



Development of Refrigeration and Air-Conditioning Technologies for
Practical Use of Next-Generation Low-GWP Refrigerants

Volume 6

Equipment Compatible with Low-GWP Refrigerants

Development of Residential/Commercial Air
Conditioners, Refrigerated and Frozen Display Cases,
and Related Equipment

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1. Development of a Condensing Unit Using Green Refrigerants

(Hitachi Global Life Solutions, Inc.)

In response to the Kigali Amendment, developed countries are required to reduce their HFC consumption, expressed in GWP-equivalent terms, by 85% by 2036. Condensing units currently use high-GWP HFC refrigerants, and the transition to low-GWP refrigerants is now underway. However, because equipment placed on the market remains in service for long periods, refrigerants that leak during operation continue to be emitted into the atmosphere over extended periods, thereby affecting the global environment. Therefore, the adoption and market introduction of green refrigerants with a GWP of less than 10 are effective measures. Accordingly, this research and development project aimed to develop a condensing unit using green refrigerants, thereby contributing to the wider dissemination of equipment compatible with such refrigerants.

1.1 Background, Objectives, and Relationship to the Project Outcome Targets

1.1.1 Background

The condensing unit addressed in this research and development project is widely used in combination with refrigerated and frozen display cases and unit coolers in convenience stores, supermarkets, refrigerated warehouses, and similar facilities. Although CO₂ refrigerant has already been put into practical use as a low-GWP alternative for condensing units, it is considered inferior to conventional fluorocarbon refrigerants in terms of performance. In addition, because key components cannot be shared with fluorocarbon-based equipment, it is less favorable in terms of economic efficiency, and the initial installation cost becomes high, thereby constituting a barrier to widespread adoption. In recent years, however, refrigerant manufacturers have proposed green refrigerants with a GWP of less than 10 that use hydrofluoroolefins (HFOs), indicating the possibility of reducing environmental impact while maintaining compatibility with existing equipment.

1.1.2 Objectives

In this study, we investigated and developed a condensing unit using a green refrigerant with a GWP of less than 10, with the technical objective of achieving performance equivalent to or better than that of the current fluorocarbon refrigerant unit while maintaining the initial installation cost at a comparable level.

Through this study, we aimed to reduce barriers to market introduction, including those associated with the replacement of existing equipment, and contribute to the reduction of greenhouse gas emissions in the refrigeration field through the early dissemination of equipment using low-GWP refrigerants.

1.1.3 Relationship to the Outcome Targets

The green refrigerant examined in this study is characterized by an operating pressure close to that of existing refrigerants and does not require major changes to equipment specifications. Therefore, without requiring new large-scale capital investment, it can maintain installation workability as well as maintainability and serviceability at a level equivalent to that of current equipment.

These characteristics indicate that this technology can be positioned as one that lowers barriers to introduction into the existing market and promotes the dissemination of low-GWP equipment.

1.2 Research and Development Items

In this research and development project, seven items, as listed in Table 1.2-1, were established with the aim of bringing a condensing unit using a low-GWP refrigerant into practical use.

First, (1) “Performance Evaluation and Selection of HFO Refrigerant Mixtures by Simulation” and (2) “Evaluation and Selection of Refrigeration Oils and Materials” were conducted as fundamental investigations from the perspectives of refrigerant characteristics and reliability. Based on these results, (3) “Compressor Design” and (4) “Condensing Unit Design” for the selected refrigerant were conducted to identify specifications capable of ensuring long-term reliability.

Next, based on the design results obtained from (3), (5) “Prototype Development of Compressor and Performance/Reliability Evaluation” was conducted, and (6) “Prototype Development of Condensing Unit and Performance Evaluation” was performed using a prototype unit equipped with the developed compressor. In the final stage, the prototype condensing unit was connected to display cases, and (7) “Monitoring Evaluation under Actual Store-Equivalent Conditions” was conducted in a test facility simulating an actual store, thereby enabling a comprehensive evaluation of performance and reliability.

