AIR CONDITIONING SYSTEM OF UMEDA DT TOWER

Takashi Shinojima, Section HEAD, Mechanical and Electric Department, Takenaka Corporation, Osaka City, Osaka Prefecture, Japan

Abstract: Umeda DT Tower is an office building located on center of Umeda which is the best location in Osaka. This building ensures high safety in structural aspect by the high-performance seismically intermediate floor isolation system. On a purpose of environment load reduction, our equipment plan was designed to save energy, level electric load, improve reliability, improve safety, improve comfort, respond IT. We combined ice heat storage system, VCS (Vapor Crystal System), thermal storage in structural elements and the perimeter air conditioning system as an air conditioning system. We adopt “cold and warm blast blowing upper floor slab system” as a thermal storage in structural elements. Because of the combination of the thermal storage system in structural elements and ice thermal storage system, 95% of the thermal load in daytime is transferred to in night time. At even peak hour in summer, ice thermal storage system levels electrical demand in day time and in night time. Maximum electrical demand became about 66% compared with usual buildings.

Key Words: environment load reduction, ice heat storage system, thermal mass storage system

1 INTRODUCTION

The Umeda DT Tower was completed as the final project in the redevelopment of the Diamond District in front of Osaka Station. The redevelopment was initially conceived in 1926. Located in Umeda, the best business district in central Osaka, this tower is an office building of a highly symbolic nature, which is covered on all sides with glass curtain walls and with its center placed on the major urban axis extending from in front of JR Osaka Station. The building’s public open space, which accounts for 55% of its site area, provides comfort and a disaster evacuation zone in the busy downtown district.

The design of high-rise buildings in the urban center and their safety were re-examined in the wake of the Great Hanshin Earthquake, which occurred during the planning of the tower. As a result, we adopted an intermediate-floor seismic isolation structure, which has higher floors built on top of a seismic isolation system installed in the upper part of the entrance hall on the first floor. This structure has provided greater freedom to the design of floors above the seismically isolated layer, making it possible to adopt a single-core design for the office floors separate from the underground floors. The facility plan, which was focused on reducing environmental load, was made based on design concepts with the aim of saving energy, leveling electric loads, improving reliability, safety and comfort, and supporting the introduction of IT systems. **Figure 1** shows the facilities adopted based on these design concepts.

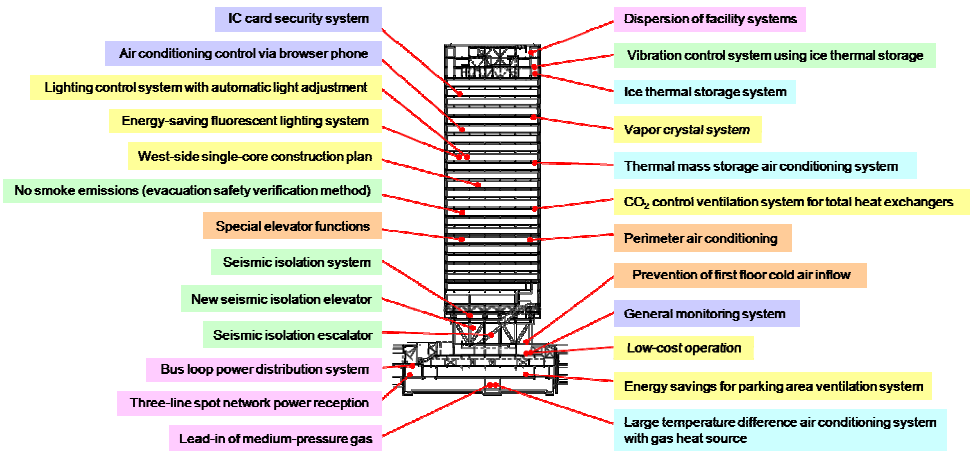


Figure 1: Facilities adopted based on design concepts

2 BUILDING OVERVIEW



Photo 1: Outward Appearance

Address:	1-chome, Umeda, Kita-ku, Osaka City
Design and construction:	Takenaka Corporation
Site area:	3,609.27 m^2
Construction area:	1,616.95 m^2
Total floor area:	47,608.13 m^2
Number of floors:	4 underground floors, 27 above-ground floors and 2 tower floors
Structure:	Steel framework, reinforced concrete Reinforced concrete with steel framewo
Usage:	Offices, stores and parking
Construction period:	November 1, 2000 to January 28, 2003

3 AIR-CONDITIONING FACILITY PLAN

3.1 Overview of Heat-source/Air-conditioning Facilities

In order to maximize reliability and safety, we separated the heat-source facility systems for floors above and below than the seismic isolation layer as far as was possible, and in order to use diverse energy sources, we adopted an electric heat source system for floors above the layer and a gas heat source system for floors below it.

