ICE THERMAL STORAGE SYSTEM USING DYNAMIC ICE

IN HERBIS OSAKA PHASE I AND II PROJECTS

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ABSTRACT

From the view point of the global environmental agenda, the energy conservation and the cut in CO2 generation during the operation are increasingly getting important in the building facilities recently. At the same time, the ice thermal storage system is promoted to level the electric power demand during the day-time and night-time. Ice thermal storage system is fully introduced in HERBIS Osaka Phase I (referred to as Phase I Project) and HERBIS Osaka Phase II currently under construction (referred to as Phase II Project).

In case of the ice thermal storage system, the efficiency of the heat source drops when ice is generated. In order to supplement the efficiency drop, it is important to conserve the energy as the air conditioning system as a whole by saving the energy of transfer power tapping the low temperature of the ice.

Considering the afore-mentioned points, the ice transfer system using the fluidity of the dynamic ice is developed and introduced in the Phase I Project. During the development phase of the ice transfer system, the field experiments are conducted to study the fluidity, pressure loss, IPF, etc., of the ice, which results are reflected in the application of the Phase I Project. The Phase II Project introduced chilled water operation + melt ice cascading system in the heat source besides the ice thermal system to realize highly efficient operation of the heat source system. As the Phase I Project and II Project are integrated into the single electric power service contract with the utility company, the detailed electric power demand projection is conducted. The power demand is almost levelled throughout the day by setting the capacity of the heat source to flatten the power demand. Together with the ice transfer system and the highly efficient heat source system, the air conditioning system as a whole is to save the energy in the current project.

1. INTRODUCTION

It is over 15 years since the ice thermal system is introduced in the full-fledged manner to level the electric power load. With the improvement in the system reliability, the ice thermal system is rapidly prevailing in the building facilities recently. Such expansion is attributable to the background conditions that the Japanese electric power utility companies are improving the load ratio of the power generating plants and is keeping the nigh-time power consumption tariff low to control the wasteful investment on the power generating plants. Among the wide-ranging alternative ice thermal systems, high fluidity of the ice generated in the ice thermal system using dynamic ice is focused and the ice itself is transferred in the projects. This paper refers to the energy-saving technologies related to the ice thermal system introduced in the large-scale building, highlighting the ice transfer system.

2. OUTLINE OF ICE TRANSFER SYSTEM

2.1 Ice Transfer System Configuration

The outline of the air conditioning system with the ice transfer system is shown in Fig.1. The system is consisted of heat source which is the ice thermal storage system and the secondary air conditioning system, between which the ice is transferred. Ice thermal system used is the dynamic ice thermal storage system (named Crystal Liquid Ice Thermal Storage System-Heat Recovery Type: CLIS-HR). As for the secondary air conditioning system, the refrigerant natural circulation system (named Vapor Crystal System:VCS) is used. By the ice transfer, cooling capacity of air conditioning system is improved by sending the low-

