The Development of High Temperature Water Heater using CO_2 Heat Pump

Contents

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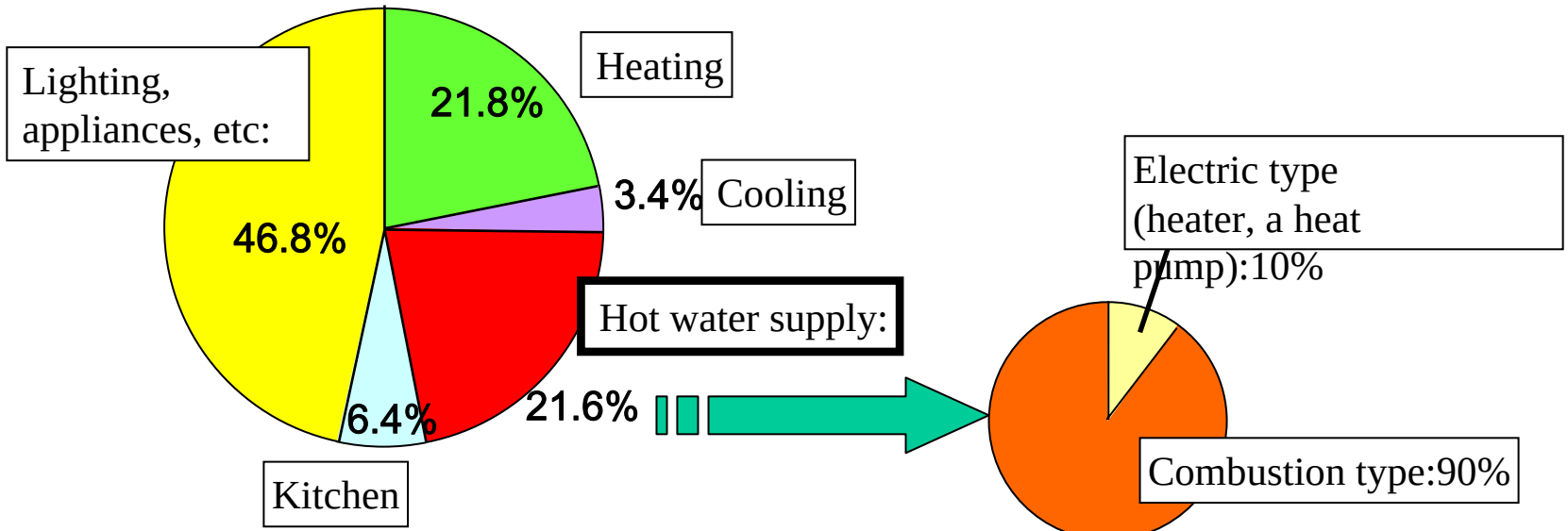
1. Introduction

Background : Problem of Japanese GHG emission situation

- Water heating emits more than 20% of residential CO_2 emission in Japan.
  ⇒It's a very important challenge to reduce CO_2 emission from this usage.
  (CO_2 emission due to residential energy is about 14% of Japanese total emission)
- Furthermore, more than 90% of water heaters are combustion-type
  ⇒There is a good chance for heat pump to reduce CO_2 emission
- Mid-night power is surplus due to nuclear power plants. Electricity charge is determined according to the demand and the supply correlation.
  ⇒An efficient thermal storage system utilize mid-night power is ideal!



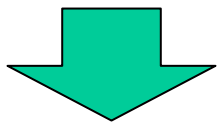
Household direct CO_2 emission in Japan 2005 (Greenhouse Gas Inventory Office of Japan)

1. Introduction

Background : Challenges in refrigerant choice

- HFC is energy efficient and reasonable cost
  ⇒Effectiveness of heat pump water heater as a measure against global warming may be diminished by high GWP of HFC.
- Research to utilize CO_2 for air conditioning have been under way for more than decade. (in Europe and Japan in particular)
  ⇒For air conditioning, it has not been considered commercially practical yet.

However, CO_2 for water heating has potential of equivalent or better performance than HFC



We decided to develop high temperature water heater for thermal storage system with CO_2 heat pump.
Compressor as well as water heat exchanger are developed to meet the properties of CO_2.

2. Refrigerant characteristics

Comparison of a refrigerant

- HFC R410A, R407C have considerably higher COP but far higher GWP than CO_2. Even if the heat pump water heater has lower CO_2 emission, the effect to reduce global warming impact (against fossil fuel heating systems) would be deteriorated if HFC refrigerant is not fully recovered.
- CO_2 is not suitable for the reversible air source heat pump because of its low theoretical COP especially in cooling operation. But, it has good potential for high temperature heat pump due to trans-critical operation in high pressure side.

