

The Effect of Refrigerant Charge on the Performance of a Split-Unit Type Air Conditioner Using R22 Refrigerant

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Abstract. Numerous air conditioners are running without a proper refrigerant charge due to leakage and improper charging during installation. Therefore, there is a need to understand the performance of the air conditioner if it is not properly charged for the means of optimal operation and cost saving. This study is focusing on the usage of a used small capacity split-unit type air conditioner using R-22 refrigerant. The objective is to study the condenser performance over a variation of refrigerant charges. From the results, it is clear that the optimum refrigerant charge is 100%. The highest cooling capacity and COP were 3,330 J/s and 3.05 respectively.

1 Introduction

One of the appliances that consume a huge amount of energy in everyday life is an air conditioner. Nowadays, the air conditioner can be seen operating everywhere on the planet, from residential, commercial as well as industries and the usage has been extensive. It is one of the major electrical energy consuming appliance in residential [1,2]. Globally, it accounts for more than 50% of building energy usage [3]. According to a report by U.S. Department of Energy (2008), the nation's total energy consumed in residential and commercial buildings accounted for 40% of total U.S. energy used [4]. In residential, the most common air conditioner type used is split-type, mainly because of its simplicity and flexibility [5].

In Malaysia context, the number of an air conditioner installed in residential has increased over the last few decades. The results of national census showed that a total number of households with air conditioner has dramatically increased from 13,000 (1970), 229,000 (1990), 775,000 (2000) and the number is even higher in 2018 [6]. They also reported that a survey done in Johor Bahru in 2009 indicated that 65% of households owned air-conditioning systems.

The air conditioner is known to be an energy-intensive appliance that is essential to human's comfort. One of the primary parameters that influences the energy consumption of the air conditioner beside having high efficiency compressor is the amount of refrigerant

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charge [7–11]. Any discrepancy from the optimal charge will degrade air conditioner performance as well as deteriorate the system's reliability [1,7,8,12,13]. Domanski et al. found that systems that run with 30% undercharged of refrigerant used as much as 17 to 23% energy [14].

Majority of the cooling appliances are running without a proper refrigerant charge due to leakage and improper charging during installation. It is common that the refrigerant charge in the air conditioning system is not at the optimal level. This is due to improper charging during installation and leakage over its operation. Proctor sum up based on tests of more than 4,000 residential cooling system in California, 62% are improperly charged [15]. Meanwhile, Domanski et al. highlighted that only 18% of systems installed in the United States had the correct refrigerant charge [14]. The optimal level of refrigerant charge is determined in accordance with the cooling capacity of a refrigeration system [8,16,17]. The system performance is always linked to the appropriate refrigerant mass charge into the system [18].

The information from the appliance's catalogue mainly indicates the approximate weight of refrigerant to be charged and did not determine the performance of the unit with different refrigerant charge. Previous studies by researchers concluded that undercharge or overcharged system would have a significant impact on the performance and causing it to operate with higher electrical input to produce a cooling effect. Therefore, there is a need to understand the performance of the air conditioner if it is not properly charged for the means of optimal operation and cost saving.

All of these researches used a large capacity air conditioner. Therefore, in this research, a small capacity split-unit type air conditioner using R22 refrigerant is used to determine the effect of improper refrigerant charge on its performance. The results of total cooling capacity, total electric power consumption, and coefficient of performance will be presented.

2 Methodology

The experiment setup was designed and fabricated by using a split-unit air conditioner, relevant equipment and accessories. Experiment work was performed by setting up the system with the determined input value (refrigerant charge and outdoor temperature settings). The experiment was repeated for all pre-determined settings. Then, all the data obtained was analysed and compared to the previous research works and the data from the manufacturer's data catalogue.

In any performance testing of unitary air-conditioning equipment, the Air-Conditioning & Refrigeration Institute (ARI) Standard 210/240 has to be applied [19]. All the tests conducted must be in accordance with the test methods and procedures as described in the standard so that the standard ratings can be verified.

However, due to limitations of this research equipment setup (inadequacy of psychrometric room to provide and maintain specific accurate indoor and outdoor temperature), this study could not be performed to the ARI 210/240 standard. Therefore, the results of the study were incomparable to the manufacturer's data sheet and previous works by researchers. Nevertheless, the results would determine the trend and provide information on the effect on the performance of the specific experimental setup. In this study, the air-conditioner indoor temperature setting was set to 26°C and the blower fan was set at the lowest setting to provide more stable air flow.

The experiment setup was designed as per Fig. 1. In this research, the experiment work utilised a standard 1.5 HP, 13,000 Btu/hr (3.81 kW cooling) rated used the split-unit type air conditioner (2012 model). The unit used R-22 refrigerant as the working refrigerant gas. The setup included sensors in specific locations to measure parameters such as dry-bulb and wet-bulb temperatures, air flow rate, refrigerant pressure (low and high), pipeline temperatures as well as electrical power input.

