(coil)} = \dot{m}\,(h_2 - h_{2'}) \quad (5)$$

- Coefficient of Performance as Refrigerator

$$COP_R = \frac{Q_L}{W_{net,in}} \quad (6)$$

- Coefficient of Performance as Refrigerator (*R*) + Heat Pump (*HP*)

$$COP_{R+HP} = \frac{Q_L + Q_{H(coil)}}{W_{net,in}} \quad (7)$$

$$\text{- Energy Saving (\%)} = \frac{(R-22\ Energy)-(HCR-22\ Energy)}{(R-22\ Energy)} \quad (8)$$

$$\text{- } COP_R \text{ Increase (\%)} = \frac{(HCR-22\ COPR)-(R-22\ COPR)}{(HCR-22\ COPR)} \quad (9)$$

$$\text{- } COP_{R+HP} \text{ Increase (\%)} = \frac{(HCR-22\ COPR+HP)-(R-22\ COPR+HP)}{(HCR-22\ COPR+HP)} \quad (10)$$

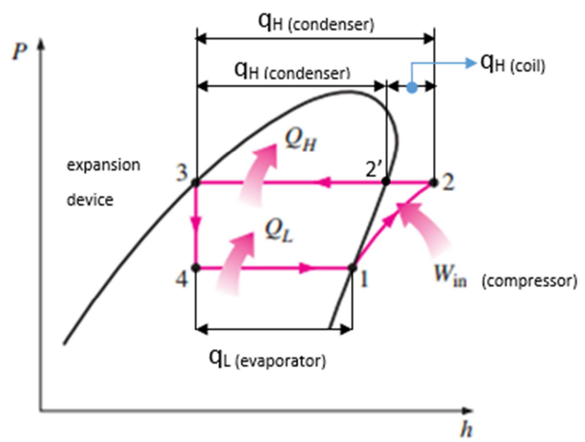

Figure 2: P-h diagram of vapour compression cycle (modified from [19]).

3.0 RESULTS AND DISCUSSION

Figure 5 shows the comparison of compressor pressure inlet (Pi) and outlet (Po) between R-22 and HCR-22 at different cooling load (0W, 1000W, 2000W and 3000W). There is a pressure difference between R-22 refrigerant and HCR-22 as shown in Figure 5. The compressor pressure inlet and outlet with HCR-22 are around 70-76 psi and 196-204 psi, respectively, while the compressor pressure inlet and outlet with R-22 are around 62-70 psi and 205-217 psi. As shown in Figure 5, the pressure of HCR-22 is lower than R-22, because the less refrigeran mass charge in RSACWH system using HCR-22 compared to R-22 so the pressure inlet and outlet are lower too.

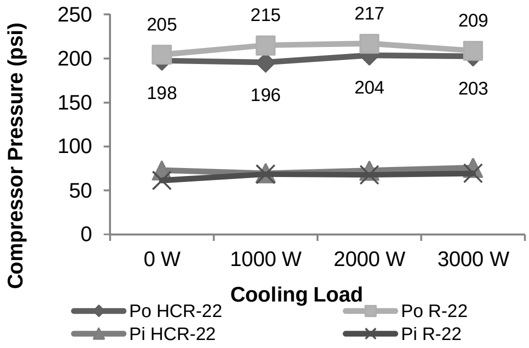

Figure 3: Compressor pressure inlet and outlet with HCR-22 and R-22 at different cooling load.

Figure 6 shows the comparison of compressor temperature inlet (Ti) and outlet (To) between R-22 and HCR-22 at different cooling load (0W, 1000W, 2000W and 3000W). In Figure 6 is also showed the temperature difference of R-22 refrigerant and HCR-22 while in and out from the compressor. As shown in Figure 6, the HCR-22 refrigerant temperature is lower than R-22. It is clear from [19] when a substance at lower pressure, thus temperature also lower.

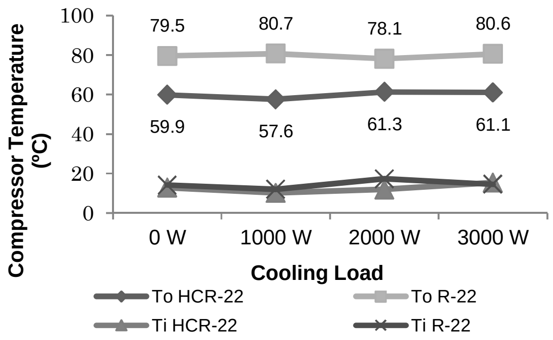

Figure 4: Compressor temperature inlet and outlet with HCR-22 and R-22 at different cooling load.

