Effect of heat recovery water heater system on the performance of residential split air conditioner using hydrocarbon refrigerant (HCR22)

AAziz¹, Thalal¹, I Amri², Herisiswanto¹ and A K Mainil³
¹Department of Mechanical Engineering, Universitas Riau, Jl.Subrantas km 12, Pekanbaru 28293, Indonesia
²Department of Chemical Engineering, Universitas Riau, Jl. WR Supratman, Kandang Limun, Bengkulu 38371A, Indonesia
³Department of Mechanical Engineering, Universitas Bengkulu, Jl.Subrantas km 12, Pekanbaru 28293, Indonesia
azridjal.aziz@lecturer.unri.ac.id

Abstract. This paper presents the performance of residential split air conditioner (RSAC) using hydrocarbon refrigerant (HCR22) as the effect on the use of heat recovery water heater system (HRWHS). In this study, RSAC was modified with addition of dummy condenser (trombone coil type) as heat recovery water heater system (HRWHS). This HRWHS is installed between a compressor and a condenser by absorbing a part of condenser waste heat. The results show that RSAC with HRWHS is adequate to generate hot water with the temperature range about 46.58°C - 48.81°C when compared to without HRWHS and the use of dummy condenser does not give significant effect to the split air conditioner performance. When the use of HRWHS, the refrigerant charge has increase about 19.05%, the compressor power consumption has slightly increase about 1.42% where cooling capacity almost the same with slightly different about 0.39%. The condenser heat rejection is lower about 2.68% and the COP has slightly increased about 1.05% when compared to without HRWHS. The use of HRWHS provide free hot water, it means there is energy saving for heating water without negative impact to the system performance of RSAC.

1. Introduction
One of the ways to improve energy efficiency is recovery or reuse of waste heat energy from the energy conversion device like residential split air conditioner (RSAC). The most commonly reason was used in an attempt to modify the refrigeration system is energy efficiency. Refrigeration system that serves as air conditioning machine is commonly used to achieve comfortable zone by utilizing the cooling effect of the evaporator for human activity in home, office or another building. Refrigeration system is one type of energy conversion machines, where the amount of energy is needed to produce a cooling effect. Vice versa, the amount of energy as heat rejected by the system into the surrounding to meet the principles of thermodynamics. In thermodynamics energy balance analysis, the heat energy rejected (heating effect) from the condenser are combination of compressor work and cooling effect energin the evaporator. It means that heat energy rejection in the condenser is bigger than cooling effect in evaporator, so that some of this energy has the potential to be recovered for heating water. There is saving energy by using it to produce hot water [1-4].

The objective of refrigerator is to maintain refrigerated room at low temperature by remove heat from it. Rejected heat to higher temperature medium is only part of the operation to meet the principles of thermodynamics equilibrium, not the purpose. Vice versa, the
The objective of heat pump is to maintain heated room at high temperature by absorbing heat from low-temperature sources such as water or ambient air in winter, and this heat is supplied to a warmer zone such as a house [5]. The objective of hybrid refrigeration device is to maintain a refrigerated room at low temperature by removing heat \( (Q_L) \) from it and at the same time maintain heated zone of high temperature and rejected some of heat to higher temperature to meet the principles of thermodynamics equilibrium \( (Q_H) \). 

The ozone depleting potential (ODP) and global warming potential (GWP) have become the most important criteria for choosing a refrigerant that will be used in the refrigeration system [6]. The most of the refrigeration systems operate with the refrigerant R22. The long-term alternatives for R22 include hydro fluorocarbon (HFC) refrigerants [7]. HFC have a significant GWP and could be replaced by hydrocarbon (HC) refrigerants in most of refrigeration systems. The use of HC refrigerants has an environmental advantage of a greatly reduced GWP when it is compared with HFC refrigerants [8]. Many researchers focused in the research into substitutes for R22 with hydrocarbon refrigerant (HCR22) at low and medium condensing temperatures [9-11]. 

Several studies of waste heat recovery from condenser in air conditioning for water heating has been performed by many researchers, including applying heat recovery process[12-14], heat recovery technique and economics analysis [15-16]. The use of evaporative cooling [17] can be applied to improve RSAC performance using HRWHS.Wang et al. [18] conducted a study about the experimental investigation on a conventional airconditioner working as air-water heat pump. The results are shown that COP got 10% improvement and the average temperature of tank water affects COP of the equipment working as air-water heat pump significantly.