Table 0-1 Research and Development Items

Item	Title	Overview
No.1	Performance Evaluation and Selection of HFO Refrigerant Mixtures by Simulation	Using our proprietary simulation technology to shorten evaluation time, we studied refrigerant types and compositions and estimated their performance. Based on these results, candidate refrigerant mixtures were evaluated and selected.
No.2	Evaluation and Selection of Refrigeration Oils and Materials	Stability evaluation of refrigeration oils and material compatibility assessments were conducted to identify issues related to long-term product reliability. In addition, appropriate refrigeration oils and materials were selected for the proposed refrigerant mixtures.
No.3	Compressor Design	Based on the findings obtained from No.1 and No.2, compressors were designed using in-house compressor development technology to ensure long-term reliability.
No.4	Condensing Unit Design	The following performance enhancement measures were implemented, and their combined effects on performance improvement were evaluated: • Compressor injection port design • Injection control technology • Subcooling bypass technology • Air heat exchanger technology • Optimization of fan design
No.5	Prototype Development of Compressor and Performance/Reliability Evaluation	Prototype compressors were manufactured and preliminary tests were conducted. In the event of any issues, improvements were made to the prototype compressors.
No.6	Prototype Development of Condensing Unit and Performance Evaluation	Prototype condensing units were fabricated to evaluate and verify performance enhancement measures. If any issues occurred, improvements were implemented on the prototype units.
No.7	Monitoring Evaluation under Actual Store-Equivalent Conditions	A condensing unit was connected to display cases and long-term monitoring tests were conducted in a test facility simulating actual store conditions. Performance and reliability were evaluated to confirm that there are no issues during long-term operation.

1.3 Project Organization

Figure 1.3-1 shows the project organization for this study. This study was conducted with Hitachi Global Life Solutions serving as the core organization.

However, because a condensing unit alone does not constitute a complete commercial product, evaluation support was also provided, through subcontracting arrangements, by display-case manufacturers not shown in the figure.

In addition, technical support regarding refrigerant property information and material evaluation was provided by the refrigerant and refrigeration-oil manufacturers, and the research and development proceeded within a framework of intercompany collaboration.

