# Performance analysis of the electric vehicle air conditioner by replacing hydrocarbon refrigerant

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# Performance Analysis of the Electric Vehicle Air Conditioner by Replacing Hydrocarbon Refrigerant

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**Abstract.** The thermal comfort in passenger cabins needs an automotive air-conditioning system. The electric vehicle air conditioner system is driven by an electric compressor which includes a compressor and an electric motor. Almost air-conditioning system uses CFC-12, CFC-22 and HFC-134a as refrigerant. However, CFC-12 and CFC-22 will damage the ozone layer. The extreme huge global warming potentials (GWP) values of CFC-12, CFC-22, and HFC-134a represent the serious greenhouse effect of Earth. This article shows new experimental measurements and analysis by using a mixture of HC-134 to replace HFC-134a. The result is a refrigerating effect, the coefficient of performance and energy factor increase along with cooling capacity, both for HFC-134a and HC-134. The refrigerating effect of HC-134 is almost twice higher than HFC-134a. The coefficient of performance value of HC-134 is also 36.42% greater than HFC-134a. Then, the energy factor value of HC-134 is 3.78% greater than HFC-134a.

## INTRODUCTION

Global warming is one of the biggest threats on our life on earth lately. Global warming is triggered by the depletion of the ozone layer and greenhouse effect in the atmosphere. The global warming is also caused by the use of not environmentally friendly refrigerants containing halogen elements, such as Chlorofluorocarbons (CFCs), Hydrochlorofluorocarbons (HCFCs) and Halocarbons (HFCs) [1]. In Indonesia, the use of HFCs that lead to global warming is still found, particularly in air-conditioning systems of vehicles using HFC-134a. Although HFC-134a has zero ODP (ozone depletion potential), the global warming potentials (GWP) values are extremely large to impact on global warming.

The search for environmentally friendly refrigerant substitution is an important topic to be researched. Hydrocarbon refrigerant is one example of green refrigerants because they have a small value of GWP and ODP equal to zero [2]. Previous researchers have studied the feasibility of hydrocarbons as a replacement for HFC-134a, as summarized in Table 1. The researchers found that when an HC refrigerant is used, the refrigerating effect will be greater than HFC-134a. Some researchers say that the coefficient of performance (COP) of higher HC-134 than HFC-134a and some declared lower because it depends on the respective test equipment and settings. The total power consumption of hydrocarbon usage is less than HFC-134a. The energy factor of hydrocarbon was also larger than HFC-134a. It shows that in addition to environment-friendly hydrocarbon (HC) refrigerant also has the capability sufficient to replace HFC-134a.

The hydrocarbon has a significant potential to replace HFC-134a because of its excellence properties. However, it is too vulnerable to have flammability properties highly. The hydrocarbon refrigerant is in the category A3 based on the classification of safety level. It means that the hydrocarbon refrigerant is non-toxic but highly prone to flammability properties. The use of hydrocarbon refrigerants, especially regarding its flammability properties, a regulation standard has been established to prevent harm things to occur. The regulation standard governs every aspect of application, including ISO-5149, ISO-817, IEC 60335-2-24, IEC 60335-2 -40 and IEC 60335-2-89 [3].

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**TABLE 1.** The previous experimental study results that compare HC refrigerants with HFC -134a

| Author | Tool Test | HC Alternative | Results |
| --- | --- | --- | --- |
| Wongwises et al. [4] | AC car | HC-290 / 600a / 600a (50/40/10) | • The refrigeration capacity in average, compression work and COP of HC are larger than HFCs. |
| Jwo et al. [1] | Domestic Refrigerator | HC-290 / 600a (50/50) | • The best of HC mass 40% less than the mass of HFC.<br>• The HC energy factor is 4.5% greater allowing for energy consumption reduction by 4.4% compared to HFCs. |
| Perang et al. [5] | AC car | HC-290 / 600a / 600a | • The HC COP in average is higher than HFC.<br>• The average compression ratio, the cabin temperature, and power consumption are HC less than HFC. |
| Yu and Tang [6] | Domestic Refrigerator | HC-290 / 600a (50/50) | • The HC energy factor is 12.2% higher than HFC<br>• The COP, compression ratio, and power consumption of HC are 2.7%, 5.1% and 10.9% lower than HFCs. |
| Wellid et al. [7] | AC car | HC-290 / 600a (56/44) | • The HC COP is smaller of 4.74% than the HFC with immediate replacement<br>• The HC COP increases by 5.23% greater than the HFC after subcooling |

