EXAMINATION REGARDING AIR-CONDITIONERS AND HEAT PUMPS, USING THE NEXT GENERATION REFRIGERANTS

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Abstract: In recent years, to meet the Montreal Protocol requirements, reduction of the fluorocarbon refrigerants designated by the Protocol has almost been completed in Japan by replacing them with HFCs that have zero-Ozone Depletion Potential (ODP).However, although HFCs have zero-ODP, some HFCs known as alternatives to HCFCs have high Global Warming Potential (GWP). Now it has become imperative to find refrigerants that could satisfy the requirements of both the Montreal Protocol and the Kyoto Protocol at the same time. When choosing refrigerants, we should not focus on GWP only since the degree of global warming impact is greatly affected by various factors such as capacity of equipments in use, safety, economy, and Life Cycle Climate Performance (LCCP).When used in heat pump systems, those factors vary from country to country according to the climate of regions, their operating conditions, the way they are used, electricity rate system, and applicable laws and regulations. In this paper, we propose a notion of diversity of refrigerant choice, in which we suggest the most suitable refrigerants for various applications in various regions by employing the best available technology. Our proposal includes not only developed countries but also developing countries whose contribution to global warming has been becoming more significant than before due to their rapid economic growth.

Key Words: Refrigerant, GWP, LCCP

1 INTRODUCTION

In recent years, the refrigeration and air conditioning industry and academic researchers have been studying the possibility of adopting new refrigerants to save energy and reduce the environmental impact to help mitigate global warming. When selecting a new refrigerant, environmental consciousness, safety, performance, economy and other aspects, as shown in Figure 1, under given application and operating conditions must be considered to make a scientific and rational choice to have a substantial impact on global warming. At present, possible new refrigerants have been identified for car air conditioners, which present relatively few technological problems to be overcome. On the other hand, more studies are needed on new refrigerants for stationary air conditioners (Taira and Nakai 2010). Figure 2 shows trends in adoption of next-generation refrigerants for use in air conditioning and hot water supply. In Figure 2, we see that since the Kyoto Protocol came into effect, Europe has led the way in adoption of next-generation refrigerants, prioritizing leakage prevention and implementation of substance control regulations. These substance control regulations have first been applied to automotive air conditioners, which feature relatively few technical hurdles and easily replaceable refrigerants. Regulation of stationary air conditioners is the next on the agenda.

In fact, in highly eco-conscious Europe, a great amount of research is already underway on new low-GWP (Global Warming Potential) refrigerant candidates such as ammonia, hydrocarbons (HC), CO2 and others, as well as on air conditioning, refrigeration and hot water supply systems employing these natural low-GWP refrigerants. In terms of synthetic

