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STUDY ON THERMAL PERFORMANCE OF R-32 AIR-CONDITIONER

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ABSTRACT

In this study, cooling performances of an air-conditioner with R-32 refrigerant compared with R-410a under controlled conditions similar to Thai climate were evaluated. Two air-conditioners with R-32 and R-410a refrigerants were installed in a well-insulated testing room of 2.45 m x 2.60 m x 6 m. The testing room was separated into two sections for each evaporating unit and condensing unit. The thermal performances were considered when the distances between each evaporating unit and condensing unit were at 10 m and 15 m. The air temperatures entering to the condensing coils and the evaporating coils were controlled by electrical heaters and in the vicinity of the evaporating coils there was a water spray to control the humidity. It could be seen that the lapse time to achieve steady state condition of R-32 unit was around 15 minute which was 3 minute quicker than that of R-410a unit. For 10 m of the piping tube, the EER_{Sys} of R-32 unit was slightly higher than that of R-410a unit for all testing conditions. The values were 3.401 kW_{th}/kW_e and 3.395 kW_{th}/kW_e for R-32 and R-410a units at the evaporating temperature and the condensing temperature around 25^{o}C and 40^{o}C, respectively. For 15 m of the piping tube, it could be found that the EER_{Sys} of R-32 unit was also slightly higher than that of R-410a unit for all testing conditions. It could be concluded that R-32 air-conditioner gave better cooling performance compared with R-410a unit. It was also noted that R-32 was friendly more to the environment thus this one was appropriate to replace R-410a.

1. INTRODUCTION

Due to the global warming aspect, there are a lot of meetings with co-operations from many countries to find out the methods to relief this problem such as the Kyoto Protocol which was launched out in 1997 [1]. Many types of refrigerants were banned such as R-11 and R-12 and some have been regulated such as R-22 and R-134a. For R-134a, this refrigerant will be also banned in Europe in 2017.

For Thailand, R-22 has been replaced by other refrigerants such as R-410a and R-32 [2, 3-5]. Comparison of some of these refrigerants is shown in Table 1.

From Table 1, it could be seen that R-410a has high GWP compared with R-32 [2]. Anyhow, R-410a has lower critical point and lower latent heat of vaporization then the operating range is limited compared with R-32. Moreover, higher GWP for R 410a is found.

Table 1 Properties of various refrigerants [3-5].

Working fluids	R-22	R-32	R-410a
Critical temperature (^{o}C)	96.15	78.11	71.36
Critical pressure (MPa)	4.99	5.78	4.90
Critical density (kg/m^3)	523.84	424.00	459.53
Boiling point (^{o}C)	-40.81	-51.65	-51.36
Heat of vaporization (kJ/kg	166.60	237.09	158.93
Flammability	NO	Lower	NO
Toxicity	NO	NO	NO
Atmospheric life time (y)	13.3	4.9	32.6
ODP[1] (CO_2-ralated)	0.055	0	0
GWP[2] (100 y)	1810	675	2100

Note: [1] Ozone Depletion Potential: the relative amount of degradation to the ozone layer with R-11 fixed at ODP of 1.0
[2] Global Warming Potential: the potential of a substance to contribute to global warming

R-32 has been used as refrigerant in refrigeration units and air conditioners in Japan [6]. Ryuzaburo et al. [7] reported that the COPs of air conditioners could be up around 10% compared with those with R-410a. The results

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were confirmed by AHRI Low-GWP AREP [8-9] for split-typed heat pumps of which the R-410a refrigerant was drop-in replaced by R-32. Xu et al. [10] also reported the result of a vapor injection cycle with R-32 refrigerant compared with that of R-410a. The COP of R-32 was found to be higher than that of R-410a.

It could be noted that R-32 is an interesting refrigerant due to its high latent heat with a high critical temperature, low GWP and low flammability. From the literature reviews, the system performances were better than R-410a. However, a lack of results on the refrigerator or air-conditioner with this refrigerant for Thai climate was reported. Therefore, in this research work, cooling performance of R-32 air-conditioner under Thai climate condition was observed.

