

Efforts to Reduce Greenhouse Gas Emissions for Air Conditioning and Refrigeration Products



TOYOTAKA HIRAO*1

HISAO MIZUNO*2

KENJI UEDA*3

MASAKAZU KAI*4

HIROYUKI YAMADA*5

The use of fluorocarbons enabled refrigeration and air conditioning systems to be introduced widely across the world. However, since it turned out that fluorocarbons could be a threat to the ozone layer and global warming, their regulations have been strengthened under the framework established internationally. As a company offering a wide range of refrigeration and air conditioning units, Mitsubishi Heavy Industries Thermal Systems, Ltd. has taken on the conservation of the global environment as its prime responsibility. With compliance with fluorocarbon regulations as the norm, we developed refrigeration and air conditioning units using a non-fluorocarbon refrigerant with very limited environmental impact, high-efficiency heat pumps that can serve as a boiler alternative, and all-electric-driven transport refrigeration units without the need for power from the engine. Through the development of such environmentally-safer products, we contribute to building a sustainable low-carbon society.

1. Introduction

The global market for refrigeration and air conditioning is worth more than JPY 13 trillion. As shown in **Figure 1**, it is expected to continue to grow especially in the Asian and North American markets.¹ The very beginning of such a globally-growing market dates back to 1824 when the refrigeration cycle theory was first described by Sadi Carnot. Initially, natural substances such as ammonia (NH₃), sulfur dioxide (SO₂), carbon dioxide (CO₂) and ether were used as refrigerants. However, it was not realistic to think that refrigeration and air conditioning systems met domestic applications because of safety management issues such as toxicity, flammability and high operating pressure.

In 1930, “fluorocarbons (often known as Freon)” were developed and synthesized in the U.S. Because of their properties such as low toxicity, non-flammability and high chemical stability, fluorocarbons were used as a refrigerant in refrigeration and air conditioning systems. Moreover, as fluorocarbons with thermophysical properties suitable for refrigeration and air conditioning applications were less costly, they were considered to be an ideal refrigerant and had become widely used in domestic applications such as air conditioners and refrigerators.

However, initiated by the findings of Dr. Roland and his colleague regarding the destruction of the ozone layer by CFCs (first published in the journal *Nature* in 1974), such fluorocarbons came to be placed under international regulations as environmentally-harmful substances. Since then, refrigeration and air conditioning units have evolved hand in hand with these regulations (the regulatory background will be described in detail in Section 2).

As we consider global environmental issues to be our most important challenge, compliance with fluorocarbon regulations is a given. As large refrigeration units, centrifugal chillers throughout all capacity ranges use a refrigerant with very limited environmental impact. For our high-performance condensing units, CO₂ has been adopted as a non-flammable, non-toxic natural refrigerant. In industrial applications, we developed boiler-alternative heat pumps that can generate hot air of 90°C. Transport refrigeration units are all-electric-driven without the need for power

*1 Acting General Manager, Air-Conditioner Designing & Engineering Department, Mitsubishi Heavy Industries Thermal Systems, Ltd.

*2 Project Manager, Air-Conditioner Designing & Engineering Department, Mitsubishi Heavy Industries Thermal Systems, Ltd.

*3 Deputy Director, Chiller & Heat Pump Engineering Department, Mitsubishi Heavy Industries Thermal Systems, Ltd.

*4 Manager, Transportation Refrigeration Department, Mitsubishi Heavy Industries Thermal Systems, Ltd.

*5 Manager, Air-Conditioner Designing & Engineering Department, Mitsubishi Heavy Industries Thermal Systems, Ltd.

from the engine, thus considerably cutting CO₂ emissions compared with conventional units. We are also promoting our new air conditioners around the world. The refrigerant in these models has a global warming potential (GWP) nearly one-third that of the conventional refrigerant. This report introduces our commitment to developing such environmentally-safer products.

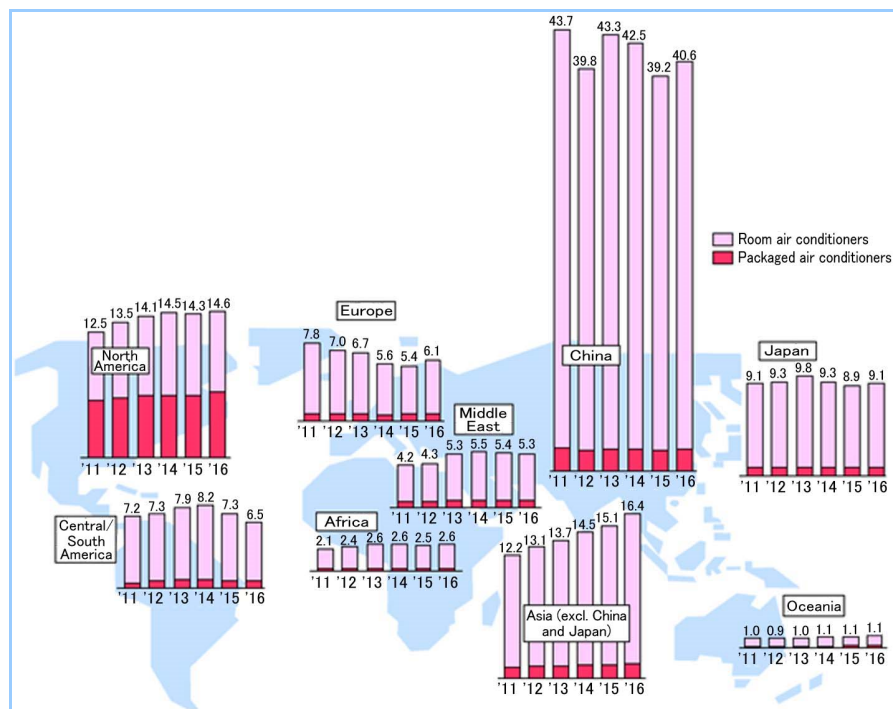


Figure 1 Temporal change in the demanded unit numbers of room air conditioners and packaged air conditioners (units in millions)

2. Refrigerant regulations

Table 1 lists representative refrigerants and their characteristics such as ozone depletion potential (ODP), GWP relative to CO₂, safety (toxicity and flammability) and saturation pressure at 65°C.