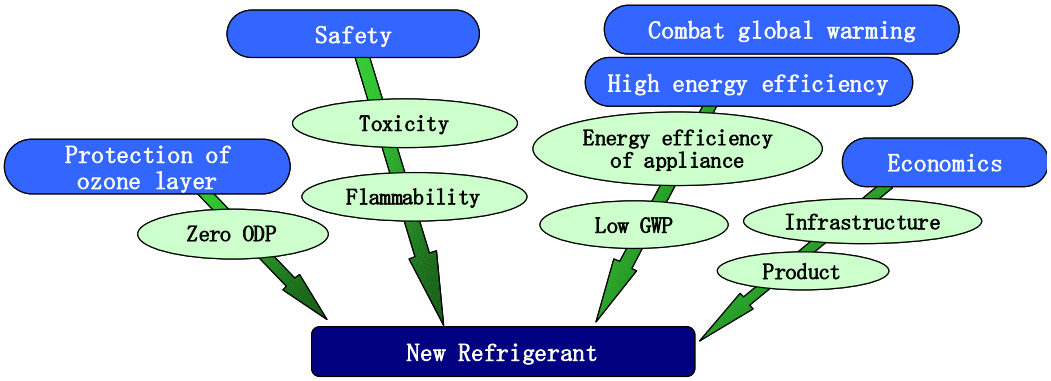


Figure 1: Examination Item for selection of New Refrigerant

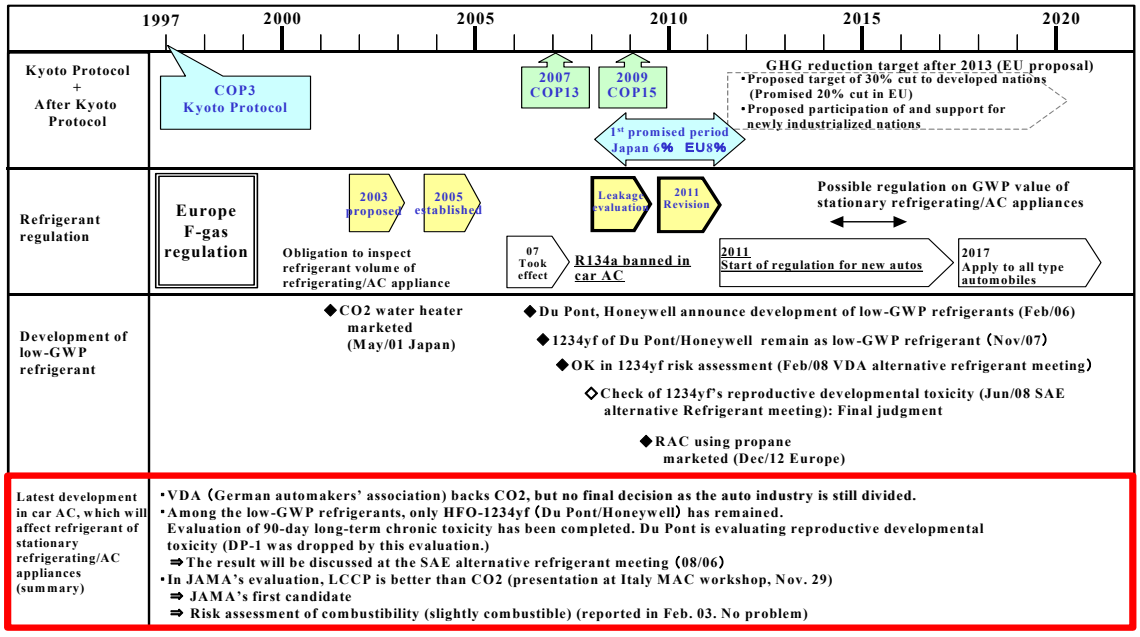


Figure 2: New refrigerants for air-conditioning and hot water supply

Table 1: Properties of refrigerants compared to R410A

		Cond. Press Mpa*1 @45℃	Volumetric Capacity*1 kJ/m3	COP	GWP (IPCC4)	Flamm-ability	Toxicity
HFC	R410A	2.73	100%	100%	2088	No	Low
	R32	2.80	100-110%	100-103%	675	Low*2	Low
	HFO-1234yf	1.15	40-45%	100-106%	4	Low*2	Low
	R32/yf Mix *3 (50% : 50%)	2.26	80-85%	100-103%	340	(Low)	(Low)
HC	R290 (Propane)	1.53	55-60%	100-106%	<3	High	Low

*1 : Calculated by NIST Refprop Ver.8.

low-GWP refrigerants, R32 has already been developed. Some major refrigerant manufacturers have developed HFO-1234yf, intended as a new low-GWP refrigerant option, which is now undergoing wide-ranging assessments. Meanwhile, in Japan, 2001 saw the introduction of heat-pump water heaters employing CO2, a natural refrigerant and one of the next-generation refrigerant candidates. Around the same time, air conditioners using propane went on the market, albeit in negligible quantities. However, national and regional variations in operating conditions, usage configurations, electric power networks, and laws and regulations mean that natural refrigerants are not a panacea for prevention of global warming, nor always the best possible option.