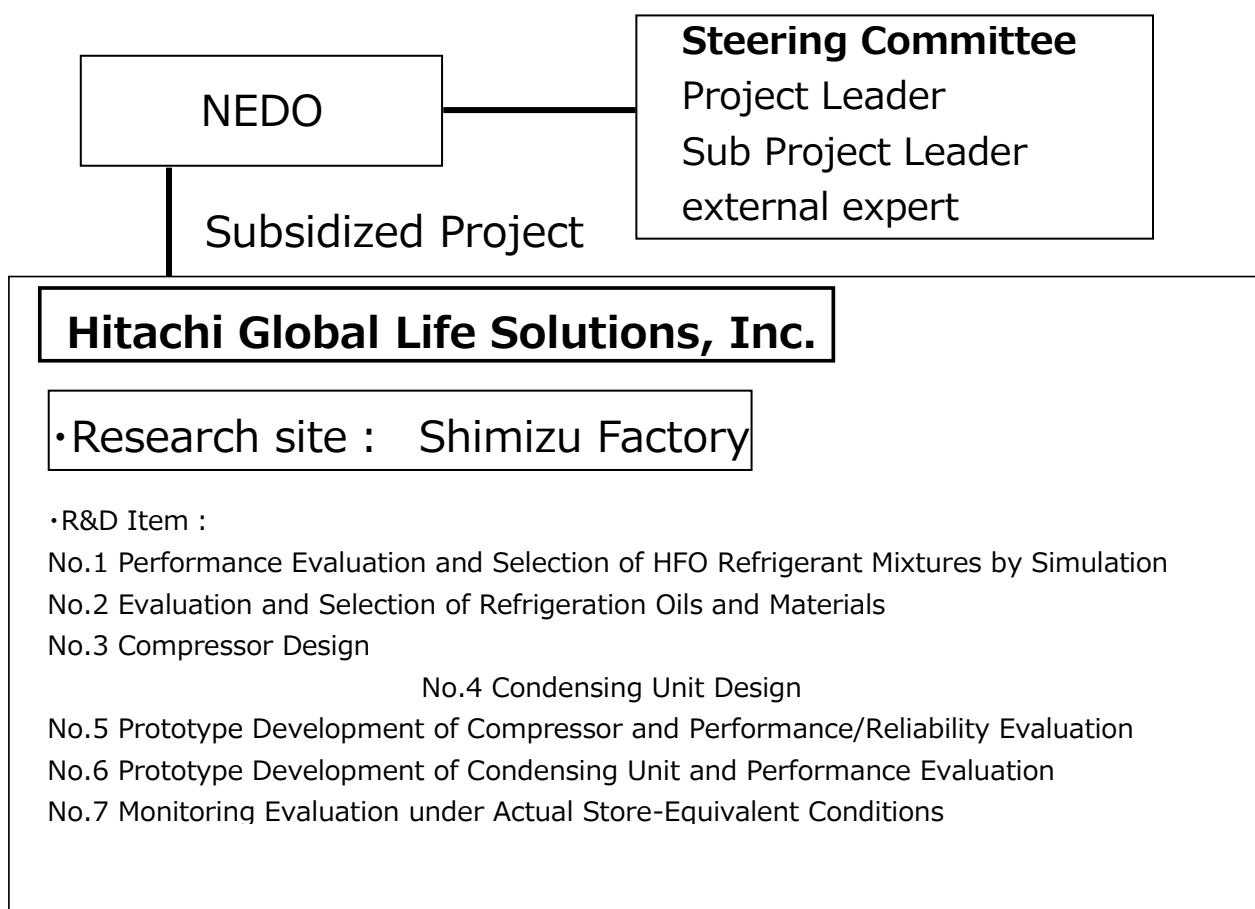


Figure 0-1 Project Organization

1.4 Implementation Overview, Targets (Interim and Final), and Their Basis

1.4.1 Implementation Overview

As described in the previous section, the research and development comprised seven items. Figure 1.4-1 illustrates the relationships among these development items. In (1), refrigerant selection was conducted by incorporating refrigerant properties provided by the refrigerant manufacturer into our in-house simulation and examining refrigeration-cycle performance. In (2), appropriate refrigeration oils and materials were selected for the chosen refrigerant. In (3), a compressor capable of ensuring long-term reliability was designed using the selected refrigerant and refrigeration oil. Based on the design results obtained from (3), (5) was conducted to evaluate the prototype compressor. In addition, for

the selected refrigerant, (4) was conducted with due consideration of performance. In (6), performance evaluation was conducted using a prototype unit equipped with the previously prototyped compressor. In (7), the fabricated condensing unit was connected to display cases and subjected to monitoring tests in a test facility simulating an actual store. Thereafter, the validity of the design was verified through performance and reliability evaluations using the prototypes, and the knowledge obtained was fed back into design improvements to establish specifications capable of withstanding actual operating conditions.