Table 1 Characteristics of the representative refrigerants used in refrigeration and air conditioning systems

Refrigerant			Ozone depletion potential (ODP)	Global warming potential (GWP)	Safety*	Pressure in MPa (abs) Saturation pressure at 65°C
CFC	R12	CCl ₂ F ₂	1.0	10900	A1	1.69
HCFC	R22	CHClF ₂	0.055	1760	A1	2.70
HFC	R404A (R125/R143a/R134a)		0	3943	A1	3.21
	R410A (R32/R125)		0	1924	A1	4.28
	R134a	CH ₂ FCF ₃	0	1300	A1	1.89
	R32	CH ₂ F ₂	0	677	A2L	4.38
HFO	R1234yf	CF ₃ CF=CH ₂	0	<1	A2L	1.83
	R1234ze(E)	CF ₃ CH=CHF	0	<1	A2L	1.44
	R1233zd(E)	CF ₃ CH=CClH	0	1	A1	0.45
Natural refrigerant	R717	NH ₃	0	<1	B2L	2.95
	R290	C ₃ H ₈	0	~20 Up to 20	A3	2.34
	R744	CO ₂	0	1	A1	7.38 (critical pressure) or higher

* A: less toxic, B: toxic, 1: non-flammable, 2L: very slightly flammable, 2: slightly flammable, 3: highly flammable (Based on ASHRAE 31: Refrigerant Safety Classification Standards)

Although non-flammable and less toxic, both CFC and HCFC refrigerants (i.e., R12 and R22) are ozone-depleting substances with a high GWP value and can be a threat to the global environment. The three HFC refrigerants (i.e., R404, which is a near azeotropic refrigerant blend with a weight percent ratio of R125/R143a/R134a = 44/52/4; R410A, which is a near azeotropic refrigerant blend with a weight percent ratio of R32/R125 = 50/50 and R134a) have zero ODP, but their GWPs are high (3943, 1924 and 1300, respectively). Although the GWP of R32 is nearly one-third that of R410A, its slightly flammable property raises a concern about the possibility of

refrigerant leakage leading to localized ignition depending on the charged amount. HFO refrigerants of R1234yf and R1234ze(E) are not ozone-depleting substances with a GWP of <1, and thus have a very limited environmental impact. As R1233zd(E) contains chlorine, the risk of ozone depletion cannot be ruled out. However, as it has a short atmospheric lifetime of 26 days (indicating its decomposition before reaching the stratosphere), the ODP is considered virtually zero. Like R32, both R1234yf and R1234ze(E) are slightly flammable. R1233zd(E) is a low-operating-pressure refrigerant with a low gas density, requiring compressors that can handle a large gas volumetric flow rate and preventive measures against pressure drop in the gaseous refrigerant flow paths. Natural refrigerants also have their own challenges (e.g., toxicity for NH₃, high flammability for C₃H₈ and high operating pressure for CO₂).

(1) Measures to protect the ozone layer

Figure 2 shows how regulations on fluorocarbons have been amended.² The regulations are established mainly from two perspectives: ozone layer protection and mitigation of global warming. The review of the initial use of CFC and HCFC refrigerants started in response to Dr. Roland and his colleague's findings in 1974 (which indicate that once released into the air, fluorocarbon gases can destroy the ozone layer) to protect the ozone layer. In 1985, agreement on the "Vienna Convention for the Protection of the Ozone Layer" was reached, and an international framework was established. Based on this framework, the "Montreal Protocol on Substances that Deplete the Ozone Layer" was adopted in 1987 to determine concrete regulatory measures against ozone-depleting substances such as CFCs and HCFCs. The use of CFC refrigerants was terminated by the end of 2009. The complete elimination of HCFC refrigerants shall be achieved, in principle, by 2020 in developed countries and by 2030 in developing nations.