2. SYSTEM DESCRIPTIONS AND EQUATIONS

Figure 1 shows a schematic diagram of an air-conditioner of which the main components are compressor, condenser, evaporator and expansion valve. At state 1, the refrigerant in vapor phase is compressed in compressor to state 2 and the vapor is condensed in condenser at a high pressure (P_C) and a temperature to be liquid at state 3, the liquid refrigerant is throttled to a low pressure (P_E) at state 4, the refrigerant could absorbed cooling load at the evaporator where the refrigerant boils at low temperature to be vapor again and the new cycle restarts.

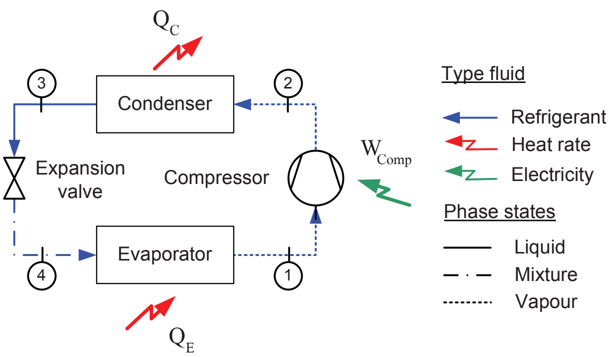

Figure 1 A vapor compression heat pump [11].

The heat capacities at evaporator and condenser are as follows:

$$Q_E = \dot{m}_{da}(h_{air,i} - h_{air,o}) - M_W h_W , \quad (1)$$

$$Q_C = \dot{m}_{da} Cp_{da}(T_{air,o} - T_{air,i}) . \quad (2)$$

Energy efficiency ratio (EER) of the air-conditioner is defined by

$$EER_{Sys} = \frac{Q_E}{W_{Sys}} ; kW_{th} / kW_e . \quad (3)$$

3. TESTING EQUIPMENT AND MEASUREMENTS

In this study, 2 units each of 1 TR air-conditioner for R-410a and R-32 as working fluid were used to find out their cooling performances based on Daikin standard. Both air-conditioners each used the same models of evaporating and condensing units. The descriptions of the air-conditioners were given in Table 2.

Table 2 Descriptions of the air-conditioner components.

Components		Details
Cooling capacity (kW)		3.7
Cooling capacity (BTU/h)		12,700
Running current (A)		1.057
Indoor unit		
Model		FT13HV2S
Air flow rate (m^3/min)	High	9.9
	Medium	8.3
	Low	6.8
Dimension (H x W x D; mm)		283 x 800 x 195
Outdoor unit		
Model		R13HV2S
Compressor type		Rotary type
Motor output (kW)		1.000
Dimension (H x W x D; mm)		550 x 765 x 285

Two air-conditioners of R-32 and R-410a were tested under the controlled conditions in a testing well-insulated room. Figure 2 shows the installation of the evaporating and the condensing units in the testing room. In this study, the tube lengths between the two units at 10 m and 15 m were considered.

For the testing process, Thai climate is considered by the setting operating conditions similar to the climate of Thailand as given in Table 3. The cooling load and humidity of the air entering evaporator are controlled at around 3.5 kW and 80%, respectively.