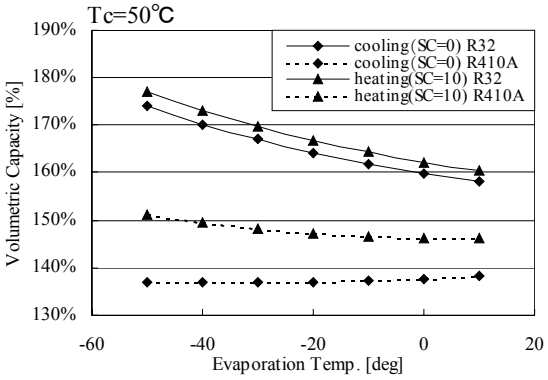


Figure 3: Volumetric Capacity (compared with R22)

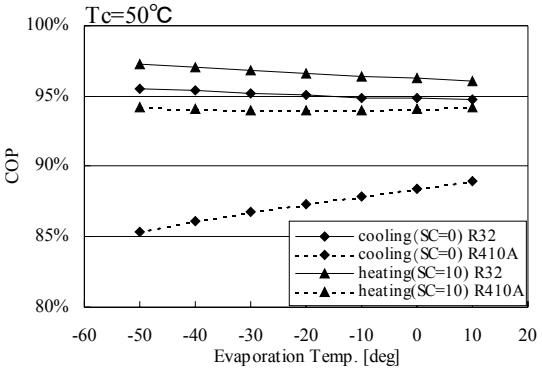


Figure 4: COP (compare with R22)

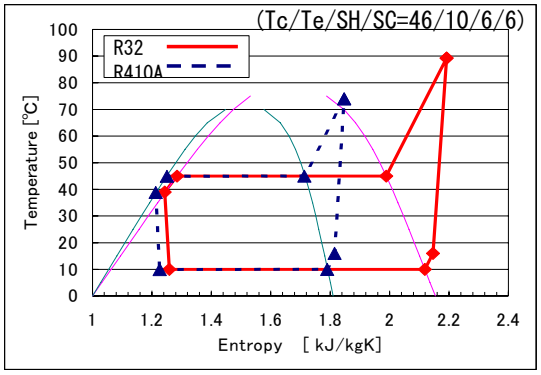


Figure 5: Characteristics of R32 on T-S diagram

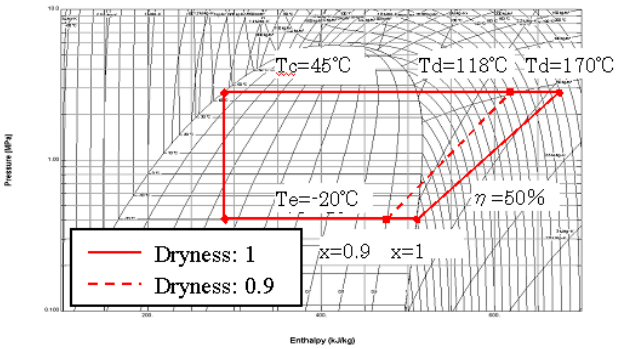


Figure 6: To reduce discharge temp of R32

Table 1 shows properties of new refrigerants. Each has a problem in either flammability, efficiency or GWP. No refrigerant is perfect – which means that the most suitable refrigerant must be chosen depending on the application and the volume of refrigerant to be charged.
For residential and package air conditioners, possible new refrigerants under consideration include fluorocarbon refrigerants with very low flammability - HFO-1234yf and R32 - and their mixture, as well as propane, a hydrocarbon refrigerant with superior performance and low GWP but high flammability. For VRV, which requires a large volume of refrigerant, CO2 is also a possibility. Technological development is underway to put them to practical use. Against this background, a new category “lower flammable refrigerants with a maximum burning velocity of <= 10cm/s” (2L) has been created in safety standards for HFO-1234yf, R32 and other refrigerants whose flammability is so low that they may be able to be used as virtually nonflammable in practical use when treated properly. This move is intended to promote the use of these refrigerants, which offer advantages in combating global warming.