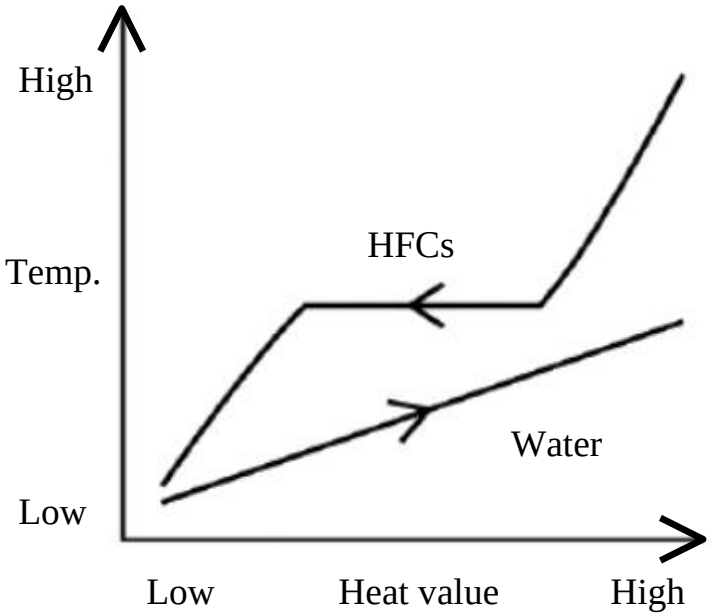
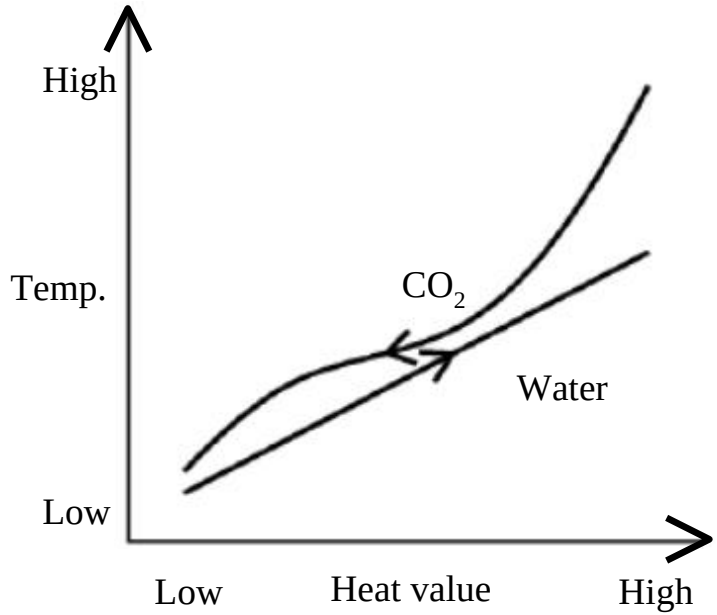
Refrigerant	HFCs		Natural refrigerant	
			CO_2	
	R410A	R407C	A/C	High Temp
ODP*1	0	0	0	
GWP*2	1975	1652.5	1	
Flammability	No	No	No	
Toxicity	Low	Low	Low	
Discharge Pressure [MPa]	2.7-3.0	1.8 -2.0	9.5 -11	
COP [relative to 410A]	100	95 -100	60-80	90

Note:*1: Ozone depletion potential，*2: Global warming potential（IPCC2001）

2. Refrigerant characteristics

Comparison of a refrigerant

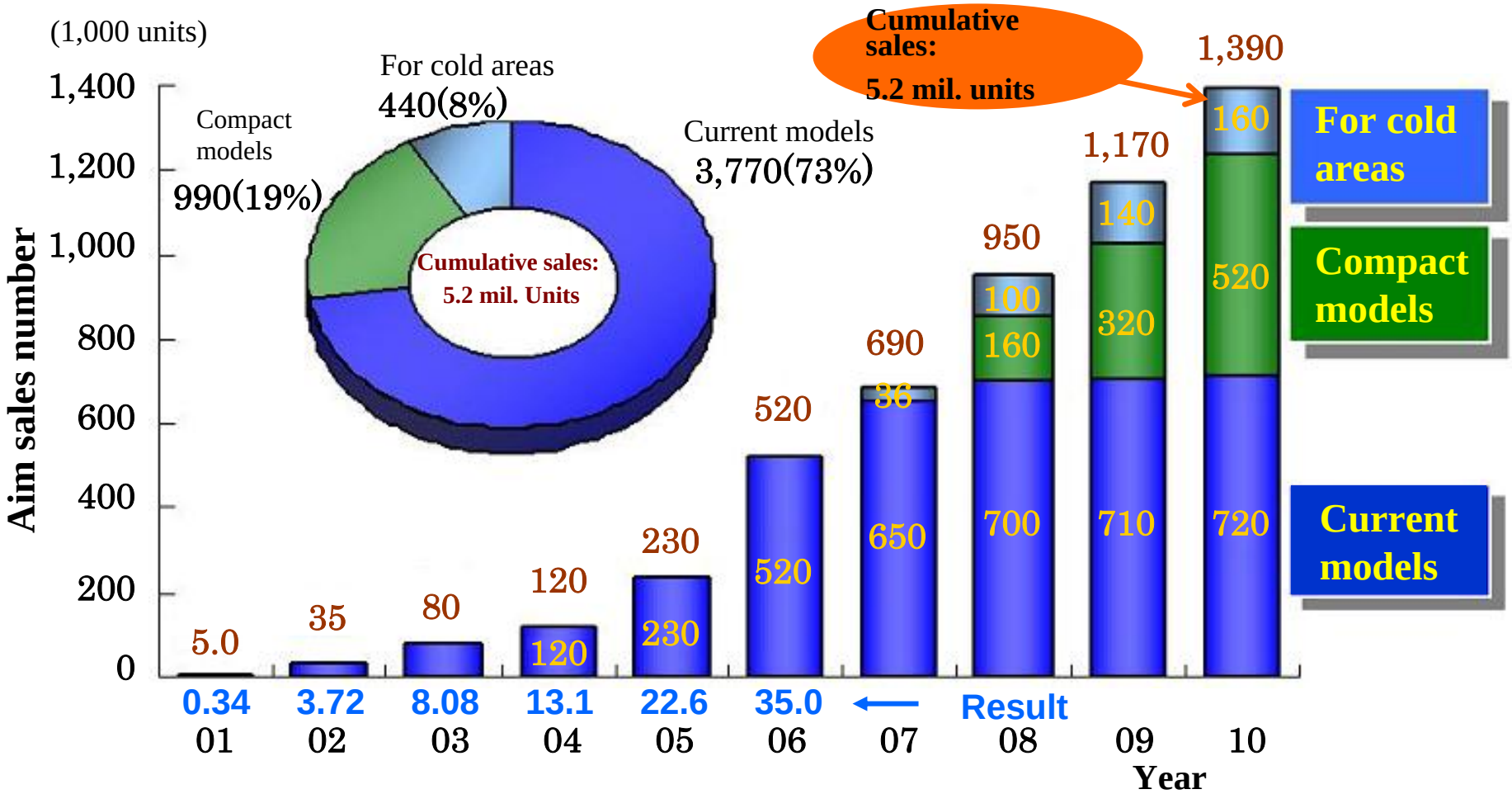
- CO_2 is suitable for water heaters and other once-pass heating applications with large temperature differences.

