DEVELOPMENT OF THE ICE THERMAL STORAGE MULTI-SPLIT SYSTEM AIR CONDITIONER UTILIZING AN ALTERNATIVE REFRIGERANT

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Abstract

In recent years, the penetration of air conditioners and office automation facilities increase the electric power demand disparities among seasons and even for daytime and nighttime uses in Japan. Thus, the ice thermal storage air conditioners have been rapidly spreading to level the annual power load. Also, the needs of the HFC refrigerant, which has zero ozone depletion potential, are increasing from a viewpoint of ozone layer protection.

In cooperation with The Tokyo Electric Power Co., Inc., Chubu Electric Power Co., Inc., The Kansai Electric Power Co., Inc. and Daikin Industries Ltd., the ice thermal storage multi-split system air conditioner "EXG50Z series", utilizing the HFC refrigerant, R407C, has been developed to contribute power load-leveling and energy saving.

In this paper, the technical features of the ice thermal storage multi-split system air conditioner "EXG50Z series" are clarified.

1 Introduction

Figure 1 shows the variations in daily electric power consumption in Japan. The disparity between the maximum load in the daytime and the minimum load in the nighttime, which has resulted from the spread of air conditioners, has been increased year after year.

Figure 2 shows the combination of the energy source to meet the changing demand. The electricity use in the nighttime leads to less consumption of fossil fuels and helps restrain the emissions of CO_2, NO_X and SO_X.

The air conditioning system utilizes nighttime electric power for the ice thermal storage, which energy is converted into air conditioning use in the daytime, thus effectively kick out the electric power load peaks of the day. And this system also has merits concerning of environmental considerations.