Among the numerous new refrigerants, this paper focuses on R32, which makes a substantial contribution to energy conservation and requires minimal modification of equipment configurations. This paper discusses various considerations regarding the benefits and challenges of practical adoption of R32.

2 COMPARISON OF REFRIGERANT CHARACTERISTICS

Figure 3 and Figure 4 show a comparison of theoretical performance of R410A and R32. Considering the possibility of switching from R22 equipment, they are presented as in comparison to R22 (Yajima et al. 2010)

Compared with R410A, R32’s volumetric capacity ratio and COP tend to increase as the evaporation temperature drops. R32 is advantageous in cold areas because the lower the evaporation temperature, the higher the volumetric capacity ratio.

As shown in Figure 5, a disadvantage of R32 is that its discharge temperature is higher than that of R410A. A refrigerant with larger volumetric capacity ratio tends to have a higher discharge temperature due to an increase in the specific heat ratio.

3 MAIN SOLUTION OF PROBLEM POSED BY R32

There are three main issues with R32. One is the rise in discharge temperature, another is selection of refrigerant oil, and the third is the protocol for handling of slightly flammable refrigerants.

First, let us consider the high discharge temperature. Figure 6 shows discharge temperature considerations for a cycle employing R32. In Figure 6, compressor efficiency is set at 50%, condensation temperature at 45 °C, and evaporating temperature at -20 °C, and an example of discharge temperature change when compressor intake dryness changes are given. At compressor intake dryness 1, the discharge temperature is 170 °C, not a viable value when taking into consideration compressor and refrigerant oil reliability. It is possible to bring the discharge temperature from 170°C to 120 °C by lowering the compressor intake dryness to 0.9 from 1.

However, excessive lowering of the intake dryness runs the risk of liquid compression occurring inside the compressor, or obstruction of compressor lubrication due to a decline in refrigerant oil viscosity inside the compressor. Accordingly, it is necessary to pinpoint the dryness limit in accordance with the characteristics of the compressor and refrigerant oil, and to take this limit into consideration.

Table 2: Frequency of low temperature conditions

Mean Temp.	Days of Mean Temperature (Jan.–Dec. 2009)						
	Beijing	Cicago	N.Y.	Munich	Helsinki	Moscow	Sapporo
< −10℃	1	10	0	1	12	24	1
< −15℃	0	2	0	0	2	7	0
< −20℃	0	2	0	0	0	3	0
< −25℃	0	0	0	0	0	0	0

Min. Temp. (day)	Days of Minimum Temperature (Jan.–Dec. 2009)						
	Beijing	Cicago	N.Y.	Munich	Helsinki	Moscow	Sapporo
< −10℃	18	34	4	12	39	42	5
< −15℃	1	9	0	5	10	24	0
< −20℃	0	2	0	0	1	7	0
< −25℃	0	1	0	0	0	2	0