We combined an ice thermal storage system, a vapor crystal system (VCS), a thermal mass storage system and a perimeter air-conditioning system for floors above than the seismic isolation layer (**Figure 2**). A dynamic ice thermal storage system is employed in combination with a VCS in order to use low temperatures more efficiently. The VCS is an energy-saving air conditioning system that can both cool and heat buildings without the need for power to transport coolant. To improve ease of use, air conditioning control operations, such as the turning-off of air conditioning and the setting its temperature, are designed to be performed on the screens of personal handset systems (browser phones) carried by office workers. Office lighting is automatically adjusted with motion/light sensors so as to reduce energy consumption by about 50% and to decrease the air conditioning load.

The major heat source devices used for floors above the seismic isolation layer are shown in the following figure:

Twelve 290-kW chillers with air heat-source heat pumps (six of which are ice makers)

Two 225-m^3 ice thermal storage tanks (37,330 MJ/10 hrs) and one 138-m^3 ice thermal storage tank (18,790 MJ/10 hrs) (**Figure 3**)

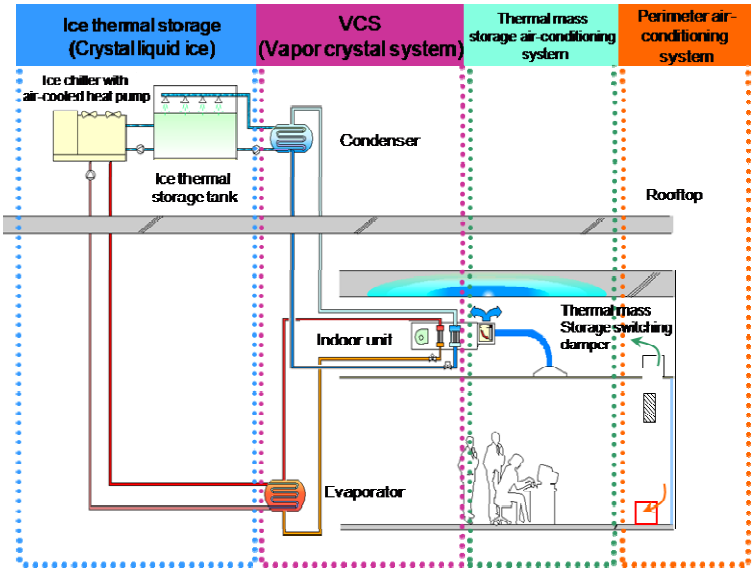


Figure 2: Diagram Showing the Heat Source and Air Conditioning for Higher Floors

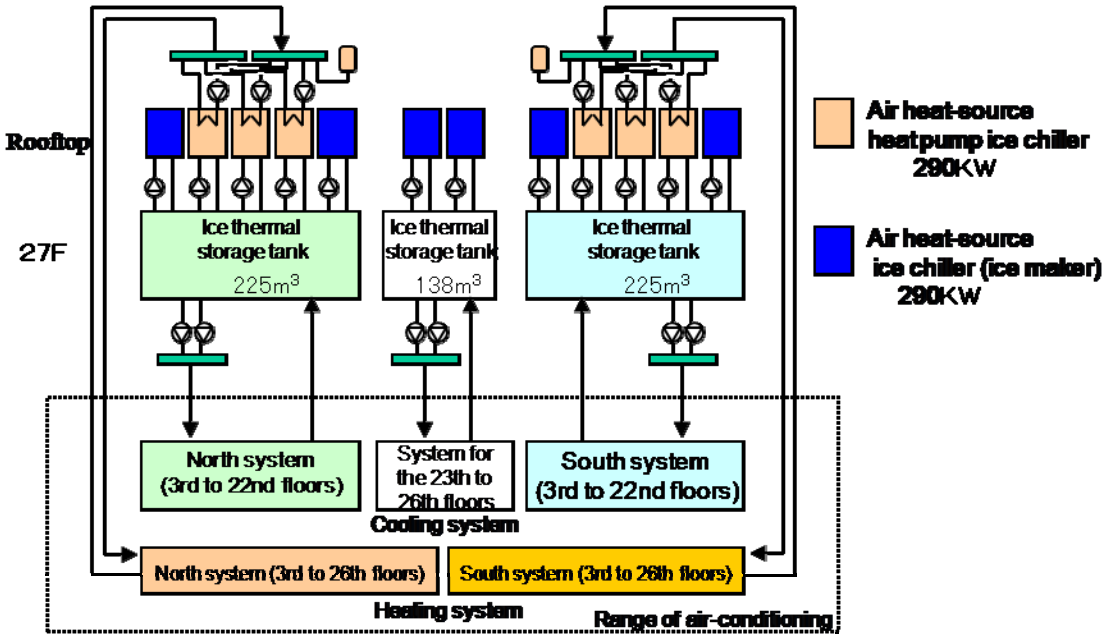


Figure 3: Heat Source System for Higher

3.2 Thermal Mass Storage System

A cold and heat blast slab floor system was adopted for thermal mass storage. More specifically, switching dampers were installed in ceiling areas surrounded by large and small beams, as shown in **Figure 4**, in order to improve the thermal storage efficiency of the building. The thermal mass storage system was designed to be used in combination with ice thermal storage in order that about 95% of the air-conditioning load in the office zone could be transferred to nighttime hours.