The experiment was performed to investigate and to analyze the performance of a refrigeration system using CFC-12 and HFC-134a refrigerant. Tests have conducted by giving the variation in operating temperature of the condenser. From the experiment, it seems that the working temperature of the condenser affects the performance of the refrigeration system. The coefficient of performance (COP) decreases when the temperature of the condenser work increases [8].

The analysis on the performance of HFC-134a, CFC-12 and a refrigerant mixture of HC-290 and HC-600a is conducted. The tests carried out by varying the working temperature of the condenser from 30 °C to 50 °C. The test result shows that coefficient of performance (COP) of all the refrigerants apparently decrease along with every increment of the working temperature condenser increases [9]. For the test with HC-152a refrigerant used in the refrigeration system, hermetic compressors designed for use with HFC-134a refrigerant is employed. The compressor is a single stage reciprocating hermetic compressor type with a capacity of 12.11 $cm^3$ for 2900 rpm working rotation speed. Based on the experiment, HC-152a which has a compression ratio similar to HFC-134a can be used in hermetic compressors designed for HFC-134a. Lubricant (POE-type) and the expansion device (electronic expansion valve) are used. There are no problems found in the compressor [10].

Three well-known parameters are often used to illustrate the behavior of air-conditioning and refrigerators, which are the refrigerating effect (RE), the coefficient of performance (COP), and energy factor (EF). The refrigerating effect is defined as heat removal per unit mass flow of refrigerant. COP is an important parameter to predict working effect for cooling and heating systems. For cooling system, the COP value means the proportion of heat removal from the hot reservoir to imported work. Energy factor here is defined as cooling capacity per unit power consumption. Based on the refrigerant properties that have been described previously, the experimental research on the use of hydrocarbon refrigerants as alternatives to HFC-134a in car air-conditioning refrigeration system is conducted. The purpose of this study was to determine the relationship of refrigeration capacity with refrigeration system performance parameters, i.e. the refrigerating effect (RE), the coefficient of performance (COP) and the energy factor (EF). Then all three performance parameters are compared between HC-134 and HFC-134a at the same temperature conditions. The present study is different than previous studies in which the use of hermetic compressors in air conditioning (AC) cars that can be applied to an electric car (electric vehicle). In addition, this study is expected to be a guarantee to support hydrocarbon refrigerant that can be an alternative solution for halocarbons refrigerant consumption reduction (CFCs, HCFCs, and HFCs) in Indonesia.

## EXPERIMENT APPARATUS AND METHOD

Ideal vapor compression cycle can be seen on the pressure-enthalpy diagram in Fig. 1. The cooling capacity is the amount of heat absorbed by the evaporator. The cooling capacity defined in Equation (1) - (3).

$$\dot{Q}_{in} = \dot{m}_{ref} \,.\, (h_1 - h_4) \tag{1}$$
$$\dot{Q}_{in} = \dot{m}_{ud} \,.\, (h_{ud,out} - h_{ud,in}) \tag{2}$$
$$\dot{Q}_{in} = \rho_{ud} \,.\, v_{ud} \,.\, A \,.\, (h_{ud,out} - h_{ud,in}) \tag{3}$$

Where $\dot{Q}_{in}$ = the cooling capacity, kW; $\dot{m}_{ref}$ = refrigerant mass flow rate, kg/s; $h_1$ = enthalpy of refrigerant at the outlet of evaporator, kJ/kg; $h_4$ = enthalpy of refrigerant at the inlet of evaporator, kJ/kg; $\dot{m}_{ud}$ = air mass flow rate, kg/s; $h_{ud,out}$ = enthalpy of the air at the outlet of evaporator, kJ/kg; $h_{ud,in}$ = enthalpy of the air at the inlet of evaporator, kJ/kg; and $\rho_{ud}$ = the density of air, kg/m$^3$; $v_{ud}$ = air flow rate, m/s; and $A$ = cross-sectional area, m$^2$. The refrigerating effect (RE), kJ/kg is formulated in Equation (4).

$$RE = h_1 - h_4 \tag{4}$$

The of compression work is defined as the difference of enthalpy in the processes 1 and 2, as shown in Fig. 1.

$$w = h_1 - h_2 \tag{5}$$

Where $w$ = compressor work, kJ/kg; and $h_2$ = enthalpy of the refrigerant at the outlet of the compressor, kJ/kg.

