JRAIA INTERNATIONAL SYMPOSIUM 2025

Development of Commercial Multi-split Air conditioners Using Natural Refrigerants

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ABSTRACT

The implementation of the F-Gas Regulation in Europe is shifting to considerations of selecting natural refrigerants for split air conditioners exceeding 12 kW. This paper focuses on carbon dioxide (CO2) refrigerant, a natural refrigerant, and compares its performance and cost with hydrofluorocarbon (HFC) refrigerants based on its characteristics. Results indicate that performance issues with CO2 are minor under partial load conditions, and improvements are possible under rated conditions using functional components like ejectors. Regarding cost, leveraging CO2's high gas density enables smaller diameters and higher densities for functional components. Furthermore, economies of scale from sharing equipment with the low-temperature refrigeration systems offer potential cost reductions. This demonstrates that CO2 refrigerant is sufficiently practical in terms of both performance and cost. Furthermore, CO2 VRF systems meeting the Minimum Energy Performance Standard (MEPS) have been introduced to the European market. Moving forward, it is necessary to explore the deployment of equipment with further improved performance and cost.

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Keywords: CO2, The low GWP, VRF systems

1. INTRODUCTION

Efforts are underway globally to reduce the consumption of Hydrofluorocarbons (HFC) as part of sustainable solutions to combat global warming. Europe, which has a high level of environmental consciousness, imposes strict Global Warming Potential (GWP) limits on refrigerants used in HVAC&R products under the revised F-gas regulation (EU) 2024/573. Systems using refrigerants that exceed these limits face market entry difficulties. For instance, split air conditioning units above 12kW are required to utilize alternative refrigerants with a GWP below 150 from January 2033. (By 2030, the Commission needs to publish a report re-evaluating the post- 2030 product bans. Depending on this report, amendments are still possible to bans taking effect after 2030[1]). These series of regulations compels companies to enhance their technological innovation and environmental responsibility more than ever before.

Amidst these situations, interest towards natural refrigerants is increasing, and choosing the optimal refrigerant from a sustainability perspective becomes crucial for companies. Natural refrigerants such as ammonia, propane, and carbon dioxide (hereafter referred to as CO2) are prime examples. While ammonia and propane demonstrate effective properties, they carry risks such as toxicity and flammability, necessitating strict safety measures during their use.

In this regard, CO2 is a non-flammable A1 refrigerant with extremely low GWP, making it an ideal option particularly for Variable Refrigerant Flow (VRF) systems. These characteristics provide long-term benefits while fully complying with environmental regulations. Daikin Europe announced the CO2 VRV (RXYN-B) in early 2025, and this VRF systems is already being sold in the Europe (Fig.1).

Fig.1 CO2 VRV (RXYN-B)

However, in general, CO2 refrigerants face challenges such as difficulty in ensuring enthalpy difference in the supercritical region and a tendency for higher compression ratios, which are said to affect energy efficiency and operating costs. Additionally, compared to HFC-based refrigerants, higher design pressure is required, necessitating high-pressure equipment design, potentially leading to increased material costs.

2. PURPOSE

The purpose of this report is to examine the potential and challenges of CO2 refrigerants in the air conditioning sector and to evaluate their performance and cost to explore their practicability. This report particularly looks into the competitiveness of CO2 refrigerants compared to HFC-based refrigerants. Additionally, it discusses the product features of the CO2 VRV system being marketed by Daikin Europe and outlines future developments.

3. PERFORMANCE: PARTIAL LOAD CONDITIONS

When evaluating the performance of air conditioners using CO2 refrigerant, it is essential to consider not only the rated capacity but also partial load conditions. With revisions to national standards, the introduction of annual comprehensive evaluation systems reflecting actual operating conditions is progressing.