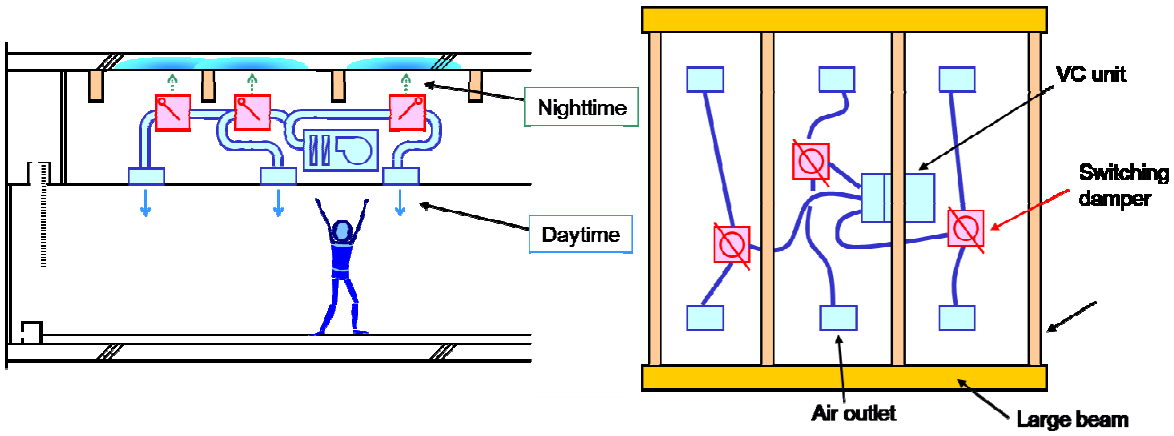


Figure 4: Conceptual Diagram of the Thermal Mass Storage System

3.3 Perimeter Air-conditioning System

The building is covered on all sides with glass curtain walls, and in order to reduce its energy load, office rooms on standard floors are arranged on the east, north or south side of the building where the solar radiation load is relatively small, with a single core placed on the west side. The building is protected by Low-e double glass with high-thermal resistance, high-heat insulation (with a shading coefficient of 0.64 and a thermal transfer rate of 2.5 kW/m^{2}h°C). In order to reduce heat radiation in the perimeter space during summer and discomfort caused by cold drafts in the office space during winter, we adopted an air-conditioning system with different air outlets for summer and winter (the pull-pull method), as shown in **Figure 5**. This air-conditioning system is designed to let heated air out around windows through a slit in the blind box in summer and to let out cold air accumulated in the air pocket between the perimeter cover and the curtain wall through a slit in the perimeter cover in winter. **Figure 6**, which shows a simulation comparing temperature distributions in the office space during winter, reveals that our method improves comfort and reduces air flow compared with the air-barrier push-pull method. It also reveals that the cold air pocket in the perimeter cover reduces the effects of cold drafts by the same amount. This pull-pull method reduces running costs by about 73% compared with the push-pull method.