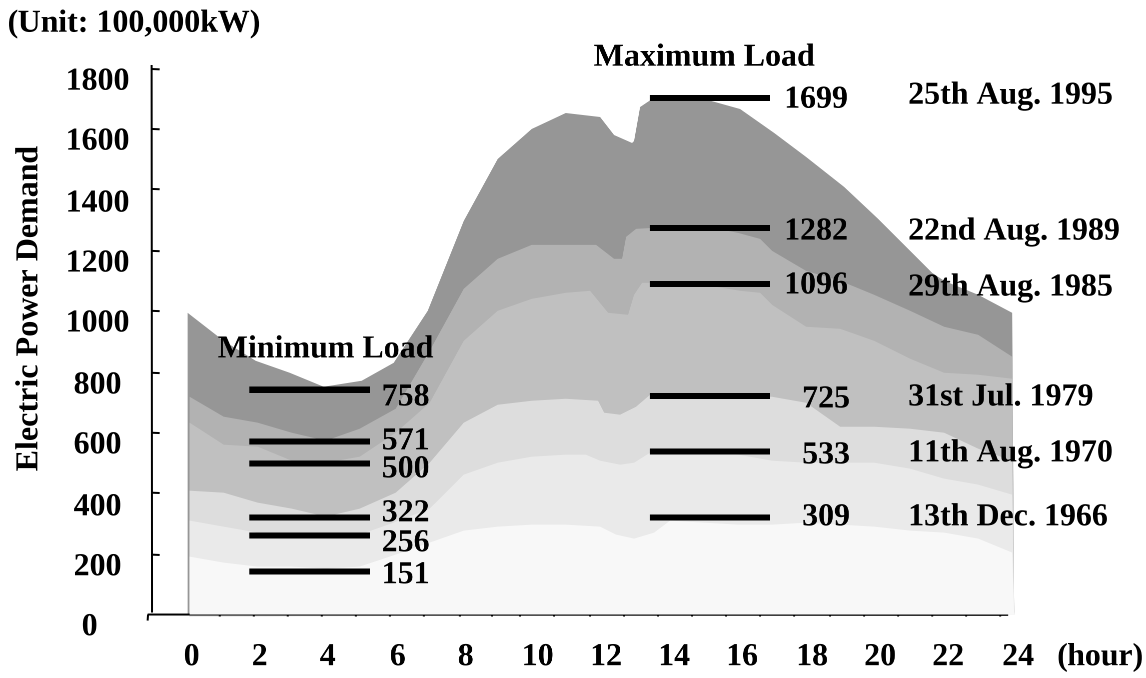


Figure 1. Variations in Daily Electric Power Consumption in Japan

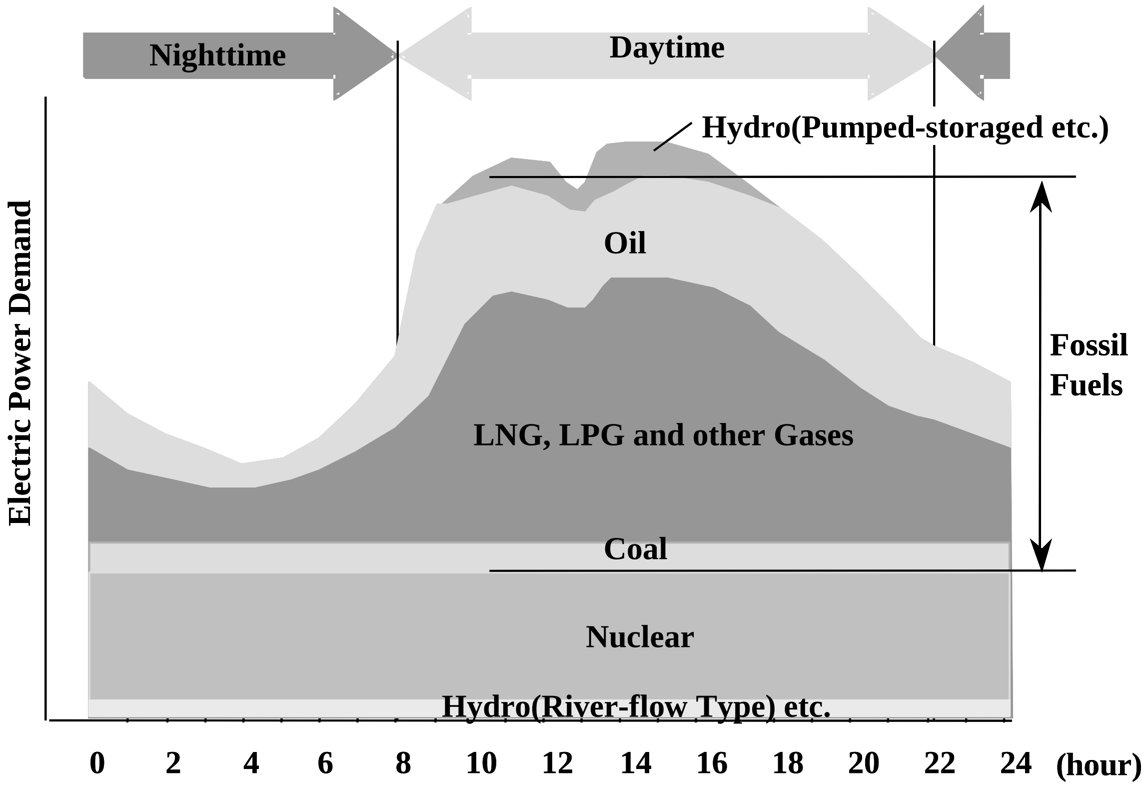


Figure 2. Combination of Energy Sources to Meet Changing Demand

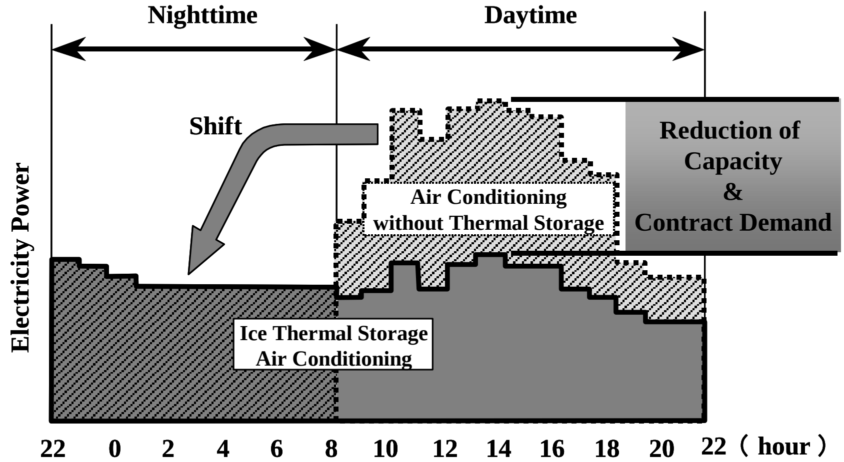


Figure 3. Daily Load Curve of Ice Thermal Storage Air Conditioning System and Air Conditioning System without Thermal Storage

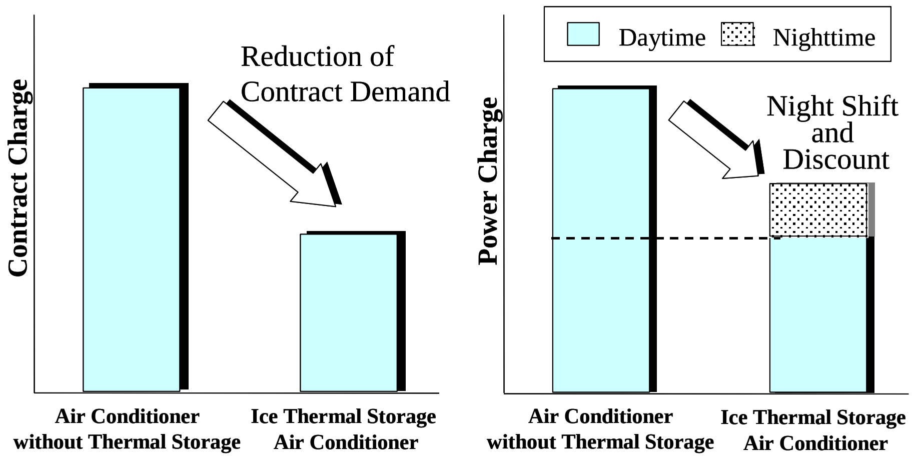


Figure 4. Reduction of Electricity Charge of Ice Thermal Storage Air Conditioning System against Air Conditioning System without Thermal Storage