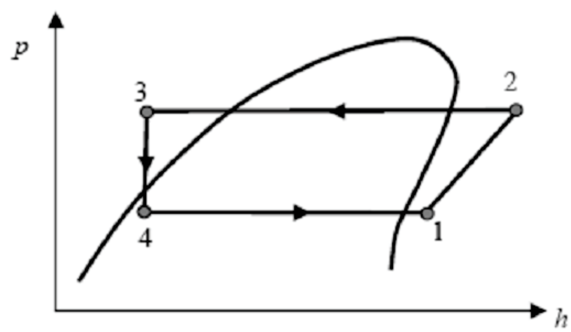



**FIGURE 1.** Vapor compression cycle [6]

The coefficient of performance (COP) of the ideal vapor-compression cycle is a comparison between the refrigerating effect and the compressor work, which is defined in Equation (6) [6].

$$COP = \frac{h_1 - h_4}{h_2 - h_1} \tag{6}$$

Energy factor (EF) is a number that represents the ratio of cooling capacity with the amount of electrical power required by the system. In the vapor compression refrigeration system in general, there are three components require power, namely the compressor, evaporator, and condenser. Energy factor defined in equation (7) [1].

$$EF = \frac{\dot{Q}_{in}}{P_{tot}} \tag{7}$$

Where $\dot{Q}_{in}$ = the cooling capacity, W; and $P_{tot}$ = total power, W.

Equipment used in the study is a refrigeration system that consists of basic components. The schematic experimental of the test rig is shown in Fig. 2. The system mainly consists of a hermetic compressor equipped with a condenser, receiver dry-filter, evaporator and block expansion valve. The compressor is ¾ HP and 220 volts. The evaporator and the condenser are the type of automotive air conditioning with air load. Temperature and pressure measurements were performed at the four points indicated in Fig. 2. Temperatures sensor is copper-constantan thermocouples with an accuracy of ± 1°C. The refrigerant pressure was measured using pressure gauge with an accuracy of ± 1 psi. The current supplied was measured by a clamp meter with an accuracy of ± 0.01 A [11].

The system was tested for different cooling capacity under the constant heat removal rate at the condenser. The primary parameters observed during the experiment are pressure, temperature, and power consumption for different cooling capacities. The cooling capacity is determined by the blower speeds of evaporator and condenser. The experiment is conducted with 4 variations of heat absorption rate and 4 types of heat rejection rate, so there are 16 combinations for the testing of one refrigerant. For each corresponding refrigerant, 19 combinations of data are measured. Then, the main three parameters of refrigeration system performances, RE, COP and EF will be calculated.