As a specific example, we will discuss European standards. Table 1 shows the percentage impact of each condition on performance for the Seasonal Energy Efficiency Ratio (SEER) and Seasonal Coefficient of Performance (SCOP) specified in EN14825. While the impact rates for the rated conditions—Cooling Condition A and Heating Condition TOL—are 12% and 1% respectively, the impact rates for the partial load conditions—Cooling Condition C and Heating Condition B—are significantly higher at 37% and 49%. In other words, when determining refrigerant specifications, a comprehensive evaluation considering regional market needs and environmental performance is required, and under these conditions, the superiority of CO2 refrigerant is considered to be assured.

From the perspective of rated capacity, it has been pointed out that energy efficiency is inferior compared to many HFC refrigerants. This is primarily because operation occurs under high-pressure supercritical conditions, requiring high compression ratios and enthalpy differences, which are disadvantageous for efficiency. However, considering actual air conditioner usage patterns, continuous operation at rated capacity is extremely rare, with partial load operation being far more common.

For example, in climates like Europe, partial load operation occurs frequently. Indeed, performance standards in Europe place significant emphasis on partial load conditions. Consequently, CO2 refrigerant use becomes particularly effective in these regions. Under partial load conditions, the reduction in energy efficiency compared to HFC refrigerants is minor.

Table 1 Percentage of Performance Impact Under Each Condition.

		Outdoor DB [°C]	Part Load Ratio [%]	Impact Rate [%]
Cooling	A	35	100.0	12
	B	30	73.7	28
	C	25	47.4	37
	D	20	21.1	19
Heating	TOL	-10	100.0	1
	A	-7	88.5	18
	B	2	53.9	49
	C	7	34.6	22
	D	12	15.4	6

Table 2 shows the results comparing the rated conditions and partial load conditions in the theoretical cycle. For the cooling rated conditions, an outdoor temperature condition of dry bulb temperature 35°C and wet bulb temperature 24°C is assumed. For the partial load conditions, an outdoor temperature condition of dry bulb temperature 25°C and wet bulb temperature 17°C is assumed. Furthermore, for both conditions, the indoor side maintains the same dry bulb temperature of 25°C and wet bulb temperature of 17°C. The heat exchanger inlet and outlet conditions are set to a superheat (SH) of 3K and a subcooling (SC) of 5K.

As a result, the COP reaches 73% for R32 refrigerant under rated conditions, but increases to 87% under partial load conditions. Two factors contribute to the reduced performance difference under partial load conditions. First, as shown in Figures 2 and 3, the enthalpy difference for CO2 significantly increases under partial load conditions compared to rated conditions. While R32 shows only a few percent increase, CO2 exhibits an increase rate of tens of percent. The significant performance degradation, where a large enthalpy difference is generated, is most pronounced in the supercritical region, while the trend is minor in the subcritical region. The second factor is the reduced proportion of compressor input in the total input. In other words, the standby power consumption of components like the outdoor fan drive and solenoid valves becomes relatively larger compared to the total input. Since these input values do not exhibit significant differences between R32 and CO2 due to refrigerant properties, the performance gap becomes smaller.

This suggests that under partial load conditions, the performance difference between R32 and CO2 due to refrigerant properties becomes smaller, making measures to reduce fan and component input effective. Under rated conditions, fundamental circuit improvements and utilizing CO2-specific components such as ejectors (described in the next section) are effective.

Table 2 Comparison in Theoretical Cycle Calculations Between Rated and Partial Load Conditions.

Condition		Cooling Nominal	Cooling Partial
Capacity	[kW]	22.4	10.6
Outdoor DB	[°C]	35.0	25.0
Outdoor WB	[°C]	24.0	17.0
Indoor DB	[°C]	27.0	5.0
Indoor WB	[°C]	19.0	19.0
SC	[K]	5.0	5.0
SH	[K]	3.0	3.0
COP ratio to R32	**[-]**	**73%**	**87%**