Figure 3 shows daily load curve of the ice thermal storage air conditioning system and the air conditioning system without thermal storage. By cutting the electric power for air conditioning through the use of nighttime electric power and diminishing the peak time electric power, the system makes it possible to lower the contract electric power.

Figure 4 shows the reduction of the electricity charge of the ice thermal storage air conditioning system against the air conditioning system without thermal storage. As the contract electric power is reduced, the contract charge is also reduced. And the power charge is reduced by use of inexpensive nighttime power. In addition, subsidies for the ice thermal storage air conditioning system installation as well as tax benefits are offered by political foundation. The advantages of the ice thermal storage air conditioning system have been recognized among users.

2 Development of New Ice Thermal Storage Multi-split System Air Conditioner "EXG50Z series"

Under the circumstances above mentioned, the major three electric power companies (The Tokyo Electric Power Co., Inc., Chubu Electric Power Co., Inc., and The Kansai Electric Power Co., Inc.) and Daikin Industries Ltd. have developed a new ice thermal storage multi-split system air conditioner "EXG50Z series".

Figure 5 shows the performance improvement of the ice thermal storage multi-split system air conditioner. Figure 5(a) shows the COP of the multi-split system air conditioners. COP is the instantaneous energy efficiency defined as the cooling capacity divided by the electric power. The COPs of the ice thermal storage air conditioners are increased by use of ice produced in the nighttime. Additionally, the COP of "EXG50Z series" is 45% higher than that of conventional ice thermal storage air conditioner. Figure 5(b) shows the integrated cooling efficiency per day versus the peak shift ratio. In the view point of energy saving, the energy efficiency including the nighttime electric power is important. So, we defined the integrated cooling efficiency per day as the integrated cooling capacity divided by the integrated electric power consumption in daytime and nighttime. The reduction of the electric power consumption is defined as the difference of the electric power consumption between the air conditioning system without thermal storage which has the standard COP; 2.5 and ice thermal storage system. The peak shift ratio is defined as the reduction of the electric power consumption divided by the electric power consumption of the air conditioning system without thermal storage. The cooling efficiency per day of the conventional systems before "EXG50Z series" was low, because the conventional systems tended to consume much nighttime electric power for making ice. The cooling efficiency per day and the peak shift ratio of "EXG50Z series" have been improved considerably. Moreover, with the use of the HFC refrigerant, R407C, the new system has become a more environmentally friendly ice thermal storage air conditioning system.

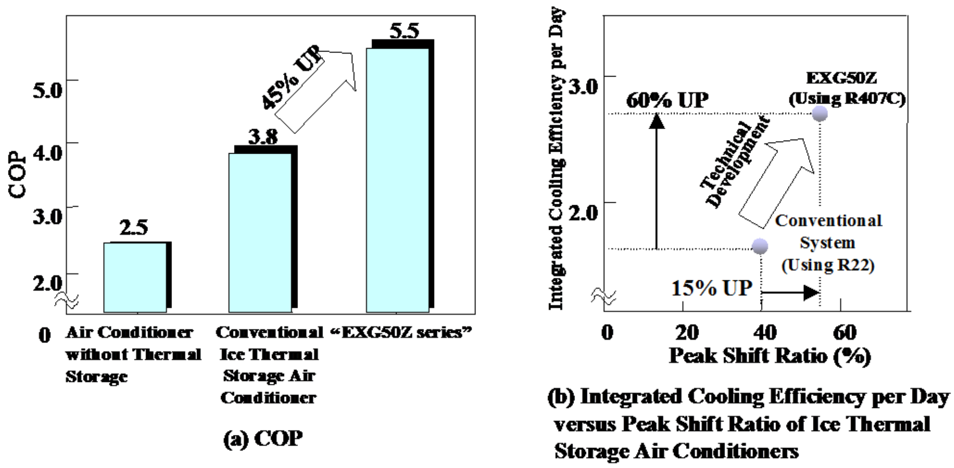


Figure 5. Performance Improvement of Ice Thermal Storage Multi-split System Air Conditioner

3 Outline of Ice Thermal Storage Multi-split System Air Conditioner “EXG50Z series”

Figure 6 shows the system appearance of “EXG50Z series”. The system is constituted of the outdoor unit, the ice thermal storage unit and the indoor units. The system can furnish 20 indoor units in maximum. The refrigerant flow ratios for each indoor unit are controlled by the electric expansion valves installed in each indoor unit, and the total refrigerant flow rate is controlled by the combination of two compressors, the inverter driven type and the constant-speed type compressors. Thus, “EXG50Z series” can drive several indoor units individually.