Figure 7, Figure 8 and Figure 9 shows a comparison of compressor power, the percentage of energy savings and cooling capacity, respectively at RSACWH system comparing refrigerant R-22 and HCR-22. The comparison is carried out on the effect of different cooling load from 0W, 1000W, 2000W and 3000W that give an impact on system performance RSACWH.

As shown in Figure 7, compressor power increase with increasing of cooling load. It means the value of compressor power depend on cooling load in the system. The compressor power in RSACWH systems using the HCR-22 range around 556W - 590W, while the use of R-22 range around 665W - 727W. The compressor power using HCR-22 refrigerant is smaller than R-22, this is because when using HCR-22 the amount of refrigerant mass lower than R-22, so the compressor power and pressure of the system also lower comparing with R-22.

Figure 8 shows the percentage of energy saving of HCR-22 compared to R-22 in different cooling load. The energy savings using the HCR-22 was 16.31% -21.64% compared to R-22, as shown in Figure 8. Usage of HCR-22 give more energy saving, the same result presented by Khalid A. Joudi and Qusay R. Al-Amir [15] where R-290 (HC) was the better alternative for R-22, R290 system required less charge which alleviates the direct emission of refrigerant and lowers compressor power consumption.

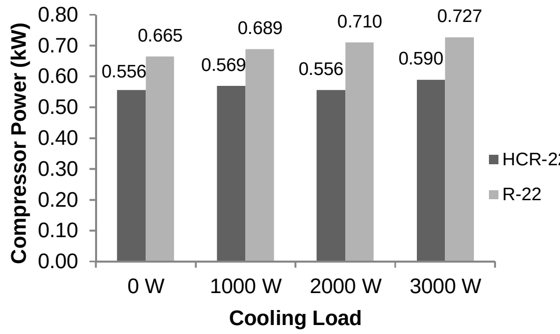

Figure 7: Compressore power of HCR-22 and R-22 at different cooling load.

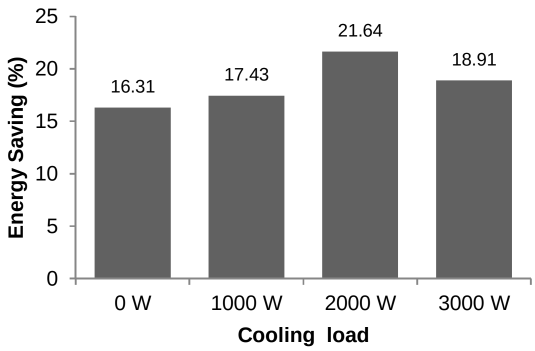

Figure 8: Percentage of energy saving with HCR-22 and R-22 at different cooling load.

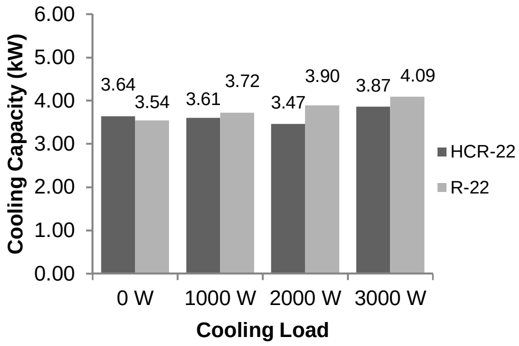

Figure 9: Cooling capacity of HCR-22 and R22 at different cooling load.

Figure 9 shows the R-22 cooling capacity range around 3,54 kW-4,09 kW, while the HCR-22 range around 3,47kW -3,8kW at different cooling load. The cooling capacity with HCR-22 is lower than R-22 around 2%-7.6% in different cooling load 0W, 1000W, 2000W and 3000W. This is because the less mass charge of HCR-22 refrigerant into the RSACWH compared to R-22, but this cooling capacity is less significant difference so the use of HCR-22 can be applied as alternative to R-22 refrigerant.

Figure 10 shows the comparison of room temperature at different cooling load with HCR-22 and R-22. The room temperature of RSACWH with R-22 is lower than HCR-22 around 1.8°C, because of the less refrigerant charge with HCR-22.

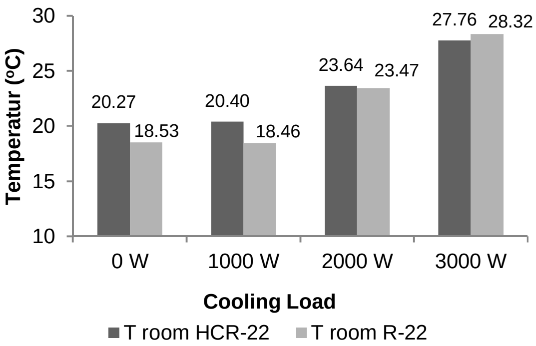

Figure 10. Test room temperature of HCR-22 and R22 at different cooling load.