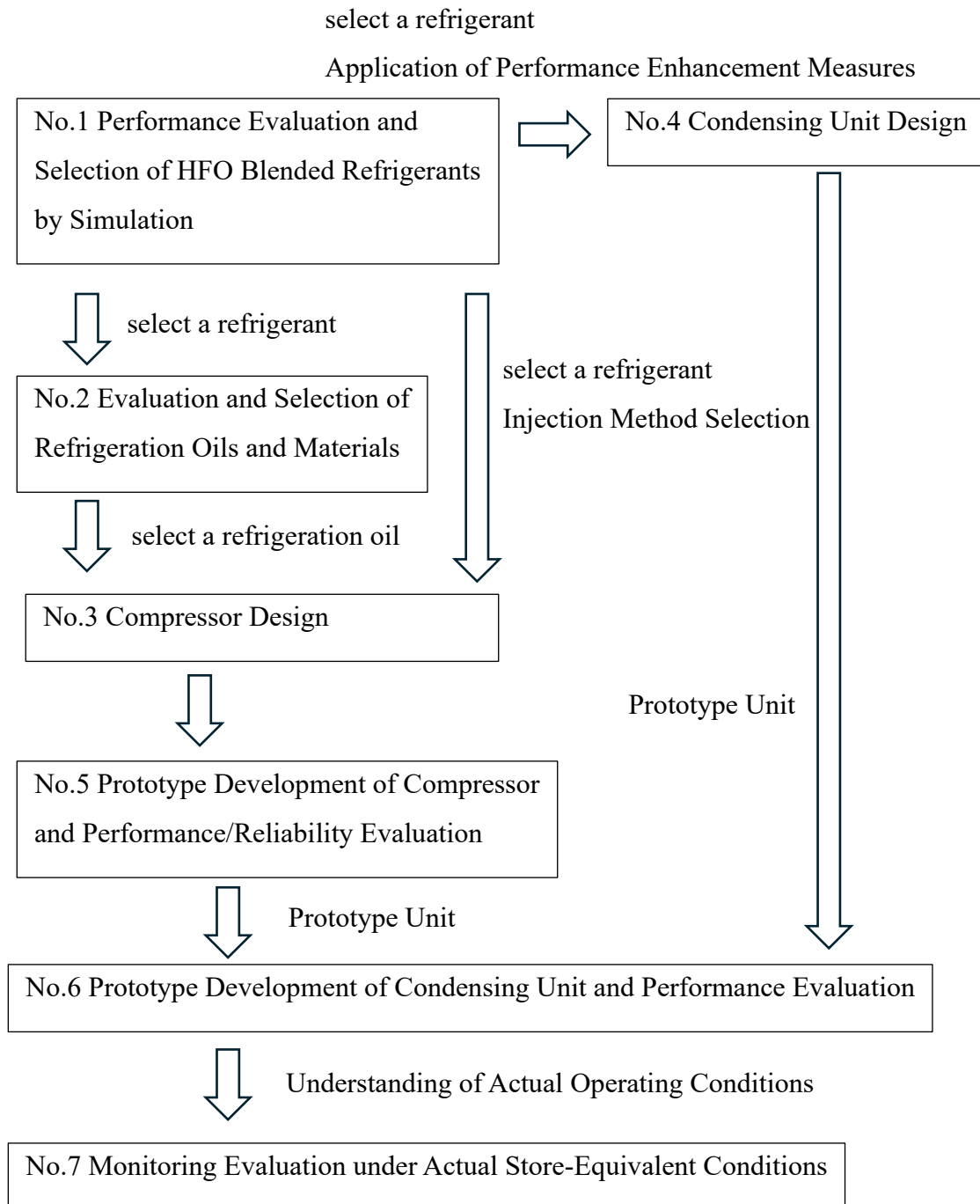


Figure 0-1 Correlation Diagram of R&D Items

1.4.2 Targets

The objective of this study was to clarify the development pathway for elemental and peripheral technologies that make it possible to achieve a performance equivalent to or better than that of currently marketed fluorocarbon refrigerant units.

Specifically, the following technical targets were established:

1. Selection of refrigerant type and refrigerant composition.
2. Evaluation of refrigeration oils and material compatibility; preparation of a list of issues related to long-term equipment reliability.
3. Formulation of measures for improving condensing-unit performance.
4. Compressor design and evaluation of prototype units; achievement of long-term equipment reliability equivalent to that of the current unit.
5. Condensing-unit design and evaluation of prototype units; achievement of a COP of 100% or more relative to our current unit (R448A).

1.5 Achievements and Significance

1.5.1 Achievements

The principal achievements of this study are summarized as follows:

- From the perspectives of environmental performance, safety, energy efficiency, and economic efficiency, R474B was identified as a low-GWP refrigerant suitable for refrigeration applications.
- The thermochemical stability of refrigeration oils was examined, and appropriate refrigeration oils and materials were selected through a material-compatibility evaluation.
- By designing a compressor compatible with the refrigerant and fabricating a prototype, the prospect of ensuring reliability equivalent to or greater than that of the current unit was established.
- A compressor and condensing unit compatible with R474B were prototyped and evaluated, and a COP equivalent to or greater than that of the current unit was achieved.