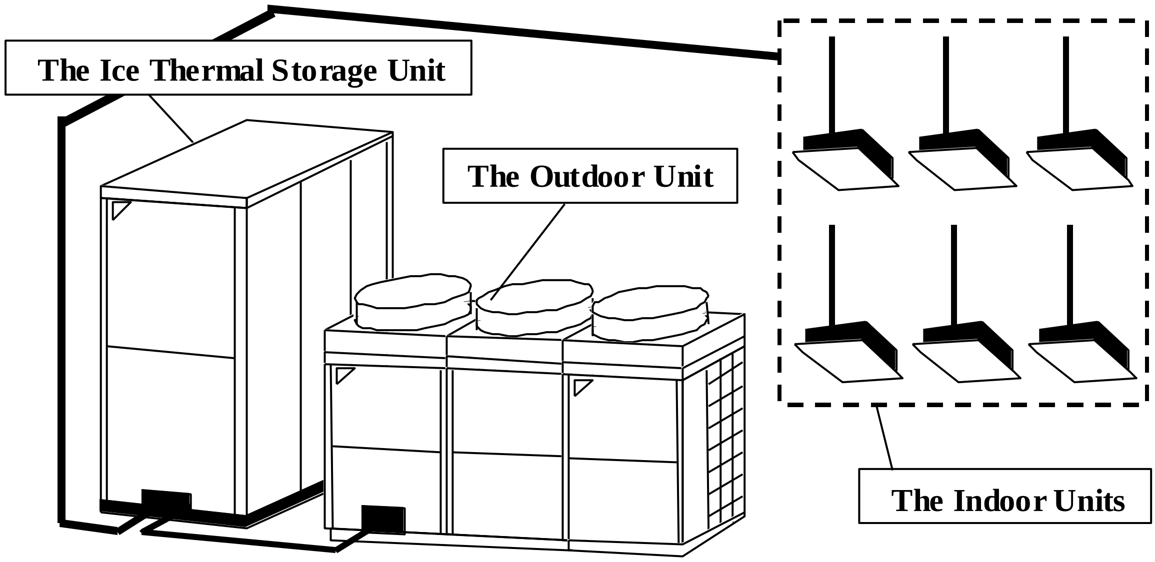
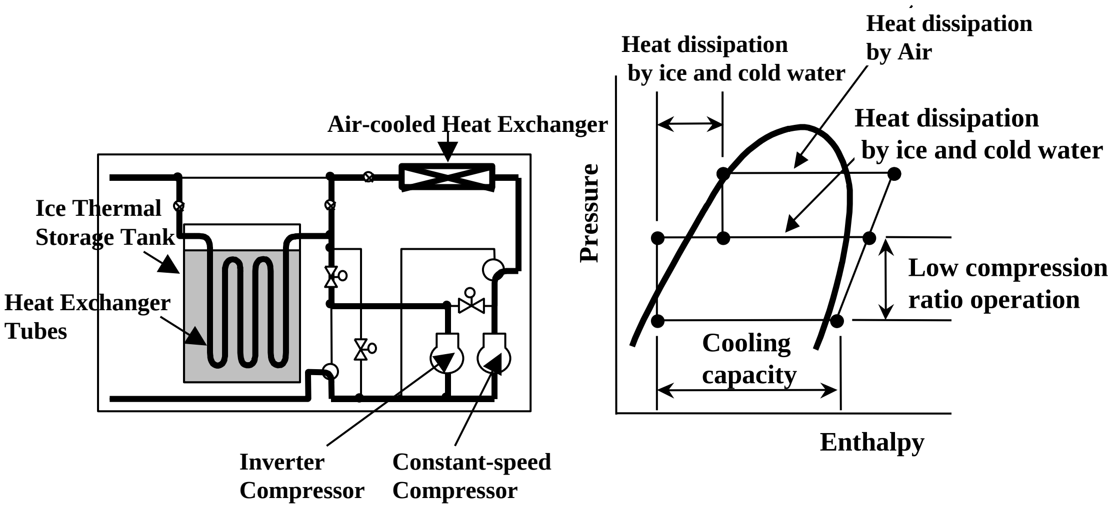


Figure 6. System Appearance of Ice Thermal Storage Multi-split System Air Conditioner “EXG50Z series”

