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To cite this article: S Traivivatana and W Yongchareon 2019 IOP Conf. Ser.: Mater. Sci. Eng. 501 012049

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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 m² 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.

| Property                                      | Value   |
|-----------------------------------------------|---------|
| 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/m³                            | 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.

\[
W = q_{co} + q_{ev}
\]

**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 (\(\eta_c\)) of 85%. The compression discharged enthalpy, \(h_2\), is calculated by using equation (1),

\[
h_2 = h_1 + \frac{(h_{2s} - h_1)}{\eta_c}
\]

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

![Figure 2. P-h diagram of the refrigeration cycle.](image)

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, $q_{ev}$; 
\[ q_{ev} = m(h_1 - h_t) \tag{2} \]

Compression work, $W$; 
\[ W = m(h_t - h_i) \tag{3} \]

Condenser heat rejection, $q_{co}$; 
\[ q_{co} = m(h_2 - h_i) \tag{4} \]

Coefficient of performance, COP; 
\[ COP = \frac{(h_i - h_t)}{(h_1 - h_i)} \tag{5} \]

Energy balance; 
\[ q_{co} = q_{ev} + W \tag{6} \]

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 $\leq$ 0.1 kg/m$^3$, heat of combustion $\geq$ 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,

\[ M_{max} = 2.5(LFL)^{5/4} h_o A_{1/2} \tag{7} \]
\[ A_{min} = \left[ \frac{M}{2.5(LFL)^{5/4} h_o} \right]^{2} \tag{8} \]

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 ($3.6 \times 10^{-4}$ per visit), and $3.1 \times 10^{-3}$ (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               | R-290 | R-32 |
|-------------------------|-------|------|
| Refrigerant             | 55.5  | 55.5 |
| Compressor Work         | 311.4 | 277.7|
| Condenser Heat Reject   | 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        | AR15MYFTAUN| 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 |
|----------------------|-------|-------|-------|-------|-------|-------|
| hₒ, m                | 82    | 146   | 328   | 584   | 1541  |
| 0.6                  |       |       |       |       |       |       |
| 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 m²/RT and 18 m²/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, m² | 12   | 18   | 24   | 30   |
| R290 mass, kg    | 0.33 | 0.41 | 0.50 | 0.59 |

Minimum Area for R-290, m²

| Installation Type, h₀ | 0.6  | 1.0  | 1.8  | 2.2  |
|-----------------------|------|------|------|------|
| Floor Installation    | 167  | 269  | 396  | 547  |
| Window Installation   | 60   | 97   | 143  | 197  |
| Wall Installation     | 19   | 30   | 44   | 61   |
| Ceiling Installation  | 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, m² | 18   | 27   | 36   | 45   |
| R290 mass, kg    | 0.33 | 0.41 | 0.50 | 0.59 |

Minimum Area for R-290, m²

| Installation Type, h₀ | 0.6  | 1.0  | 1.8  | 2.2  |
|-----------------------|------|------|------|------|
| Floor Installation    | 167  | 269  | 396  | 547  |
| Window Installation   | 60   | 97   | 143  | 197  |
| Wall Installation     | 19   | 30   | 44   | 61   |
| Ceiling Installation  | 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 m² 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
The researchers appreciate GIZ for funding this project to Chulalongkorn University.

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