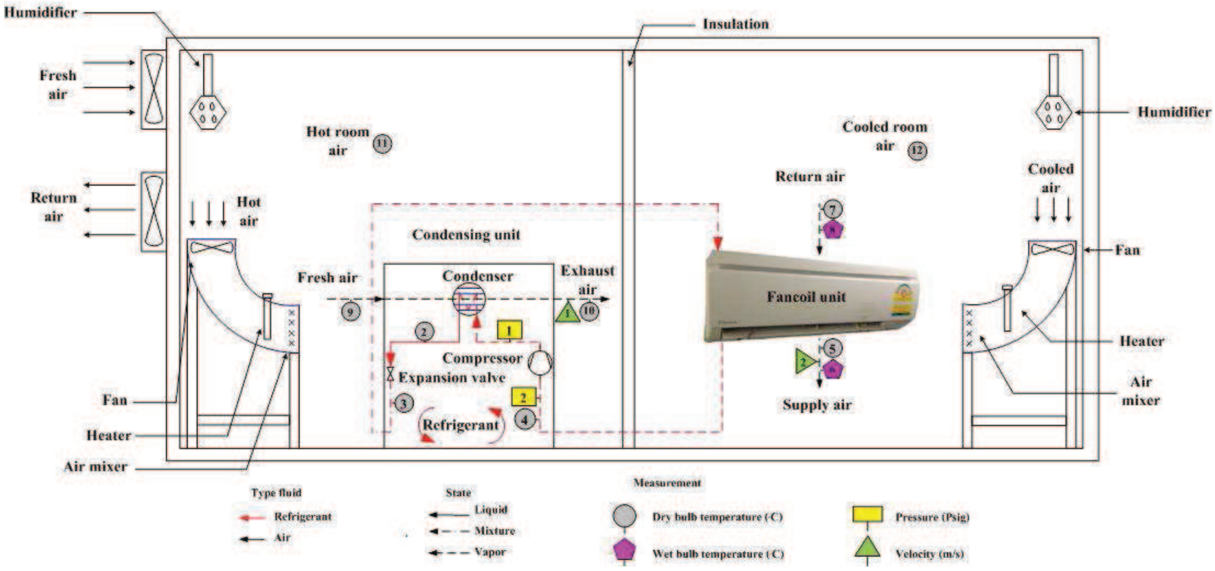

Figure 2 Measuring positions of the testing room for air-conditioner.

Table 3 Description of the temperature conditions for testing room.

Controlled conditions	Temperatures (^{o}C)
Evaporating coil room	20, 22, 25
Condensing coil room	30, 35, 40, 45

Various parameters for calculating thermal performances of the air-conditioner were measured and the descriptions of the measurements were as follows:

The Temperature Distribution

The measurements of the air temperature distribution in the testing room were carried out as shown in Figures 3 and 4 by a set of K-type thermocouples with an accuracy of ±0.1^{o}C.

The Air Velocity

To measure the air velocity at the condensing and the evaporating units, each part, there was a hood to control the air flow direction and the velocities at the hood exit at various positions as shown in Figures 5 and 6. A vane-anemometer with an accuracy of ±0.1 m/s was an instrument to measure the values. It was noted that about 90% of the measured data deviated from the average value less than 10%.

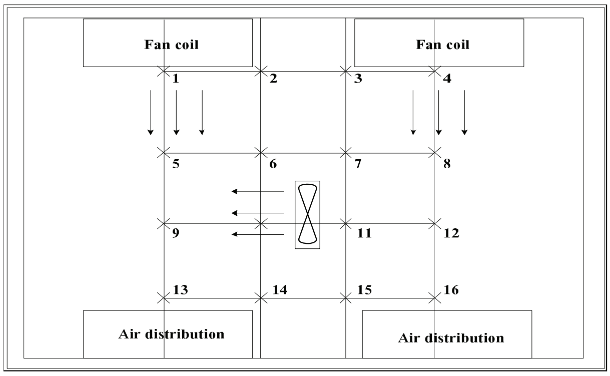

Figure 3 The measuring positions of the air temperature distribution in the evaporating unit room.

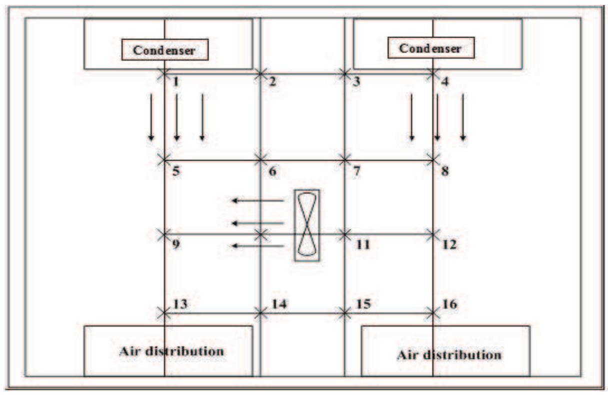

Figure 4 The measuring positions of the air temperature distribution in the condensing unit room.