Refrigerant	HFC	CO_2
Figure of outline	 **1-Stage Cycle using typical Fluorocarbon**	 **Trans-Critical Cycle using CO_2**
Characteristics	Fluorocarbons heat low-temperature water by high condensing temperature. ⇒Irreversible loss is unavoidable, so the theoretical efficiency is low.	Fluid in a supercritical condition does not change the phase. The temperature of CO_2 drops gradually as the heat is transferred. ⇒Loss is smaller!

3. Advantages of CO_2 water heater

CO_2 Water heater sales target and result in Japan

- Cumulative sales targeted at 5.2 million units by 2010
  Result is lower, but expanded by 50% every year.



CO_2 Water Heater sales target (as of 2005) and result (up to 2006)

3. Advantages of CO_2 water heater

System of CO_2 water heater & thermal storage

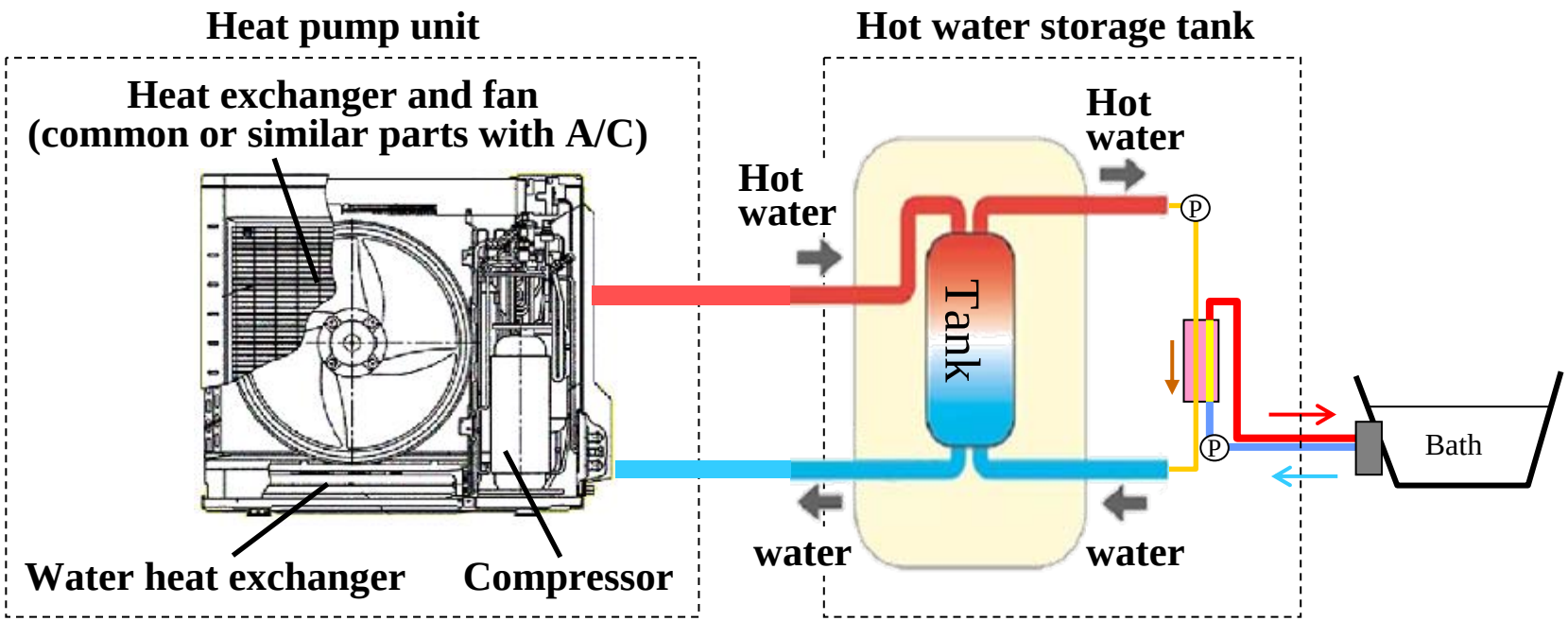
- The CO_2 heat pump water heater heats up water to high temperature at mid-night that is stored in storage tank.
- Appropriate temperature water is supplied by mixing hot stored water and cold water for day or evening time use.
- Bath water can be re-heated indirectly by stored hot water.

Kitchen RC

Bathroom RC

Heat pump unit

Hot water storage tank



3. Advantages of CO_2 water heater

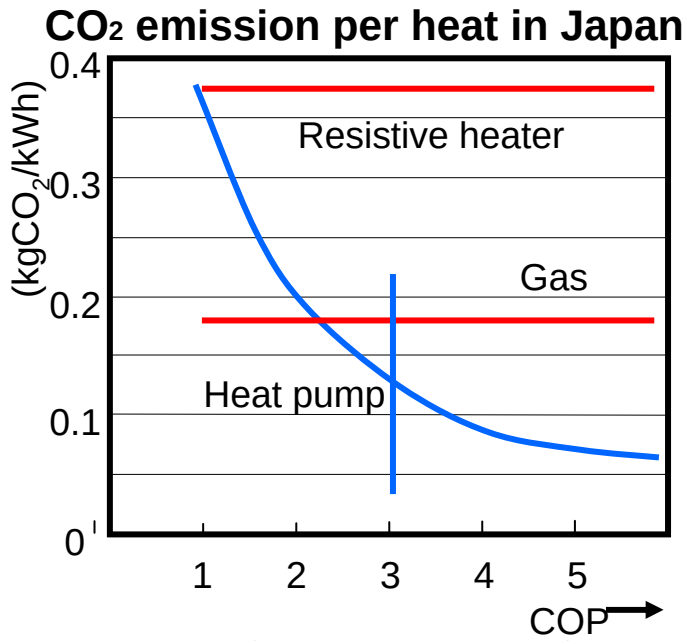
■ Environment-friendly.
CO_2 emissions: about 2/3-1/2 of gas water heater