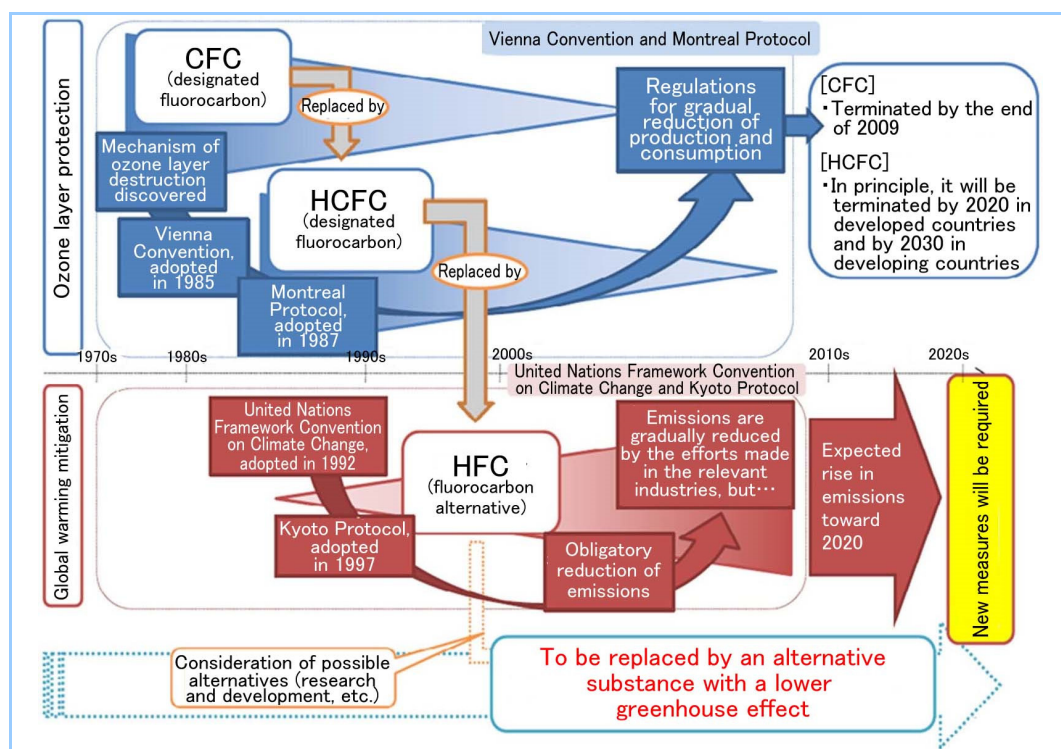


Figure 2 Development of measures against fluorocarbons

When CFC and HCFC refrigerants were regulated, there was a group of substances from which an alternative could be selected. However, possible alternatives to HFC refrigerants are still under consideration.

(2) Measures against global warming

In response to this call for the complete elimination of CFC and HCFC refrigerants, we have adopted non-ozone-depleting HFC refrigerants as an alternative since the 1990s. However, because HFCs have a very high GWP (as shown in Table 1) and their in-use stock has steadily accumulated, there is a concern that their release into the air may aggravate global warming. This then led to the adoption of the "Kyoto Protocol" in 1997 as an international framework for the commitment to the mitigation of global warming. The Kyoto Protocol prescribes obligatory emissions reductions of six types of greenhouse gases into the air (i.e., CO₂, CH₄, N₂O, HFCs,

PFCs and SF₆) for each country. In Japan, various measures have been implemented, for example, the reduction of energy consumption by elevating appliance energy efficiency and the recovery of the charged refrigerant at the time of disposal. Related laws include the “Revised Law Concerning the Rational Use of Energy” in 1999 (which introduced the “Top Runner Program”), the “Law Concerning the Recovery and Destruction of Fluorocarbons” (Fluorocarbons Recovery and Destruction Law) in 2001, the 2006 revised version of this law (for further implementing the recovery of fluorocarbons) and the “Law Concerning the Rational Use and Appropriate Management of Fluorocarbons” (Fluorocarbon Emissions Control Law) in 2015. Under the Fluorocarbon Emissions Control Law together with the Fluorocarbons Recovery and Destruction Law, a holistic approach has started by covering the entire lifecycle of fluorocarbons as a refrigerant including production, use, management, regeneration and destruction. The goals differ depending on which part of the lifecycle is being focused on (e.g., for refrigerant manufacturers, equipment/unit manufactures, users, refrigerant filling companies and refrigerant regenerating companies). For equipment/unit manufactures, the target year and the target GWP value for new low-GWP refrigerants were determined (for example, regarding residential air conditioners, 2018, with a weighted GWP average of ≤ 750)

(3) Kigali Amendment

At the 28th Meeting of Parties to the Montreal Protocol (MOP28) in October 2016, in Kigali, Rwanda, an amendment was adopted to add HFCs to the list of Montreal Protocol substances and gradually reduce them³ (Kigali Amendment, entering into force on 1 January 2019). As shown in **Table 2**, the final target reduction rate from the baseline years is 85% by 2036 in developed countries, 80% by 2045 in Group 1 developing countries and 85% by 2047 in Group 2 developing countries. R410A, which is commonly used in air conditioning systems, needs to be replaced by a refrigerant with a GWP of 310. It is essential to develop a practically applicable system using a low-GWP refrigerant, which consequently will make research and development even more important.

Table 2 HFC production/consumption gradual reduction schedule

	Group 1 developing countries	Group 2 developing countries	Developed countries
Baseline years	2020, 2021 and 2022	2024, 2025 and 2026	2011, 2012 and 2013
Baseline calculation (expressed as CO ₂ equivalent)	Average HFCs in each year plus 65% of HCFC baseline	Average HFCs in each year plus 65% of HCFC baseline	Average HFCs in each year plus 15% of HCFC baseline
Freeze	2024	2028	NA
Step 1	2029 – 10%	2032 – 10%	2019 – 10%
Step 2	2035 – 30%	2037 – 20%	2024 – 40%
Step 3	2040 – 50%	2042 – 30%	2029 – 70%
Step 4			2034 – 80%
Final target reduction	2045 – 80%	2047 – 85%	2036 – 85%

(Note 1) Group 1 developing countries: developing countries that do not belong to Group 2

(Note 2) Group 2 developing countries: India, Pakistan, Iran, Iraq and other Gulf countries

(Note 3) The technological assessment will be conducted in 2022 and every five years thereafter.

(Note 4) For Group 2 developing countries, the technological assessment will be conducted in 4-5 years before the freeze year (2028), to consider the necessity of a delay of two years in the freeze year.

(Note 5) Belarus, Russia, Kazakhstan, Tajikistan and Uzbekistan, all of which are developed countries, follow a different course of gradual reduction (25% of HCFC baseline is used for baseline calculation, and reductions are scheduled as follows: 5% by 2020 as Step 1 and 35% by 2025 as Step 2).

3. Brief description of each product

We offer a wide range of products in terms of both refrigeration capacity (from residential air conditioners to centrifugal chillers used for district cooling/heating) and applicable temperature setting (from -60°C ultra-low freezers to 90°C hot-air or hot-water supply heat pumps). Moreover, transport refrigeration units, which play a part in the cold chain, are also available. This report focuses on the environmental aspects of our major products. To contribute to the mitigation of global warming, it is important to adopt/charge a low GWP refrigerant and use less energy during operation, while realizing higher performance when making new products available commercially.