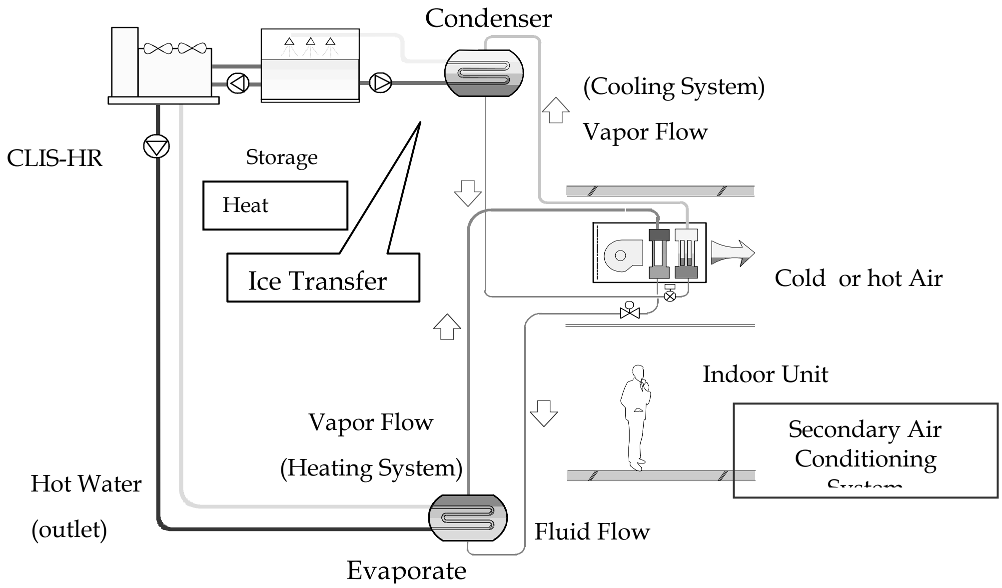


Fig 1: Air Conditioning System Outline

temperature brine to the condenser as well as lowering the pump power.

2.2 Crystal Liquid Ice Thermal Storage System – Heat Recovery(CLIS-HR)

CLIS-HR is consisted of the conventional air-cooled heat pump and the super-chiller where the ice is generated. The refrigerant is evaporated at -8°C in the jacket at the peripheral of the super-chiller. Then the binotherm solution, the low concentration brine, is cooled, and thus the ice is generated. As the ice is generated in the super-cooled condition, the generated ice is in 50 - 100 micron fine particles with the fluidity, thus is called as the crystal liquid ice. As the generated ice is continuingly sent out from the super-chiller, the heat conductivity of the ice-generating part does not drop, different from the case of static type system. Accordingly, the heat exchange ratio is high and is excellent in meeting the load. The ice thermal storage tank, without the ice generating coils, is in the panel tank structure, simple and high reliability. IPF can be as high as 50%.

2.3 Refrigerant Natural Circulation System (Vapor Crystal System-VCS)

As the heat transfer system to the secondary air conditioning system, the refrigerant natural circulation system (VCS) is used. In the VCS, the state of the refrigerant is changed using the low temperature of the ice and the refrigerant is circulated in the pipings by the difference in the specific gravity.

VCS is consisted of condensers, evaporaters, and indoor units. During the cooling operation, the refrigerant gas sent in from the above of the condenser, located at the top, is heat exchanged with the brine extracted from the ice thermal storage tank, condensed, and liquified. Liquified refrigerant flows into the indoor unit with its own gravity, is heat-exchanged with the indoor air, and is evaporated. Evaporated refrigerant gas is raised due to the difference between the liquid in the specific gravity and returns again to the condenser. This air conditioning cycle of the natural circulation is repeated. As the cooling/heating is operated with the refrigerant naturally circulating between the condenser and the indoor unit, the pump power is not required in the secondary system which results in major energy conservation. During the heating operation, in the evaporater located at the bottom, the refrigerant is heat exchanged with the hot water generated in the CLIS-HR, is evaporated, is raised due to the difference in the specific gravity, and flows into the indoor unit. In the indoor unit, evaporated refrigerant is heat exchanged with the indoor air. Thus condensed and liquified refrigerant returns to the evaporater with its own gravity. This heating cycle of the natural circualtion is continued. HFC-134a, not destroying the ozone layer, is used as the refrigerant.

2.4 Ice Transfer System

Conventionally, the chilled heat is supplied via heat exchanger between the ice thermal storage tank and the secondary system. On the other side, the ice in case of CLIS-HR is in sherbet status with high liquidity. So the ice generated in the super-chiller can be transfered directly to the condenser with the secondary pump.

2.4.1 Advantages of Ice Transfer System

The ice transfer system has the following advantages.

1) Improvement of the condenser efficiency

In VCS, the brine in 1°C is normally sent. On the other hand, tapping the low temperature of the ice. The ice transfer enables to send the brine in the lower temperature. There are two alternative ways to be benefited from the brine in the lower temperature: improve the efficiency of the condenser or improve the efficiency of the indoor unit. When the condensing pressure is constant in the condenser, the lower brine temperature improves the cooling capacity or when the condenser capacity is constant and the condensing pressure is lowered, the cooling capacity of the indoor unit is improved.