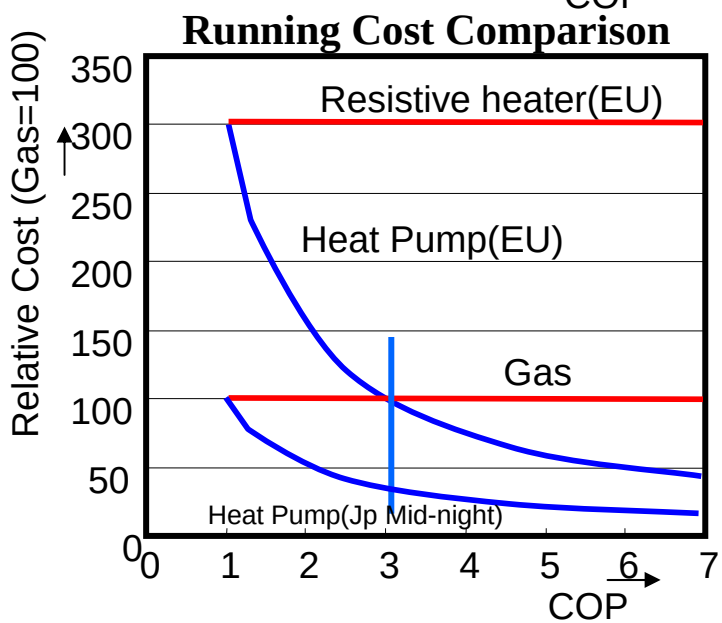
■Safe
Heats water up to 90°C without flame

■Energy efficient against conventional resistive heater system
- Annual average COP = 3.0 or higher

■Incentive & Low running cost
- Heat water at mid-night when electric power is cheaper under current electricity rate in Japan →Running cost is about 1/4 to 1/5 that of gas
- Cost comparison with European Average gas and electricity shows little cost merit.

(See right figure)