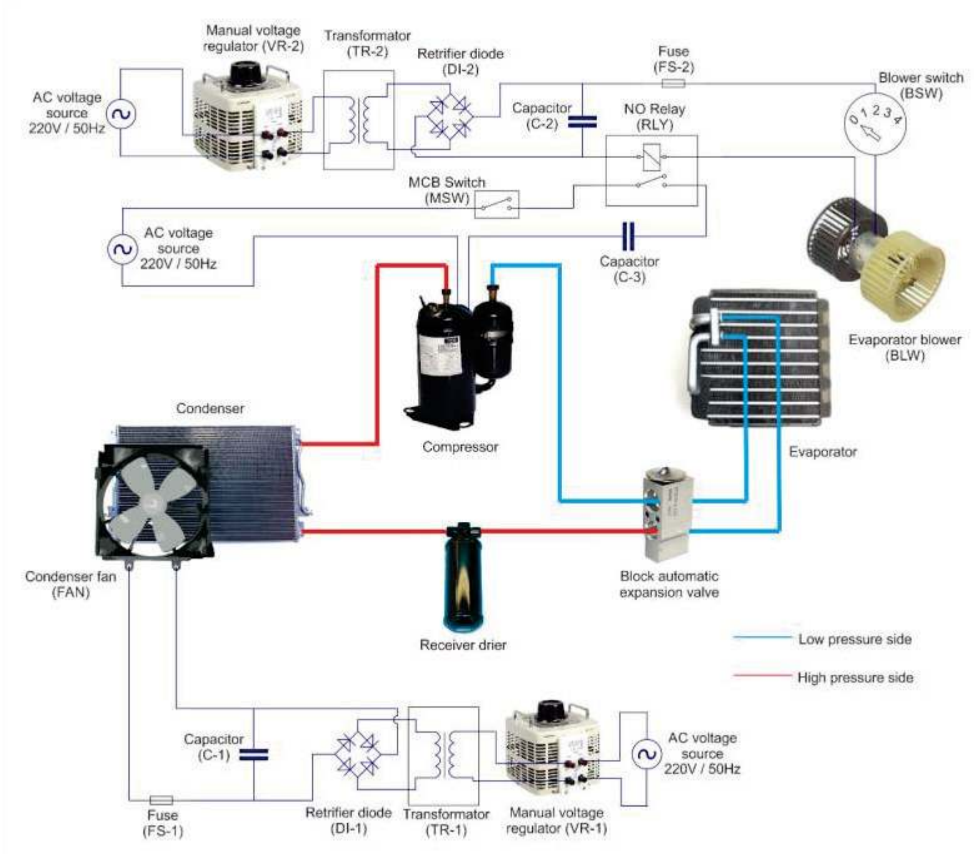
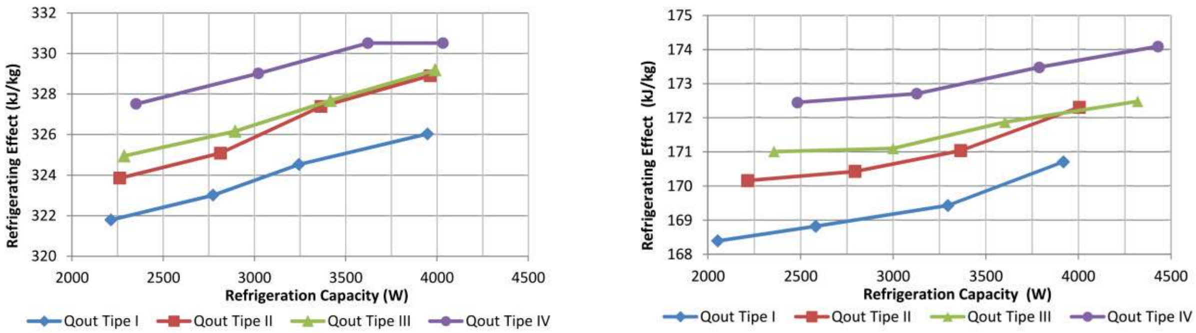



**FIGURE 2.** The schematic of experimental test rig

## RESULTS AND DISCUSSION

Figure 3 shows that the refrigerating effect continues to increase with a positive gradient correspond to the refrigeration capacity, both HC-134 and HFC-134a. The larger the refrigeration capacity, the greater the effect of refrigeration. Thus, the value of the refrigerating effect is proportional to the capacity of refrigeration. Moreover, the refrigerating effect also increases along with heat release increase in the condenser. The increase in the value of refrigerating effect along with heat release increase is due to the phenomenon of subcooling (under-cold) that occurs at the end of the process of condensation.

The increase in the value of refrigerating effect along with heat release increases is due to the occurrence of the subcooling phenomenon at point 3 in the cooling process as shown in Fig. 4. It shows one example of the subcooling on HC-134. The figure demonstrates that the lower the temperature of point 3, then the process lines 3-4 will be more shifted to the left so that a specific enthalpy at point 3 and 4 will decrease. However, the point 1 does not experience significant changes in specific enthalpy. Therefore, the area under the curve-line 4-1 that represents the value of refrigerating effect will increase along with heat release increase in the condenser.