2) Cut in the transfer power

As the flow quantity in the brine pump in the primary system is smaller, the pump transfer power is cut, which results in the energy conservation. The reduction in the pump volume also lowers the initial cost.

3) Reduction in the piping size

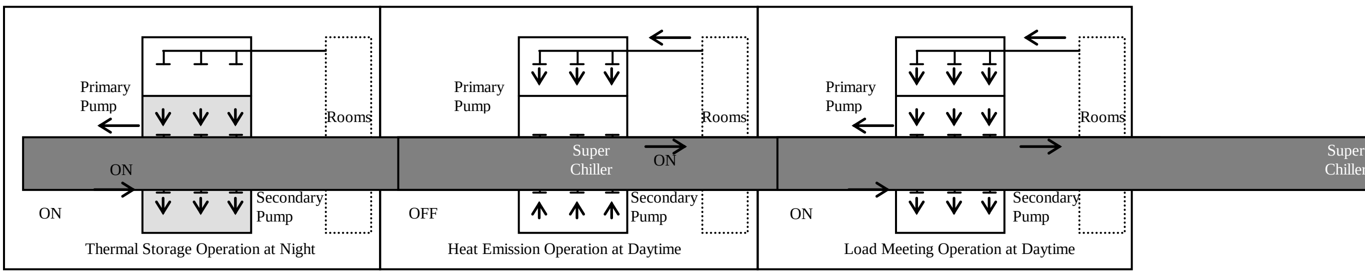
As both the brine flows between the ice thermal storage tank and the condenser and the refrigerant flows between the condenser and the air handling unit are in the lower temperature, the chilled heat can be supplied in the smaller quantity, the pipings can be smaller, which lowers the initial cost.

2.4.2 System Configuration of the Ice Transfer System

As shown in Fig. 2, there are, normally, three 3 operating status in the ice thermal storage system.

1) Night-time ice storage operation - the operation only stores the ice in the thermal storage tank
2) 2)Day-time normal operation - the operation only releases the heat from the thermal storage tank
3) 3)Day-time load-meeting operation - the opeation conducting heat release and the operation of the super-chiller in case of the large cooling load

In this system, the ice transfer system is used in case of 3) day-time load-meeting operation. The size of the air conditioning system equipments (AHU, pumps, etc.) and the pipings are normally set assuming the maximum cooling load. When the ice transfer system is used in case of the large cooling load, the size of the equipments and pipings can be largely reduced. At the same time, when the load-meeting operation of the super-chiller is conducted during the period with large cooling load in the day-time, the ice transfer system can be operated. Namely, the period for the load-meeting operation of the super-chiller coincides with the period requiring the ice transfer system. The ice transfer system in case of the load-meeting operation directly connects the pipe sending the ice generated in the super-chiller to the ice thermal storage tank and the pipe sending the brine from the ice thermal storage tank to the cooling load side; the ice is sent to the cooling load side while operating the super-chiller. When the water volume in the secondary brine pump is about double than that in the primary brine pump, the brine including 10% ice sent out from the super-chiller joines with the brine within the ice thermal storage tank. Then the brine including about 5% ice is sent to the cooling load



side. The melting heat of 5% ice is equivallent to the 4°C difference. If the temperature of the supply and the return differes by 5°C, the ice transfer results in the total temperature difference of 9°C. This means that the 1.8 times of the heat can be sent.

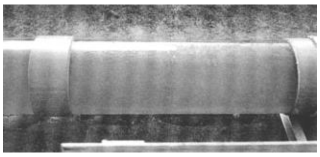
Fig. 2 Operation Pattern of Ice Transfer System

3. EXPERIMENT OF ICE TRANSFER

3.1 Ice Flow Status and Flow Velocity

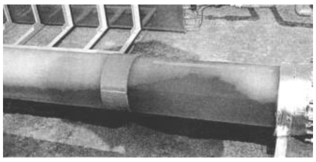
In order to understand the phenomenon in the pipings in case the ice is transferred, the experiment was conducted with about 260m-long ice transfer pipings in the site of the former Takenaka ‘s research center since 1990. The status of the ice is checked by changing the flow quantity and the flow velocity in the pipes. As a result, in case of the velocity faster than 0.3m/s, the ice tranport is possible without separating the ice from the brine. Fig. 3 shows the status within the pipes when the flow velocity is changed.