The previous literature shows that most of studies have been performed on residential air conditioning integrated with water heater system using R22 as the refrigerant and their components. But there has little reports presented about the performance of HCR22 refrigerant used in residential air conditioning integrated water heater system with trombone coil dummy condenser as heat exchangers which are widely applied in present residential air-conditioning water heater system or heat pump.In this paper, a performance comparison of residential split air conditioner (RSAC) with and without heat recovery system using hydrocarbon refrigerant (HCR22) were investigated.Some of the parameters being analyzed and discussed include: the cooling capacity, COP, heat rejection, compressor power, condensing pressure, evaporating pressure, test room temperature and hot water temperature.

2. Methods
The performance comparison as effect of heat recovery water heater system is evaluated using the similar experimental apparatus performed by Azridjal et al. [14]. The schematic diagram of the experimental apparatus is shown in figure 1[19]. The experimental apparatus is modified from RSAC with cooling capacity 2.6 kW. The trombone coil type dummy condenser as heat exchanger for heating water was made up from 3/8 inch diameter of copper pipe, with 5 windings and 5.5 meters length [14]. The modified RSAC has two mode of operation: AC original mode without HRWHS or cooling mode from original AC and RSAC with HRWHS mode (simultaneously cooling and heating mode). This experimental apparatus is equipped with 3 valves (valve 2, 2a and 2b), so that the apparatus can serve as AC original mode or ACWH mode by set up the valves. The working fluid in this experimental apparatus is HCR22. The HCR22 refrigerant mass circulating in original AC mode (without HRWHS) and RSAC with HRWHS mode are 252 gram and 300 gram respectively.
The test room facility with size 2.26 x 1.75 x 2 m (length x width x height) is equipped with 30 pieces of 100 Watt incandescent lamp as the cooling load to indoor unit (evaporator) with variation of 0 W, 1000 W, 2000 W, and 3000 W at 19°C room temperature reference setting. The first experimental test was started with original AC mode by opening valve 2 and closing valves 2a and 2b. Then, the second test was conducted by closing valve 2 and opening the valves 2a and 2b as RSAC with HRWHS mode. The data were collected every 5 minutes during 2 hours of testing for cooling load variation of 0 W, 1000 W, 2000 W, and 3000 W. The temperatures from apparatus were measured by K-type thermocouple using data acquisition module with accuracy 0.2% (± 0.5°C) and has a resolution 0.1°C. The pressures were measured by bourdon type pressure gauge in condenser side (high pressure) and evaporator side (low pressure) with accuracy ±5 psi and ±1 psi, respectively. The electric current input and voltage input were measured by ampere-meter (accuracy ± 2.0 percent and 3 digits) and voltmeter (accuracy ± 1.0 percent and 3 digits), respectively. The charge of refrigerant mass was measured by digital weight scale with accuracy ±10 gram. The calculation of system performance was done by assuming ideal vapor compression cycle, where the enthalpy is calculated based on the high pressure and low pressure [5]. The thermodynamics properties calculation was carried out by software of REFPROP ver. 6.01 base on pressure data collection. Data without heat recovery as comparison in this study was used data from previous publication [20].

![Figure 1](image)

**Figure 1.** The schematic of the experimental apparatus [20].

### 3. Results and Discussion

The compressor power at different cooling load with and without HRWHS is shown in figure 2(a). While figure 2(b) shows the average pressure of the compressor inlet (low pressure) and outlet (high pressure) with and without HRWHS at different cooling loads from 0W, 1000W, 2000W and 3000W. It can be seen from figure 2(b) that the compressor pressure differences with and without HRWHS about 8.9% and 6.8% at the compressor inlet and outlet respectively.
Figure 2. Compressor power at different cooling loads with and without HRWHS (a) and compressor pressure at different cooling loads with and without HRWHS (b).

Figure 3(a) shows the cooling capacity for two hours operation of system with and without HRWHS in different cooling load. In general, there was no significant difference in the variation of the cooling load against the cooling capacity with or without heat recovery HRWHS as seen in figure 3(a). It is because, the cooling capacity with HRWHS decrease only about 0.39% (very small portion) in different of cooling load from low to high. It can be stated that the use of heat recovery system for utilization hot water not affecting the cooling capacity of RSAC. At the simultaneously operation for cooling and heating, the free hot water was obtained from the use of HRWHS.