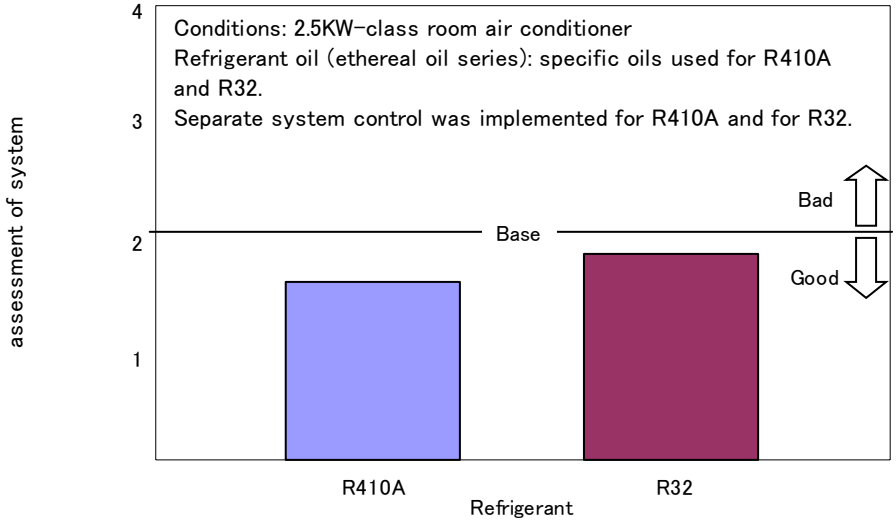


Figure 7: assessment of system

Part of the evaporation capacity of the refrigeration cycle will be consumed by cooling of the discharge gas, leading to a decline in COP. However, as evidenced by Table 2, under the winter temperature conditions in major cities of the world, operating conditions such as these occur infrequently, and year-round impact on COP is negligible.

When the evaporating temperature reaches -30 °C, it is necessary to decrease dryness in order to further lower the discharge temperature. When -30 °C conditions constitute a steady state, it is likely to have a major impact on compressor reliability and performance, necessitating the consideration of measures such as use of different compressor material or refrigerant oil, or use of a liquid or gas injection cycle.

Next, Figure 7 shows the results of a system reliability evaluation after 4,000 hours of operation, using R410A and R32. The evaluation test was conducted under the operating conditions of a 2.5KW-class room air conditioner. In accordance with refrigerant characteristics, operation was carried out with different system control software for R410A and for R32. Ether-series refrigerant oil, (however, detailed formula was selected to be appropriate to the unique properties of each refrigerant) was used in the compressor for both R410A and R32. The results showed that product reliability after 4,000 hours when R32 was used with the next-generation refrigerant oil X was well within the same scope as, and nearly equal to currently employed R410A.

Regarding the flammability of R32, a new category, class 2L (lower flammable refrigerants with a maximum burning velocity of <= 10cm/s), has been created in addition to the existing flammability classification, as shown in Table 3, ASHRAE34/ISO817 safety classification. Organizations in various countries are in the process of establishing a practical safety standard. R32 and HFO-1234yf belong to the class A2L, and a realistic safety standard different from that for A2 will facilitate its practical application. As shown in Figure 8, the charge limit for R32 and HFO-1234yf in relation to room area is higher than that for R290 and other flammable refrigerants, so their practical application is foreseeable in the near future.

Table 3: ASHRAE34/ISO817 safety classification

A1 (No toxicity, noncombustible)	A(B)2L (A: No toxicity, slightly combustible, B: Toxic, slightly combustible)	A2 (No toxicity, combustibility: low)	A3 (No toxicity, combustibility: high)
R744(CO_2) R410A R22	R717(ammonia, B2L) **HFO-1234** **R32**	R152a	**R290 (propane)**