(1) 0.3 m/s < flow velocity



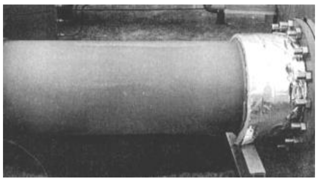
Ice, in the particle status, uniformly flows in the pipe.

(2) 0.3 m/s > flow velocity > 0.03 m/s



In the upper part, ice in slower flow velocity forms the mass. In the lower part, finer ice particles in faster velocity flow.

(3) 0.03 m/s > flow velocity



The inside of the pipe is covered with the ice.

Fig 3 Ice Flow Status and the Flow Velocity

3.2. Ice Flow at the Curved and Branched Parts of the Pipings

It is checked whether the ice is blocked in the branch pipes, curved part, riser/extended/drop pipings, and sharply extended/shrinked parts. In any case, the flow velocity in the pipe largely affects the status of the ice flow. When the flow velocity is fast, ice and water flow together. When the flow velocity is slower, the ice flowing in the pipe is changed from the fine ice particles to the larger mass, and finally the ice is blocked. At the location where the pipe is sharply extended, the slower flow velocity results in separating the ice from the brine leaving the ice in the upper part of the pipe.

3.3 Pressure Loss within the Pipes

The change in the pressure loss within the pipes when the IPF is changed is experimented. IPF is changed with constant flow velocity of 1.7 m/s. Fig. 4 shows the pressure loss ratio of the pipe, assuming the pressure loss in case of IPF:0% (namely, without ice) as 1.0, in relation to the IPF. When IPF is 10%, the pressure loss is slightly lower than that without ice. Then, the larger the IPF, the pressure loss gets larger. But in case IPF is 20% or lower, the incremental pressure loss is less than about 3%.

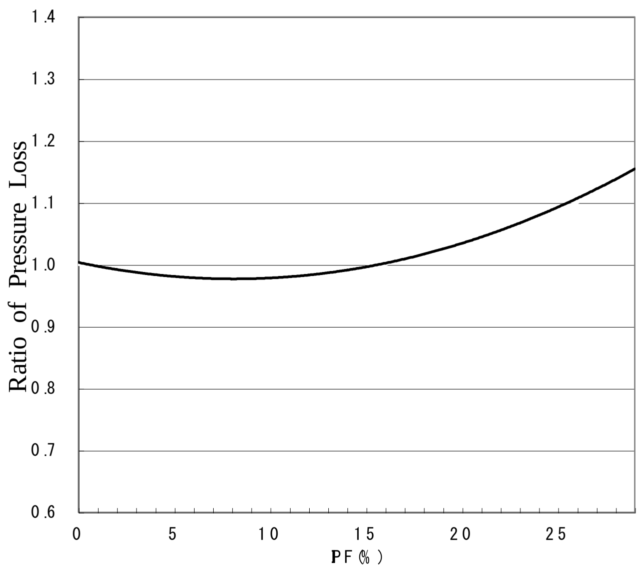


Fig 4 IPF and Presssure Loss

3.4 Summary of the Experiments

Based on the results of the afore-mentioned experiments, in order to realize the effective ice transfer, flow velocity in the pipe is 0.3 m/s or faster and the IPF is 20% or less.