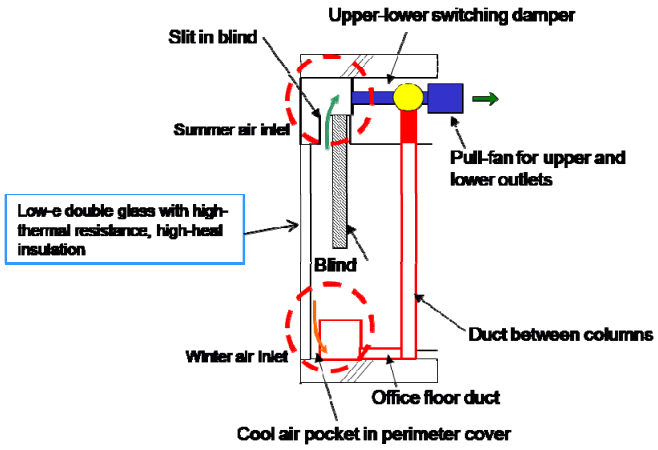
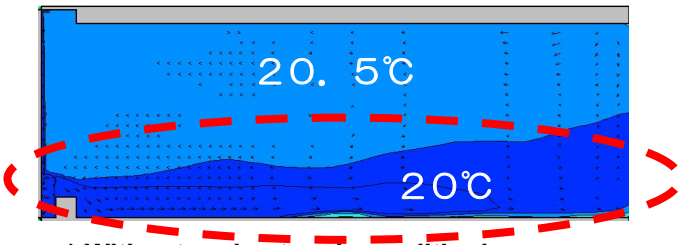
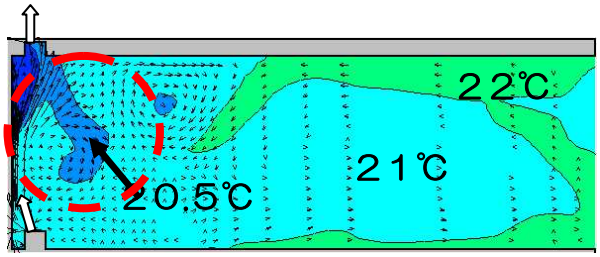


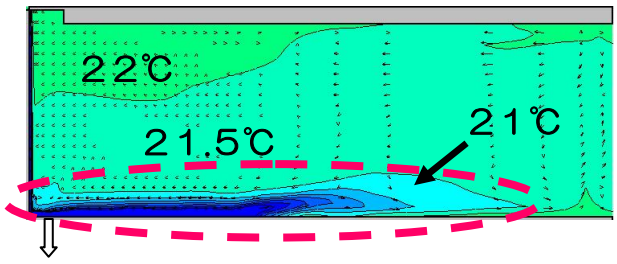
Figure 5: Conceptual Diagram of the Pull-pull Method



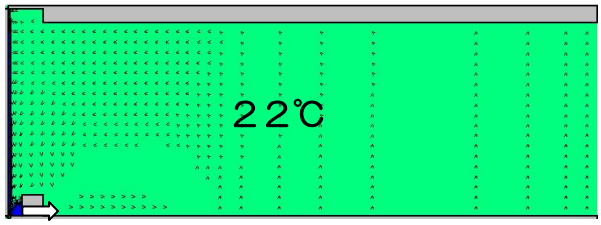
a) Without perimeter air conditioning



b) Push-pull method (150 CMH/m)



c) Pull-pull method without air pockets (60 CMH/m)



d) Pull-pull method with air pockets (60 CMH/m)

Conditions:
Outdoor air temperature: 0°C
Room temperature: 2.2°C
Without air conditioning

Figure 6: Simulation Comparison in Winter

3.4 Saving Ventilation Energy

Total heat exchangers are used to collect heat for the ventilation of the office space, and the following measures are implemented to further reduce energy consumption:

- Automatic air flow switching using CO_2 controls
- Fresh air cooling based on an entropy comparison of the outdoor and indoor air
- Simplified night-purging operation during the intermediate seasons
- Dispersed filter units for intermittent operation independent of air conditioning and ventilation

3.5 General Monitoring Function

In order to improve efficiency and save energy in the operation of facility systems, we introduced a Building and Energy Management System (BEMS). This system makes it possible to check how much energy is being saved, to improve the efficiency of the operation of facilities and to reduce running costs required for their operation.