1.5.2 Significance

These findings are significant for the following reasons:

- It was demonstrated that conversion to R474B is feasible while maintaining performance and cost at levels equivalent to those of current fluorocarbon refrigerant units.
- Compared with CO₂ refrigerant, R474B operates at a lower pressure and therefore exhibits high compatibility with current equipment in terms of pressure-resistant design, workability, and maintainability.
- The R474B condensing unit can be readily introduced, even in markets that assume replacement of existing equipment; therefore, it is expected to make a substantial contribution to the realization of carbon neutrality through the dissemination of equipment using low-GWP refrigerants.

1.6 Specific Technical Content

1.6.1 Item (1): Performance Evaluation and Selection of HFO Refrigerant Mixtures by Simulation

In developing a condensing unit using a low-GWP refrigerant, refrigerant selection is the most important factor affecting performance, safety, reliability, and economic efficiency. In this study, multiple candidate HFO refrigerant mixtures were evaluated through desk-based analysis using our proprietary refrigeration-cycle simulation technology.

Specifically, cycle characteristics, such as refrigerating capacity, COP, discharge temperature, and compression ratio, were calculated for different refrigerant compositions, and comparative evaluations were conducted against conventional fluorocarbon refrigerants. Moreover, comprehensive assessments that considered the safety and environmental

performance, including flammability classification and GWP, were performed.

For R1132(E)-based refrigerant mixtures intended for refrigeration applications, refrigerant information was provided by the refrigerant manufacturer, and simulations reflecting that information were performed. Consequently, R474B was selected as the refrigerant because its balance of performance and safety best matched the target conditions.

This selection indicates that GWP can be substantially reduced while maintaining operating conditions close to those of existing fluorocarbon refrigerants.

1.6.2 Item (2): Evaluation and Selection of Refrigeration Oils and Materials

Although R474B has a low GWP, it is expected to present challenges in terms of the thermochemical stability of refrigeration oils relative to current fluorocarbon refrigerants. Therefore, this study placed particular emphasis on evaluating the compatibility among the refrigerant, refrigeration oil, and materials constituting the compressor.

First, for multiple candidate refrigeration oils, thermal stability tests and chemical degradation evaluations were performed under a refrigerant atmosphere. Moreover, the compatibility of the materials constituting the interior of the compressor was evaluated.

As a result, even when R474B was used, a refrigeration oil with sufficient thermochemical stability could be selected with little concern regarding performance or material degradation during long-term operation. It was also confirmed that, for each component constituting the compressor, materials with a stability equivalent to or greater than that of the current unit could be applied.

Accordingly, long-term reliability equivalent to that of the current unit could be ensured even when R474B was used.

1.6.3 Item (3) and (5): Compressor Design and Prototype Development of Compressor and Performance/Reliability Evaluation

Compared with existing fluorocarbon refrigerants, R474B is characterized by a lower refrigerating capacity per unit circulation rate. To address this issue, this study adopted a design policy of increasing the refrigerant circulation rate (displacement $\times$ rotational speed) through higher-speed operation without changing the external size of the compressor.

Regarding the lubrication conditions and reliability of the bearings, which were potential concerns associated with higher-speed operation, elemental tests were conducted in advance to determine the lubrication conditions at the sliding portions of the bearings. Based on these results, the operating range was examined while maintaining the bearing structure of the current unit, and design specifications capable of ensuring reliability even during long-term operation were established.

Based on the above design, a prototype compressor was fabricated, and its performance and reliability were evaluated using a gas-cycle test apparatus for standalone compressors. The results confirmed stable operation within the operating range assumed in the design. Moreover, no abnormalities were observed in the reliability test under the maximum rotational-speed condition, confirming that the compressor was sufficiently reliable for long-term operation.

1.6.4 Items (4) and (6): Condensing Unit Design and Prototype Development of Condensing Unit and Performance Evaluation

R474B has a low environmental impact; however, its performance degradation relative to the conventional refrigerant R448A is a concern. Therefore, to satisfy the market requirement of performance equivalent to or greater than that of the current unit, it is essential to examine measures for performance improvement.

First, simulation of the current condensing unit using R474B as a drop-in refrigerant indicated that the COP decreased to approximately 94% of the current level. In response, the factors causing performance degradation were organized, and multiple COP-improvement measures, including enhancement of the heat-exchange performance and utilization of subcooling, were examined in combination.