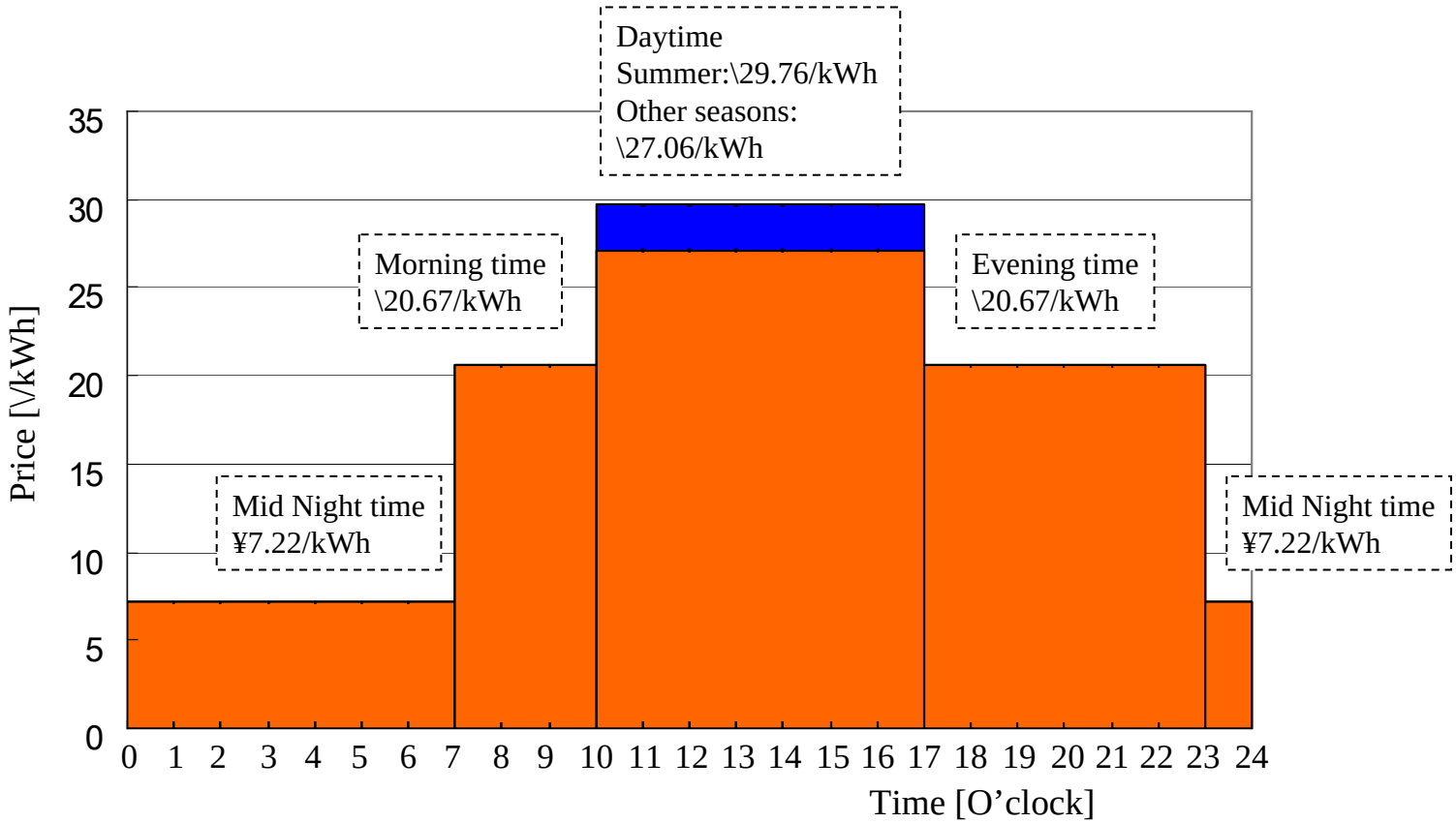




3. Advantages of CO_2 water heater

Heating water at mid-night

- Electricity rate is determined according to the demand and the supply correlation. The water heater is operated to maximize the benefit of this kind of rate system.



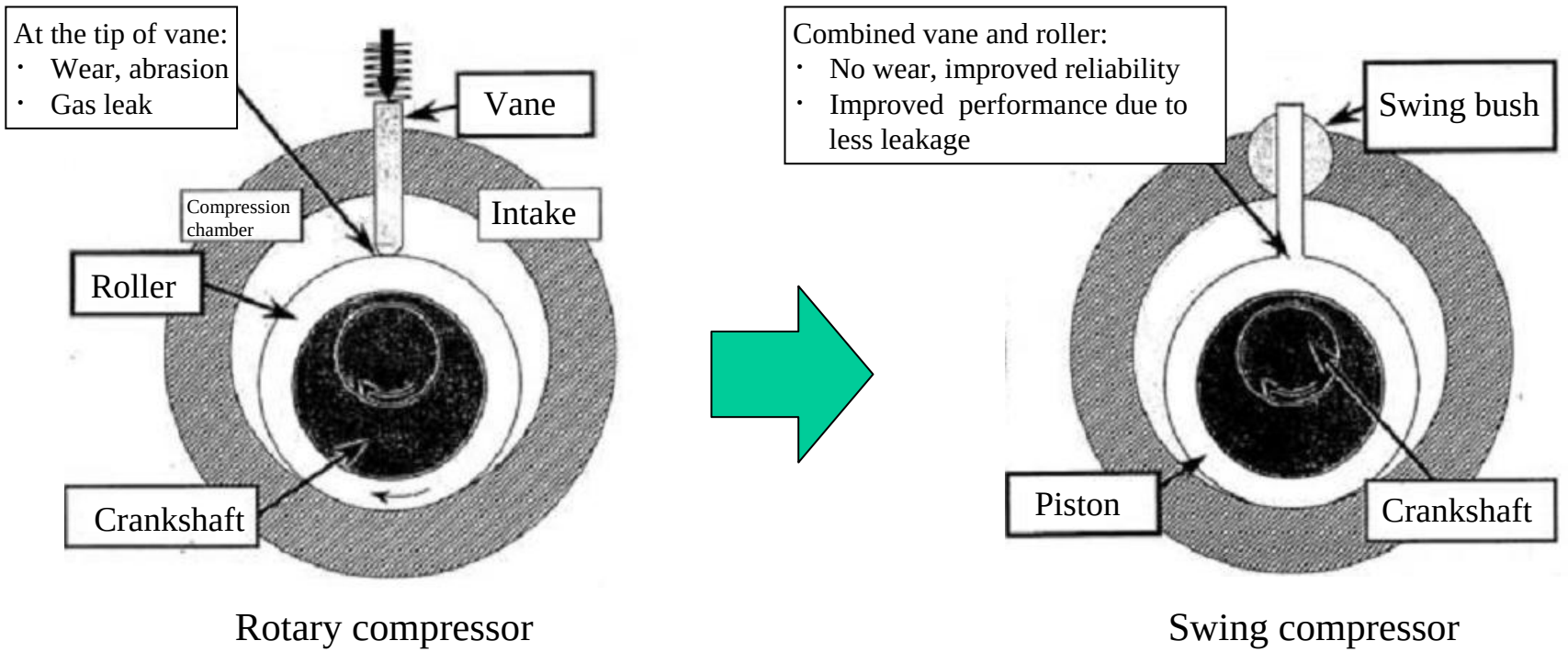
Electricity rates by time and season(KANSAI ELECTRIC POWER CO.)

*web of KEPCO 2008

Development of swing compressor

- Operating pressure of CO_2 is higher than R410A, so it enhances the merit of swing compressor. Combined vane and roller of swing compressor achieves higher reliability and lower leakage than conventional design.

Refrigerant	R410A	CO_2
Discharge pressure [MPa]	3.0	12.0
Intake pressure [MPa]	0.8	3.5
Pressure difference[MPa]	2.2	8.5
Sound Velocity [m/sec at 50°C 1MPa]	192	273



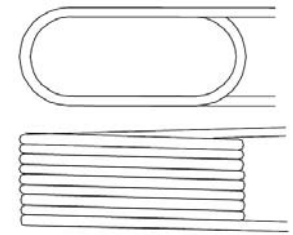
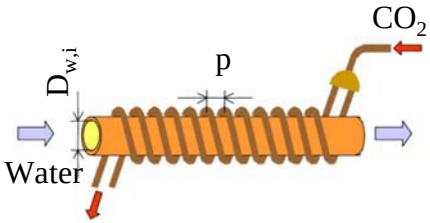
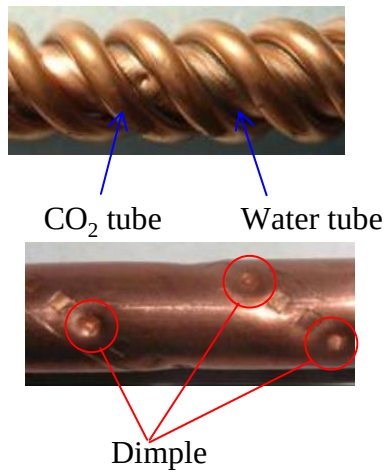
Rotary compressor