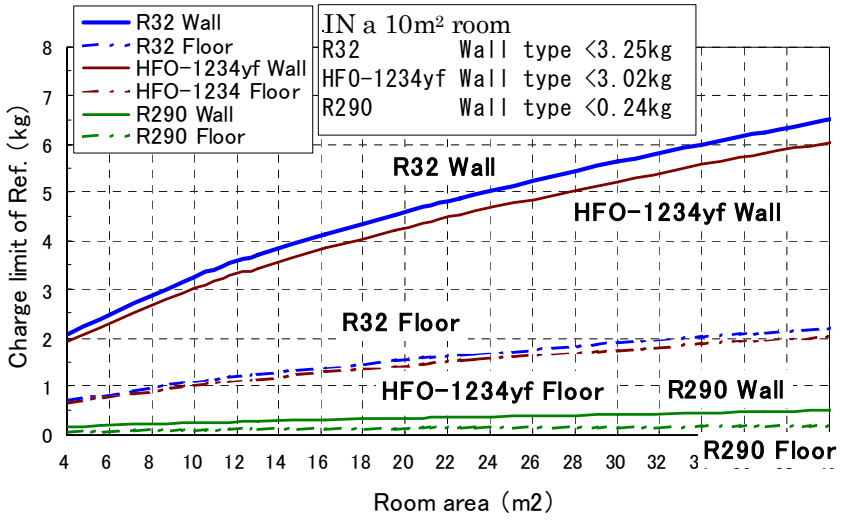


Figure 8: Charge Limit or Refrigeration

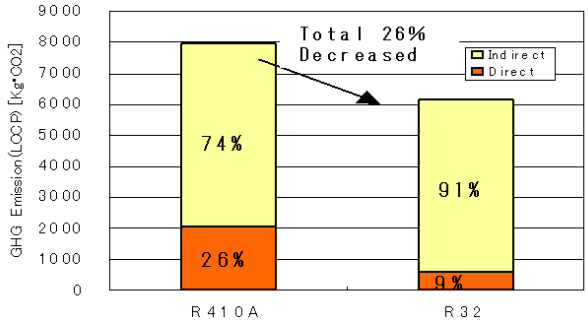


Figure 9: RAC 4kW LCCP(Amount of GHG Emission)

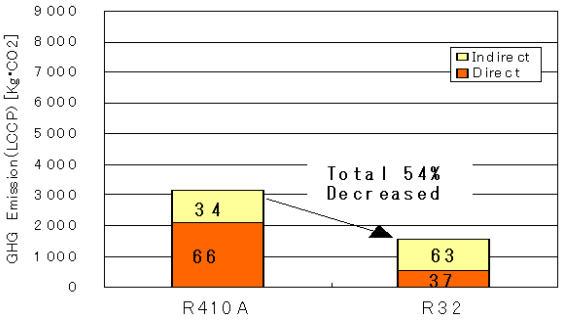


Figure 10: RAC 4kW LCCP(Amount to GHG Emission) Indirect 20%

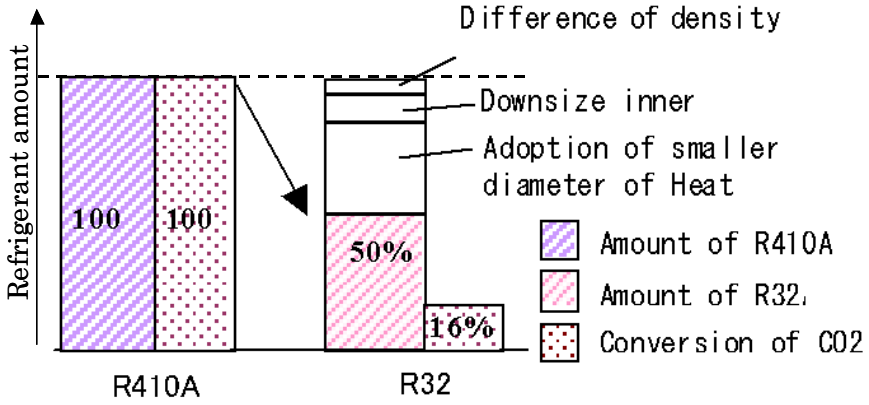


Figure 11: Reduction of Refrigerant

4 POTENTIAL TO MITIGATE GLOBAL WARMING

The impact of an air conditioner on global warming throughout its lifetime is evaluated based on life cycle climate performance (LCCP), an index covering both the direct impact of its refrigerant and the indirect impact of consumption of energy. The direct impact is calculated by multiplying the amount of refrigerant emitted into the atmosphere by its GWP. As far as direct impact is concerned, the lower the GWP, the better.

Figure 9 shows R32's effect to reduce LCCP based on APF of JISC9612. R32's GWP is about one third of that of R410A, so the direct impact can be reduced to one third. As mentioned earlier, R32 has higher efficiency than R410A, so it can reduce indirect impact by cutting annual and instantaneous power consumption. By switching from R410A to R32 refrigerant, LCCP can be reduced by 26%.