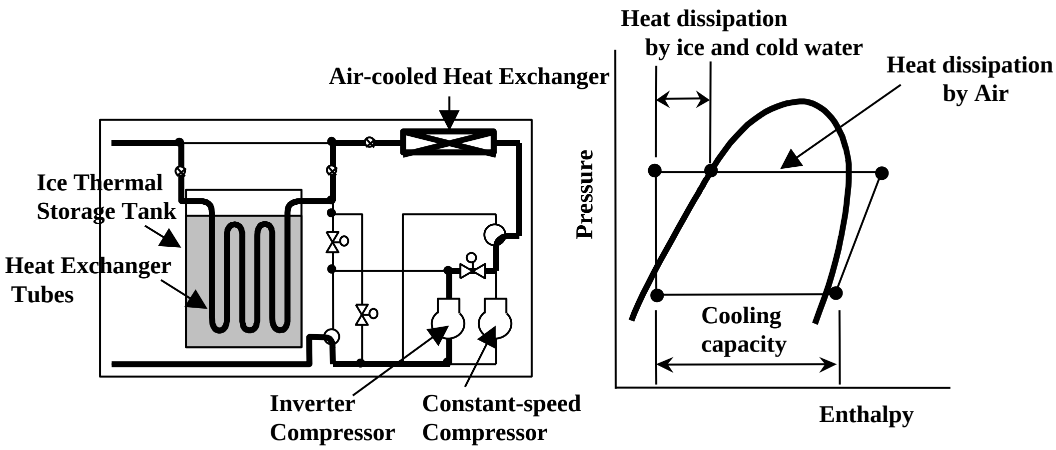
4 Technical Description of “EXG50Z series”

4.1 Refrigerant Circuits of “EXG50Z series”

Figure 7 shows the refrigerant circuits and the Morie charts of “EXG50Z series” in the cooling operation. As shown in Figure 7(a), the gaseous refrigerant discharged from the constant-speed compressor is liquefied in the air-cooled heat exchanger and mixed with the gaseous refrigerant discharged from the inverter compressor. The mixed refrigerant flows into the heat exchanger tubes cooled by ice and cold water in the ice thermal storage tank to recover the heat energy.



(a) In case of Heavy Load



(b) In case of Light Load

Figure 7. Refrigerant Circuits and Morie Charts of "EXG50Z series" in Cooling Operation

In the refrigerant circuit of the constant-speed compressor, the refrigerant can transfer the heat energy to the indoor units and the cooling capacity increases, even the input power of the compressor can not be reduced. In the refrigerant circuit of the inverter compressor, the low-compression ratio operation can be performed, so the input power of the compressor can be much reduced, even large amount of the ice is consumed. By the combination of these two refrigerant circuits, "EXG50Z series" can achieve the high peak shift ratio in case of the heavy load such as midsummer.

In case of the light load, only an inverter compressor is operated as shown in Figure 7(b). The gaseous refrigerant discharged from the compressor is liquefied in the air-cooled heat exchanger and flown into the heat exchanger tubes cooled by ice and cold water in the ice thermal storage tank to recover the heat energy. The system can achieve high efficiency operation because of less consumption of the ice to meet the load.

4.2 Improved Efficiency with MPB Circuit

The MPB circuit (Multi-Path refrigerant Blend circuit) is a unique refrigerant circuit, in which the refrigerant coming from the different compressors is mixed at the inlet of each heat exchanger tube of the ice thermal storage unit. Figure 8 shows the outline of the MPB circuit. In the MPB circuit, the liquefied refrigerant from the air-cooled heat exchanger and the gaseous refrigerant discharged from the inverter compressor are equally distributed to each path of the heat exchanger tube in the ice thermal storage unit before mixing of the liquefied refrigerant and the gaseous refrigerant in order to melt the ice uniformly in the ice thermal storage unit.