To control the outdoor temperature, three-stage coil heaters (1.5 kW each) was used to achieve specific outdoor temperature (see Fig. 2). To measure the air flow rate of the indoor unit, ductwork was attached at the unit's outlet with the dimension of 0.635 x 0.084 m cross-section. For the purpose of high-pressure side's reading, the modification was done by installing a port for manifold gauge attachment.

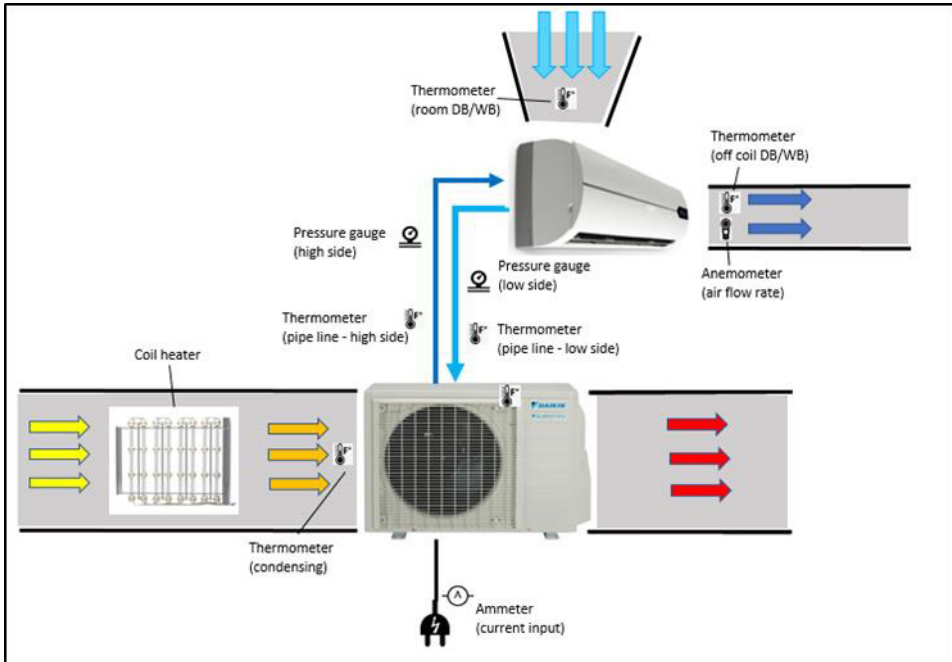


Fig. 1. Schematic diagram of the experiment setup.



Fig. 2. Three stages of coil heater installed in the outdoor unit's ductwork.

In this research, 9 different refrigerant charges and constant outdoor temperatures were used, as shown in Table 1.

Table 1 Parameters of refrigerant charge and outdoor temperature.

| | |
|---------------------------------|---|
| Refrigerant charge, [%] | 80, 85, 90, 95, 100, 105, 110, 115, 120 |
| Outdoor temperature, T_o [°C] | 30 |

3 Performance indicators

To quantify the performance of the air conditioner in the experiment work, three variables are used: total cooling capacity (C_T), total electric power consumption, and coefficient of performance (COP).

The calculation of total cooling capacity (C_T) will be using the measurement of air-side of the evaporator [20]. Total capacity is determined by using Equation (1) [20]. Since the cooling on the evaporator involves both sensible and latent heat, the equation is:

$$C_T = VFR \times \rho_{air} \times \Delta h \quad [W] \quad (1)$$

Here, VFR is the volume air flow rate, ρ_{air} is air density, and Δh is the enthalpy change.

The total electric power consumption ($TEPC$) is determined by using Equation (2) [20]. In single-phase power,

$$TEPC = \frac{V \times A \times PF}{1000} \quad [W] \quad (2)$$

Here, V is voltage, A is current, and PF is power factor.

The coefficient of performance (COP) is defined as the total cooling capacity divided by the work of the compressor, as shown in Equation (3) [19,21].

$$COP = \frac{C_T}{TEPC} \quad (3)$$

4 Results and discussions

The result of total cooling capacity (C_T) as a function of refrigerant charge is shown in Fig. 3. At 80% charge, the total cooling capacity was at the lowest point. Generally, all the (C_T) figures were lowest for all outdoor temperatures at this charge. The C_T increased with the increase of refrigerant charge and peaked at 100% charge (3,330 J/s at 30° outdoor temperature). Then the figure declined in overcharged conditions (>100%). The slope of the C_T at undercharged conditions was steeper than at overcharged conditions.

At undercharged conditions (<100%), the C_T dropped, caused by the reduction of refrigerant flow rate. The suction temperature trend remained fairly constant, showing there was not much effect on the compressor efficiency throughout the refrigerant charge reduction. Meanwhile, at overcharged conditions (>100%), the cooling capacity dropped with the increase of refrigerant charge. These trends were relatively similar as reported in previous studies by Houcek et al. [22], Mohsen Farzad et al. [1] and J.M. Choi et al. [8]. Compare to the peak value at 100% charge, the C_T dropped 17.7% at 80% charge, and 11.4% at 120% charge, respectively.

