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# MATHEMATICAL MODELLING FOR WINDOW AIR–CONDITIONING USING R–290 DROP–IN REPLACEMENT OF R–22

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**Abstract:** New working fluids with favorable features of moderate environmental effects are presently being developed to avoid high global warming potential. These hydrocarbon refrigerants have excellent energy efficiency and a low global warming potential, which means they have a low overall environmental impact. Some of these choices are non–flammable, and the flammable ones have substantially lower flammability than the much more flammable hydrocarbons. This paper examines the performance of hydrocarbon refrigerants in commercial refrigeration applications as alternatives for R–22. The findings of MATLAB software analysis of R–22 and R–290, as well as comparisons of the results in various parameters, systems, and components, are presented, demonstrating the benefits of using these hydrocarbon refrigerants. R–290 shows better performance at various evaporator and condenser temperatures. R–290 has a 4% higher performance than R–22.
**Keywords:** Window Air–Conditioning, MATLAB and Hydrocarbon Refrigerants

## INTRODUCTION

The industrial revolution in the twentieth century raised the demand for new equipment for human comfort. These products need more energy, which has become a necessity in today's world.[1] As a result, a main goal in the engineering industry is vital to reduce energy consumption through efficient utilization. This decrease in energy use has a direct impact on global warming reduction.

Energy consumption is directly linked to a country's economic progress; yet, due to rising costs of conventional fuels and worldwide environmental concerns, this subject is receiving a lot of attention right now. To reduce costs, experts are looking for alternative and sustainable energy sources. Due to rising energy consumption, environmental degradation, global warming, ozone layer depletion, and other factors, efficient energy usage for practical applications are critical.

Following the Kyoto and Montreal Protocols, researchers are focusing on alternative and environmentally kind refrigerants. However, in the current situation of competitive business, the a highly significant effort to identify alternate and environmentally kind refrigerants [2].

Because thermal comfort is so important in both the home and industrial sectors, air conditioning comes at a high price. The major challenge is to reduce power consumption and make them more efficient and environmentally friendly for Air–conditioning. The thermodynamic processes in any system are critical for optimal utilization and proper optimization.[3] A large number of practical and theoretical studies on performance evaluation and optimization are accessible in the literature.[4–8] The Montreal Protocol was established in 1987 as a framework for protecting the ozone layer by phasing out the refrigerants that cause ozone depletion. [9]

Table 1. Thermodynamics properties of R–22 and R–290

| Properties | | Refrigerants | |
|---|---|---|---|
| | | R–22 | R–290 |
| Molecular weight | [g/mole] | 86.5 | 44.10 |
| Critical temperature | [°C] | 96.2 | 96.8 |
| Critical pressure | [bar] | 50.5 | 42.5 |
| Latent heat | at 25°C[kJ/kg] | 180.3 | 423.3 |
| Bubble pressure | at 25°C[bar] | 10.4 | 11.06 |
| Saturated liquid density | at 25°C[kJ/m$^3$] | 1191 | 580.88 |
| Saturated vapour density | at 25°C[kJ/m$^3$] | 44.8 | 241.162 |
| Saturated liquid specific heat | at 10°C[kJkg/k] | 1.29 | 1.48 |
| | at 50°C[kJkg/k] | 1.46 | 1.62 |
| ODP | | 0.055 | 0 |
| GWP | (100 years) | 1700 | 11 |
| Freezing point | °C | –160 | –97 |

As prospective refrigerant replacements, Dalkilic and Wongwises [10] examined the energy performance of various refrigerants and R–600a blends to different refrigerants. The results showed that the refrigerant mixes R–290/R600a (40/60 wt%) and R–290/R1270 (20/80 wt%) is the most viable R–12 and R–22 alternatives, respectively. To charge R–290 and R–1270 for performance trials, an original R–22 AC cooling capacity of 2.4 kW and energy efficiency ratio of 3.2. According to the findings, adopting a larger displacement compressor would result in higher performance for R–290 [11]. As a result, hydrocarbon refrigerants may one day become a solution of component of refrigerant solutions.

The calculations were performed on a 2TR window air conditioning system that used R–22 as the refrigerant. Energy analysis was performed using R–290 to determine the losses for the vapour compression cycle under various operating circumstances. REFPROP software to determine the refrigerant properties, and the results are described in detail. To get the best system performance, more research is being done on the design and operating circumstances. Because hydrocarbons have a larger latent heat than R–22, their absence of chlorine atoms results in zero ozone layer depletion potential. The thermodynamic properties of R–290 and R–22 are shown in Table 1.