3. HIGHLY EFFICIENT OPERATION OF HEAT SOURCE BY CHILLED WATER OPERATION + MELT ICE CASCADING CONTROL

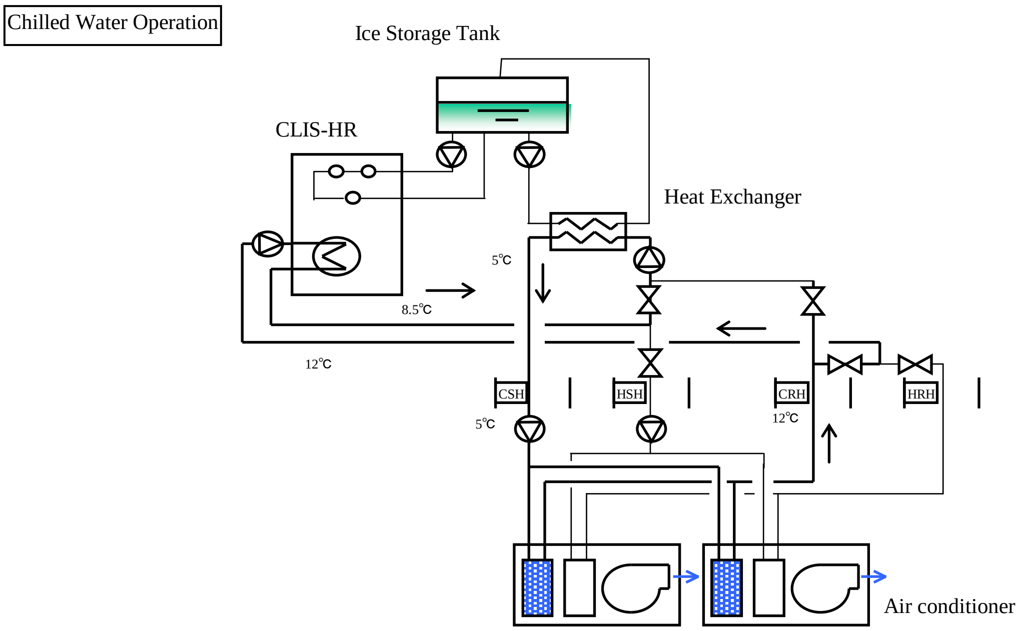


Fig. 5 Heat Source Operation Flow during Summer Time (Day-Time)

CLIS-HR, by being equipped with chilled/hot water coils, enables the chilled water operation, hot water operation and heat recovery from the ice generation process under the hot water operation besides the ice

the hot water operation besides the ice generation operation. During the night-time, ice is stored by the ice generation operation. In case of the day-time in summer season requiring the operation to meet the demand, if ice generation operation is conducted, the evaporation temperature of the refrigerant is low as –8°C, which in turn lowers the performance coefficient. In the current project, as shown in Fig. 5, the chilled water operation is conducted in the same heat source installation, lowering the temperature of the chilled water from 12°C down to 8.5°C, further lowering the temperature down to 5°C by using the ice stored during the night-time in the solution-water heat exchanger (which is referred to as chilled water operation + melt ice cascading control). By replacing the ice generation operation with the chilled water operation during day-time, the performance coefficient can be improved by 23%. Furthermore, by raising the chilled water outlet temperature of the chiller by 1.5°C than the normally set temperature of 7°C, the performance coefficient is further improved by 4%. As a result, the performance coefficient of the heat source installation can be improved by 27%. This system is now introduced in the Phase II Project.

5. APPLICATION TO THE ACTUAL PROJECTS

5.1 Outline of Phase I Project and Phase II Project

The outline of building facilities is sumarized in table1 and the building section plan is indicated in Fig. 6,respecrively.