Swing compressor

Comparison of water heater exchanger

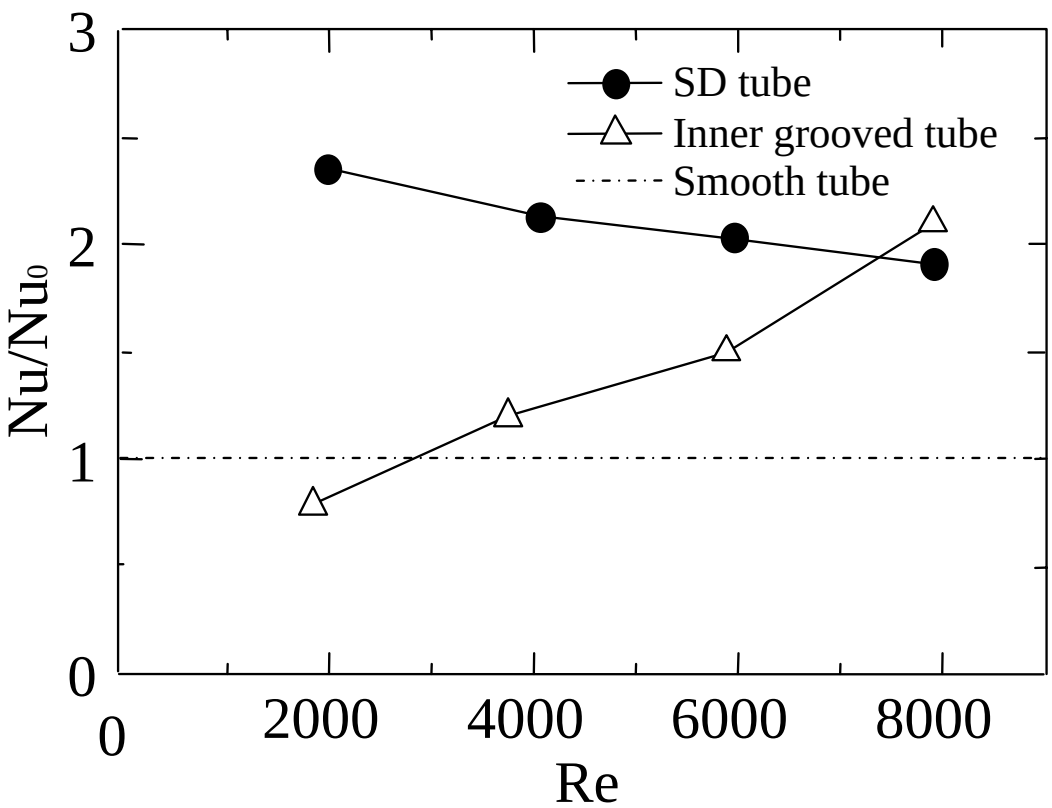
- The weight and volume of the dimpled water heat exchanger is about 10 to 30% less than those of a double-tube exchanger.

Photo of appearance of water heat exchanger

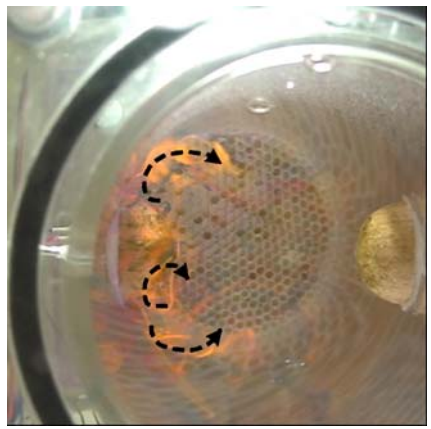
	Traditional	Developed	
Spec	Double tube	Smooth tube (initial)	Dimpled (latest)
Outline of shape			
Volume ratio	1.00	0.89	0.89
Weight ratio	1.00	0.74	0.64
Performance	1.00	1.00	1.00

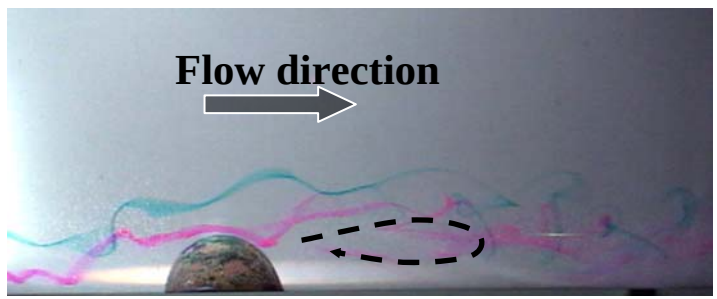
Visualization of flow in a dimple tube

- Performance of the water heat exchanger improved by adopting the dimpled heat transfer pipe (SD tube) in the water side.
  - Heat transfer is doubled from smooth tube.
  - Enhanced heat transmission can be seen especially in low Reynolds flow.