## MATHEMATICAL MODELLING

The equation of states of refrigerant can be determine the thermodynamic parameters. The NIST procedures, which are currently an industry standard, were utilised to calculate these attributes in the MATLAB–SIMLINK calculations. The mathematical formulation of thermodynamic relations for systems and system components was done using mass, energy, and work conservation principles[12].

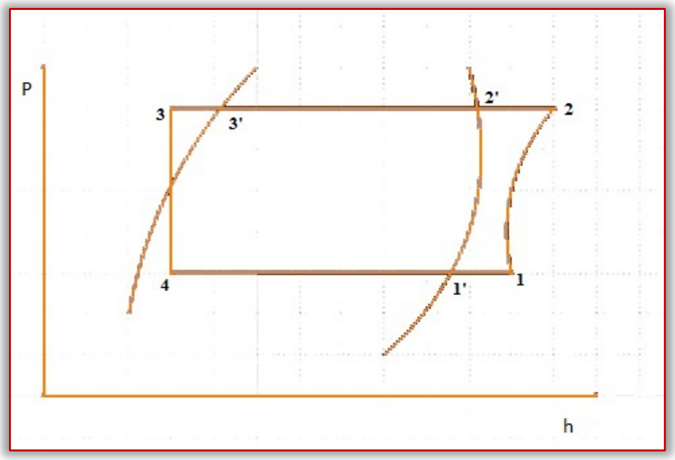


Figure 1. P–h diagram for refrigeration cycle

The figure–1 shows the four salient points (1,2,3 and 4) of an ideal cycle on the p–h diagram.

The cycle consists of:

- 1–2 – Compression (Isentropic process)
- 2–3 – Condensation (Isobaric process)
- 3–4 – Expansion (Isenthalpic process)
- 4–1 – Evaporation (Isobaric process)
- 1'–1 – Superheated
- 3–3' – Sub cooled

The energy performance are as follows[13]:

- Pressure ratio

$$P_r = P_c / P_e$$

- Mass Flow Rate (Kg/s)

$$m = \frac{\text{Displacement rate} * \eta v * N}{v1 * 60}$$

- Refrigeration effect (kJ/kg)

$$q_e = h_1 - h_4$$

- Coefficient of Performance

$$COP = \frac{h1 - h4}{h2 - h1}$$

- Isentropic compressor work (kJ/kg)

$$W_{isen} = h_2 - h_1$$

- Refrigeration Capacity (kW)

$$Q_e = m * (h_1 - h_4)$$

- Compressor Power (kW)

$$P = m * (h_2 - h_1)$$

- Overall performance index (kJ.°C/m³)

$$OPI = \frac{(Tc - Te) * (h1 - h4) * Pe}{v1 * Pc}$$

OPI = Temperature Drop * Volumetric heat of vaporization/ $P_r$

Enthalpies $h_1$,$h_2$ and $h_4$, specific volumes $V_1$ and $V_2$ and $P_c$ (condenser pressure), $P_e$ (evaporator pressure) are taken from saturation and super–heated table of R–22 and R–290 from REF PROP 7.0 software.

## RESULTS AND DISCUSSIONS

Because R–290 has good performance, it was chosen as an R–22 substitute based on thermodynamic cycle simulation study. The results were compared to R–22 and R–290 refrigerants. R–290 is thought to be the best performing refrigerant. R–290, on the other hand, is extremely combustible. As a result, it is recommended that R–290 refrigerant be used, particularly in practical applications.

### — COP

Figure 2 shows the COP variation for R–22 and R–290 refrigerant at evaporator temperatures ranging from 1°C to 10°C which enhances the COP. The COP drops as condenser temperature varies between 40°C, 45and 50°C. It is identified that as the condenser temperature rises, the cop value falls, and as the evaporator temperature rises, the cop value rises. The highest cop attained R–290.