According to some reports (Tahara and Takada 2010), (Takada and Tahara 2010), actual operating time of air conditioners in total is only about 20% of the figure used by JISC9612. Figure 10 shows calculations based on operating time of 20% of that JIS9612 describes. LCCP is reduced to 54% of that of R410A..

Switching to R32 whose the GWP is one third of R410A will change the ratio of direct and indirect impacts. Direct impact by the refrigerant will not be a dominant factor in emission of greenhouse gasses anymore. Continued efforts to reduce indirect impact are important.

Reducing the amount of refrigerant charge is another way to reduce direct impact (Yajima et al. 2000). As R32 has larger volumetric capacity than R410A, the amount can be reduced to 50% of that of R410A for equal performance, as shown in Figure 11, by design optimization such as using thinner heat exchanger tubes, and downsizing the compressor cylinder as well as by the difference of density.

Table 4: New refrigerants compartmentalization

Application	Existing refrigerant	Possible new refrigerant		**Remarks**
MAC	R134a	HFO-1234yf CO_2		- HFO-1234yf is waiting for result of toxicity evaluation to be released in June 2008.German manufacturers support CO_2.
Direct expansion RAC	R410A	High outdoor temperature, warm area	R32 other	- HFO-1234yf is a low-pressure refrigerant and not suitable for direct expansion system due to pressure loss. Measures must be taken to reduce pressure loss. - CO_2 has low cooling COP, which is about 65% that of HFC, so it is not suitable for application in warm areas. Its heating COP is about 85% that of HFC and capacity drop under low outdoor temperature is small, which makes CO_2 a possible candidate in cold areas. - R32 can replace R410A because property of R32 is similar to R410A's.
		Cold area	R32 CO_2	
Positive displacement chiller	R134a	Large size	HFO-1234yf	-R134a can be simply replaced with HFO-1234yf.
	R407C R410A	Medium to small size	R32 Other	
Centrifugal water chiller	R134a	HFO-1234yf		-R134a can be simply replaced with HFO-1234yf.
Water heater, hot water heating	R134a	Hot water heating	HFO-1234yf	- HFO-1234yf and its mixed refrigerant for heating water to about 65℃ - CO_2 has advantage in applications to heat low-temperature water to high temperatures, such as Eco Cute - CO_2 is not suitable to applications to circulate hot water, because its COP drops sharply when the temperature of returning water is high.
	R407C R410A	Water heater & hot water heating	R32 Other	
	CO_2	Hot water supply only	CO_2	

5 CONCLUSION

Our studies so far have revealed the following:

- R32 has higher discharge temperatures than R410A, but by lowering the compressor inlet dryness, it can be used under climate conditions found in many cities.
- The problem of flammability is being solved as standards are in preparation to treat it as having very low flammability.
- R32's effect to mitigate global warming is significant when air conditioner operating time is assumed to be shorter than that assumed by JIS.
- Because R32 has higher volumetric capacity, the charge amount can be reduced.
- Product reliability after 4,000 hours when R32 is used with the next-generation refrigerant oil X is well within the same scope as, and nearly equal to currently employed R410A.

All in all, it can be concluded that R32 is a refrigerant enabling quick action against global warming, since it has fewer hurdles to its practical application and early launch of products can be expected.

However, R32 is not almighty. Other refrigerants can be suitable depending on environment and intended purpose. Table 4 shows a "refrigerant map" listing the various applications of the next-generation refrigerants. It is evident that, at present, rather than narrowing down refrigerants excessively, the most effective way of combating global warming is to use the most efficient refrigerant in each field and selecting the most appropriate refrigerant for each application from among a wide range of options.

Along with development of an innovative new refrigerant, which would require extensive studies before commercialization, introducing a quick, practical measure is another way to contribute to the fight against global warming.

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