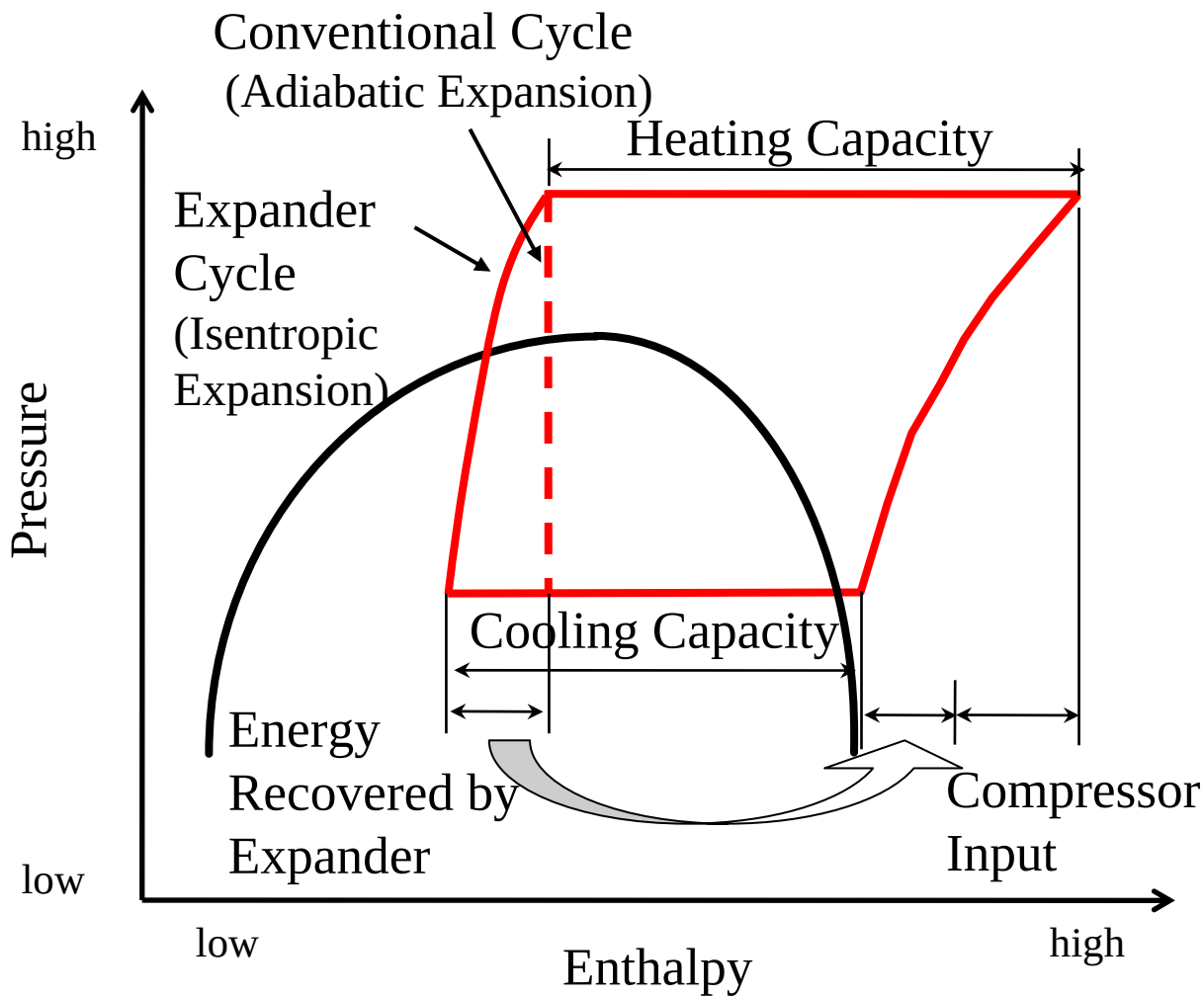
Turbulent flow occurs by a dimple.





