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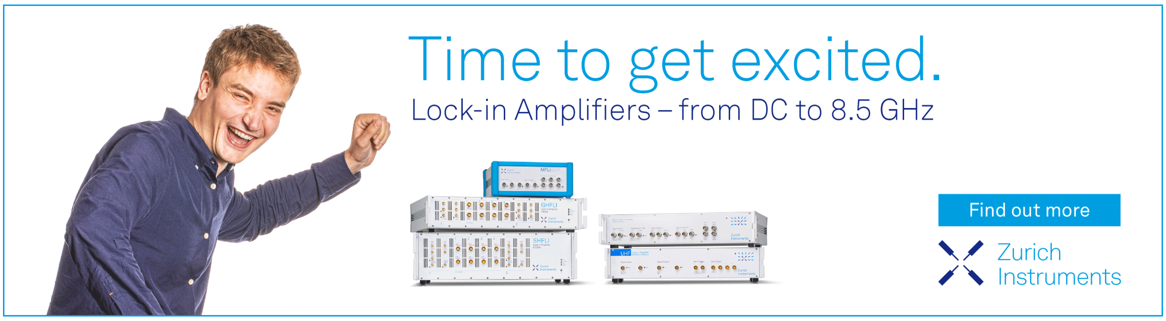

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Investigation on Seasonal Energy Performance of Residential AC Systems using R-32 a Low GWP Refrigerant

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Abstract. Residential air conditioning (AC) systems commonly use R-410A refrigerant for the new systems. The R-410A refrigerant has high global warming potential (GWP 100 years) of 2100 and it is not environmentally friendly. Moreover, energy consumption of AC systems also indirectly contributes to the GWP. Thus, energy performance of AC system becomes important. This paper aims to investigate seasonal energy performance of residential AC system using R-32 as refrigerant. R-32 has much lower impact to the environment compared to R-410A. The investigation applied a thermodynamic simulation using EES (Engineering Equation Solver) distributable program. The energy performances of the AC system were evaluated in one year based on Bali-Indonesia weather conditions. The performance evaluations include power and energy consumption, coefficient of performance, and seasonal energy efficiency ratio (SEER). For comparison analysis, the investigation was also performed on AC system using R-410A. The results indicated that the AC system using R-32 could provide better seasonal energy performance than a such system using R-410A. Therefore, R-32 becomes supplementary promising refrigerant for residential applications.

INTRODUCTION

Energy consumption in the residential or household sector continues to show an increase. Where the type of energy used in this sector is dominated by electrical energy sources. This increase in electrical energy consumption is driven by an increase in the use of household appliances, one of which is air conditioning system [1].

Air conditioning systems play a very important role in maintaining indoor thermal comfort, especially for tropical and humid climates. The energy consumed by the HVAC system can exceed 50% of the total energy consumption of a building [2]. Therefore, there is tremendous potential for increasing the overall efficiency of air conditioning systems in buildings. One way to increase the efficiency of the AC system is through the application of heat recovery that is integrated with the AC system [3,4] and optimization of the heat recovery system by utilizing thermal energy storage [5]. The use of large amounts of energy in the buildings contributes to high operating costs by 17-30% and a significant contribution to greenhouse gas emissions, global warming and climate change [6-8].

Initiatives for building types with zero energy are increasingly important to address climate change and reduce energy use [9,10]. Greater efforts are required from developers to achieve this goal, and energy audits are becoming increasingly important [11]. An audit was carried out for the building envelope, description of the air conditioning system including usage practices, annual electricity consumption associated with cooling zones. The audit also provides the possibility to determine potential improvements in reducing energy consumption [12,13]. By discovering the potential for energy savings, it can help to use energy more efficiently in a building and reduce CO_2 emissions to the environment for sustainable development.