(a) HC-134 (b) HFC-134a

**FIGURE 3.** Refrigerating effect changes correspond to the refrigeration capacity

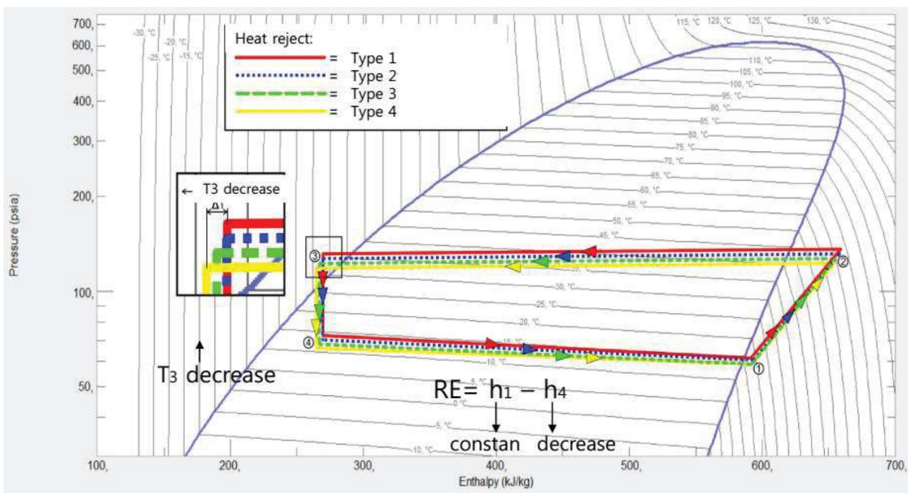
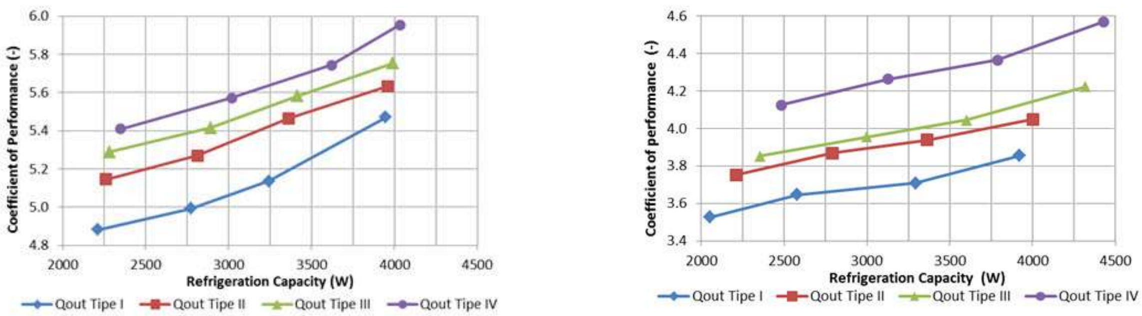



**FIGURE 4.** Detail of $T_3$ in p-h diagram of HC-134

Figure 5 shows that the COP has a positive gradient corresponding to refrigeration capacity that increases for each variation of heat release, both HC-134 and HFC-134a. Thus, the value of the coefficient of performance is proportional to the refrigeration capacity. The increase in COP also occurs along with heat released in the condenser that increases. The increase in the value of COP is due to the T2 temperature drops. It is the refrigerant temperature in the output of the compressor. When $T_2$ decreases the specific enthalpy of point 2 will also be shifted to the left so that the value is smaller, while the specific enthalpy of point 1 tends to exhibit a constant value. Therefore, the specific compressive force that is the area under the curve-line 1-2 decrease along with the heat released increases in the condenser, both for the systems that use of HFC-134a or HC-134. The cooling effect tends to increase, and the specific compression power decrease causes the COP values always increase.

The increase of COP also occurs along with heat released that increase in the condenser. The increase of COP is also due to the $T_2$, the refrigerant temperature in the output of compressor drops [12]. Figure 6 shows one example of the events when temperature $T_2$ decreases when heat released in the condenser is varied. When $T_2$ decreases the specific enthalpy of point 2 will also be shifted to the left so that the value is smaller, while the specific enthalpy of point 1 tends to exhibit a constant value. Therefore, the specific compressive force that is the area under the curve-line 1-2 decreases along with the heat released in the condenser that increase, both for the use of HFC-134a or HC-134. The cooling effect that tends to increase and the specific compression power that decreases cause the COP value always increase.




