



## Performance Evaluation of a Split Unit Air-Conditioner Retrofitted with Hydrocarbon Refrigerant (HC22)

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### ABSTRACT

The performance evaluation of a small capacity split unit air-conditioner when retrofitted with hydrocarbon refrigerant (HC22) was presented in this paper. Unlike traditional hydrofluorocarbon refrigerant (HCFC22) which possess ozone depletion potential (ODP) and high global warming potential (GWP), the HC22 refrigerant has zero ODP and a GWP value less than 3. Experimental work was carried out in a controlled environment which mimics an office room, with surrounding temperature varied from 25°C, 30°C and 35°C to simulate the typical cooling loads in Malaysia. The performance of HC22 refrigerant was compared with that of HCFC22 at these temperatures. The results show that the coefficient of performance (COP) of HC22 is higher, ranging from 3.5% to about 11% in comparison to HC22. The observation during experiments also shows that a typical HCFC22 can be retrofitted without any issue. The COP values obtained were 6.03, 6.35 and 6.15 for HC22 and 5.71, 5.66 and 5.63 for HCFC22 respectively. It can be concluded from this study that HC22 can be retrofitted directly to a HCFC system but other issues such as refrigerant flammability and safety issues shall be taken into account.

## 1. Introduction

Among the United Nation's Sustainable Development goals are addressing the climate change issues and promote sustainable development of cities and communities. One of the largest environmental impacts today was caused by cooling and refrigeration industry, particularly the refrigerant itself [13]. Environmental and economic sustainability have piqued the interest of researchers, prompting them to explore alternative approaches that provide maximum energy at the lowest possible cost [11,12]. Although continuous R&D activities around the globe has resulted the introduction of many alternative refrigerants such as the CO<sub>2</sub>, their acceptance and utilization in the market are still very low due to the cost as well as awareness among users. At present, the commonly used refrigerants

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are chlorofluorocarbon (CFC) based, which has high Global Warming Potential (GWP) as well as Ozone Depletion Potential (ODP) [1,2].

The usage of CFC base hydrocarbon (HC) has been detrimental to the environment, causing depletion of ozone and global warming. Though a variety of substitute refrigerants are being used based on hydrofluorocarbons (HCFC), the global potential warming is still high. Therefore, many developed countries such as Australia, Korea and Europe have adopted for refrigerant based on hydrocarbon due to many benefits such as low Global Warming Potential (GWP) apart from having equivalent or better co-efficient of performance. As stated by Kubba [3], in 2007, parties to the Montreal Protocol, including the United States, agreed to accelerate the phase out of HCFCs refrigerant used in air conditioning because of their impact on ozone depletion and to combat climate change.

Beneath these circumstances, Hydrocarbon refrigerants, so-called 'natural refrigerants', have been explored as modern refrigerants rather than Hydrofluorocarbons (HCFCs) since they are promptly accessible and their GWP and ODP are near to zero. A number of hydrocarbons have interesting properties as refrigerants. They have higher heat exchange coefficients than that of the engineered refrigerant [14]. Hydrocarbon (HCs) refrigerants include methane (R-50), ethane (R-170), propane (R-290), butane (R-600), isobutene (R-600a), ethylene (R-1150) and propylene (R-1270). HCs are ozone friendly and have a lower GWP as compared to HFCs [15]. HCs offers excellent miscibility with synthetic oil, lower refrigerant charge and are compatible with the material of existing refrigeration and heat pump systems. Methane (R-50) and Ethane (R-170) are a flammable cryogenic liquid has an extremely low boiling point of  $-162^{\circ}\text{C}$  and  $-88.58^{\circ}\text{C}$ , respectively. These are used for extreme low temperature refrigeration ( $-80^{\circ}\text{C}$ ). HCs such as propane appear, excellent candidates, to which researchers in contact with industry have reported safety issues [2,4]. R-290 and R-600 have similar characteristics as halogenated HCs but are flammable materials.

Discovery of CFCs and HCFCs accelerated the industrial growth and human comforts at the expense of ozone depletion and climate change. Regular synthetic refrigerants from 1930 to 2000, HFC (R-134a, R-32, R-125, R-143a, R-152a), HCFC (R-22, R-141a, R-141b, R-123), PFCR-14), PCC (R-110), HFO (R-1132). CFCs (R-12 and R-114), were replaced easily by HCFC (R-134a) and HCFCs, but some of CFC refrigerants such as R-11, used as a solvent and blowing agent, could not find alternatives. HFCs do not cause global warming; however, when it is exposed to UV in the troposphere, it may decompose to form an acid and poisonous substances, which rain down sooner or later. Large scale use of HFCs may cause another catastrophe, like fossil fuels electricity driven electric cars, which might be even worse than CFCs [2,5]. After the ban on CFC (R-12) production in 1995 the HCFC (R-22), HFC (R-134a), PFC (R-14), PCC (R-110), HFO (R-1132a) and HFO (R-1132a) were timely permitted for a few decades to retrofit the widespread systems to low GWP synthetic and natural refrigerants. Retrofitting of refrigerant requires consideration of several economic and technical aspects for correct decisions [2].