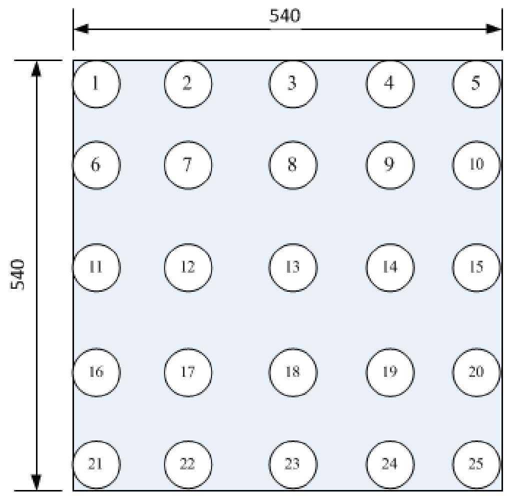

Figure 5 The measuring positions of air velocity at the hood of the condenser.

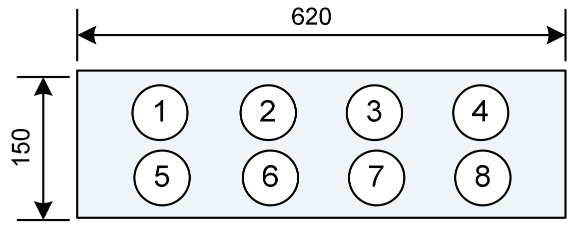

Figure 6 The measuring positions of air velocity at the hood of the evaporator.

4. RESULTS AND DISCUSSIONS

Temperature Distribution

Figures 7 and 8 show the measuring data of air temperatures in the evaporator room and the condenser room given in Figures 3 and 4, respectively at no load condition. It could be seen that the air temperature distributions of the two testing rooms were quite uniform with an accuracy around ±0.5°C. The air temperatures were varied in ranges of 27-30°C and 32-37°C for the evaporator room and the condenser room, respectively.

Air Velocity

The air velocities at the evaporator and the condenser of R-410a and R-32 air-conditioners were found to be uniform with an accuracy of ±3%. Table 4 shows the measuring data of average air velocities at the evaporator and the condenser as shown in Figure 5.

Table 4 Average air velocities of the air-conditioner.

Conditions	Evaporator		Condenser	
	R-410a	R-32	R-410a	R-32
Velocity (m/s)	1.6	1.6	3.68	3.67
Flow rate (m^3/s)	0.15	0.15	1.05	1.05

Operating Period to Steady State

Figures 9 and 10 show temperature histories of the refrigerant and the room temperature for R-410a air-conditioner. It could be seen that the lapse time to achieve steady state condition is around 15 minute which was 3 minute quicker for R-32 unit compared with R-410a one. R-32 showed better performance due to its lower boiling point and high latent heat then higher heat transfer rate could be obtained.

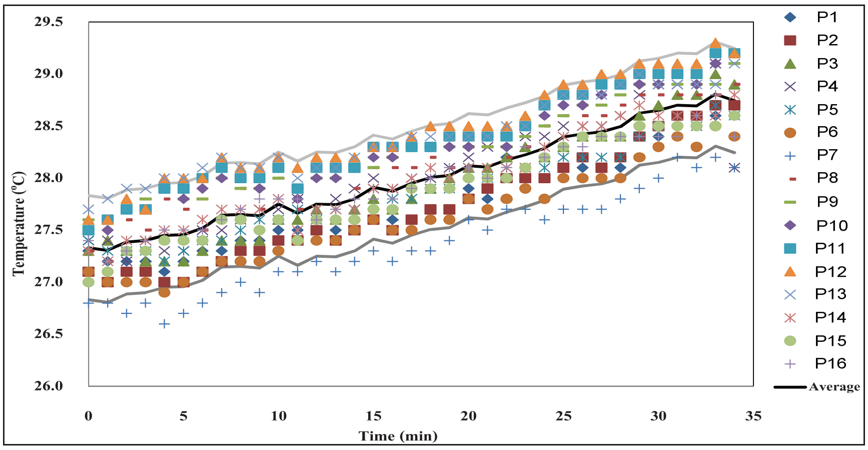

Figure 7 The air temperature profile of the evaporating unit room.

