Energy Efficiency and Safety for Wall Type Air Conditioner with Propane Refrigerant

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Abstract. Thailand has been used the R-32 refrigerant in air conditioner since 2016, while it has high global warming potentials (GWP = 675). A propane refrigerant (R-290) is introduced as a newly alternative refrigerant, due to the global issue on refrigerant substitution for friendly environment. It has GWP of 4, which is 169 times lower than R-32. In this study, the theoretical energy efficiency was analysed under the Thailand's conditions at the saturated evaporation temperature of 10°C and the saturated condensation temperature of 47°C. However, the propane is highly flammable; therefore, the safety must be considered. The results showed that the coefficient of performance of propane was 5.54, which was 7% higher than R-32. The wall type air conditioner with propane refrigerant would be safe from fire if it was installed at a height higher than 1.8 m above the floor level and the floor area was larger than 17 and 23 m^2 for air conditioner cooling capacity of 3375 W and 5000 W, respectively.

1. Introduction

The R-32 refrigerant has commonly been used in air conditioners in Thailand since 2016. However, it has high global warming potentials (GWP = 675). Hence, the worldwide interest is focusing on alternative refrigerant substitutions for environmental friendly that reaches zero-GWP. The newly propane refrigerant (R-290) has GWP equal to 4, which is 169 times lower than R-32 and it might be one of the alternatives. Nonetheless, R-290 is highly flammable, therefore, energy and safety conditions are focused in this study.

2. R-290 Air Conditioner System

2.1. *Properties of propane*

The propane gas is heavier than air and may travel along the ground, there is a possibility of distance ignition. Moreover, due to low electric conductivity, the substance can generate electrostatic charge as a result of flow, agitation, etc. Therefore, do not use compressed air for filling, discharging or handling. Furthermore, the rapid evaporation of liquid may cause frostbite. If there is an ignition source and propane concentration is between 2-9.5%, the fire will be ignited. The properties of propane are shown in table 1.

Table 1. The properties of propane.

Formula	C_3H_8
Relative molecular mass	44.1
Boiling point, °C	-42.0
Melting point, °C	-187.0
Flash point, °C	-104.0
Autoignition temperature, °C	465.0
Critical temperature, °C	96.7
Relative density (water = 1)	0.5
Relative vapour density (air = 1)	1.6
Vapour pressure at 20°C, bar	8.5
Solubility in water	none
Explosive limit, vol.% in air	2.0-9.5
Limit (LFL), kg/m^3	0.038
Minimum ignition energy (MIE), mJ	0.25
Heating value, MJ/kg	49.58

2.2. *System description*

In the vapor compression refrigeration system as shown in Figure 1, there are four major components; evaporator, compressor, condenser, and expansion valve. External work (W) is supplied to the compressor and the heat (q_{ev}) from the air condition space is added to the system in the evaporator. Whereas in the condenser, the heat rejection (q_{co}) is transferred from the system to the surrounding. Heat rejection and heat addition are dissimilar to different refrigerants, which cause a change in energy efficiency (COP) and exergy efficiency for the systems.

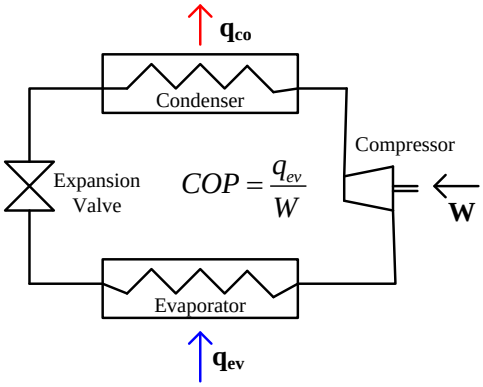

Figure 1. The vapour compression refrigeration system.

The P-h diagram of the refrigeration cycle is shown in Figure 2. The compression, condensation, expansion, and evaporation processes are shown between points 1–2, 2–3, 3–4, and 4–1, respectively. The evaporator saturated temperature was set to 7°C, while the condenser saturated temperature was

taken as 47°C for comparison purpose. State 1 and 4 are assumed to be saturated vapour and saturated liquid, respectively. Whilst state 2s and 2 are obtained by the assumption that a compression process is isentropic and adiabatic with a compression efficiency (η_c) of 85%. The compression discharged enthalpy, h_2, is calculated by using equation (1),

$$h_2 = h_1 + \frac{(h_{2s} - h_1)}{\eta_c} \quad (1)$$

where h_{2s} is the discharged enthalpy for isentropic compression.

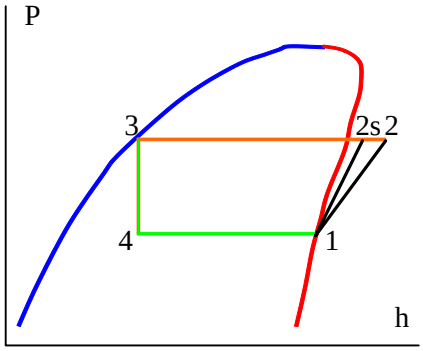

Figure 2. P-h diagram of the refrigeration cycle.