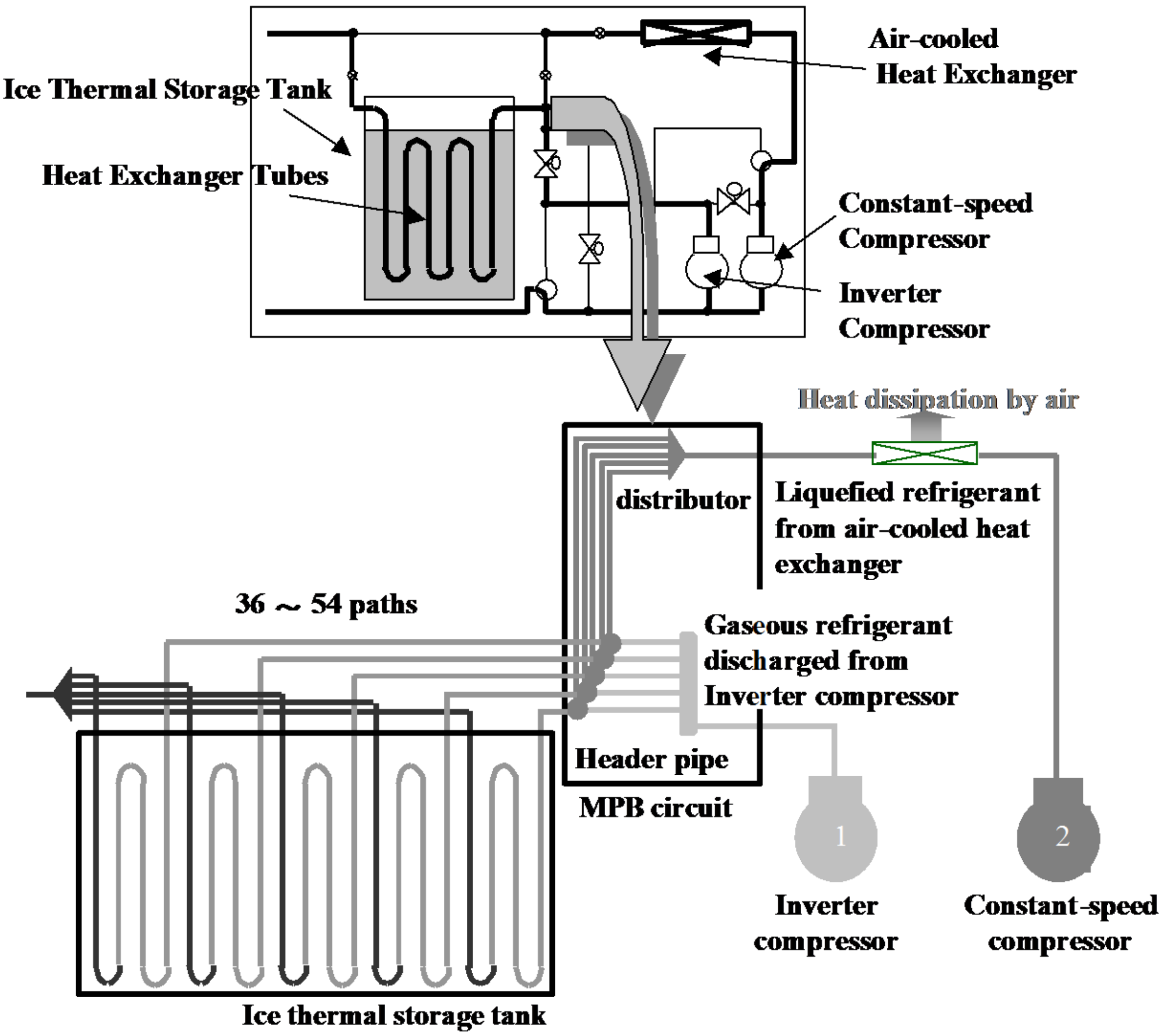


Figure 8. The Outline of the Multi-Path Refrigerant Blend Circuit

4.3 Improved Efficiency by Using the HFC Refrigerant, R407C

4.3.1 Improved Ice-Making Efficiency by Non-Azeotropic Refrigerant Mixture

Figure 9 shows the ice thermal storage operation along the heat exchanger tubes. Within the ice thermal storage tank, many heat exchanger tubes used for making ice are arranged densely. In case of using the conventional refrigerant R22, the decrease of the refrigerant temperature makes it difficult to obtain uniform thickness of ice because the pressure loss occurs along the heat exchanger tubes. Re-designing the heat exchanger tubes by taking into account of the pressure loss and the thermal gradient of non-azeotropic refrigerant mixture, the thickness of the ice along the heat exchanger tubes becomes uniform and the ice-making efficiency is also improved.