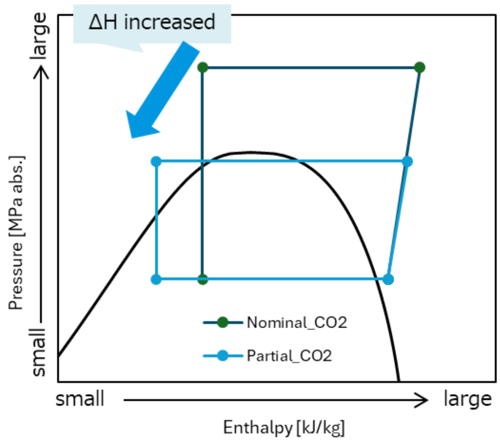

Fig.2 P-h Diagram for CO2 at Rated Conditions and Partial Load Conditions

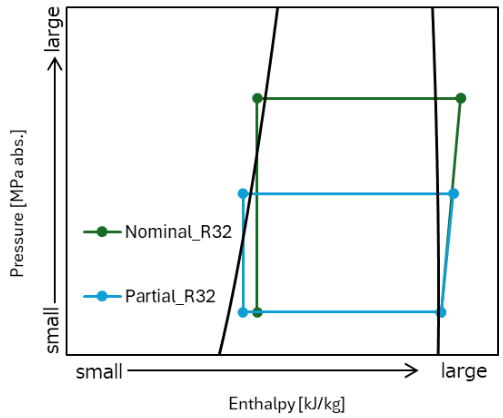

Fig.3 P-h Diagram for R32 at Rated Conditions and Partial Load Conditions

4. PERFORMANCE:CO2-SPECIFIC IMPROVEMENTS

As mentioned in the previous section, CO2 refrigerant exhibits a significant performance gap compared to R32 refrigerant, particularly under rated conditions. However, there exist functional components that leverage characteristics unique to CO2 refrigerant. One such example is the utilization of ejectors. An ejector is a means to recover expansion losses, pressurize the suction gas, and improve exergy efficiency—thereby enhancing the overall efficiency of the refrigeration cycle.

Fig. 4-5 shows the T-s diagrams for R32 and CO2 to evaluate expansion losses and exergy efficiency. As shown in the graph, expansion losses differ by approximately a factor of two between R32 and CO2. Furthermore, CO2 always undergoes temperature changes in the supercritical region, resulting in poorer exergy efficiency.

In other words, compared to R32, CO2 has greater expansion losses and poorer exergy efficiency, making the ejector effect relatively larger. Based on preliminary calculations, we anticipate an improvement in SCOP of approximately 1 to 4%.

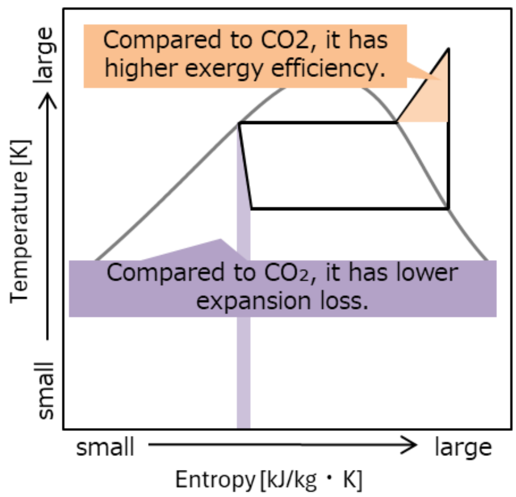

Fig.4 The T-s Diagram for R32.

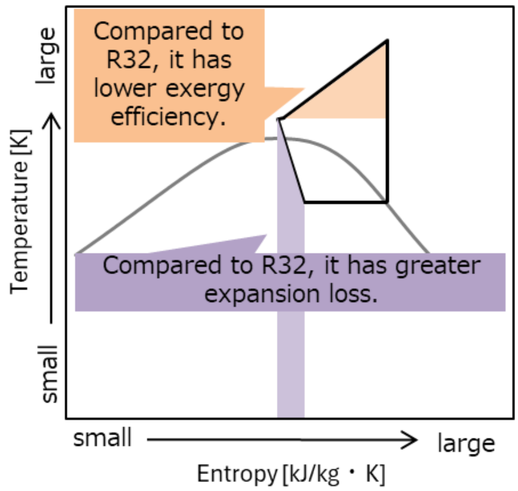

Fig.5 The T-s Diagram for CO2.