The simulation in this study uses split type AC system which is very commonly used in residential buildings. There are many factors found that can affect AC performance which include set-point temperature, high condensing temperature, low vaporization temperature, very hot compressor, noisy compressor and very low level of refrigerant superheat entering the compressor. Other factors include temperature split condenser, condenser approach temperature and temperature of the ambient fluid that cools the condenser as reported by Suamir et al. [14].

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The installation of the AC system can also be a factor that can cause the AC system to waste energy and can also cause premature damage to the split type AC compressor [15]. Such premature damage can occur from two or three years after installation. Although the service life of a split type air conditioning system under normal operating conditions can be up to 15 years. In addition, service experts advise users to consider replacing the split type air conditioning system after every 10 years [16].

Various refrigerants have been used in split type air conditioners to date. Regulations are increasingly becoming more stringent out of greater consideration for the global environment. The Montreal Protocol in 1987 and the Kyoto Protocol in 1997 resulted in the switch from using refrigerants to refrigerants with lower environmental impact. Refrigerants that are widely used today for residential air conditioning systems and small-scale commercial air conditioning are R-22 and R-410A. However, R-22 has an ozone depletion potential (ODP) of 0.055 and a global warming potential (GWP) of 1810 $kgCO_2/kg$. While R-410A even though it has zero ODP but still has a high impact on climate change with a GWP of 2088 $kgCO_2/kg$ [17]. The Indonesian government, which belongs to the Article 5 group of countries of the Montreal Protocol, imposes a ban on the use of refrigerant type R-22 for new units, but R-22 can still be used until 2030 limited to rental, service and repair of units already installed [18].

Refrigerant R-410A does not have ozone depletion potential (ODP), however, it has a high global warming potential (GWP). Therefore, this refrigerant remains an environmental problem and is included in the phase down refrigerant group program according to the Kigali Amendment [18]. While R-32 also has no ozone depletion potential, it only has about 1/3 of the GWP refrigerant R-410A or about 675 $kgCO_2/kg$. If all air conditioning systems with R-410A refrigerant were converted to use R-32, the global warming impact of HFCs by 2030 would be reduced by the equivalent of about 800 million tons of CO_2 emissions (accounted for 19%) compared to continuing to use R-410A [19]. R-32 refrigerant also has the advantage of being able to efficiently distribute heat, so it can reduce electricity consumption by about 10% compared to air conditioners that use R-22 refrigerant. So that R-32 has the potential to be a promising next generation refrigerant [20].

This paper presents an annual energy performance evaluation of split air conditioners with refrigerant R-32 applied to residential buildings in Bali, Indonesia. Refrigerant R-32, which is a low GWP refrigerant and no ozone depletion potential (ODP = 0) [17]. The performance simulation covers power consumption, energy, COP and EER within a one year investigation period. Annual performance comparison with another refrigerant such as R-410A is also presented and discussed.

METHOD

The research results presented in this paper are the results of thermodynamic simulations of annual or seasonal performance of residential AC systems. The simulation was carried out using a computer program based on EES (engineering equation solver) software. This program is a distributable program from the EES which was specially developed to simulate the performance of split type AC systems which are generally used in residential buildings. The program has also been validated and tested by conducting simulations based on performance data and technical specifications of various residential AC systems. Based on technical data from various specifications, the program can estimate the performance of the AC system very accurately and in agreement with the performance specifications issued by the manufacturer. In this study, the simulation analysis was carried out on an AC system specified for 5.28 kW cooling capacity and power consumption of 1.63 kW. The specification is tested according to ISO 16358 Class T1. The AC system uses refrigerant R-32.

Thermodynamic simulations were carried out based on environmental conditions for the area of Bali, Indonesia. Weather data for the Bali area was obtained using the Climate Consultant 6.0 program which is weather data sourced from ISD-TMYx with the World Meteorological Organization (WMO) station index number 972300 (Denpasar Ngurah Rai International Airport). The data obtained is hourly data for a period of one year. Seasonal simulations of AC system performance are also carried out hourly in one year. The AC system performance parameters include: seasonal power consumption of the compressor and the overall AC system, seasonal coefficient of performance (SCOP), seasonal energy efficiency ratio (SEER) and seasonal energy consumption.