3.1 Centrifugal chillers

Centrifugal chillers are mainly used in the following systems: district heating and cooling systems; heating, ventilation and air conditioning (HVAC) systems in large buildings and plants

and process cooling systems in chemical and food factories. With the use of centrifugal compressors, the cooling capacity of centrifugal chillers ranges from 150 refrigeration tons (RT) to 5000 RT. We have always taken on the challenge to reduce CO₂ emissions from chillers, by dedicating our efforts to realizing higher efficiency of compressors and heat exchangers and their optimal control for reduced power consumption during operation, as well as enhancing maintenance services such as regular leak inspections to minimize the release of refrigerant to the air. To satisfy the market's fundamental needs, we have used low GWP refrigerants in all centrifugal chiller series models throughout all capacity ranges,⁴ ahead of our competitors in Japan. None of the models of these series are subject to the Fluorocarbon Emissions Control Law.

When selecting a suitable low GWP refrigerant for centrifugal chillers, we took the following requirements to be indispensable: (1) environmental soundness (not destructive to the ozone layer and a GWP of 100), (2) physical properties (refrigeration cycle efficiency as good as that of the conventional refrigerant R134a and not requiring extremely high design pressure in any chiller components), (3) availability (a certain level of production being expected because it is also used in applications other than a centrifugal chiller refrigerant) and (4) safety (with low toxicity and non-flammable as per the High Pressure Gas Safety Act of Japan).

The new refrigerants were examined for centrifugal chiller applications (these new refrigerants and the conventional refrigerants are listed in **Table 3**). The low-GWP HFO refrigerants, R1234yf and R1234ze(E), exhibit thermophysical properties that are relatively similar to those of R134a and are classified as special inert gases according to the High-Pressure Gas Safety Act. On the other hand, the thermophysical properties of R1233zd(E) are close to those of R245fa rather than R134a. When used in air conditioning systems, it yields only a refrigerant pressure of <0.2 MPaG, and therefore the above Act is not applicable. Because the GWPs of these substances are all below 1, none of them are bound by the Fluorocarbon Emissions Control Law. Based on the detailed examination regarding (1) to (4) and other considerations such as risk assessment results, we have decided to use R1233zd(E) for chillers with small capacities and R1234ze(E) for chillers with large capacities, respectively.

Table 3 Centrifugal chiller refrigerant comparison

	Conventional refrigerant (HFC)			New refrigerant (HFO)		
	R245fa	R134a	R32	R1234yf	R1234ze(E)	R1233zd(E)
Global warming potential (GWP) ^(Note 1)	858	1300	677	<1	<1	1
Ozone-depleting substance ^(Note 2)	No	No	No	No	No	No
Classification (High Pressure Gas Safety Act, Refrigeration Safety Regulation)	NA ^(Note 3)	Inert gas	Inert gas ^(Note 4)	Inert gas ^(Note 4)	Inert gas ^(Note 4)	NA ^(Note 3)
Atmospheric lifetime	7.7years	13.4years	5.2years	10.5days	16.4days	26days
Long-term exposure toxicity [ppm] (allowable concentration)	300	1000	1000	500	1000	800
Boiling point [°C] (at atmospheric pressure)	15.1	-26.1	-51.7	-29.4	-19.0	18.3
Saturation pressure (at 6°C) [kPaG] ^(Note 5)	-32.1	260.7	879.8	282.0	167.3	-39.1
Saturation pressure (at 38°C) [kPaG] ^(Note 5)	133.1	861.9	2258	866.4	624.3	100.8
Specific volume of saturated gas [m ³ /kg] ^(Note 5)	0.241	0.056	0.037	0.047	0.069	0.277
Specific volume of saturated gas [m ³ /kg] ^(Note 5)	0.075	0.021	0.014	0.018	0.026	0.091
Theoretical COP ^(Note 6)	6.86	6.58	6.38	6.31	6.56	6.93
Availability	Medium	High	High	Low	Low	Low
Overall rating ^(Note 7)	△	△	○	○	◎	◎

(Note 1) 5th IPCC

(Note 2) Montreal Protocol

(Note 3) The High Pressure Safety Act is not applicable to R-245fa and R-1233zd(E), when used for chillers under the specified conditions.

(Note 4) Special inert gas

It is necessary to install a mechanical ventilation system (interlocking mechanism between the chiller and the ventilator) with a prescribed ventilation capacity, as well as a refrigerant leak detection and alarm system.

(Note 5) RefProp Ver9.1

(Note 6) Two-stage compression/two-stage expansion sub-cooler cycle. Refrigeration cycle efficiency at evaporation temperature of 6°C, condensation temperature of 38°C, and adiabatic efficiency of 90%.

(Note 7) ◎: Low GWP and high theoretical COP, ○: Low GWP, but theoretical COP not as good as HFO-1234ze(E) or HFO-1233zd(E), △: High GWP

Our centrifugal chillers with low GWP refrigerants are commercially available in the ETI-Z series (small capacity range of up to 700 RT) and the GART-ZE/ZEI series (large capacity range of up to 5000 RT). **Figure 3** shows the capacity range of each series, together with that of the earlier series using R134a. **Figure 4** gives the exterior views and performance indicators of both the ETI-Z and GART-ZE/ZEI series.