Figure 11 shows the comparison of heat rejection at different cooling load with HCR-22 and R-22, the heat rejection capacity increases with the increasing of cooling load in small quantity. The heat rejection capacity of HCR-22 is between 3.92 kW-4.34 kW while the R-22 between 3.78 kW-4.34 kW.

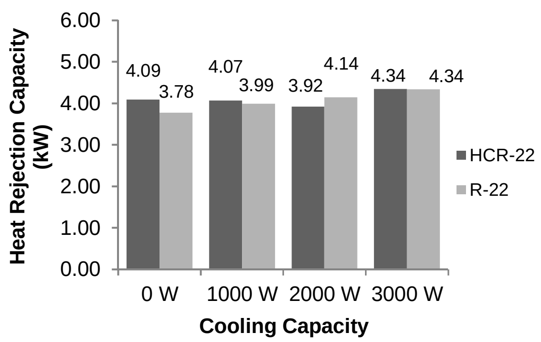

Figure 11: Heat rejection capacity of HCR-22 and R-22 at different cooling load

Figure 12 shows the comparison of COP_R at different cooling load with HCR-22 and R-22. The COP_R with HCR-22 is higher than COP_R with R-22. This is because the compressor power with HCR-22 lower than R-22 at the same cooling capacity, the COP_R depend on compressor power quantity. The percentage of increasing COP_R with HCR-22 compared to R-22 are presented in Figure 13. The increase in COP_R using the HCR-22 is 11.89% -18.69% as shown in Figure 13.

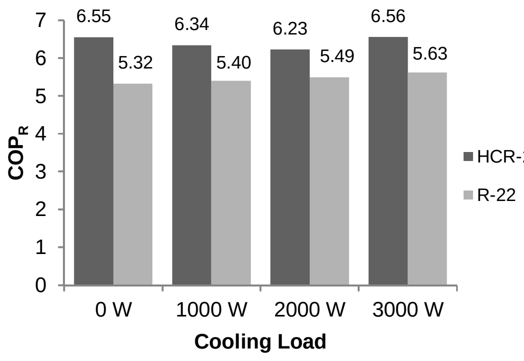

Figure 12: COP_R of HCR-22 and R22 at different cooling load.

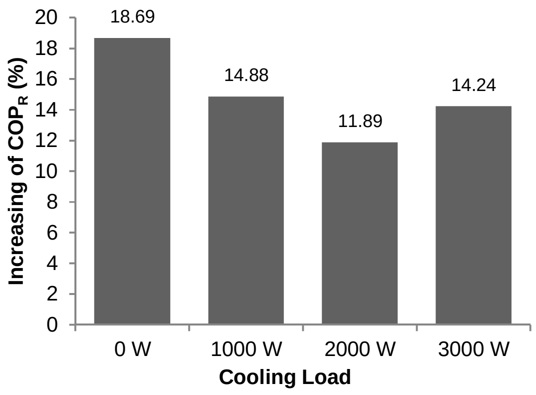

Figure 13: Percentage of increasing of COP_R HCR-22 and R22 at different cooling load.

The superiority of ACWH is the usage of condenser heat rejection partially for heating water. When compression process occurs, the pressure of refrigerant is increase to the high pressure in condenser, phase of refrigerant out of the compressor is superheated vapor phase, in this phase refrigerant temperature is also very high. In original air conditioning system, refrigerant at high temperature is rejected into the surrounding through the condenser without utilized.

Figure 14 shows the comparison of heat recovery capacity at different cooling load with HCR-22 and R-22. As shown in Figure 14, the heat recovery capacity of HCR-22 is lower than the R-22, so that the temperature of the hot water obtained by HCR-22 is also lower than R-22 as shown in Figure 15.

Figure 15 shows the comparison of hot water temperature in a water tank from heat recovery system at different cooling load with HCR-22 and R-22. In Figure 15 is shown the water temperature due to heating by a dummy condenser after 120 minutes of testing at different cooling load, the water temperature has increased with the increasing of the cooling load from low to high. The maximum water temperature is obtained when the cooling load of 3000 W applied, where the water temperature with HCR-22 and R-22 is 48.81°C and 63.40°C, respectively as shown in Figure 15.