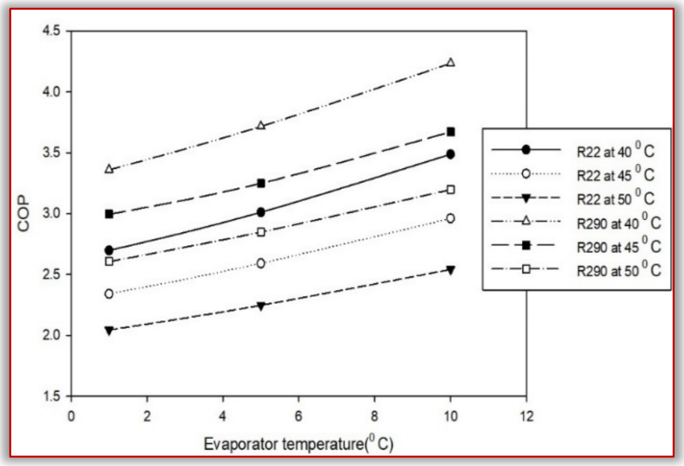


Figure 2. Evaporator temperature vs COP at various condenser temperature

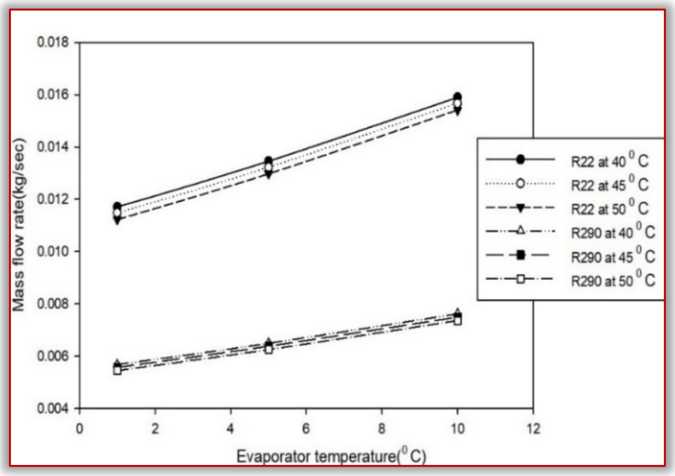


Figure 3. Evaporator temperature vs Mass flow rate at various condenser temperature

— Refrigeration mass flow rate

Figure 3 shows the mass flow rate fluctuation for refrigerants R–22 and R–290 when the evaporator temperature is varied from 1°C to 10°C which increases the mass flow rate. It drops in the range where the condenser temperature varies between 40°C and 50°C.

— Refrigeration capacity

The Refrigeration Capacity variation for R–22 and R–290 refrigerant is illustrated in figure 4. The refrigerant combination enhances the Refrigeration Capacity as evaporator temperature increases. It decreases in the range where the condenser temperature varies between 40°C and 50°C.

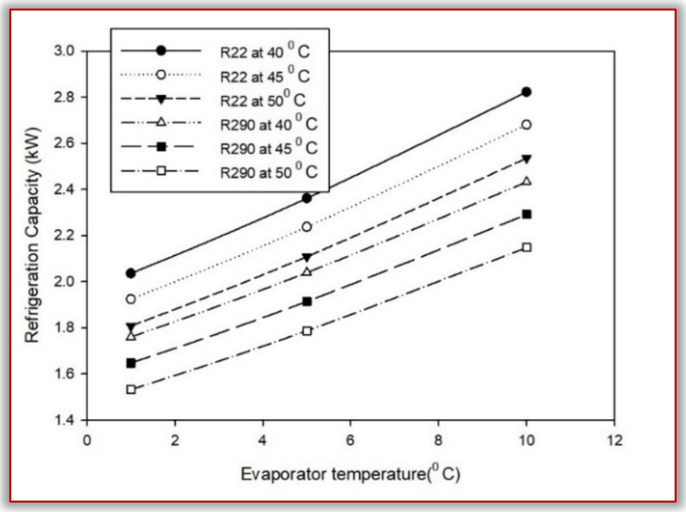


Figure 4. Evaporator temperature vs Refrigeration capacity at various condenser temperature

— Compressor power

The Compressor Power variation for refrigerant R–22 and R–290 while the evaporator temperature is adjusted from 1°C to 10°C which increases the Compressor Power shown in figure 5. When the condenser temperature varies between 40°C and 50°C, the compressor power rises.