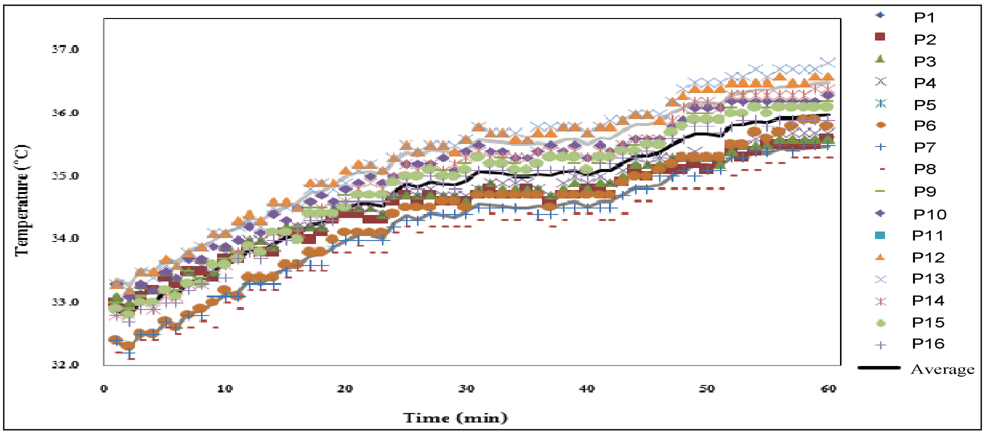

Figure 8 The air temperature profile of the condensing unit room.

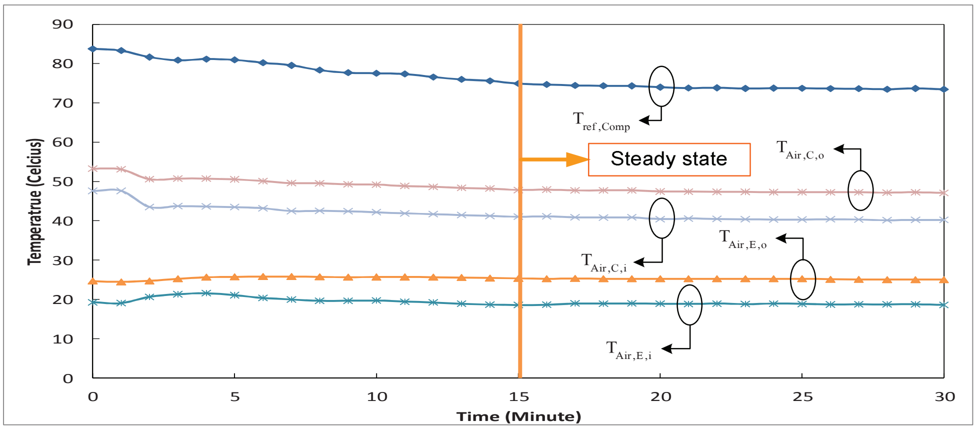

Figure 9 Temperature histories of refrigerant and room temperature for R-410a air-conditioner at the air entering evaporator and condenser temperature around 18°C and 40°C.

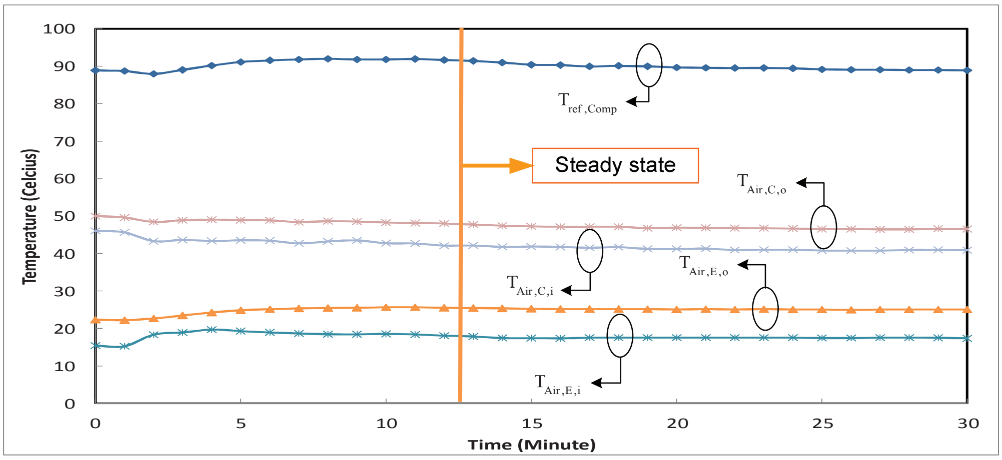

Figure 10 Temperature histories of the refrigerant and the room temperature for R-32 air-conditioner at the air entering evaporator and condenser temperature around 18°C and 40°C.