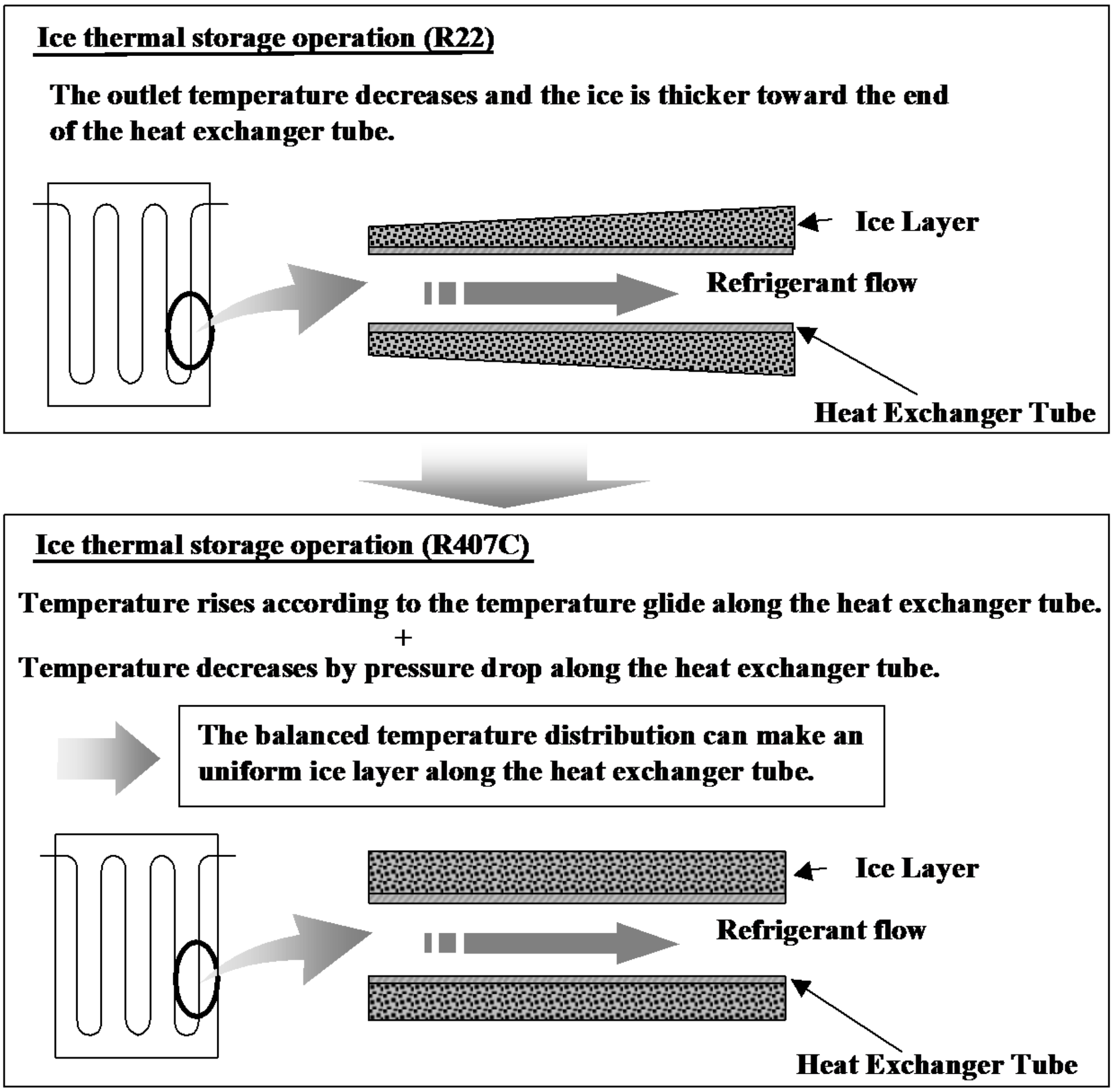


Figure 9. Ice Thermal Storage Operation along the Heat Exchanger Tubes

4.3.2 Improved Cooling Efficiency with High Degree of Subcooling

As the degree of subcooling at the end of the condenser is higher than that of the air conditioner without thermal storage, the lower inlet refrigerant temperature of each evaporator obtains the same cooling capacity as the air conditioner without thermal storage in spite of the lower refrigerant flow rate. In addition, the evaporating temperature of “EXG50Z series” using R407C is lower than that using R22 at the same subcooling. The refrigerant flow rate is controlled less than conventional system and the input power of the compressors is reduced.

4.3.3 Improved Efficiency with the Development of the Compressors

The performance of the compressor has been improved by reduction of suction pressure loss, mechanical loss and electric loss. The reduction of the pressure loss of the refrigerant between the suction pipe of a compressor and the suction point of scroll has been achieved by adoption of asymmetrical scroll as shown in Figure 10. It makes refrigerant gas lead directly to the suction point of scroll.

The use of the sliding bearing instead of the cylinder bearing reduced the mechanical loss of the compressor, and the improvement of the motor efficiency reduce the electric loss of the compressor. In addition, the torque of the motor is increased for high condensation pressure of R407C.