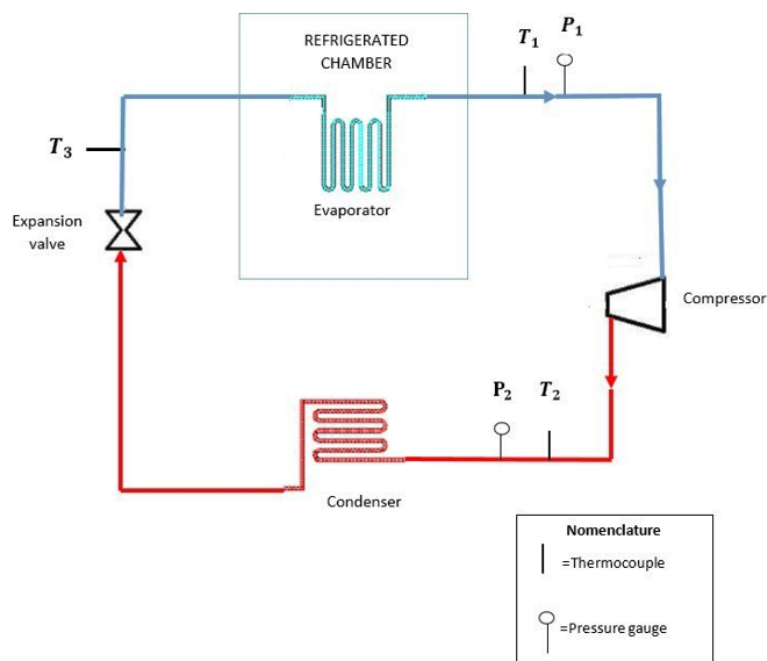
Unfortunately, the usage of HC refrigerants is still new in Malaysia and also has not been approved by our local authorities for domestic usage[10]. Hence, the actual performance and effect of using this refrigerant in HCFC based air-conditioning system in Malaysia has not been reported hitherto. Table 1 shows the physical and thermodynamics properties of refrigerant HC22 and HFC22 that will be used in this study. Hence this study aims to evaluate the performance of hydrocarbon based refrigerant system (HC22). Therefore, a test rig of 1.5 HP (split unit air-conditioning) has been developed and tested with hydrocarbon refrigerant (HC22).

**Table 1**  
 Physical and thermodynamics properties of refrigerant HC22 and HCFC22

Physical Properties	HC22	HCFC22
Molecular Weight (kg/kmol)	44.19	86.47
Boiling Point (°C) at 1 atm	-42.01	-40.81
Critical Temperature (°C)	96.98	96.15
Critical Pressure (MPa)	4.29	4.99
Liquid Phase Density at 25°C (kg/m <sup>3</sup> )	498.48	1190.7
Liquid Phase Enthalpy at 40°C (kJ/kg)	375.23	205.05
Toxicity	No	No
ODP (Ozone Depletion Potential)	0	0.05
GWP (Global Warming Potential)	<3	1810

## 2. Methodology

To evaluate the performance of HC22 and compare with HCFC22, an experimental setup has been developed as shown in the schematics in Figure 1.



**Fig. 1.** Schematics of the experimental setup

In this experiment, a 1.5 HP split unit of air conditioning (brand: LG) was used to study the refrigerants' performance. Both HCFC R22 and HC22 were tested at three room temperatures of 25°C, 30°C and 35°C to simulate the typical room temperatures in Malaysia. Pressure of high side and low side was measured (P1 and P2) together with three temperatures (T1, T2 and T3 as T3 ≈ T4). All of this measurement for temperature and pressure were crucial in order to plot the p-h diagram and to estimate the enthalpy values as mentioned points. The COP value can be calculated using Eq. (1)

$$COP = \frac{\text{cooling load}}{\text{compression power}} = \frac{h_3 - h_2}{h_2 - h_1} \quad (1)$$

## 2.2 Details of Experimental Setup

Experimental setup in Figure 2 and Figure 3 is pre-arranged with measuring instruments like pressure measurement, temperature measurement. The measuring instrument used in this research are digital thermometer (accuracy  $\pm 0.1^\circ\text{C}$ ), omega TC-08 data logger with K-type thermocouple (accuracy 0.2 percent  $\pm 0.5^\circ\text{C}$  and has a resolution of better than  $0.1^\circ\text{C}$ ) and pressure gauges with the working range of (0-300 psi) and (0-150 psi) are used with accuracy with accuracy  $\pm 5$  psi (high pressure refrigerant in condenser side) and  $\pm 1$  psi (low pressure refrigerant in evaporator side). In this system HCFC22/HC22 as a refrigerant are utilized within the vapour compression refrigeration framework. All the data were recorded only after the steady-state condition was achieved, indicated by the stable pressure and temperature values before enthalpy values were determined from property tables. Finally, COP values were calculated.