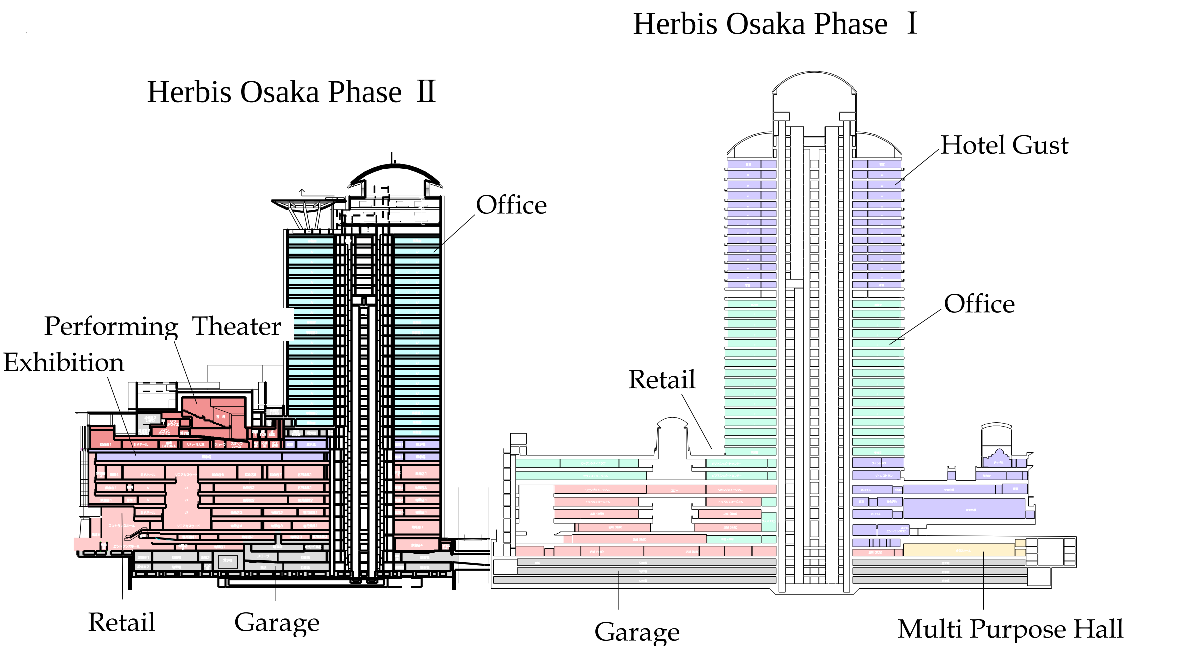


Fig 6 Building Section Plan

Table 1 Outline of building facilities

Name	HERBIS Osaka Phase I	HERBIS Osaka Phase II
Location	Umeda, Kita-ku, Osaka Japan	Umeda, Kita-ku, Osaka Japan
Use	Retail, hotel, offices, multi-purpose hall, garage	Offices, retail, performing theater, exhibition halls, garage
Total Floor Area	136,823 ㎡	107,000 ㎡
Structure	Steel, steel & reinforced concrete, reinforced concrete	Steel, steel & reinforced concrete, reinforced concrete
No. of floors	Base 5 floors, 40 floor super-structure, 1 pent-house floor	Base 4 floors, 28 super-structure, 2 pent-house floors
Construction	December 1993 through February 1997	December 2001 through Autumn 2004
Heat source	31 Ice-generating air-cooled heat pump chiller (CLIS-HR) Per unit ice generating capacity: 260kw/ Heating capacity:335kw 16 ice thermal storage tanks ($140m^3$ x 15 units and $70m^3$ x 1 unit) 62 Primary brine pumps 16 Secondary brine pumps	28 Ice-generating air-cooled heat pump chiller (CLIS-HR) Per unit ice generating capacity: 260kw/ water chilling capacity:326kw/ Heating capacity:335kw 8 ice thermal storage tanks ($173m^3$ x 4 units and $276m^3$ x 4 unit) 28 Primary brine pumps 16 Secondary brine pumps
Air Conditioning System	Non-retail area:refrigerant natural circulation system Retail area: Four-pipe air conditioning with chilled/hot water	Office area:refrigerant naturalcirculation system Other areas: Four-pipe air conditioning with chilled/hot water

In both the Phase I Project and the Phase II Project, CLIS-HR and ice thermal storage tanks are decentralized to be located near the area where the load is required; in Phase I Project located by the building use; offices, hotel guest room tower, hotel low-rise (public floors), retail, and multi-purpose hall and in Phase II Project located on the roof-top of the high-rise and low-rise. Thermal storage capacity is 22,940RTh (318,780MJ) only with the Phase I Project, the largest capacity for the single building-complex in Japan. In the secondary air-conditioning system, the refrigerant natural circulation system is used in all area except for the retail in the Phase I Project and only in the office area in the Phase II Project. In both projects, the ice is transferred between the ice storage tank and the condenser (VCS) to cut the power required for transfer as much as possible. The chilled water operation + melt water cascading control are introduced in the area other than offices in the Phase II Project.