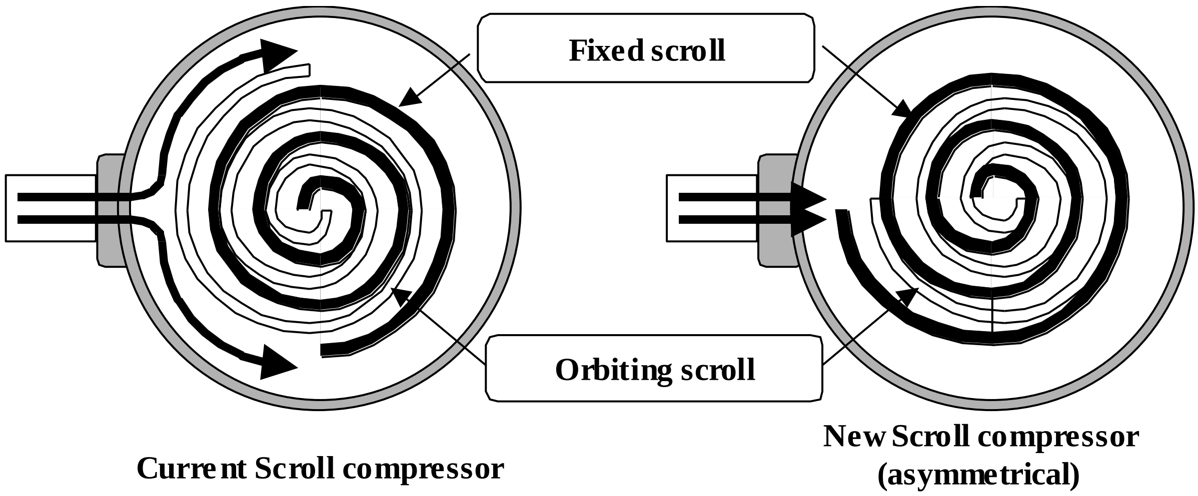


Figure 10. Improvement of the Scroll Compressor

4.3.4 Improvement of the Air-Cooled Heat Exchanger Tubes

Figure 11 shows the shape of the inner groove of the air-cooled heat exchanger tubes. The new inner groove design of the air-cooled heat exchanger tubes promotes the evaporation and condensation of non-azeotropic refrigerant mixture. The former air-cooled heat exchanger tube for R22 has spiral type groove which the inner surface area is expanded for more heat exchange. For R407C, the non-azeotropic refrigerant mixture, the inner surface is also grooved but with N shaped to disturb the refrigerant flow compulsorily to obtain the good heat transfer. The heat transfer coefficient is improved more than 150% comparing with the spiral type groove.

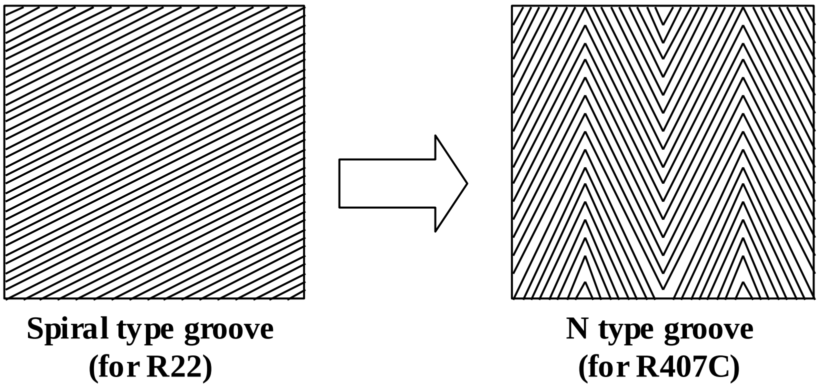


Figure 11. Shape of the Inner Groove of the Air-cooled Heat Exchanger Tubes

5 Performance of "EXG50Z series"

5.1 The Effect of the New Technologies

Table 1 shows the improvement of the integrated cooling efficiency per day, referring to the conventional ice thermal storage air conditioner. "EXG50Z series" has the integrated cooling efficiency of 2.6 which is approximately 60% improved referring to the conventional ice thermal storage air conditioner.

Table 1. Improvement of the Integrated Cooling Efficiency per Day of "EXG50Z series", Referring to the Conventional Ice Thermal Storage Air Conditioner

New Technologies	Total
MPB Circuit	20%
Equalization of the Ice layer	10%
High Degree of Subcooling	10%
Compressors	14%
Air-cooled Heat Exchanger Tubes	6%
Total	60%

5.2 Running Cost

An annual air conditioning load simulation test was performed at Chubu Electric Power Co., Inc., where the first facility for testing under all climatic and thermal load conditions has been built in Japan. As a result of the test, the annual electricity charge as the running cost was assessed to be 45% less as compared to that of air conditioner without thermal storage.

5.3 Other Performance Improvement

In addition to its energy saving performance, other performance improvement of "EXG50Z series" encourage the ice thermal storage air conditioner sales.

5.3.1 Acceptable Level Difference of 40m between Indoor and Ice Thermal Storage Units

By the optimized pressure control, the level difference has been enhanced up to 40m between the indoor unit and the ice thermal storage unit. This difference allows installation of the units on the roof top where sufficient space is hard to secure.

5.3.2 Low-Noise Operation

A low-noise ice thermal storage operation mode is equipped to cut noise during nighttime operation to prevent from bothering neighbors. This enables a low-noise operation, which is reduced to 50dB from 57dB for the cooling capacity of 35.5kW class, without loosing the ice thermal storage capacity.

5.3.3 "Up-mode" for Heating

The "up-mode" for heating improves the starting capacity of heating mode by 40%. This mode provides faster heating performance on cold winter mornings.

6 Conclusions

Featuring the new technologies, this system marks a breakthrough in ice thermal storage air-conditioning, and achieves both unique performances of leveling off electric power load peaks and conserving energy. In addition, the HFC refrigerant, R407C, provides environment-friendly performance. The system attains the highest peak-shift ratio in its class by 55% and a 45% reduction in running costs compared with air conditioner without thermal storage.

Acknowledgments

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References

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