The coefficient of performance (COP) and seasonal COP (SCOP) are calculated from the AC system cooling capacity (Q_{eva}) and the compressor power (W_{com}) Eq.(1) and (2). The units of Q_{eva} and W_{com} are in kW.

$$COP = \frac{Q_{eva}}{W_{com}} \tag{1}$$

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$$SCOP = \frac{\sum_{1}^{8760} COP}{8760} \quad (2)$$

While the energy efficiency ratio (EER) and seasonal EER (SEER) are calculated from the AC system cooling capacity (Q_{eva}) and the compressor power (W_{com}) Eq.(3) and (4). The unit of Q_{eva} is in Btu/h and W_{com} are in W.

$$EER = \frac{Q_{eva}}{W_{com}} \text{ (Btu/Wh)} \quad (3)$$

$$SEER = \frac{\sum_{1}^{8760} EER}{8760} \text{ (Btu/Wh)} \quad (4)$$

Seasonal energy consumption of the AC system is determined from the overall power consumption (W_{sys}) in kW and time of operation t (in h) as stated in Eq. (5). Where time of operation is estimated from the use factor (UF) and total hours in a year (8760 hours). In this study, UF value is assumed to be 80%.

$$Seasonal\ Energy\ Consumption = \text{UF} \sum_{1}^{8760} (W_{sys} . t) \text{ (kWh)} \quad (5)$$

Schematic of the AC system and points of investigation are shown in Figure 1(a). While Figure 1(b) presents the log pressure and enthalpy diagram which corresponds to the schematic diagram. From the figure, it can be described that point (1) is investigation point at the suction line of the compressor, point (2) and (3) are at discharge line of the compressor and exit line of the condenser. At the inlet and outlet of the evaporator are marked with investigation points 4 and 5. Between point (5) and (1) is considered as investigation section on the connection pipe between indoor and outdoor unit. Heat gain due to improper insulation and long distance of the connection pipe can be critical especially for the suction line. Heat gain of this section can affect degree of superheat of refrigerant entering the compressor. In this simulation heat gain equivalent to an increase of suction line temperature of 1 °C is applied. Degree of superheat (ΔT_{sh}) at suction line and degree of sub-cooling (ΔT_{sc}) of the condenser are assumed to be 8 °C and 2 °C respectively. The evaporation temperature is also maintained constant at 5 °C (Figure 2).