(a) HC-134

(b) HFC-134a

**FIGURE 5.** COP changes correspond to the refrigeration capacity

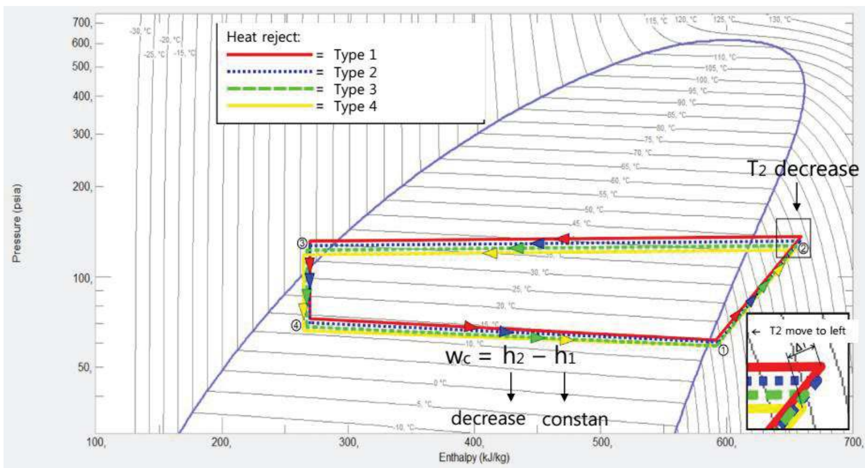
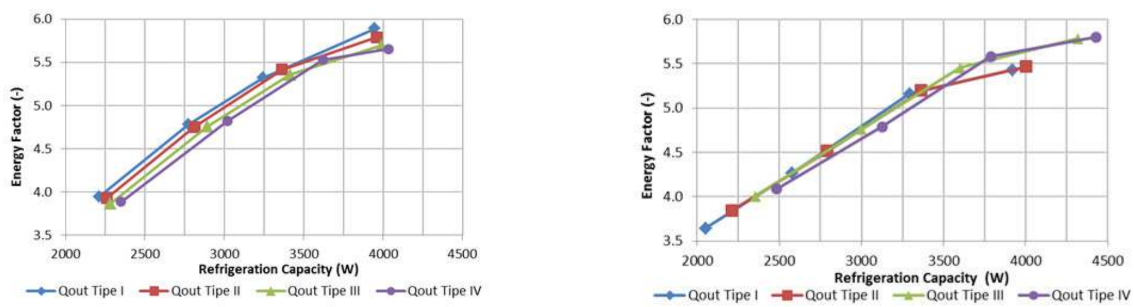