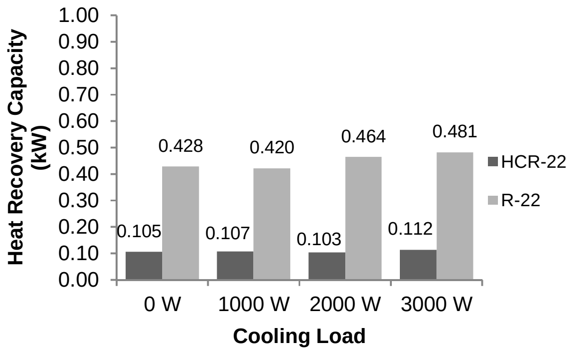

Figure 14: Heat recovery capacity with HCR-22 and R22 at different cooling load.

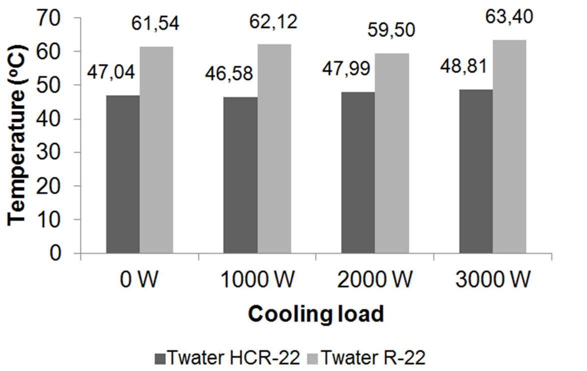

Figure 15: Hot water temperature from heat recovery with HCR-22 and R-22 at different cooling load.

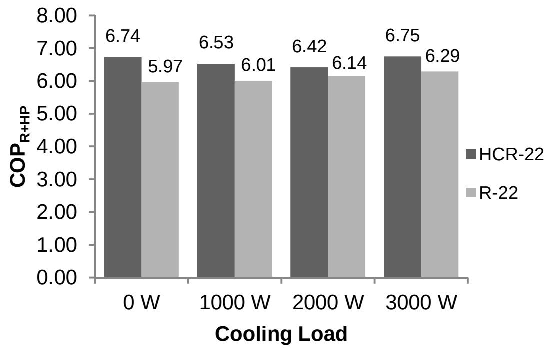

Figure 16: Comparison COP_{R+HP} of HCR-22 and R22 at different cooling load.

Figure 16 shows the comparison of COP_{R+HP} at different cooling load with HCR-22 and R-22. The COP_{R+HP} with HCR-22 is higher than COP_R with R-22. This is because the compressor power with HCR-22 lower than R-22 at the same cooling capacity. The highest COP_{R+HP} of the RSACWH system with HCR-22 and R-22 are 6.75 and 6.29, respectively.

The percentage of increasing COP_{R+HP} with HCR-22 compared to R-22 are presented in Figure 17, where the COP_{R+HP} depend on compressor power quantity. The increase in COP_{R+HP} using the HCR-22 is around 4.26% -11.41% as shown in Figure 17. The quantity of COP_{R+HP} is calculate using equation 7.

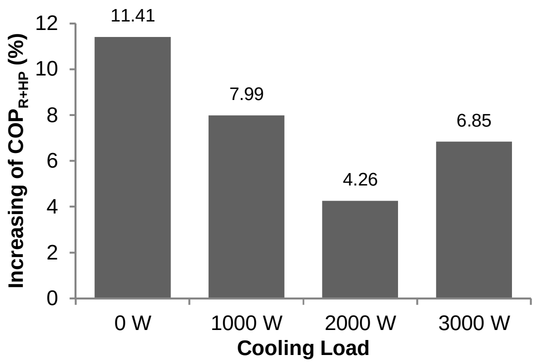

Figure 17: Percentage of increasing COP_{R+HP} with HCR-22 and R-22 at different Cooling Load

4.0 CONCLUSION

Replacement of R22 refrigerant and HCR-22 as the working fluid in the RSACWH has been conducted to determine the performance comparison of the system. The amount of refrigerant mass charge of HCR-22 refrigerant is 40% more efficient than R-22. The test results showed that the use of the HCR-22 refrigerant can save energy consumption for compressor power about 16.31%- 21.64%. The cooling capacity and heat rejection capacity is nearly the same for R-22 and HCR-22 with little discrepancies. The COP_R and COP_{R+HP} increases around 11.89%- 18.69% and around 4.26%-11.41%, respectively for HCR-22 compared to R-22 as effect less refrigerant mass charge. The room temperature with HCR-22 is nearly the same compared to R-22 with little discrepancies at cooling load 0W and 1000W. The hot water temperature from heat recovery system (dummy condenser) using HCR-22 and R-22 are about 46.58˚C-48.81˚C and 59.50˚C-63.40˚C respectively. The use of HCR-22 provides energy saving and better performance at the same cooling capacity.

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