The building was designed so as to that power demand during daytime and nighttime would be nearly the same even during the summer peak period by operating the ice thermal storage system at full capacity at night. By doing so, we expected to reduce the daytime maximum power demand by 1050 kW. By this design, we planned to reduce daytime power demand to about two-thirds of that conventional buildings and to level power loads. We also developed a plan that would make daytime peak power consumption in summer basically the same as peak power consumption in winter by operating the cooling thermal storage system during daytime in the summer at a level equivalent to the winter operation of the heat thermal storage (**Figure 7**).

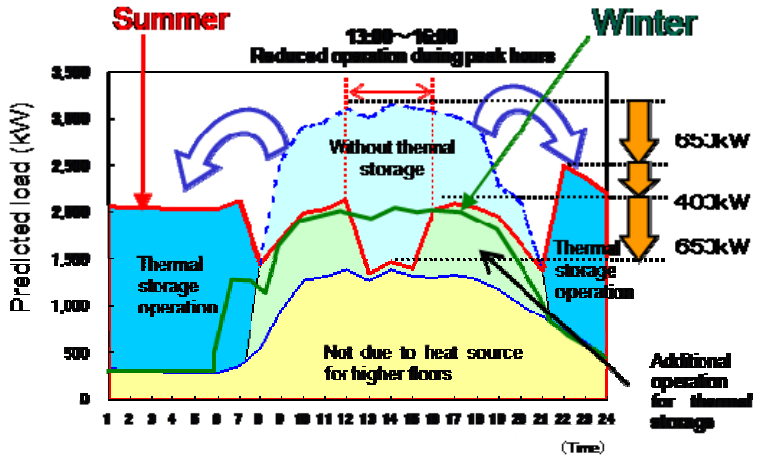


Figure 7: Peak Daytime Power Loads in Summer and Winter Predicted during Planning

4 OPERATIONAL PERFORMANCE

4.1 Ice Thermal Storage and Thermal Mass Storage Systems

Figure 8 shows the annual hours of operation of the ice thermal storage system. Winter operational data shows that heat collection (simultaneous) is being appropriately performed except in January and February, when the outdoor air temperature is low. Data also shows that nighttime ice storage is being appropriately performed throughout the year and that additional operation of the storage is being performed during daytime in the summer to provide the energy that cannot be supplied by operating the ice storage system at full capacity at night. As a result, the annual nighttime thermal transfer rate in 2009 was 93%, which was close to the planned level. If heating is included, the annual thermal transfer rate was 70%.