Performance Analysis of the Air-conditioner

Figure 11 shows the air temperature entering the evaporator and the condenser including EER_{Sys} of R-32 air-conditioner at steady state. It was found that the average EER_{Sys} was around 3.400 kW_{th}/kW_e at the evaporating temperature and the condensing temperature around 25°C and 40°C, respectively. At the same conditions,

Figure 12 shows the performance data of R-410a air-conditioner. The EER_{Sys} was slightly lower than that of R-32 air-conditioner. The value of the average EER_{Sys} was around 3.395 kW_{th}/kW_e.

For 10 m of the piping tube between the condenser and the evaporator, with various values of room air temperatures, the condenser and the evaporator temperatures, the air-conditioner performance of each air-conditioner could be evaluated. The results were shown in Tables 5 and 6.

Table 5 EER_{Sys} of R-32 air-conditioner with 10 m of piping tube.

Unit: kW_{th}/kW_e

Evaporating room (°C)	Condensing room (°C)			
	30	35	40	45
25	3.431	3.419	3.401	3.398
22	3.423	3.410	3.391	3.382
20	3.417	3.396	3.388	3.362

Table 6 EER_{Sys} of R-410a air-conditioner with 10 m of piping tube.

Unit: kW_{th}/kW_e

Evaporating room (°C)	Condensing room (°C)			
	30	35	40	45
25	3.402	3.411	3.395	3.390
22	3.409	3.400	3.383	3.369
20	3.397	3.377	3.361	3.348

From Tables 5 and 6, relations of the related parameters from the experimental data were set up and used to predict the thermal performance under various operating conditions.

Figure 13 shows the relationship of the related data between an energy efficiency ratio (EER) and the different temperature of the entering air temperatures at the condenser and at the evaporator. It could be seen that the EER decreased when the temperature difference increased which followed the Carnot efficiency concept. The COP or EER decreases when the temperature difference of the heat source and heat sink increases. The results were similar to the studies in the literatures [12, 13].

Table 7 EER_{Sys} of R-32 air-conditioner with 15 m of piping tube.

Unit: kW_{th}/kW_e

Evaporating room (°C)	Condensing room (°C)			
	30	35	40	45
25	3.412	3.407	3.375	3.364
22	3.396	3.369	3.379	3.348
20	3.392	3.381	3.362	3.339

Table 8 EER_{Sys} of R-410a air-conditioner with 15 m of piping tube.

Unit: kW_{th}/kW_e

Evaporating room (°C)	Condensing room (°C)			
	30	35	40	45
25	3.381	3.380	3.354	3.350
22	3.368	3.361	3.356	3.325
20	3.358	3.342	3.324	3.314

For 15 m of the piping tube between the condenser and the evaporator, the air-conditioner performance of each air-conditioner was carried out again at the same conditions as the previous case. The results were shown in Tables 7 and 8. It could be seen that the relation between EER and the different temperature of the entering air temperature at the condenser and the evaporator was also in a linear form as shown in Figure 14. The EERS with piping tube 15 m of the R-32 and R-410a air-conditioners were slightly lower than those of the previous one because longer piping tube gave higher pressure drop and higher amount of refrigerant needed then higher electrical power was consumed at the compressor.

It could be seen that the EER_{Sys} of R-32 air-conditioner was slightly higher than that of R-410a unit for all testing conditions which corresponded the results of Ryuzaburo et al. [6], AHRI Low-GWP AREP [7-8] and Xu et al. [9]. It is also noted that R-32 is friendly more to the environment in term of Ozone Depletion Potential (ODP) and Global Warming Potential (GWP) as shown in Table 1 thus this refrigerant could be used to replace R-410a.