The temperature, pressure, enthalpy and entropy of each state of R-290 and R-32 are shown in Table 2 and Table 3, respectively.

Table 2. Temperature, pressure, enthalpy and entropy of each state of R-290.

State	Temperature, K	Pressure, MPa	Enthalpy, kJ/kg	Entropy, kJ/kg
1	280	0.5779	580.6	2.3594
2	325	1.5963	636.1	2.3800
3	320	1.5963	324.7	1.4125
4	280	0.5779	324.7	1.4451

Table 3. Temperature, pressure, enthalpy and entropy of each state of R-32.

State	Temperature, K	Pressure, MPa	Enthalpy, kJ/kg	Entropy, kJ/kg
1	280	1.012	516.4	2.2190
2	356	2.930	268.4	2.1650
3	320	2.930	290.7	1.2980
4	280	1.012	290.7	1.3236

3. Energy Analysis

In this study, the following assumptions are made;

1. Steady state conditions are remained in all the components
2. Pressure loses in the pipelines are neglected
3. Heat gains and heat loses from the system or to the system are not considered

4. Kinetic energy, potential energy, and pressure losses are not considered.

The energy performance of refrigeration cycle is calculated by using the following equations,

Refrigeration effect, q_{ev}; $$q_{ev} = m(h_1 - h_4) \quad (2)$$

Compression work, W; $$W = m(h_1 - h_4) \quad (3)$$

Condenser heat rejection, q_{co}; $$q_{co} = m(h_2 - h_3) \quad (4)$$

Coefficient of performance, COP; $$COP = \frac{(h_1 - h_4)}{(h_2 - h_1)} \quad (5)$$

Energy balance; $$q_{co} = q_{ev} + W \quad (6)$$

4. Safety

4.1. *Safety standard*

The fire or explosion hazard will take place if the mixture of propane and air is ignited. There are three critical elements that have to occur at the same time. Firstly, the concentration of mixture must be equal to or greater than LFL of 0.038 kg/m^3 or 2.0%. Then, the source of ignition has energy greater than MEI of 0.14 mJ, and finally, the mixed gas velocity is lower than burning velocity.

The safety standard, ANSI/ASHRAE Standard 34-2010 [1], classifies the safety class of propane as A3 which is non-toxic, LFL ≤ 0.1 kg/m^3, heat of combustion ≥ 19,000 kJ/kg, and exhibits flame propagation. Additionally, IEC 60335-40-2 [2] limits maximum refrigerant mass, M_{max}, for a given room floor area according to equation 7 or minimum floor area, A_{min}, for a given mass according to equation 8,

$$M_{\max} = 2.5(LFL)^{5/4} h_0 A^{1/2} \quad (7)$$

$$A_{\min} = \left[\frac{M}{2.5(LFL)^{5/4} h_0} \right]^2 \quad (8)$$

where LFL is the lower flammability limit of refrigerant,
A is the room floor area,
h_o is the installation height of fan coil unit.

4.2. *Risk assessment*

The flammability risk of propane in air was studied by D. Colbourne [3]. The event tree analysis (ETA) was used to identify the combination of sequence of events that may lead to a release of refrigerant and an active ignition source that could result in ignition and eventually the probability of ignition and severity of consequences. The result revealed that the total ignition frequency and the risk for maximum thermal intensity were 106 visits per million that begin servicing (3.6×10^{-4} per visit), and 3.1×10^{-3} (s(kWm^{-2})$^{4/3}$/yr, respectively. Also the ignition frequency for an industrial average worker is slightly lower than criteria 500 visits per million, where the well trained worker value is ten order of magnitude lower.

5. Results

From the theoretical refrigeration cycle analysis, both the energy of refrigerant R-290 and R-32 are shown in Table 4. The COP of R-290 and R-32 were 4.6 and 4.3, respectively. Using R-290 was increase the efficiency by 7.0% compare to R-32. Similarly, the cooling capacity of R-290 and R-32 were 256 and 226 kJ/kg, respectively, which was 13.3% increase in the cooling capacity.

The efficiency of the air conditioner is defined by energy efficiency ratio, which is the ratio of the cooling capacity and electrical power input to the unit. The actual energy efficiency ratio (EER) is

usually depended on many factors such as refrigerant type, brand, cooling capacity size, and cost. However, most of the air conditioner using R-290 is more efficient than R-32.
At present, some of the split type air conditioners with refrigerant R-290 and R-32 are available in the market as shown in Table 5.

Table 4. Energy Efficiency of R-290 and R-32.