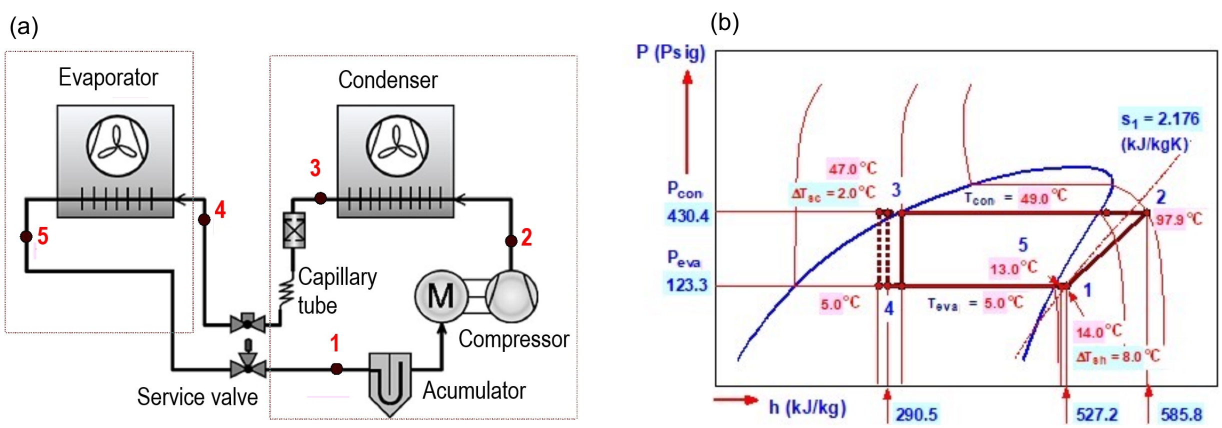

FIGURE 1. (a) Simplified schematic of the residential AC system completed with points of investigation; (b) Log pressure and enthalpy diagram of the AC system with R-32 refrigerant, investigated at evaporation temperature (T_{eva}) 5 °C and condensation temperature (T_{con}) 49 °C

RESULTS AND DISCUSSION

Effects of Ambient and Condensation Temperatures

Variation of ambient temperature in one year period applied for the simulation analysis is presented in Figure 2. Ambient temperatures tend to increase throughout January to the highest peak in February. It was relatively stable until May. From June to September the ambient temperature decreased and was relatively lower than the previous months. Then it increased again in October to November and decreased slightly in December. The highest ambient

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temperature of 35.4 °C occurred in February and the lowest temperature of 20 °C can be found in August. Seasonal average ambient temperature is 27.4 °C.

The condensation temperature of the AC system was found to follow fluctuations of ambient temperature with a seasonal average of 44.4 °C. This is because, in this study, it is assumed that the condenser is kept clean and the cooling air flow is still as specified by the manufacturer. Therefore, split temperature or TD (temperature difference) of the AC system condenser can be considered constant at standard value 17 °C.

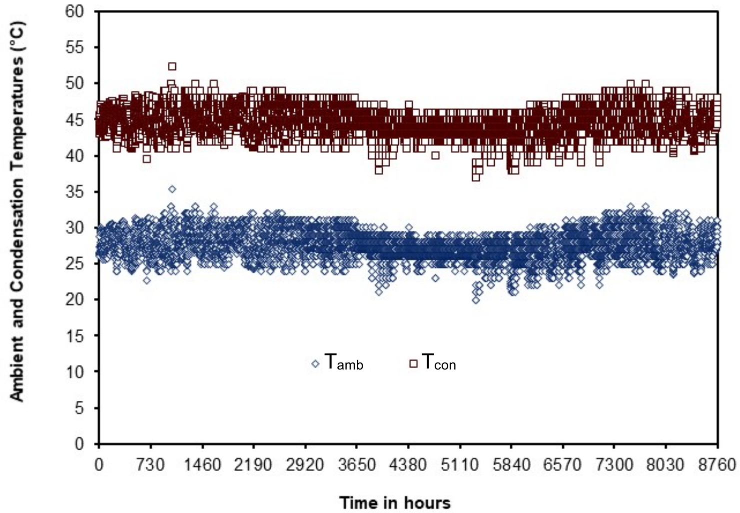

FIGURE 2. Seasonal ambient and condensation temperatures (T_{amb} and T_{con})

Effects of ambient temperature on the condensation temperature can be clearly seen in Figure 3. The figure also presents that the compressor power (W_{com}) and overall AC system power consumption (W_{sys}) increase with the ambient temperature; where W_{sys} includes compressor power and fan power consumption. When the ambient temperature rises from 20 °C to 35 °C, the compressor power is found to increase from 1.1 kW up to 1.5 kW and overall AC power consumption increases from 1.2 kW to 1.7 kW. The increase of compressor power is caused by compressor efficiency reduction as a result of temperature lift upsurge when the condensation temperature increases. In addition, the increase in condensation temperature can also be accompanied by an increase in the compressor discharge temperature which also causes the compression work to increase and can further increase the compressor power.