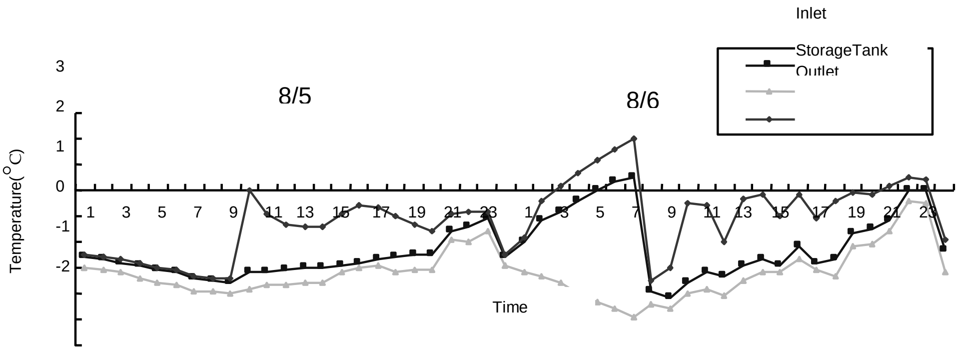
5.2 Performance of Ice Transfer System in the Phase I Project

In the Phase I Project, the ice is transferred between all ice storage tanks and the condensers (VCSs). As for the offices, the condenser in the lowest location is on the 9thfloor. So the ice is transferred vertically for 100 m (max) from the roof-top of the high-rise tower to the office floors. As for the remaining portion, the ice is horizontally transferred in the pent-house.

Fig. 7 shows the changes in the ice transfer temperature in August 5 - August 6, 1997 (summer time). At the dawn of August 5, the thermal storage operation is conducted and the ice thermal storage tank temperature drops, while the secondary system is in operation with small flow. At 9:00, the heat release and the load-meeting operation starts. The brine temperature including the ice is maintained at -3°C to -1°C. The cooling load should be increased at 10:00 through 13:00, but the return temperature is gradually lowered to narrow the temperature difference between the supply and the return. It is because the ice transfer is in operation during the load-meeting operation and heat exchange with the latent heat should take place. From 13:00 to 16:00, the load-meeting operation is stopped in order to lower the peak of electricity power demand, so the return temperature gets higher.

By lowering the return temperature of the brine than conventional temperature of 1°C, the capacity of the condenser is improved. Fig.8shows the change in the condenser capacity in relation to the brine entry temperature. When the brine entry temperature is -2°C, the condenser capacity is about 1.4 times better than that in case of brine entry temperature of 1°C.

By combining the VCS with the ice transfer, the transfer power is largely cut. Comparing with the building in the same scale with differenct air conditioning system,



the electric power capacity was cut by about 33% .

As the flow quantity between the thermal storage tank and the condenser drops, the size of the pipes is reduced. Especially, the pipes to the condensers in the office area are reduced from 200 mm diameter to 150 mm. As the total pipe length is long, the cost cut impact is large.