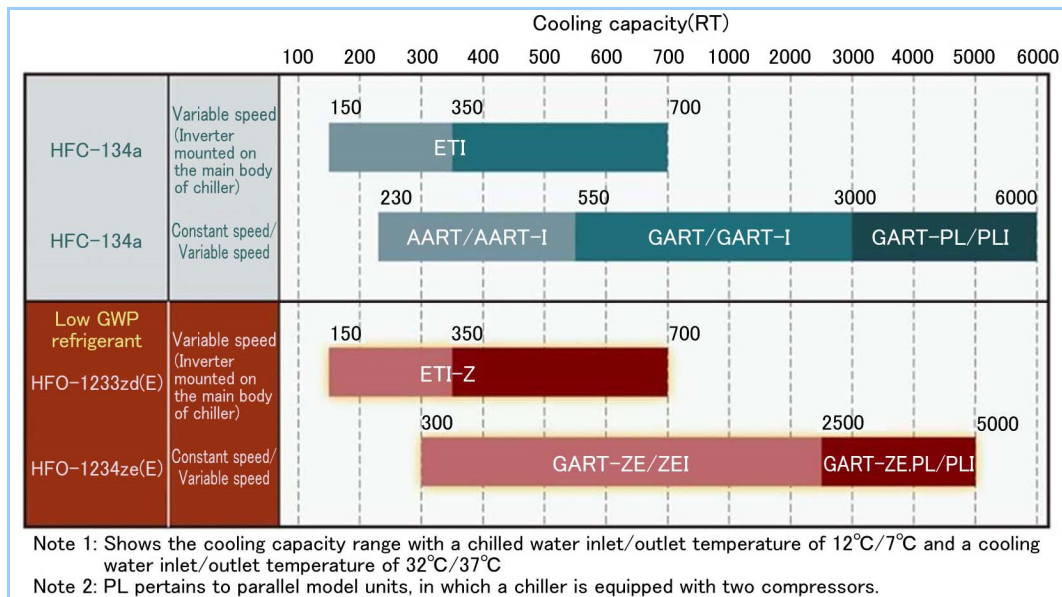


Figure 3 Product line-up of our centrifugal chillers



Figure 4 ETI-Z series and GART-ZE/ZEI series

3.2 Heat pumps

Equipment to generate heat of 90°C is in high demand for industrial and commercial applications. Although currently natural gas or oil-fired boilers and electric heaters are widely used, these are being replaced by heat pumps for the sake of reducing CO₂ emissions and running costs. Unlike conventional heat pumps in which heat is transferred from hot water, our units are characterized by using air as a source of heat, along with the advantages in terms of installation cost and space requirements. Described below are the two types of heat pumps, one of which the final product is dispensed in the form of hot air and the other in hot water.

(1) Air to air heat pump: “Neppu-ton”

In “Neppu-ton,” a heat pump is employed to supply hot air of 60°C to 90°C, which is mainly used in drying processes at factories. To produce such hot air, two compressors are arranged in series to create a two-stage compression cycle.⁵ The refrigerant used is R134a, which can be heated to 90°C or higher corresponding to the saturation pressure. To improve the efficiency, the indoor unit has an electronic expansion valve to realize optimized control of the refrigerant, while DC motors^(*) are installed in the compressor and the air blower. A COP of 3.5^(*) has thus been achieved.

To demonstrate its energy-saving effect, “Neppu-ton” was incorporated in the drying system of a dry laminator.^(*) The incorporated system diagram is given in **Figure 5**. In the

existing drying system, a steam boiler was used as a heat source, by which hot air of 70°C to 80°C was generated to dry films. “Neppu-ton” is added to produce hot air, which is supplied in this drying process.

- *1: Inverter-driven brushless DC motors
- *2: COP stands for Coefficient of Performance and can be obtained by dividing the heating capacity required to supply hot air by the electricity consumed. The higher the COP, the more efficient the device.
- *3: The value under the conditions in which the outside air temperature is 25°C (with a 70% relative humidity), the indoor unit intake air temperature is 20°C and the air temperature from the vent is 80°C.
- *4: A machine by which two or more films are glued together. Hot air is used to cure the adhesive between the films.

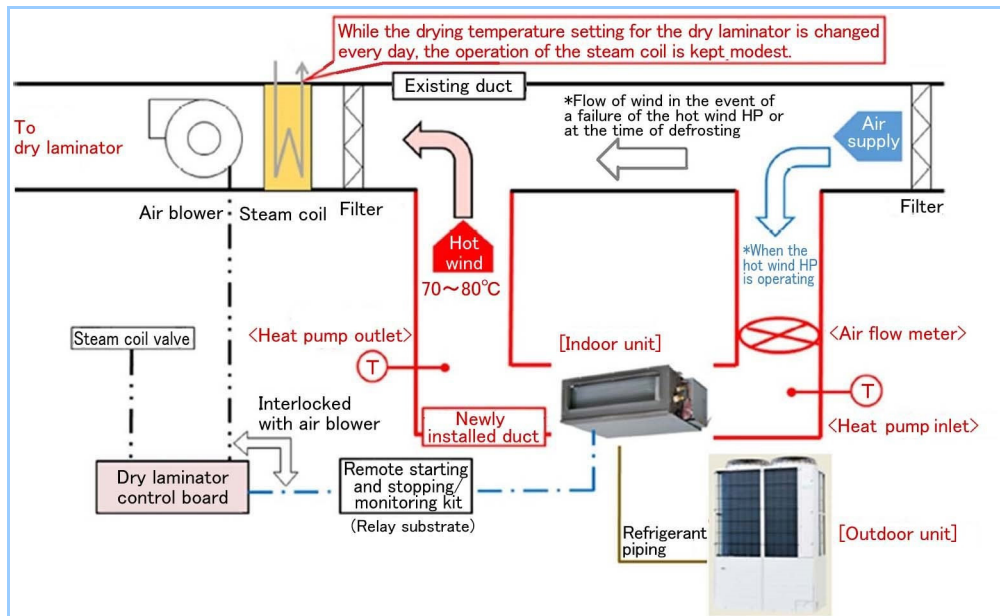


Figure 5 System diagram of the Neppu-ton incorporated dry laminator

The graphs in Figure 6 are based on the measurement results between November 27 and December 28, 2016, which indicate the high every-saving performance of “Neppu-ton” with the energy consumption, CO₂ emissions and running cost nearly halved. Moreover, the defrosting caused the drying temperature to fluctuate within the range of $\pm 5^{\circ}\text{C}$, which was confirmed to be an allowable fluctuation range of dry laminator drying temperature. Thus, it has been demonstrated that “Neppu-ton” can function as a year-round alternative to boilers. We contribute to the conservation of the global environment by promoting this product in industrial fields.