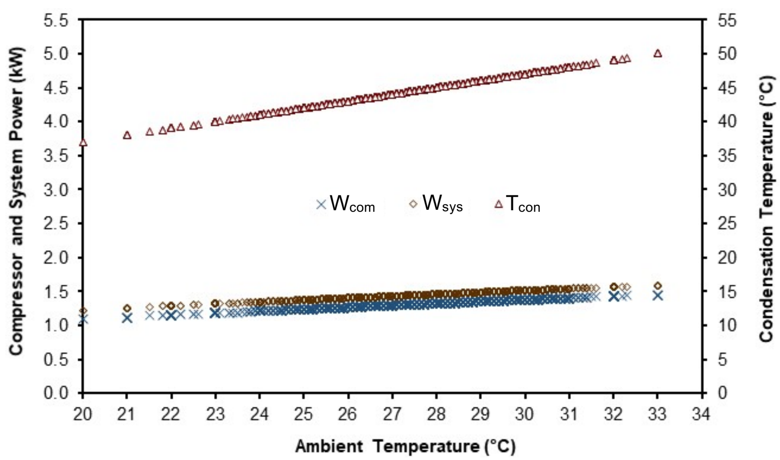

FIGURE 3. Effects of ambient temperature on the compressor power and AC system power consumption

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On the other hand, there is a decrease in AC system performances (include: cooling capacity, COP and COP_{sys}) of the AC system when the condensation temperature increases (Figure 4); where COP_{sys} is calculated from cooling capacity (Q_{eva}) and overall AC system power consumption (W_{sys}). This is mainly due to the reduction of refrigeration effect. However, the decrease in COP and COP_{sys} is also intensified by the increase in compressor power and overall power consumption respectively as shown in Figure 3. The COP of the AC system decreases from 5.90 down to 3.20 when the condensation increases from 37 °C up to 52 °C and COP_{sys} consequently also decreases from 5.25 to 2.94.

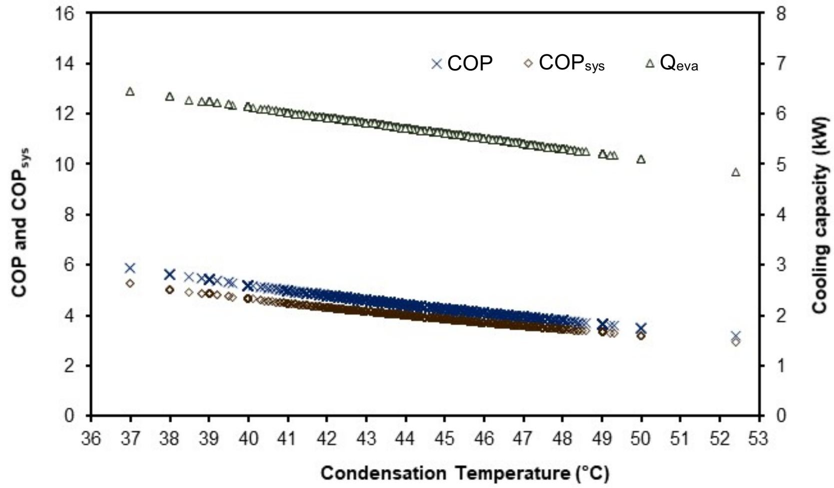

FIGURE 4. Effects of condensation temperature on energy performances (COP, COP_{sys} and Q_{eva}) of the AC system

Similar to COP, the decrease in energy efficiency ratio of the AC system also occurs when the condensing temperature increases as shown in Figure 5. EER decreases from 20.13 to 10.92 and EER_{sys} decreases from 17.91 to 10.03 when the condensing temperature increases from 37 °C to 52 °C.