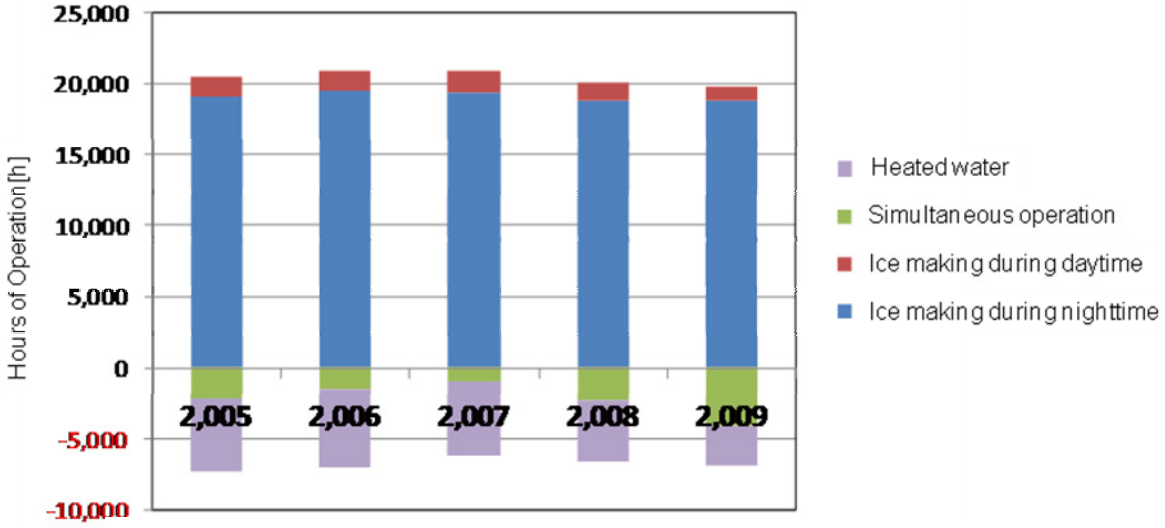


Figure 8: Annual Hours of Operation of the Ice Thermal Storage System

The results of thermal mass storage during the five hours from 3:00 to 8:00 in summer are presented below. **Figure 9** shows points representing the floor slab framework temperature and energy storage and release in perimeter and interior zones. In both zones, the floor temperature decreased by around 3°C during Monday to Friday, increasing again on Saturday and Sunday. The thermal mass storage on Monday caused the floor temperature to decrease by 1°C to 2°C, resulting in a pleasant temperature environment when office work began at the beginning of each week. The room temperature before the beginning of office work was 26°C to 27°C, which was lower than the set temperature (27°C). The framework temperature decreased from the beginning of thermal storage in the following order: lower surface, inside surface and upper surface. Overall, temperature changes in the inside and on the upper surface were similar, while changes on the lower surface strongly reflected temperature changes in the ceiling chamber. The data on energy storage and release shows that heat release effects were small on Monday mornings but became stronger on Tuesday, and remained at the same level during the rest of the week. The dispersed thermal mass storage system maintained the floor temperature uniformly at around 25°C before the beginning of office work and proved to be effective. While the degree of thermal storage varies depending on the location (distance from the heat outlets of thermal mass storage system), it was about 500 kJ/m^2-5h in both perimeter and interior zones.

Data on the two hours from 6:00 to 8:00 in winter shows that the thermal mass storage was about 250 to 300 kJ/m^2-2h.

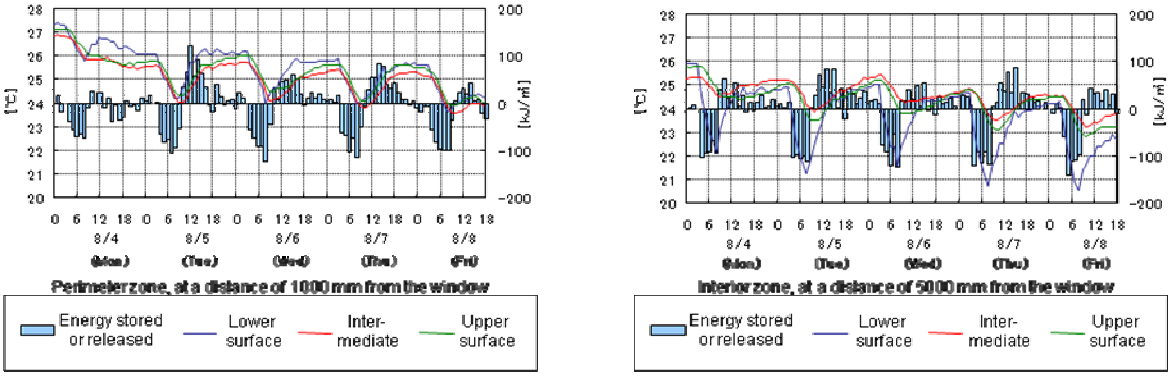


Figure 9: Weekly Changes in Framework Temperature and Energy Storage and Release in Summer

4.2 Power Consumption Performance of the Entire Building

Figure 10 shows the peak power consumption for the entire building in summer and winter. A gas heat source system is used for floors below the seismic isolation layer and the peak power consumption is significantly affected by the heat source used for floors above it.