Subsequently, performance evaluation was performed under drop-in conditions using actual-machine testing, and

consistency with the calculation results was confirmed. Relative to the test results for the current refrigerant, increases in low-pressure-side pressure loss and compressor rotational speed were observed, and examination of the compressor efficiency revealed a substantial decrease relative to the current unit.

To reduce pressure loss on the low-pressure side, a prototype incorporating an additional subcooling circuit was fabricated and evaluated. Consequently, a COP improvement of +4.6% was confirmed, demonstrating that reduction of low-pressure-side pressure loss has a substantial effect.

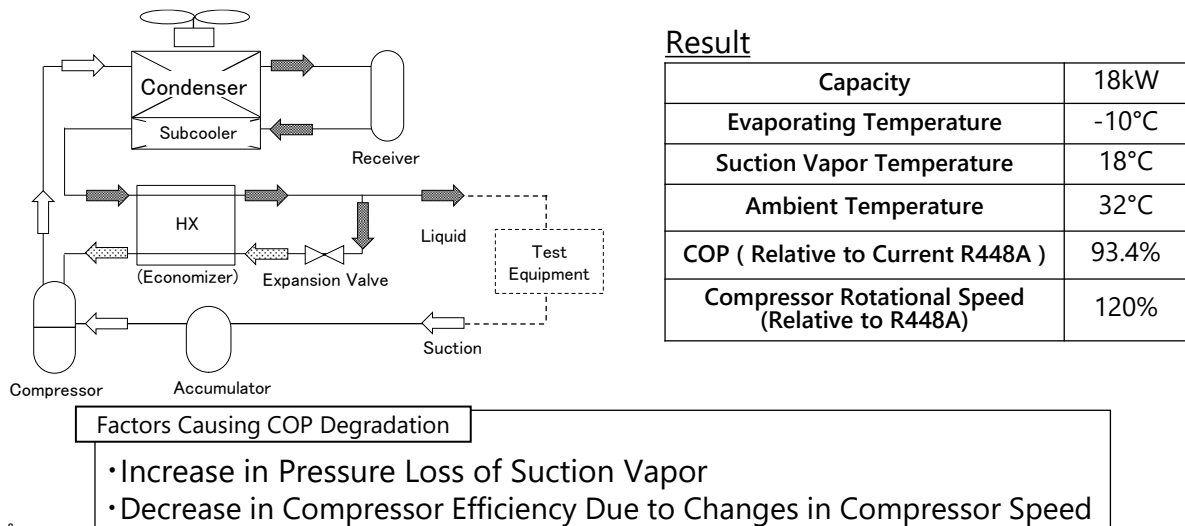


Figure 0-1 Drop-In Test of R474B on an Existing R448A Unit

Analysis of the test results revealed that the primary cause of low-pressure-side pressure loss was the accumulator; therefore, efforts were made to reduce the pressure loss across the accumulator. In addition, our proprietary fan-shape development technology was used to improve fan efficiency and reduce fan-motor input. Figure 1.6-2 presents the measurement results obtained when these two technologies were applied to the R474B condensing unit.

By reducing low-pressure-side pressure loss across the accumulator, the COP improved through an increase in suction pressure from the perspective of thermophysical properties, yielding an effect of +3.8%. Simultaneously, the compressor efficiency improved owing to a decrease in compressor rotational speed, resulting in a COP effect of +2.8%. In addition, revision of the fan shape reduced fan-motor input, yielding a COP effect of +0.5%. Using these technologies, 100.5% of the COP of the current refrigerant was achieved.

These results demonstrate that, through appropriate design improvements, a COP equivalent to or greater than that of the current unit can be achieved, even when R474B is used.