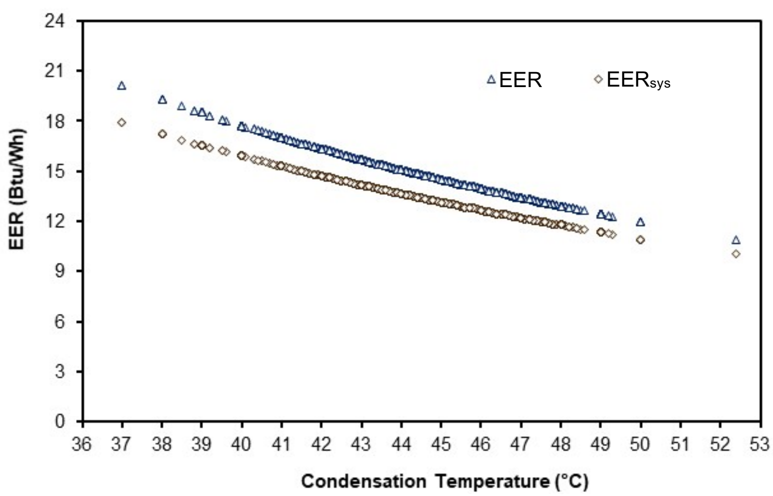

FIGURE 5. Effects of condensation temperature on energy efficiency ratio (EER and EER_{sys}) of the AC system

Seasonal Performance Parameters

Variations of cooling capacity, compressor power and system power consumption in one year period (8760 hours) are presented in Figure 6. The cooling capacity of the AC system tend to be stable from January to May. It slightly increase during June and September and it is stable again from October to December. Seasonal average cooling capacity of the AC system can reach 5.67 kW. This seasonal cooling capacity is 7.4% higher than specified cooling

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capacity. The improvement in cooling capacity is mainly due to the difference in ambient temperature applied to the specification test and the seasonal average ambient temperature applied in this study.

In terms of compressor power and overall power consumption of the AC system, from Figure 6 it appears that there is not much variation throughout the year. The seasonal compressor power and seasonal overall power consumption of the AC system are 1.31 kW and 1.44 kW, respectively. The seasonal overall power consumption of the AC system is found to be 11.7% lower than specified power consumption. The reduction in seasonal power consumption is also due to lower seasonal average ambient temperature applied in this study.

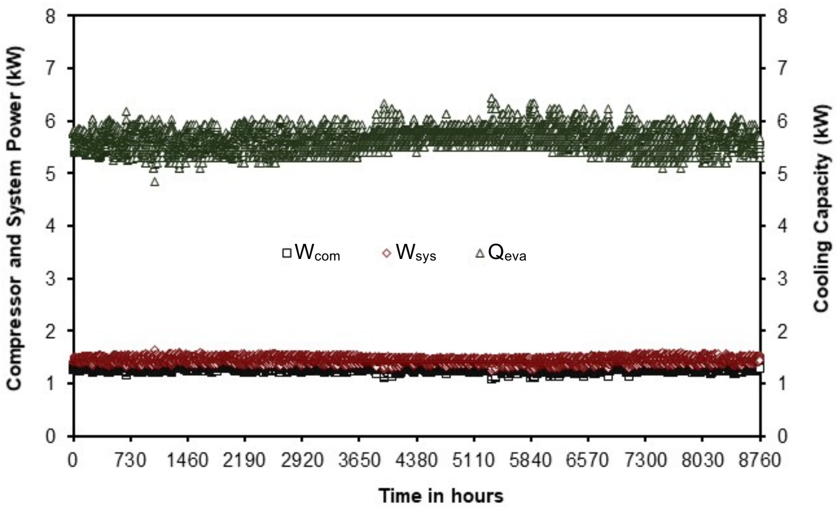

FIGURE 6. Seasonal cooling capacity, power consumption of the compressor and overall AC system

Figure 7 shows fluctuation of COP and COP_{sys} of the AC system in one year. The seasonal variation of the COP tends to follow the seasonal cooling capacity of the AC system. The trend also occurs in the seasonal EER and EER_{sys} of the AC system. Seasonal average COP and COPsys are 4.36 and 3.94 respectively. While seasonal values of EER and EERsys are respectively 14.86 and 13.45. Similar improvement to seasonal cooling capacity is also found in the seasonal COP, COP_{sys}, EER and EER_{sys} when compared with the specified value. The improvement is also due to lower seasonal average ambient temperature applied in this study.