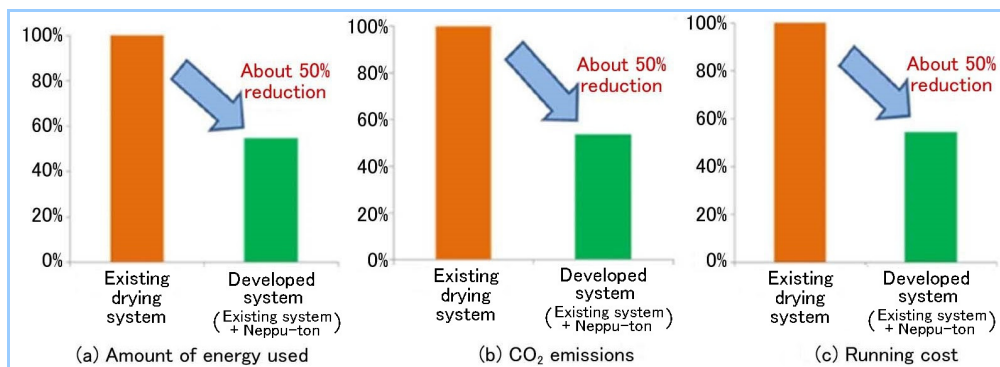


Figure 6 Effects produced by the incorporation of Neppu-ton into the dry laminator

(2) Air to water heat pump for commercial use: “Q-ton”

The rated heating capacity of “Q-ton” ranges between 30 kW and 480 kW (combined use of a maximum of 16 units), which can supply a maximum of 120 tons of 60°C hot water daily.⁶ The refrigerant circuit mainly consists of the compressor, water heat exchanger (gas cooler), expansion valve and air heat exchanger (evaporator). With the use of CO₂ as a refrigerant (GWP = 1), hot water of 90°C can be efficiently supplied. Moreover, the hot water storage tank can be downsized, the amount of heat stored can be adjusted through the hot water storage temperature and the hot water can also be used for washing.

In conventional heat pumps, as the outside air temperature is lowered, the heating capacity declines. This problem slowed down the spread of their use in cold regions. However, it was successfully dealt with by the introduction of a two-stage compression gas injection cycle in which the compression process is completed in two stages and a gaseous refrigerant is injected at its intermediate pressure to prevent the amount of circulating refrigerant in the gas cooler from falling when the outside air temperature is low. Consequently, the expected rated heating capacity (performance) can be achieved at an outside air temperature of -7°C . More than 70% of the capacity can be secured at an outside air temperature of -20°C , thus making it possible to supply hot water of 90°C at an outside air temperature as low as -25°C . These new features have made “Q-ton” applicable to facilities in cold regions, including hotels, hospitals and cafeterias.

Table 4 shows the year-round demonstration testing results in cold regions and the calculation conditions.⁷ Although the testing was carried out in especially cold regions in Japan, no problems occurred even during operation in the winter. When compared with a conventional boiler (with a supposed system efficiency of 0.8), “Q-ton” can cut the consumption of primary energy by 15-20%, running cost by 53-61% and CO₂ emissions by about 30%. Thus, its environmentally-superior performance relative to boilers has been confirmed. A contribution to the mitigation of global warming can be expected from the perspective of not only the adoption of a non-fluorocarbon refrigerant, but also the reduced CO₂ emissions during operation. We will promote this product as a replacement for boilers.

Table 4 Q-ton demonstration test results in cold regions and calculation conditions

Test region	Annual COP		Obtained effect (reduction from the conventional level)		
	Q-ton alone	Overall	Energy consumption (expressed as primary energy consumption)	Running cost	CO ₂ emissions
Northern Iwate Prefecture	3.04	2.72	20%	61%	29%
Eastern Hokkaido	2.73	2.56	15%	53%	29%

Test region		Unit price	CO ₂ emissions	Conversion to primary energy
Northern Iwate Prefecture	Electricity	Summer: JPY 11.65/kWh Others: JPY 10.70/kWh	0.546kg-CO ₂ /kWh	9.76GJ/10 ³ kWh
	Kerosene	JPY 90 /L JPY 90/L	2.49kg-CO ₂ /L	36.7GJ/kL
Eastern Hokkaido	Electricity	Night: JPY 6.5/kWh Day: JPY 13.0/kWh	0.680kg-CO ₂ /kWh	9.76GJ/10 ³ kWh
	Fuel oil A	84 JPY /L	2.71kg-CO ₂ /L	39.1GJ/kL

* Other conditions: the system efficiency of the existing boiler is 0.8.

3.3 Condensing units

In the condensing units for cold storage warehouses (refrigerator/freezer) or showcases, R404A is used as a refrigerant. As the GWP is 3943 (which is high), it is necessary to replace it with a low GWP refrigerant in response to the Kigali Amendment. For this purpose, we have developed the cold source “C-puzzle” series using the natural refrigerant CO₂ with a GWP of 1, and put them on the market in April 2017.⁸

Despite CO₂ being slightly inferior to the conventional HFC refrigerant in terms of efficiency, “C-puzzle” realizes higher efficiency by employing our proprietary CO₂ two-stage scroll/rotary compressor system (which is also used in “Q-ton”), an intermediate-pressure injection system for gaseous refrigerant, optimized design specifications for the gas cooler and the adoption of DC motors.

As the operating pressure of CO₂ is higher than HFCs, crossover piping and loading devices need to be designed in such a way as to withstand high pressure. However, with the use of our gas injection cycle, the refrigerant can be transferred to the loading devices (e.g., showcases and unit coolers) while the pressure exerted by the refrigerant is at the intermediate level after the first stage of expansion, thereby successfully keeping the design pressure of these components (i.e., cross piping and loading devices) low. As a result, piping construction has become easier and less costly, and the reliability against refrigerant leakage has been improved. We will also develop large-capacity condensing units and expand our sales in the showcase and cold storage warehouse markets.