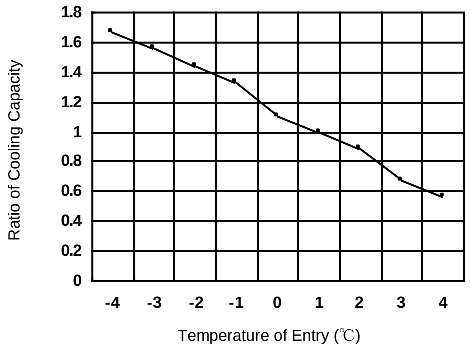


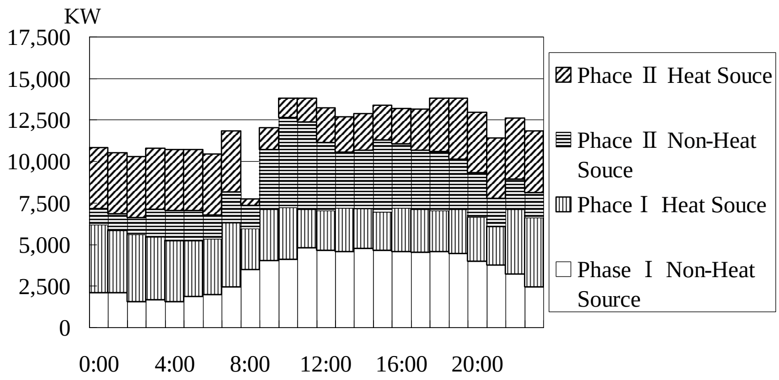
Fig 8 Changes in the Condenser Capacity

Fig 7 Changes in the Ice Transfer Temperature

5.3 Level the Electric Power Demand

Among the (day-time) electric power required for cooling, the ratio of the power which can be shifted to night-time (10 hours from 22:00 till 8:00) is referred to as shift to night-time ratio. The higher the shift to night-time ratio, the power consumption during the day-time is cut to be shifted to the night-time power. In the Phase I Project, the monthly shift to night-time ratio for the cooling in the past year, while August with the high cooling load was 56.8%, was 70% in average. The electric power shifted to night-time annually was 7226Mwh, which is equivalent to 18% of the total power consumption of the building-complex. With the application of the demand side management (DSM) and the other measures for energy conservation, the current demand is 7400Kw and 3500KWh demand could be shifted to the night-time power.

The load ratio of the Japanese power generating plants is 56% while the electric power load ratio of the office buildings is low as 20 to 45%. Such office buildings are



lowering the load ratio of the power generating plants. Accordingly, if the load ratio of the building electric power is improved, the load ratio of the power generating plants can be naturally higher. The annual load ratio of the Phase I Project is 55%. The system and measures explained in the above enables us to improve the load ratio of the Phase I Project to the level of the load ratio of the Japanese power generating plants.

Fig 9 Planned Electric Power Demand for Phase Ⅰ+Ⅱ Projects

Daily electric power demand of the day(s) with the maximum cooling load (referred to as the maximum electric power demanding day) for the Phase I Project and the Phase II Project is shown in Fig. 9. The numbers indicated in Fig 9 for Phase I Project is the actual daily electric power demand and for Phase II Project being the assumed demand, respectively. As the Phase I Project and II Project is integrated into the single power service contract with the utility company, it is important to level the electric demand in the whole program including the Phase I and II. On top of the introduction of the ice thermal system in the Phase I and Phase II as total, in the Phase II Project, its capacity of the heat source is so set as to nearly flatten the daily electric power demand for the maximum electric power demanding day based on the actual demand in the Phase I Project. In the office areas in the Phase II Project, the heat source capacity is so set as the electric power by the night-time thermal storage can meet all of the day-time cooling requirement (Air-Conditioning System Only with Thermal Storage). By these measures, the Phase II Project is targeting 80% for the annual shift-to night ratio for cooling load and 60% for the electric power load ratio.

6. CONCLUSION

The ice thermal system introduced in the current project is described high-lighting the ice transfer system in this paper. In the developed ice transfer system, with IPF=5% brine and –2°C solution temperature, the equipment capacity can be improved, the piping size can be reduced, and the transfer power can be cut while maintaining the simple configuration. This ice thermal system can be applied to the regional heating /cooling system in the future. In the Phase II Project, in order to further improve the performance in the Phase I Project, the chilled water operation + melt water cascading control, the air conditioning system only with thermal storage, and the DSM control. Theses installation and measures all in all is to flatten the electric power demand throughout the day and the overall energy conservation.

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