Peak power consumption in summer occurs during nighttime hours, and about 500-kW electricity generated during daytime is shifted to handle it. During the peak hours from 13:00 to 16:00, all ice thermal storage heat pumps are turned off for reduced peak-hour operation in order to achieve a further reduction of about 630 kW. As a result, the difference achieved in the nighttime peak power consumption is 1,130 kW. Thermal mass storage is performed for three hours, from 5:00 to 8:00, and the peak consumption occurs during these hours. However, nighttime peak power consumption is larger than was originally planned. An increase in general loads due to power consumption for servers in offices on floors above the seismic isolation layer may be the reason for this.

Peak power consumption in winter occurs during daytime and is greatly affected by the operation of ice thermal storage heat pumps. Thermal mass storage is performed for two hours, from 6:00 to 8:00, but does not cause peak consumption. Peak consumption in winter is nearly the same as that in summer, as was expected at the planning stage.

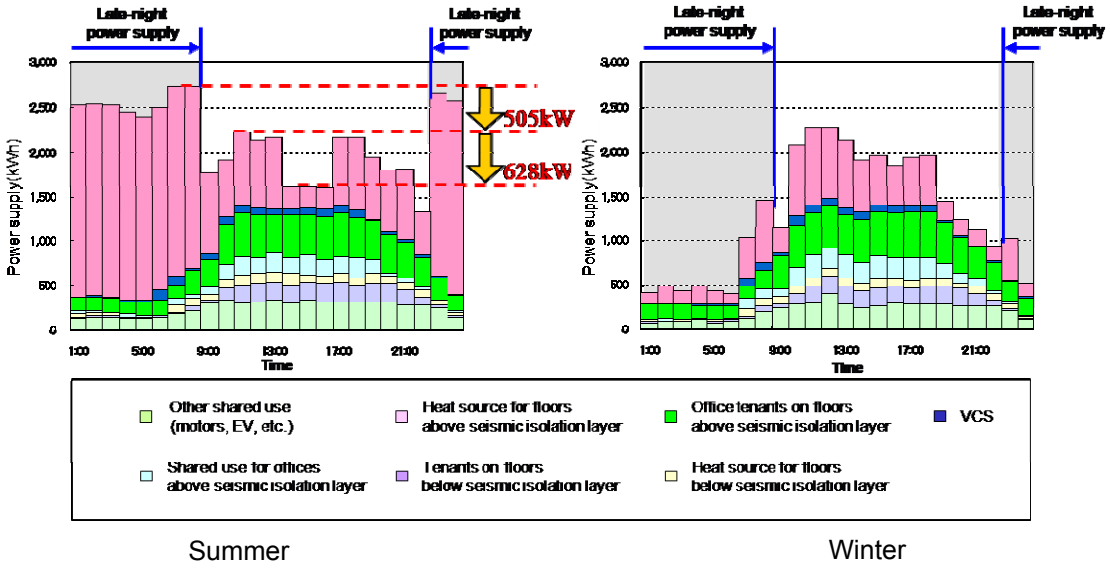


Figure 10: Peak Power Consumption in Summer and Winter

Figure 11 shows the monthly power consumption and demand performance of the building. Electricity, which accounts for a large percentage of the energy consumption required for the building, has a significant effect on energy savings and life-cycle costs. Under power rate options, electric power companies provide discounts for nighttime demand exceeding daytime demand and for turning off air-conditioning during the peak hours from 13:00 to 16:00. Therefore, we set the goal for nighttime demand to 2,900 kW and that for daytime demand to 2,400 kW and also aimed to turn off air conditioning during the peak hours to reduce electricity costs. As a result, the power demand is larger during nighttime except in April and May and there has also been a decrease in daytime demand throughout the year.

The annual power consumption data shown in **Figure 12** reveals that as a result of the efforts to improve operational efficiency, such as reducing the number of hours during which air conditioning and lights are turned on, power consumption was reduced by about 5% in 2009 compared to 2005. Primary annual energy consumption in the office areas on higher floors, excluding storage areas, was also reduced to 2,066 MJ/m^2-year, achieving a reduction of about 10% compared with ordinary office buildings.