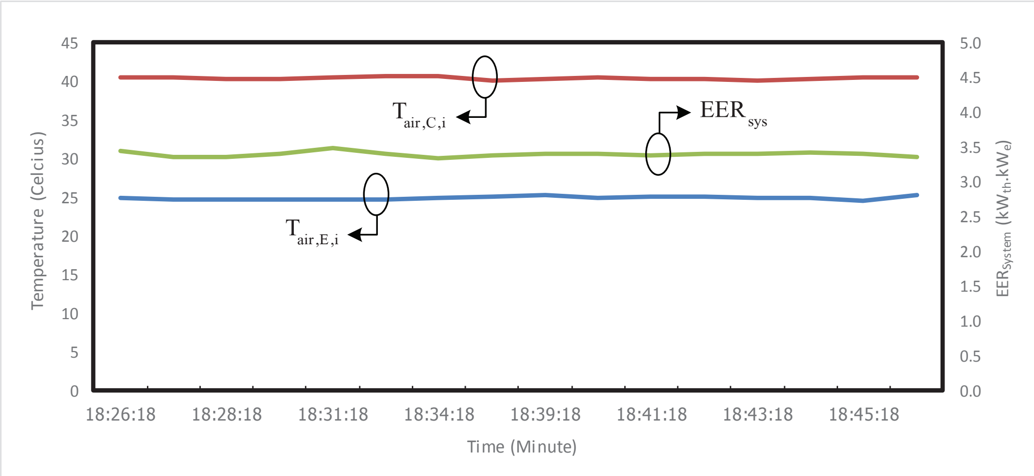

Figure 11 The air temperature profile and EER_{Sys} for R-32 air-conditioner at the air entering evaporator and condenser temperature around 25°C and 40°C with 10 m of piping tube.

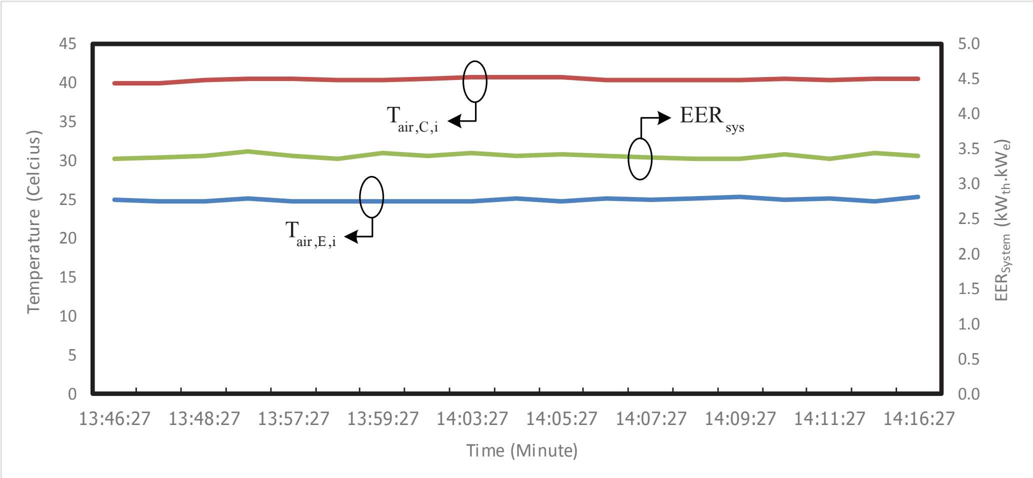

Figure 12 The air temperature profile and EER_{Sys} for R-410a air-conditioner at the air entering evaporator and condenser temperature around 25°C and 40°C with 10 m of piping tube.