**Fig. 2.** Split unit air-conditioner test rig in the present work



**Fig. 3.** Split unit air-conditioner test rig in the present work

## 3. Results

### 3.1 Pressure and Temperature of Refrigerant HCFC22 and HC22

The temperature and pressure values presented here were average values obtained from experiments which were repeated twice under same condition to ensure repeatability and preciseness of data obtained. Each value of pressure and temperature was measured for a duration of 1 hour with 5 minutes interval. The room temperature of testing facility was set at 3 different temperatures of  $25^\circ\text{C}$ ,  $30^\circ\text{C}$  and  $35^\circ\text{C}$  and COP values of both refrigerants were calculated at these temperatures. The obtained temperature and pressure values were presented in Table 2.

**Table 2**

Pressure and temperature of refrigerant HCFC22 and HC22 during experiment

Refrigerant	Temperature ( $^\circ\text{C}$ )	P1 (psi)	P2 (psi)	T1 ( $^\circ\text{C}$ )	T2 ( $^\circ\text{C}$ )	T3 ( $^\circ\text{C}$ )
HCFC22	25	65	200	24.05	85.20	17.30
	30	67	203	24.36	85.90	17.50
	35	69	205	24.97	86.70	17.71
HC22	25	60	190	24.03	73.23	11.16
	30	62	192	24.16	76.61	8.84
	35	61	193	24.30	77.98	8.24

From Table 1 above, it was evident that the HC22 refrigerant has lower suction and discharge pressures (at the compressor) in comparison to HCFC22. Inherently, the temperatures at both condenser outlet and evaporator are also lower for HCFC22. In terms of percentage, the pressure ratio ( $P_2/P_1$ ) for HC22 is lower than that of HCFC22. This is due to the fact that HC molecules is of lower density since its molecules is larger in size. Hence, during charging of refrigerant into the air conditioning system, the total mass is about half of HCFC22. This provides two benefits: (i) less refrigerant quantity is required to create same cooling effect; and (ii) lower power at compressor for compression. During experiment, it was observed that during operation with HC22, the noise and vibration generated at the compressor is noticeably lower.

### 3.2 Enthalpy Values for HCFC22 and HC22

Table 3 below presents the enthalpy values obtained from property table of HCFC22 and HC22 [LEMY-22] [6].

**Table 3**  
Enthalpy values for HCFC22 and HC22

Refrigerant	Temperature (°C)	h1 (kJ/kg)	h2 (kJ/kg)	h3= h4 (kJ/kg)
HCFC22	25	422.38	456.87	220.76
	30	421.93	457.46	221.00
	35	422.38	458.13	221.25
HC22	25	601	665	215
	30	610	673	210
	35	615	681	209

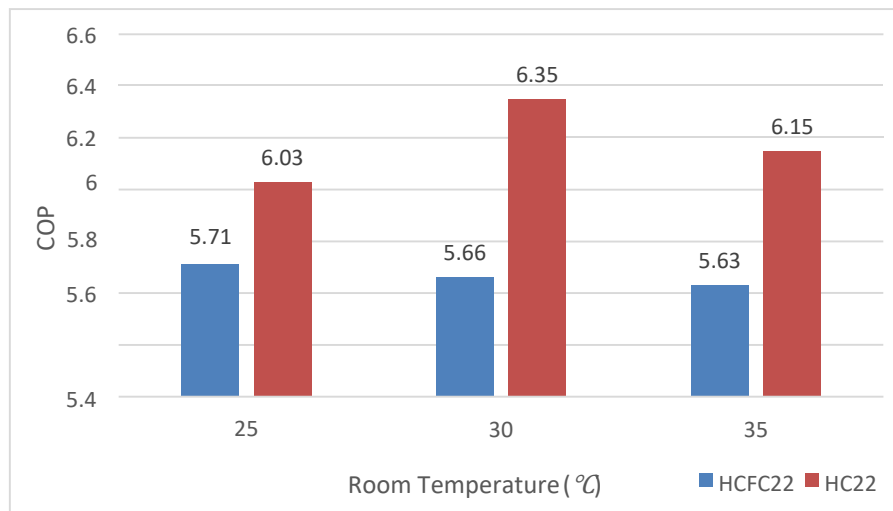
### 3.3 Analysis of Coefficient of Performance (COP)

Table 4 provides the calculated COP values of both refrigerants during experiment, while Figure 4 and Figure 5 illustrate the values for better comprehension.