3.4 Transport refrigeration units

As generally predicted, an increasing number of electric vehicles will be rapidly taking the place of internal combustion engine vehicles. To respond to this trend, we have already launched all-electric-driven transport refrigeration units, which do not require power from the engine.⁹ In our all-electric-driven transport refrigeration units, the environmental performance has been markedly improved by incorporating the energy-saving air conditioning technologies that we have acquired over years, such as compressor inverter control. Summarized below are the major environmental features.

(1) Reduced electricity consumption with the use of inverter compressor

When regulating the air temperature in a highly-insulated space such as the cargo compartment of a refrigerator truck, once the temperature has reached the target level, the termination of refrigeration unit operation causes the inside air temperature to change only gradually. Research was conducted regarding the control mechanism of compressor operation that can minimize the electricity consumption when applied in such an environment. By optimally combining the compressor's on/off control with the control of operating compressor efficiency, we have reduced the electricity consumption by 10% in refrigerating operation relative to the case in which the compressor rotates at a constant speed. **Figure 7** shows the relationship between the compressor rotation speed and the electricity consumed while the temperature is maintained.

In our all-electric-driven transport refrigeration units, the electricity consumed by the unit can be controlled by an external on-demand request, thereby enabling energy-saving management of the entire refrigerator truck in a manner coordinated with the vehicle side.

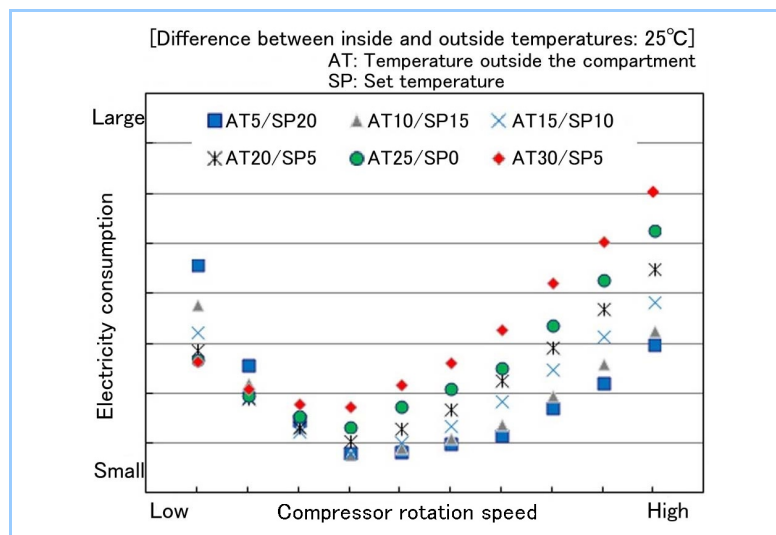


Figure 7 Relationship between the compressor rotation speed and the electricity consumed while the temperature is maintained

(2) Heating with a heat pump

Foreseeing the widespread use of electric vehicles with no available source of heat, we are in the process of adopting a heat pump heating system in transport refrigeration units with the aim to be first in the industry and look to gradually expand the range of applicable models. Comparisons regarding heating capacity and electricity consumption are given in **Figure 8**. When compared with the hot gas bypass heating system (which is commonly used in transport refrigeration units at this point), the heat pump heating system can more than double the heating capacity at a higher efficiency. Thereby the electricity consumption during heating operation to maintain the inside air temperature is reduced by nearly 70% from the level of our product with the conventional system. When it comes to a multi-temperature refrigeration unit enabling simultaneous storage of cargo at different controlled temperatures during transport, we succeeded in making the heat pump operate simultaneously for both cooling and heating (known as the cooling/heating dual system) and made it practically applicable for the first time in the industry. The energy-saving performance of multi-temperature refrigeration units has also been substantially improved.

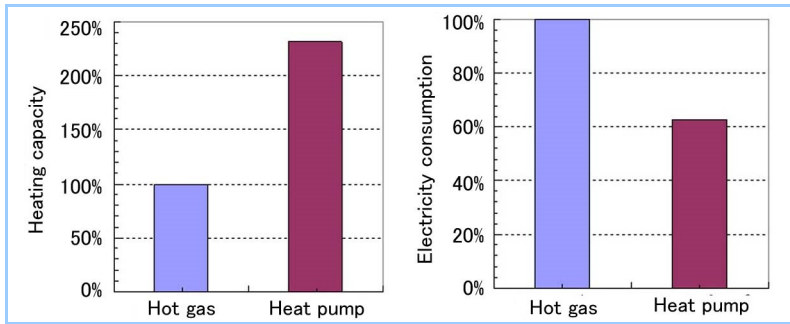


Figure 8 Heating capacity and electricity consumption comparisons

(3) Use of low GWP refrigerant

At this point, R404A is a commonly-used refrigerant in refrigeration units for creating low temperature environments. However, as the GWP is 3943 (which is quite high), there is strong need for replacing it with a low GWP refrigerant. Ahead of our competitors in the industry, we adopted R410A (with a GWP of 1924, nearly half that of R404A) as a refrigerant for all-electric-driven transport refrigeration units. In conventional engine-driven transport refrigeration units, an open compressor is installed, and the sealing of the compressor's main axis makes it difficult to use R410A as a refrigerant because of its high operating pressure. However, the development of an electric compressor has enabled the air-tightness necessary to use R410A. We will continue to actively adopt low GWP refrigerants wherever possible for the reduction of environmental impact.

3.5 Air conditioners

In both residential and commercial air conditioners, R410A has been widely used as an alternative refrigerant to fluorocarbons. However, because the GWP is high (1924), its replacement by a lower GWP refrigerant is underway.