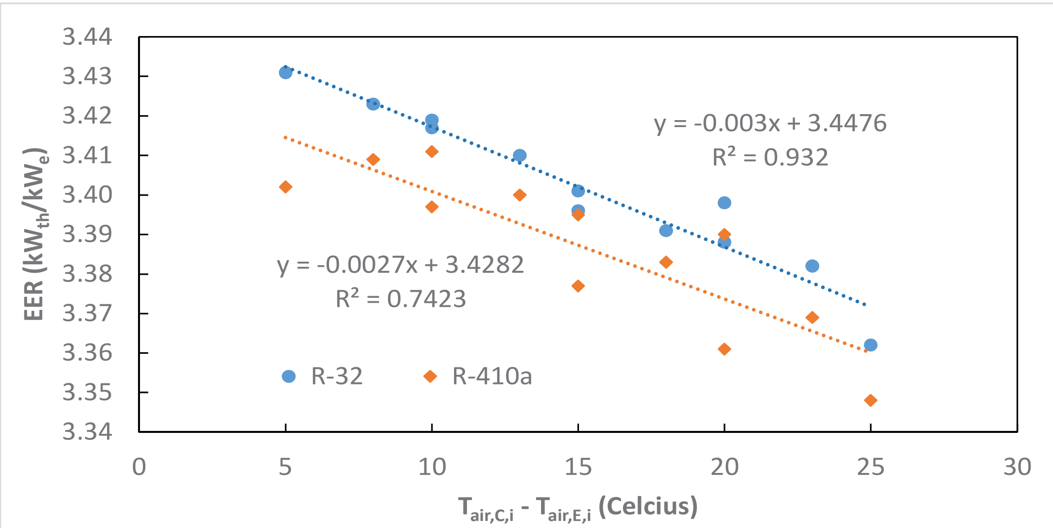

Figure 13 Performance curves of R-32 and R-410a air-conditioners with 10 m of piping tube.

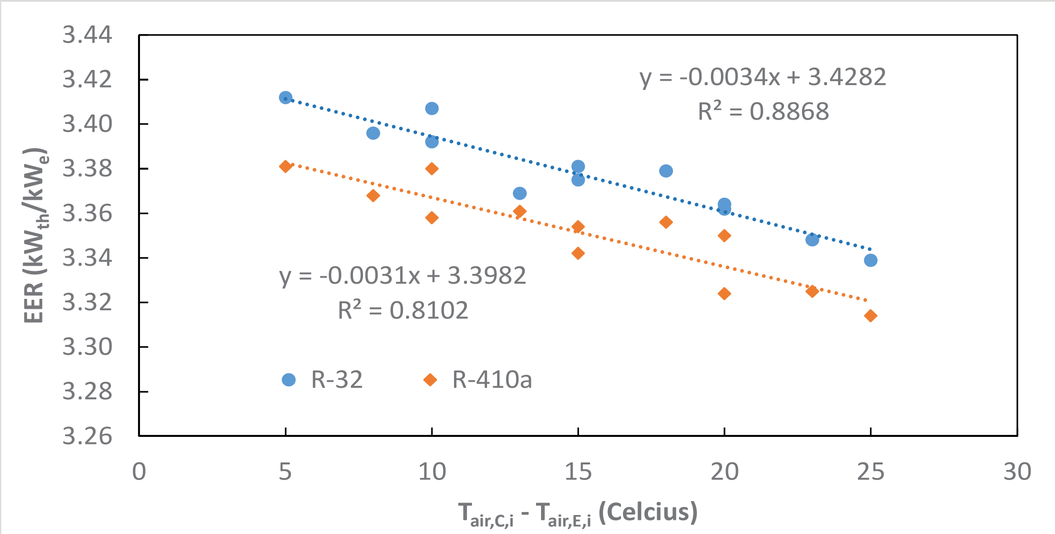

Figure 14 Performance curves of R-32 and R-410a air-conditioners with 15 m of piping tube.

5. CONCLUSIONS

From this study, the conclusions are as follows:

1. The lapse time to achieve steady state condition of R-32 air-conditioner is around 15 minute which is 3 minute quicker than those of R-410a unit.
2. The EER of R-32 air-conditioner was slightly higher than that of R-410a unit for all testing conditions.
3. R-32 was friendly more than R-410a to the environment in term of Ozone Depletion Potential (ODP) and Global Warming Potential (GWP).
4. R-32 was appropriate to replace R-410a in the air-conditioner system.

6. Acknowledgement

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ABBREVIATIONS AND SYMBOLS

Nomenclature

Cp	Specific heat capacity, (kJ/kg.K)
EER	Energy efficiency ratio, (kW_{th}/kW_{elec})
h	Enthalpy, (kJ/kg)
M	Mass, (kg)
$\dot{m}$	Mass flow rate, (kg/s)
Q	Heat rate, (kW)
T	Temperature, (°C)
W	The electrical power, (kW)

Subscript

C	Condenser
Comp	Compressor
da	Dry air
db	Dry bulb
e	Electricity
E	Evaporator
i	Inlet
o	Outlet
P	Pump
Sys	System
th	Thermal
W	Water