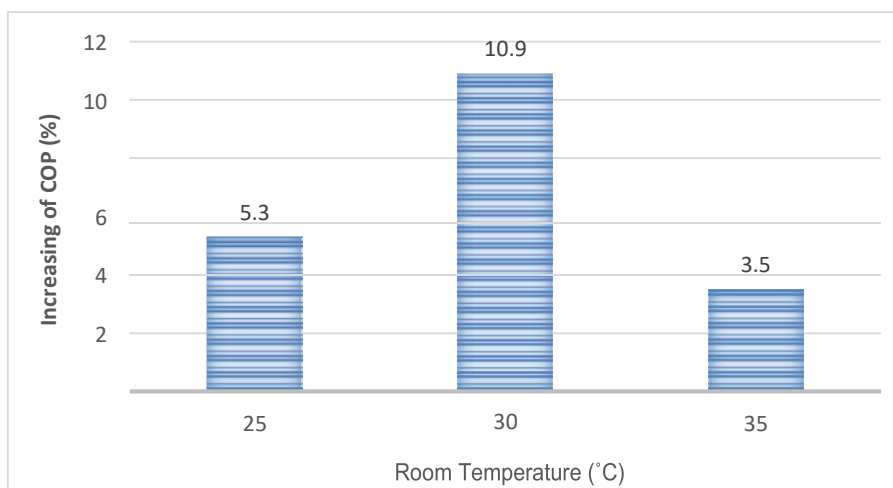
**Table 4**  
Values of Coefficient of Performance (COP) for HCFC22 and HC22

Temperature (°C)	HCFC22	HC22
25	5.71	6.03
30	5.66	6.35
35	5.63	6.15

From Table 3, it was found that the enthalpy values of  $h_1$  and  $h_2$  for HCFC22 is lower in comparison to HC22 but vice versa for  $h_3$ . As a result, the coefficient of performance (COP) values for HC22 is higher as presented in Table 4 and also Figure 3. This is true for all three-room temperatures studied: 25°C, 30°C and 35°C, with the highest COP was recorded at 30°C. The average increment of COP while operating the split unit air conditioner with HC22 refrigerant was in the range of 3.5% to 10.9%. The increase in COP may be attributed to the ability of hydrocarbon molecules to exchange heat with lower amount of power required at the compressor. The larger molecular size (hence lower molecular weight) result in less amount of refrigerant required during refrigerant charging, typically about 45% to 50% to that of HCFC.



**Fig. 4.** COP of HC22 and HCFC22 at various room temperatures



**Fig. 5.** Percentage of COP increasing of HC22 against HCFC22 at various cooling loads on HVAC standard

This finding shows that HCFC refrigerants can be retrofitted directly by HC refrigerant as a low-cost energy efficiency measure. This is possible because both HC22 and HCFC22 has quite similar physical and thermodynamic properties. Although the COP improvements seems rather small, it can give a significant impact in actual practice since millions of split unit air conditioning units, particularly with small capacity is used around the country. Apart from that, no additional equipment nor setting needs to be changed or added in the existing air-conditioner for retrofitting HC and hence no inherent increase in operational costs.

#### 4. Conclusion

Replacement of the HCFC22 with a HC22 as alternative refrigerant in a small capacity split unit air conditioner system has been investigated and presented in this paper. The performance of both refrigerants was evaluated in terms of coefficient of performance at three different room temperatures of 25°C, 30°C and 35°C which were typical room temperatures in Malaysia. The important findings were the HC22 can be retrofitted directly in HCFC air conditioning system with a quantity less than half required for HCFC22 to create same cooling effect. The COP values were higher for all three-room temperature studied, indicating less power is required by the compressor during

operation. Hence the HC refrigerants can be regarded as energy efficient refrigerant in comparison to HCFC22. However, HC refrigerants has higher flammability than HCFC and hence the usage of HC in Malaysia must also take into account safety issues. Therefore, small capacity air-conditioners, ranging from 1 HP to 5 HP seems ideal to adopt the HC refrigerants. Other merits of HC refrigerants are zero ozone depletion potential (ODP) and lower of global warming potential (GWP). It can be concluded from this study that HC refrigerants holds great potentials to be retrofitted in existing split unit air-conditioners in Malaysia.

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