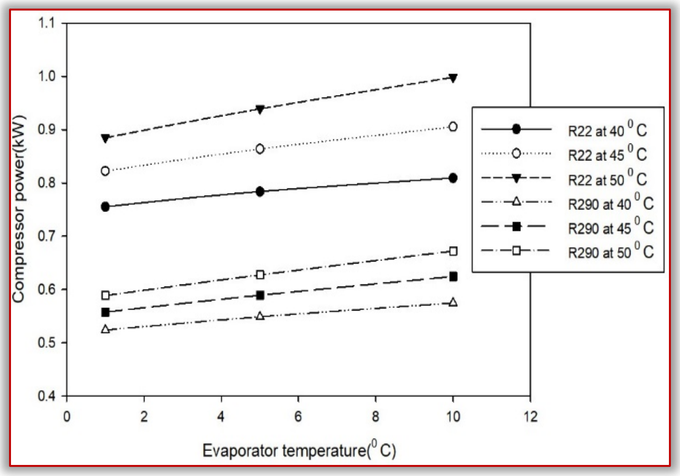


Figure 5. Evaporator temperature vs Compressor power at various condenser temperature

— Overall performance index

Figure 6 shows the overall performance index fluctuation for refrigerant R–22 and R–290 while the evaporator temperature is varied 1°C to 10°C. The refrigerant combination enhances the Overall performance index. When the condenser temperature adjusted 40°C to 50°C, the overall performance index drops.

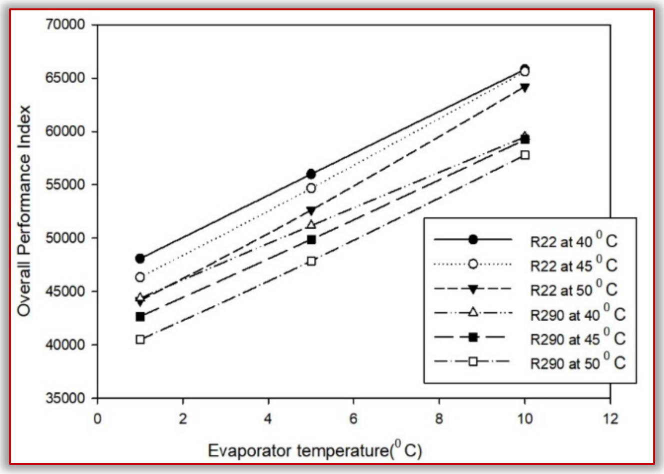


Figure 6. Evaporator temperature vs overall performance index at various condenser temperature

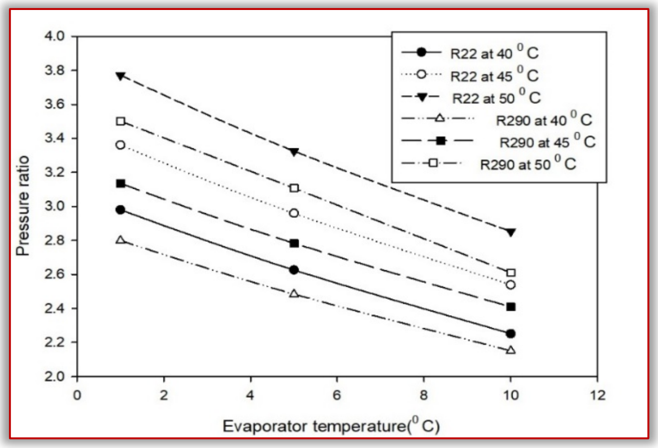


Figure 7. Evaporator temperature vs Pressure ratio at various condenser temperature

— Pressure ratio

Figure 7 shows the Pressure Ratio fluctuation for R–22 and R–290 refrigerant while the evaporator temperature is adjusted from 1°C to 10°C. The refrigerant mixture decreases the Pressure Ratio. When the condenser temperature is adjusted between 40°C and 50°C, the Pressure Ratio rises.

## CONCLUSIONS

Hydrocarbon refrigerants have a higher coefficient of performance and mass flow rate when utilized in small window air conditioners. The compressor's power consumption is reduced. We used the MATLAB–SIMLINK programme to examine the refrigerant and discovered that R–290 refrigerants perform better. The refrigerant data is calculated by the REFPROP programme.

The following findings have been reached:

- In the case of R–290, the refrigerant capacity and COP rises, but compressor power and pressure ratio drops.
- In the case of R–290, performance features such as refrigeration capacity and COP increase when the evaporation temperature rises.
- R–290 has a lower compressor power than conventional one.
- The R–290 has a 4 % higher average COP than the R–22.
- Finally, when comparing R–290–charged systems to R–22–charged systems, the R–290–charged systems consistently outperformed the R–22–charged systems. However, the refrigerant R–22 is also being phased out in favour of R–290 because to its high ozone depletion, which has a negative impact on our ecosystem. R–290 has a high volumetric cooling capacity and no ozone depletion. The R–290 refrigerant runs at a higher pressure than the R–22 refrigerant.

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