(1) Domestic engagement

The Fluorocarbon Emissions Control Law stipulates that refrigerants with a GWP of ≤ 750 should be adopted, without fail, by 2018 for residential air conditioners and by 2020 for commercial air conditioners, with some exceptions such as floor-standing air conditioners. Accordingly, we have proceeded with the development of air conditioners using R32 with a GWP of 677.

As residential air conditioners, we released the TS series in 2015 (which were our first models using R32) and in the following year, all the residential air conditioners available in the Japanese market accommodated the need for R32 adoption. For commercial air conditioners, on the other hand, the ultra-high efficiency EXCEED HYPER series was launched using R32 in 2016, followed by the completion of refrigerant replacement for all 6-horsepower or lower models except for floor-standing air conditioners in 2017.

Utilizing the characteristics of R32 to realize higher efficiency, the Annual Performance Factor (APF) has been improved by as much as 15% compared with conventional models.

Figure 9 shows these comparison results.

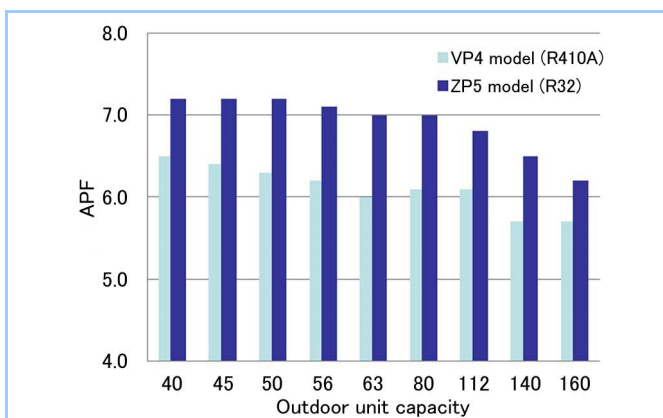


Figure 9 APF comparison between our new commercial air conditioner (R32) and the previous model (R410)

(2) Overseas engagement

In other countries, the adoption of low GWP refrigerants is also underway in response to the Kigali Amendment to the Montreal Protocol. Under the revised F-gas Regulations, European countries will gradually reduce the total amounts of HFCs in use (as a CO₂ equivalent). It is also obligatory to use, by 2025, a refrigerant with a GWP of 750 in all split-type air conditioners with an amount of charged refrigerant of less than 3 kg. To meet this requirement, we have already made R32 available in overseas models since 2017 and are proceeding with their promotion.

4. Conclusion

This report introduces how we have taken on the conservation of the global environment as our prime responsibility and have dedicated our efforts to developing environmentally-safer products. In centrifugal chillers, condensing units and air to water heat pumps for commercial use, we succeeded in adopting refrigerants with the lowest environmental impact possible. Moreover, to reduce CO₂ emissions, we also developed air to air heat pumps as a boiler alternative and all-electric-driven transport refrigeration units without the need for power from the engine. With regard to air conditioners, we are still in search of a better refrigerant that can replace R410A. The ideal refrigerant to be adopted must be superior in terms of economy, performance (thermophysical properties) and safety, and make it possible to meet the final reduction goals set by the Kigali Amendment. All companies including refrigerant manufacturers are undertaking the challenge to develop such a product.

In February 2015, the “Paris Agreement” was adopted at COP21^(*5) in Paris, which determines the legal framework after 2020. As in the case of the Kyoto Protocol, it is a legally binding agreement and the goal is to keep the rise of the world average temperature within 2°C from the preindustrial level. It is therefore considered that environmental issues will become increasingly important. We will also continue to take on these challenges as our priority and contribute to building a sustainable low-carbon society by developing environmentally-safer products.

*5: COP21 is the 21st Session of the Conference of the Parties to the United Nations Framework Convention on Climate Change. COP stands for Conference of the Parties.

References

1. The Japan Refrigeration and Air Conditioning Industry Association, World Air Conditioner Demand by Region, April 2017
<http://www.jraia.or.jp/statistic/demand.html>
2. Ministry of the Environment, Ministry of Economy, Trade and Industry, Outline of the Freon emission control method, January 2015
<http://www.env.go.jp/earth/gaiyou.pdf>
3. Ministry of the Environment, Ozone Layer Protection Promotion Office, Adoption of amendment of the Protocol relating to HFC (Kigali revision) of the 28th Conference of Parties Conference of the Montreal Protocol, October 2016
http://www.meti.go.jp/policy/chemical_management/ozone/files/law_ozone/MOP28_Kigali_Amendment.pdf
4. Togano, Y. et al., “ETI-Z, GART-ZE/ZEI” Centrifugal Chillers using Low-GWP Refrigerants for Full Capacity Range, Mitsubishi Heavy Industries Technical Review Vol. 54 No. 2 (2017)
5. Kobayashi, T. et al., Development of “Neppu-ton” Hot Wind Generator Using High-efficiency Air to Air Heat Pump, Mitsubishi Heavy Industries Technical Review Vol. 54 No. 2 (2017)
6. Toyotaka Hirao, High-efficiency CO₂ Heat pump systems, Japan Society of Refrigerating and Air Conditioning Engineers sponsorship seminar ” The latest correspondence to a refrigerant problem and view”, June 2011
7. Shigeru Yoshida, The Commercial CO₂ Heat Pump Water Heater available to Cold Regions, REFRIGERATION Vol.89 No.1039, May 2014
8. Mizuno, H. et al., Development of “HCCV1001” Commercial Condensing Unit Employing CO₂ as Natural Refrigerant, Mitsubishi Heavy Industries Technical Review Vol. 54 No. 2 (2017)
9. TEJ100A/TEJ100AM Electric Driven Inverter Type Refrigeration Units for Heavy Duty Trucks, Mitsubishi Heavy Industries Technical Review Vol. 54 No. 2 (2017)