Figure 3(b) shows the heat rejection in condenser of RSAC with and without HRWHS in different of the cooling load from 0W, 1000W, 2000W and 3000W is shown in figure 3(b). It appears that the use of heat recovery system on the air conditioner did not affect significantly to heat rejected in the condenser, although there is little big difference in the heat rejection at cooling load of 2000 W, where the heat rejection decrease slightly small around 2.68%. The same result were also obtained for compressor power, compressor pressure and cooling capacity as shown in figure 2(a), figure 2(b) and figure 3(a) respectively.

The COP in condenser of RSAC with and without HRWHS in different of the cooling load from 0W, 1000W, 2000W and 3000W is shown in figure 4(a), while COP_{R}(COP as refrigerator/cooling) and COP_{HP}(COP as heat pump/heating) are COP for cooling and heating,
respectively. The similar results are also shown in figure 4(a) when it compared with another figure (figure 2(a), figure 2(b) and figure 3(a) and figure 3(b)), where there is no significant impact on the COP with and without recovery HRWHS at different cooling load. Although there is slightly difference of the COP with and without heat recovery system, the COP increase around 1.05% compared to without heat recovery system (dummy condenser), but in general the difference is very small so there is no significant impact on COP of the RSAC system.

![COP of RSAC system at different cooling loads with and without HRWHS](image1)

![Room Temperature (indoor) of RSAC system at different cooling loads with and without HRWHS](image2)

**Figure 4.** COP of RSAC system at different cooling loads with and without HRWHS (a) and the room temperature (indoor) of RSAC system at different cooling loads with and without HRWHS (b).

The room temperature (indoor) of RSAC with and without heat recovery system in different cooling load from 0W, 1000W, 2000W and 3000W is shown in figure 4(b). As shown in figure 4(b), the increasing of cooling loads from 0 W to 3000 W causes that the room temperatures increases. It is because the higher the cooling load applied, the longer the time required to reach the reference temperature, so for cooling time 2 hours, then only the smallest cooling load (0 W and 1000 W) which can reach temperatures of reference (19°C).

The hot water temperature of RSAC with and without heat recovery system in variation of the cooling load from 0W, 1000W, 2000W and 3000W is shown in figure5. The hot water temperature with HRWHS obtained in the different cooling load from 0 W to 3000W tend to be similar, so the hot water temperature was not affected by the cooling load different. The temperature of the hot water is only obtained in the RSAC system with HRWHS. The RSAC system without HRWHS is original mode of RSAC system without dummy condenser that does not produce hot water as shown in figure 5.

The main advantage of RSAC with heat recovery system is free energy for hot water. This is one form of heat recovery in RSAC, where most of the heat released into the environment is absorbed for heating 50 liters of water. This hot water can be used for bathing and washing. As seen in figure 5, RSAC with heat recovery (dummy condenser) is adequate to generate hot water with the temperature range around 46.58°C - 48.8°C compared without heat recovery, and the use of dummy condenser does not give significant effect to the RSAC performance. The heat value which is not great but if heat accumulated for 120 minutes the hot water can be obtained, as shown in figure 5 while the room temperature is maintained for the similar evaporator cooling capacity as shown in figure 4(b).

It can be seen from figure 2, figure 3 and figure 4(a) there are no significant difference in the performance characteristics of the RSAC original without HRWHS (condenser dummy)
when compared with HRWHS (the condenser dummy). The design of the condenser dummy is expected no impact to the performance of air conditioning, so the RSAC original has been turned into hybrid RSAC system as the air conditioning system for space cooling and water heater.

![Figure 5. The hot water temperature of RSAC system at different cooling loads with and without HRWHS](image)

**Figure 5.** The hot water temperature of RSAC system at different cooling loads with and without HRWHS

4. Conclusions
The effect of heat recovery water heater system (HRWHS) on the performance of residential split air conditioner using hydrocarbon refrigerant (HCR22) was presented by different in cooling load as actual cooling load simulation. It is found that RSAC system with HRWHS (dummy condenser) capable to generate hot water in temperature range 46.58-48.81°C within 2 hours. The results show the use of dummy condenser does not have a big impact on the performance of RSAC because of the increase or decrease in RASC system performance that occurs in slightly small difference. The compressor power increase 1.42%, while cooling capacity decrease 0.39%, where heat capacity decrease 2.68% and COP increase 1.05%. The use of the heat recovery system on the RSAC as the water heater only requires additional refrigerant 19.05%. In general the use of heat recovery does not affect the performance of the RSAC and can be applied as air conditioner and water heater simultaneously to provide better performance.

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