Component	Energy, kJ/kg	
Refrigerant	R-290	R-32
Compressor Work	55.5	55.5
Condenser Heat Reject	311.4	277.7
X- Valve	0.0	0.0
Evaporator Cooling	256.0	225.7
COP	4.62	4.34

Table 5. Inverter split type air conditioners.

Refrigerant	Model	Capacity, kW	Power, kW	EER
R-290	GSC18GIG	5.28	1350	3.91
R-290	GSC12FG7	3.52	946	3.72
R-290	GSC12FIXH	3.52	684	5.15
R-32	FTRM185V25	5.19	1240	4.18
R-32	RHM50RVIN	4.86	1315	4.14
R-32	AR15MYFTAUAN	4.12	1350	3.05
R-32	AR18NYFXAWRN	5.28	1370	3.85
R-32	1V18RIN	5.28	1540	3.43
R-32	1K13RN	3.52	1030	3.42
R-32	RASDX13CJT	3.78	1182	3.20

Note: The EER based on indoor air conditions at 27˚Cdb and 19˚Cwb, outdoor air conditions at 35˚Cdb and 24˚Cwb.

The minimum room floor area according to equation 8 is shown in Table 6. There is no area requirement if the refrigerant mass is less than or equal to 0.152 kg. On the other hand, while the refrigerant mass is greater than 0.988 kg, the forced ventilation is necessary.

Table 6. Minimum room area.

Charge amount (M), kg	0.152	0.228	0.304	0.456	0.608	0.988
h_o, m		Minimum room area, m^2				
0.6		82	146	328	584	1541
1.0		30	53	118	210	555
1.8		9	16	36	65	171
2.2		6	11	24	43	115

Due to the hot and humid weather in Thailand, the typical air conditioner cooling load for building with high and light cooling load are about 12 m^2/RT and 18 m^2/RT, respectively. Likewise, the refrigerant charge in the commercial air conditioners are 0.33 and 0.41 kg for cooling capacity of 3500 W (1RT) and 5250 W, respectively. Table 7 and Table 8 illustrate the minimum room area and air condition area with high and light cooling load. According to the safety standard of International Standard IEC 60335-40-2:2018, only the 3500 W split type air conditioner with ceiling installation fan coil unit is safe. Nonetheless, the refrigerant charge in air conditioner at the same capacity depends on many factors, for example, band, model, cost, etc. Hence, if the refrigerant mass is reduced, the minimum room area or the installation height is also reduced.

Table 7. Minimum room area for air conditioner with high cooling load.

Cooling Load, W	3500	5250	7000	8750
Air Condition Area, m^2	12	18	24	30
R290 mass, kg	0.33	0.41	0.50	0.59
	Minimum Area for R-290, m^2			
Floor Installation, h_o = 0.6	167	269	396	547
Window Installation, h_o = 1.0	60	97	143	197
Wall Installation, h_o = 1.8	19	30	44	61
Ceiling Installation, h_o = 2.2	12	20	29	41

Table 8. Minimum room area for air conditioner with light cooling load.

Cooling Load, W	3500	5250	7000	8750
Air Condition Area, m^2	18	27	36	45
R290 mass, kg	0.33	0.41	0.50	0.59
	Minimum Area for R-290, m^2			
Floor Installation, h_o = 0.6	167	269	396	547
Window Installation, h_o = 1.0	60	97	143	197
Wall Installation, h_o = 1.8	19	30	44	61
Ceiling Installation, h_o = 2.2	12	20	29	41

6. Discussion and Conclusion

The results of the R-290 COP and cooling capacity, which were higher than R-32, are identical to D. Colbourne [3]. In this study, there are 7% increasing in both the COP and EER and 13.3% increasing in the cooling capacity of R-290 compare to R-32. In contrast, the R-290 compressor discharge temperature and pressure were lower than R-32 for air-cooled air conditioner. However, the refrigerant R-290 is more flammable than R-32.

The wall type air conditioner with propane refrigerant would be safe from fire if it was installed under two conditions; 1) at a height higher than 1.8 m above the floor level and 2) the floor area was larger than 17 and 23 m^2 for air conditioner cooling capacity of 3375 W and 5000 W with the propane charge of 0.31 and 0.36 kg, respectively.

To avoid fire hazard the air conditioner height and minimum room floor area should be complied to safety standard, also the service technicians should be well trained for flammable refrigerant.

Additionally, user must be aware of using flammable refrigerant and avoid any ignition source in the air condition space.

Acknowledgments
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References
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[2] IEC 2018 *Household and Similar Electrical Appliances – Safety – Part 2-40: Particular Requirements for Electrical Heat Pumps, Air Conditioners and Dehumidifiers* International Standard IEC 60335-2-40:2018 (Geneva: IEC)
[3] Colbourne D 2011 Risk Analysis of Flammable Refrigerant Handling During Service and Maintenance Activities *Proc. 23rd IIR Int. Congress of Refrigeration* (Prague: 21–26 August 2011)