5. COST: MINIATURIZATION, HIGH DENSITY, AND ECONOMIES OF SCALE.

Compared to HFC refrigerants, CO2 refrigerants require higher design pressures, which tends to increase material costs due to the resulting need for thicker components. However, we believe it is possible to suppress this cost increase through the following two points.

The first point is miniaturization and high-density packaging. Due to its refrigerant properties, CO2 refrigerant has a high gas density (approximately 3 to 5 times that of R32 refrigerant). This enables the miniaturization and higher density of components and equipment, which we believe can reduce material costs. When estimating the cost of switching the outdoor heat exchanger from HFC-based refrigerants to CO2, we expect material costs to increase by approximately 100 to 130%.

As described in the next section, the same principle allows for reducing the size of connecting pipes. As shown in Fig. 6, we believe that designing the system to minimize pressure loss in refrigerant piping—which reduces capacity—to levels comparable to HFC refrigerants offers the potential to reduce pipe sizes by 1 to 3 sizes.

The second point is economies of scale. In Europe, CO2 refrigerant has become the mainstream choice for low-temperature refrigeration applications such as showcases. We believe that standardizing components and equipment across both the air conditioning and low-temperature refrigeration markets will enable cost reductions through economies of scale in the future.

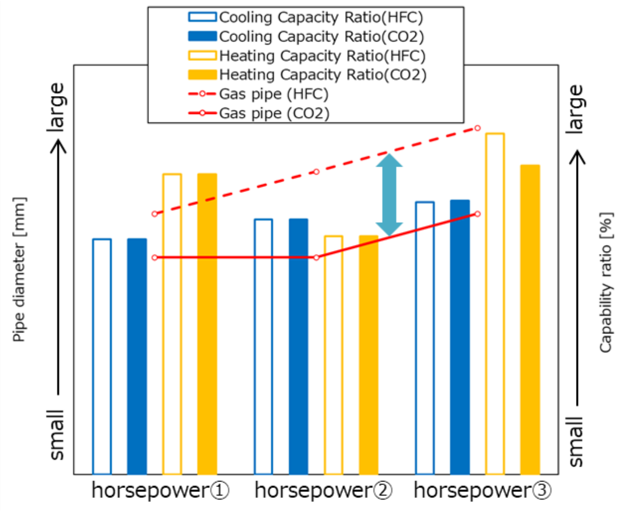

Fig.6 Impact of Pipe Pressure Loss

6. CO2 VRV (RXYN-B)

The specifications for the CO2 VRV (RXYN-B) sold by Daikin Europe are shown in Table 3. Furthermore, Fig. 7 shows the piping system diagram, and Fig. 8 shows the P-h diagram.

This system employs a VRV-specific compressor (hermetically sealed swing compressor) and possesses three major features. First, by placing an intercooler after the low-stage compressor discharge, it enables a reduction in the high-stage compressor discharge enthalpy, thereby decreasing the condensing load. Second, using a medium-pressure receiver and economizer supercools the gas cooler outlet, increasing the enthalpy difference. This effectively mitigates the efficiency drop in the supercritical region, a challenge inherent to CO2 refrigerants. Third, adopting a two-stage compression and two-stage expansion circuit reduces the large compression ratio, suppressing excessive increases in compressor input. Additionally, through surplus refrigerant control in the medium-pressure receiver and improvements in compressor technology, the unit achieved the European performance regulation values, the Minimum Energy Performance Standard (MEPS: SEER 4.8, SCOP 3.5).

From a cost perspective, the high gas density of CO2 refrigerant enabled the use of smaller gas connection pipe diameters. While the European R32 model VRV 5 (RXYA-A) uses 19.1mm refrigerant piping, the CO2 VRV (RXYN-B) uses 15.9mm piping. This results in approximately a 3% reduction in piping weight.

Going forward, we anticipate further performance improvements by implementing measures such as advancing the refrigeration cycle, optimizing heat exchangers and compressors based on CO2 refrigerant characteristics, optimizing fan shapes, and optimizing control under partial load conditions. This is expected to enable further expansion of the product lineup.