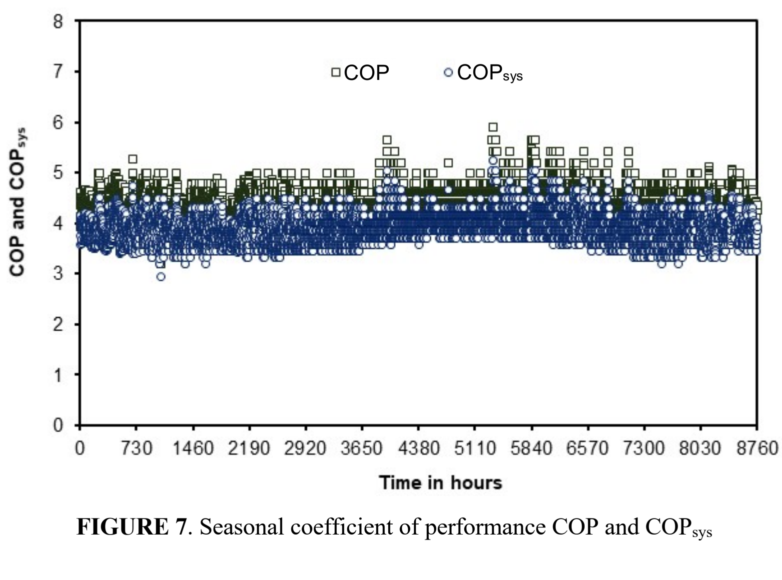

FIGURE 7. Seasonal coefficient of performance COP and COP_{sys}

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Comparison Analysis

For comparison analysis, seasonal performance and seasonal energy consumption of the AC system using R-32 is compared with that the AC system using R-410A. The seasonal performance comparison of the AC system with R-32 and R-410A is presented in Table 1. The AC system using refrigerant R-32 can perform better than AC system with R-410A. Seasonal COP (SCOP) and seasonal EER (SEER) of the AC system with R-32 are 2.4% higher than that AC system with R-410A. In term of seasonal energy consumption, it was found that AC system using R-32 specified for 5.28 kW (1.5 TR) cooling capacity can provide annual energy savings as high as 291 kWh.

TABLE 1. Seasonal performance comparison of residential AC system with refrigerant R-32 dan R-410A

Performance Parameters	AC system with R-32	AC system with R-410A
SCOP (Seasonal COP)	4,36	4,25
SEER (Seasonal EER)	14,86	14,50
Seasonal energy consumption	9149	9440

SEER in Btu/Wh

From the results of the analysis, it can be discovered that the seasonal performance of the residential AC system can be significantly better than the performance of the AC system based on the manufacturer's specifications. This is because the performance of the AC system is strongly influenced by the ambient temperature where the AC system is used. In this study, the seasonal average ambient temperature is lower than the manufacturer's test specifications.

It was also found that the residential AC system using R-32 refrigerant has advantages both in terms of instant energy performance and seasonal energy performance when compared to an AC system using R-410A. This study has demonstrated that AC system with refrigerant R-32 is prominently potential for residential applications.

CONCLUSION

Thermodynamic simulation applying EES distributable program on seasonal performance of residential AC system has been carried out. The simulation analysis was based on AC system with R-32 refrigerant specified for 5.28 kW (1.5 TR) cooling capacity and power consumption of 1.63 kW. The simulation results show the seasonal cooling capacity is 7.4% higher than specified cooling capacity. The seasonal overall power consumption of the AC system is found to be 11.7% lower than specified power consumption. It is also found that the AC system using refrigerant R-32 can perform better than AC system with R-410A. Seasonal COP (SCOP) and seasonal EER (SEER) of the AC system with R-32 are 2.4% higher than that AC system with R-410A. Such system can also provide annual energy savings as high as 291 kWh. The study results clearly demonstrate that AC system with R-32 becomes outstandingly promising AC system for residential use.

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