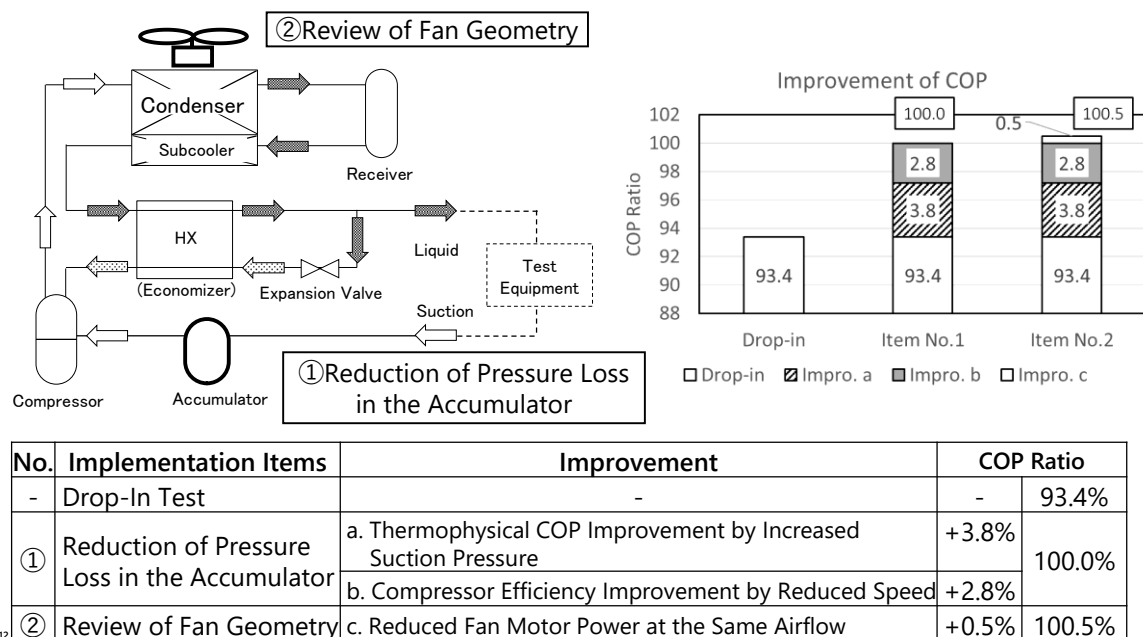


Figure 0-2 Cumulative Efficiency Improvement

1.6.5 Item (7): Monitoring Evaluation under Actual Store-Equivalent Conditions

A drop-in performance test of R474B was conducted by connecting display cases to the condensing unit in a test chamber simulating an actual store. In addition, the effect of the prototype compressor developed in Item (5) was verified.

The test was subcontracted to a display-case manufacturer, and the measurement conditions conformed to those used to evaluate the annual power consumption. Table 1.6-1 shows the system configuration under measurement, and Table 1.6-2 presents the test results.

Table 0-1 System Configuration under Measurement

Condensing Unit	Load Side
Our Condensing Unit KX-T8AMV Modified Unit for R474B	Showcase Manufacturer's Units • 3-ft chilled display cases × 5 units • 6-ft chilled display cases × 3 units • Walk-in refrigerator × 1 unit

Table 0-2 Performance Test Results under Actual Store-Equivalent Conditions

Condition	Ambient Temp. °C	In-Store Temp. °C	Current R448A Base		R474B Drop-in		R474B Compressor Change	
			Power Consumption Ratio	Average Compressor Speed	Power Consumption Ratio	Average Compressor Speed	Power Consumption Ratio	Average Compressor Speed
Summer Daytime	32	25	100.0%	30	89.2%	35	89.2%	36
Summer NT / Mid-Season DT	25	25	100.0%	32	94.5%	35	89.5%	33
Mid-Season Nighttime	20	25	100.0%	30	95.8%	32	92.1%	31
Winter Daytime	12	20	100.0%	21	97.6%	25	84.1%	23
Winter Nighttime	7	20	100.0%	21	102.7%	23	89.2%	22
Year-Round			100.0%		95.4%		89.1%	

Annual power consumption was reduced to 95.4% by changing the refrigerant from the current R448A to R474B, and it was further reduced to 89.1% by adopting the prototype compressor and making slight adjustments to the refrigerant charge. A principal factor in the reduction in power consumption associated with the refrigerant change is considered to be that, because the compressor rotational speed was increased to generate the same capacity, the compressor was able to operate in a more efficient range. The prototype compressor was designed to improve part-load performance, and this effect was reflected in the results.