Table 3 Main Specifications of RXYN-B

Capacity Range	[HP]	10
Cooling Capacity	[kW]	28
Heating Capacity	[kW]	31.5
SEER	-	**4.8**
SCOP	-	**3.5**
Compressor	-	Hermetically sealed swing compressor
Refrigerant Gas Piping	**[mm]**	**15.9**
Refrigerant Liquid Piping	[mm]	9.5

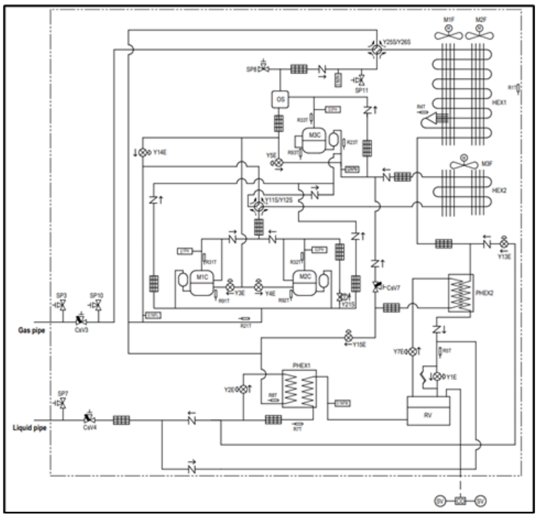

Fig.7 RXYN-B Piping System Diagram

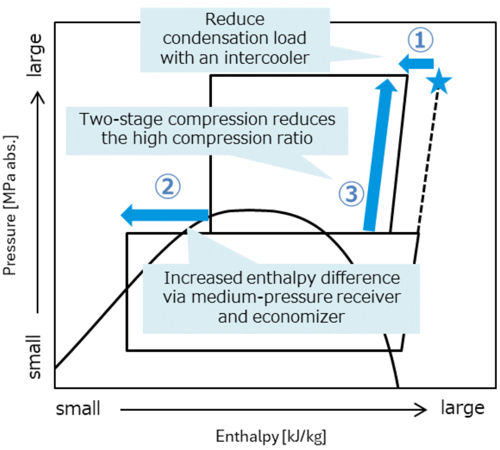

Fig.8 P-h Diagram for RXYN-B

7. CONCLUSION

Considering the European F-Gas Regulation, natural refrigerants will be selection of choice in split-type air conditioning systems exceeding 12 kW after January 2033. When comparing performance and cost, including safety aspects, CO2 refrigerant is considered one of the leading environmentally conscious options.

Performance of VRF systems using CO2 refrigerant was compared with R32 refrigerant in terms of both performance and cost. Regarding performance, while differences exist compared to R32 under rated conditions, these differences tend to decrease under partial load conditions. Furthermore, even under rated conditions, numerous methods exist to improve efficiency by utilizing the large pressure differential characteristic of CO2 refrigerant. One such example discussed was the use of ejectors. Regarding cost, while an increase in material costs is anticipated due to the rise in design pressure, it was suggested that cost reduction is possible through the miniaturization and high-density design of functional components utilizing the high gas density. Furthermore, since CO2 refrigerant is already mainstream in the existing low-temperature market, the resulting component commonality is expected to enable cost reductions leveraging economies of scale.

The specifications of CO2 VRF systems sold in the European market also meet the MEPS standards, the European regulations, through efficiency improvement measures such as adopting a two-stage compression and two-stage expansion refrigerant circuit. Furthermore, weight reduction was achieved through piping design based on the characteristics of CO2 refrigerant. Going forward, it is necessary to consider further performance improvements and model expansion for CO2 refrigerant air conditioning units.

REFERENCES

[1] Daikin Europe N.V.. "*An outlook from Daikin on refrigerant alternatives in Europe – addressing Applications, Affordability, Safety and Future-Readiness*", (Reference 2025-01-09) <https://www.daikin.eu/en_us/press-releases/an-outlook-from-daikin-on-refrigerant-alternatives-in-europe.html>