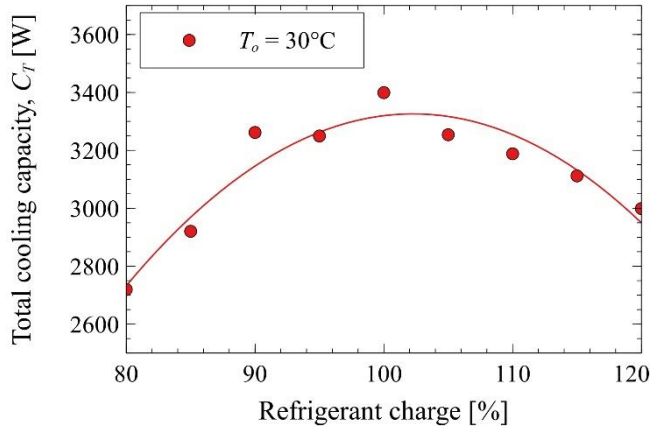


Fig. 3. Total cooling capacity as a function of refrigerant charge.

Meanwhile, as shown in Fig. 4, the total electric power consumption ($TEPC$) increased steadily throughout the increase of the refrigerant charge. This trend explained the increase of power input required as the work of the compressor increased due to the addition of the refrigerant. In this work, the reading was the combination of power consumed by both outdoor and indoor units. The highest $TEPC$ obtained was 1,164 W for 120% refrigerant charge.

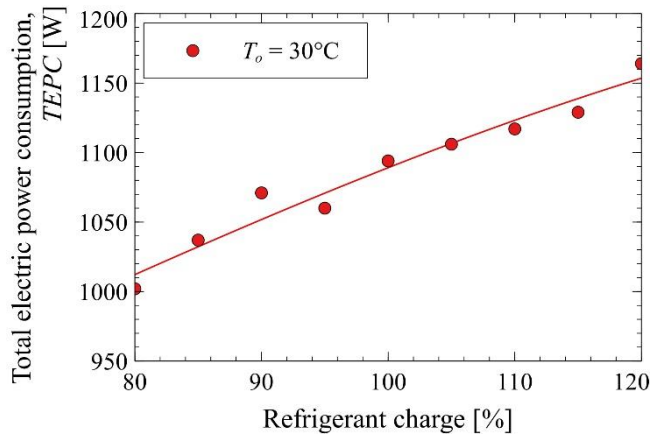


Fig. 4. Total electric power consumption as a function of refrigerant charge.

As for the coefficient of performance (COP), the result is shown in Fig. 5. It was found that the COP reduced with undercharged and overcharged conditions, and the slopes for both were fairly similar. The COP also peaked at 100% charge (3.05 at 30°C outdoor temperature). The trend was almost similar to the C_T trend as a function of the refrigerant chart (Fig. 3), but the slopes were steeper at overcharged conditions since the total electric power consumption ($TEPC$) kept increasing with the increase of refrigerant charge. Comparing with the COP at 100% refrigeration charge, the COP at 80% charge dropped 10.8%, and at 120% charge dropped 16.4%, respectively.

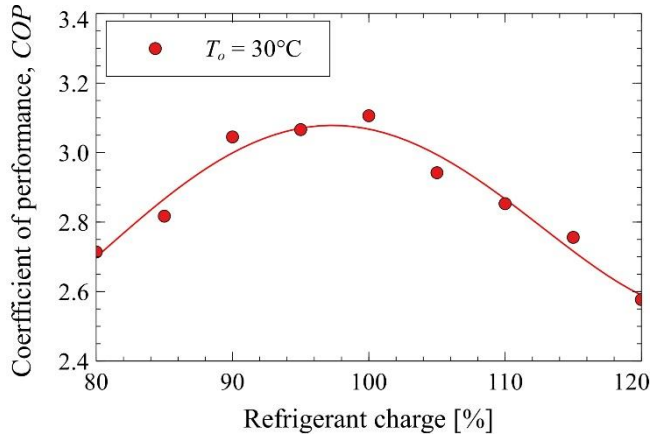


Fig. 5. Coefficient of performance as a function of refrigerant charge.

5 Conclusion

The present work emphasises on determining the performance of the air conditioner over a variation of refrigerant charges. As previously highlighted, since the experiment work was not conducted in accordance with the ARI 210/240 standard, the results could not be compared directly to the manufacturer's data and previous works by researchers. However, it provides information on how the system performs and react with an improper refrigerant charge. The conclusions are as follows:

1. The condenser performance of the air conditioner maxed at 100% refrigerant charge. The highest cooling capacity and COP were 3,330 J/s and 3.05 respectively.
2. The total cooling capacity (C_T) and COP dropped with undercharged as well as the overcharged system. Comparing with 100% refrigerant charge, for 80% system, C_T and COP dropped by 17.7% and 10.8% respectively whereby for 120% system, the C_T and COP dropped by 11.4% and 16.4% respectively.

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