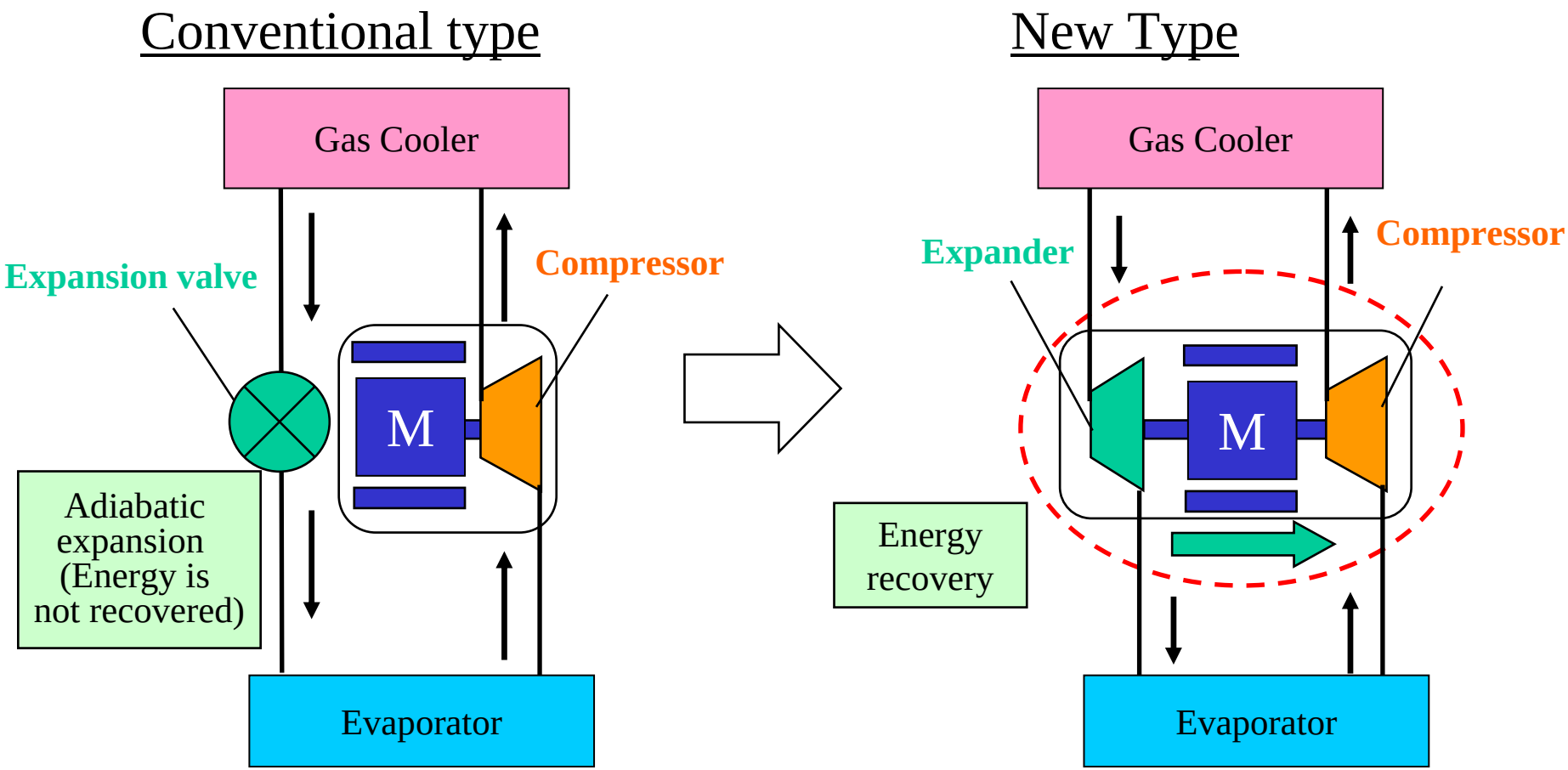
Principle of expander cycle

- Energy recovered by expander is transmitted to compressor to reduce power input.
- Cooling capacity increases because enthalpy of CO_2 at expander exit decreases.



Function of expander compressor

- The expander transmits the recovered energy directly to the compressor to reduce compressor power input.

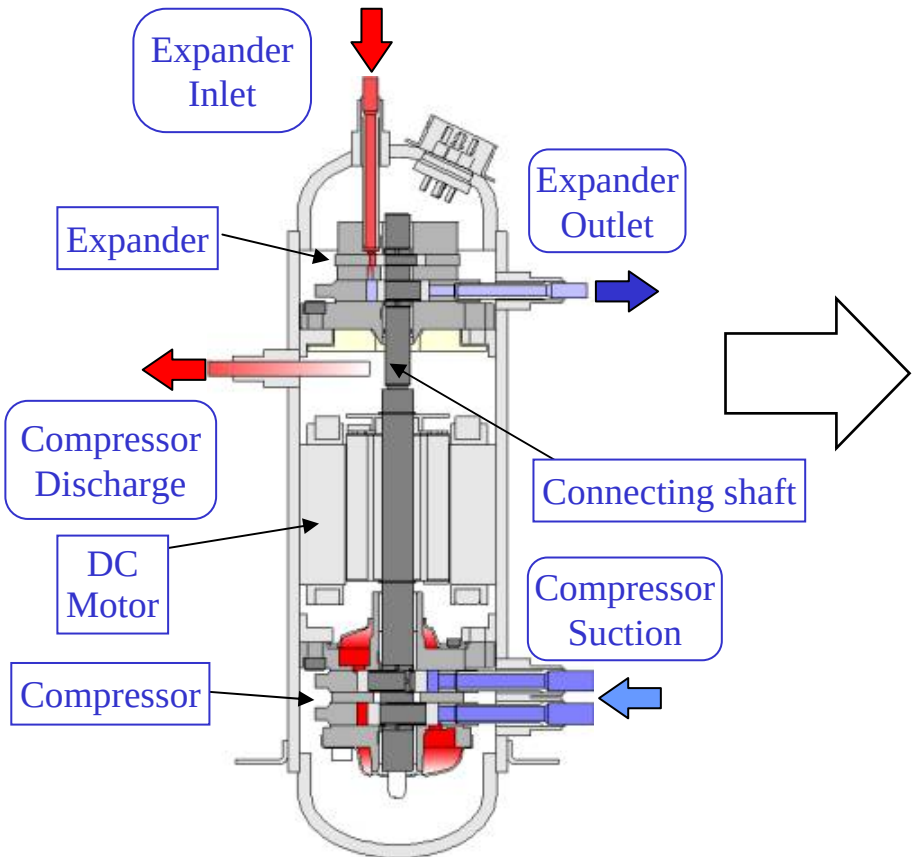


Expander-compressor

- Connecting shaft transmit power from expander to compressor.

  ⇒The technical development of water heater with this technology has been carried out under NEDO (New Energy and Industrial Technology Development Organization of Japan) financial support project.

Cross Section



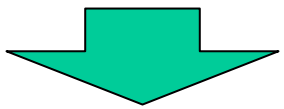
Outlook

6. Conclusion

- CO_2 is suitable for high temperature water heaters because it has low GWP and equivalent COP. In addition, it can heat water to temperatures up to 90°C without a heater.

- For domestic use, both the user and the electric power company can benefit from CO_2 heat pump operation at mid night.
  → The user can reduce the operating cost while the power company can level electric power load.

- In Japan, commercialization of residential CO_2 heat pump water heater started in 2001. Accumulated sales exceeded 1 million units in 2007.



- By development of water heat exchangers, expander-compressor, other key components, and improvement of system technology, heat pump in the future may make a greater contribution to the challenge against global warming.
- **This kind of thermal storage system may be useful to developing countries where nuclear or uncontrolable natural energy such as wind power is utilized.**

DAIKIN

We want to contribute to
a global environment
through heat pump technology
⇒Slogan ; “Heat pump relieve the earth”

Acknowledgement ;
- NEDO
- Central Research Institute of Electric Power Industry
- The Federation of Electric Power Companies of Japan
- Tokyo , Kansai , Chubu , and Kyushu Electric Power Company

Thank you for your attention!