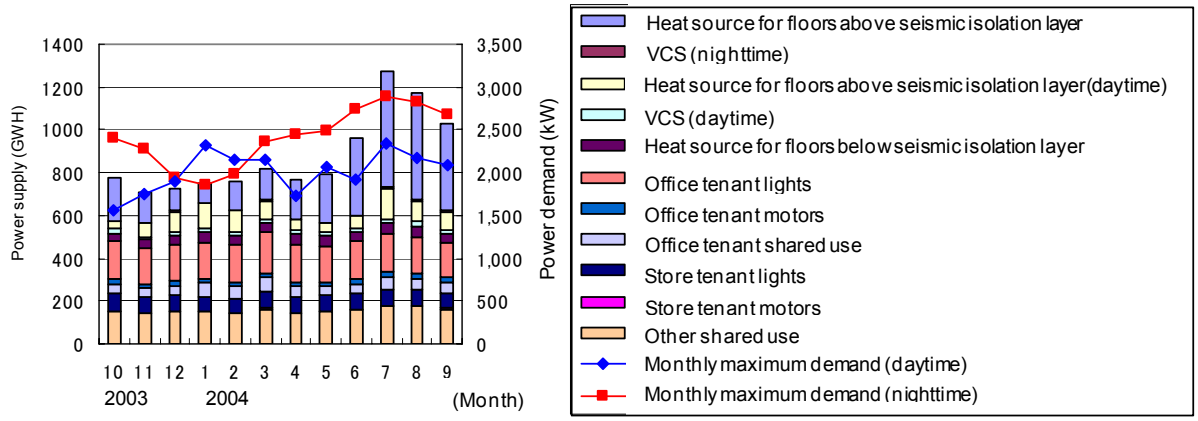


Figure 11: Monthly Power Consumption and Demand

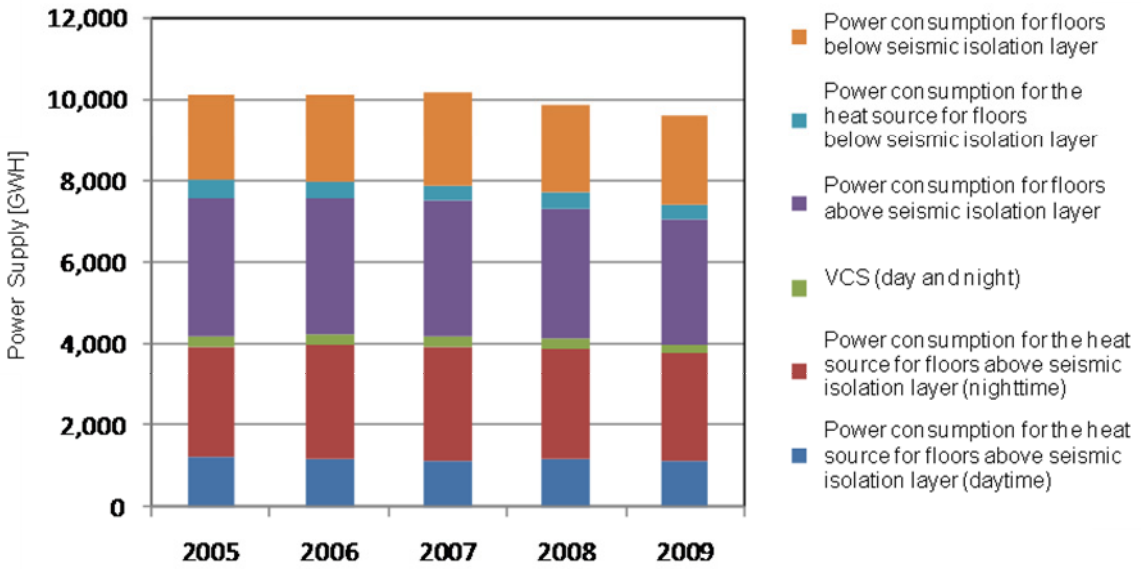


Figure 12: Annual Power Consumption

5 CONCLUSION

The Umeda DT Tower, completed as the final project in the long history of development of the district in front of Osaka Station, was designed to be a building that will continue to exist for many years in harmony with the surrounding buildings. The construction of this building took into consideration various issues—including the provision of safety in light of the Great Hanshin Earthquake, social initiatives for environmental conservation and trends for increased usage of IT—and has allowed us to study how we should make facility plans for sustainable buildings in future.

Even after the completion of its construction, we have been working to improve the efficiency of the building's operation and have gradually reduced its power consumption. We will continue to strive toward further reduction in energy consumption and CO_2 emissions, including making modifications for further energy savings.