**FIGURE 6**. Detail of $T_2$ in p-h diagram of HC-134

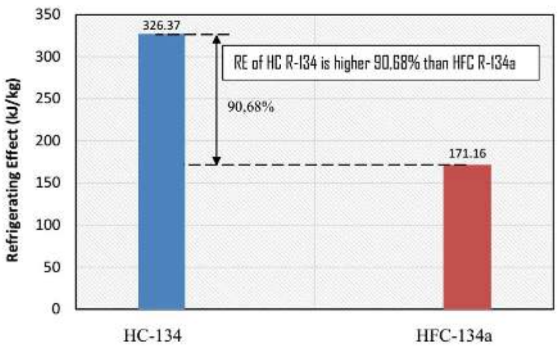



(a) HC-134

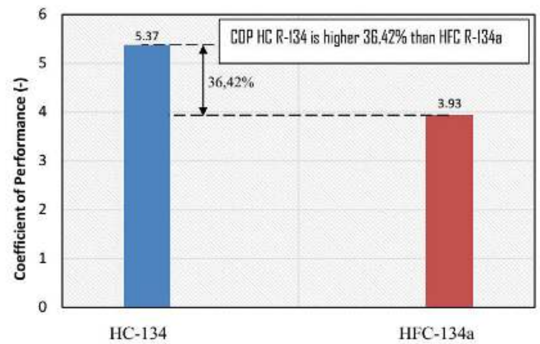
(b) HFC-134a

**FIGURE 7.** The energy factor changes correspond to the refrigeration test-capacity

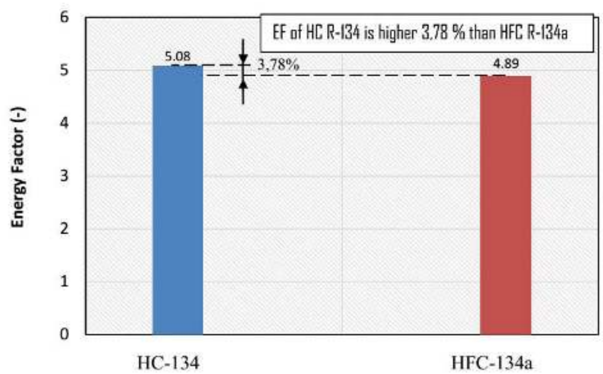
Figure 7 shows the relationship between the refrigeration capacity and the energy factor for HC-134 and HFC-134a refrigerants. Based on the curve in Fig. 7, it can be seen that the energy factor has a positive gradient according to the increase in refrigeration capacity for each variation of heat released, both for HC-134 and HFC-134a refrigerants. The value of the energy factor of HC-134 refrigerant has the same shape and slope of each curve. The curves have the same gradient however the value of the energy factor will decrease when heat released increases. In contrast to the HC-134, the curve indicates the energy factor of HFC-134 coincides at intervals capacity of 2 - 3.5 kW. Then at intervals of refrigeration capacity from 3.5 to 4.5 kW, the value of the energy factor will vary and increase along with the value of heat released. Overall, the experiment result shows that energy factors that tend to increase along with refrigeration capacity increases.




(a) The comparison of refrigerating effect




(b) The comparison of coefficient of performance




(c) The comparison of energy factor

**FIGURE 8.** The performance comparison of HC-134 and HFC-134a.

It can be seen that the refrigerating effect of HC-134 is 90.68% in average that is greater than HFC-134a. This result is almost a two times of the results in, as shown in Fig. 8(a) [1]. The cooling effect that increases will reduce the mass flow rate of refrigerant circulating in the system [6]. Also, the larger the refrigerating effect can cool the room faster. Therefore to achieve a certain cooling load, the refrigeration system will require less operation time if HC-134 used rather than with HFC-134a [1]. Figure 8(b) shows a comparison of the value of the coefficient of performance of HC-134 and HFC-134a for output air temperature of evaporator blower in the range 11-20 ºC. From Fig. 8, it can be concluded that the value of the average coefficient of performance of HC-134 increases 36.42% compared to HFC-134a. It also verifies the results of previous research conducted by Perang et al. [5] which stated that HC could produce COP up to 40% higher than HFC. The high value of the coefficient of performance is highly desirable because refrigeration systems become more efficient in their work [12]. Figure 8(c) shows the comparison of the value of the energy factor HC-134 and HFC-134a for output air temperature in 11-20ºC in evaporator blower. The fact is the energy factor is strongly influenced by the total refrigeration capacity and power consumption. When two systems have the same temperature and flow speed of the output air in evaporator blower, then their refrigeration capacity will be the same. Meanwhile, an effort to obtain the same temperature air of the output of evaporator blower requires an appropriate type of configuration for heat absorption and released heat system. The configuration of heat release type and heat absorption level can affect the total power consumption of the scheme. The experimental result shows that the electrical power consumption of HC-134 is always smaller than HFC-134a, but the energy factor of HC-134 is higher than HFC-134a.

## CONCLUSIONS

The conclusions that could be taken from this experiment are as follows:

- The result shows that refrigerating effect, the coefficient of performance and energy factor increase along with the cooling capacity increases, both for HFC-134a and HC-134.
- The refrigerating effect of HC-134 is almost twice higher than HFC -134a.

- The coefficient of performance value of HC-134 is 36.42% greater than HFC -134a.
- Then, the value of energy factor of HC-134 is 3.78% greater than HFC-134a.

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