

Study on the energy performance of an advanced office building in Japan

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ABSTRACT: Analysis and evaluation were carried out on a newly designed office building. The key feature of this building is newly developed external blinds which can resist the extremely strong winds occasionally experienced in Japan. A whole-building facilities analysis, including HVAC and indoor condition, revealed that these facilities could be operated efficiently, and they reduced energy consumption by 20% compared to a similar conventional office building in Japan.

Keywords: office building, energy saving, external blinds, facility integration

1. INTRODUCTION

Increasing awareness of the need for environmental load reduction has led to growing interest in efficient energy management; and as a result, current building facility designs are adopting a great variety of energy-saving technologies. However, installing high-end and high-cost facilities is not practical or cost-effective in all buildings. Facility design thus needs strategies to identify suitable systems.

In this paper, we have focused on the analysis and evaluation of a newly-designed office building. This building was designed as the headquarters of an architectural design company, the oldest and largest design firm in Japan. Therefore, rather than endeavoring to produce a distinctive effect for this company's building, the results of our study are intended to serve as a prototype for ordinary office buildings in the future. The design concepts are the following. 1) It had to satisfy the additional

design condition of being able to accommodate other office tenants; 2) the building had to incorporate the latest innovative technology. It also stands out as the result of use of innovative but proven technologies.

2. SUBJECT OF RESEARCH

2.1 Outline of the building and facilities

Figure 1 shows the west-facing side of the building with external blinds installed. By opening and closing the external blinds, the building's facade can be changed to create a range of impressions. They are an example of an already well-proven technology in Europe, where they have been demonstrated to save energy and distribute reflected sunlight into deeper building interiors. However, they had not been used to good effect in Japan before, so a new product had to be developed. The main design aims were increased strength to resist high wind loads, but to maintain a refined appearance.

Table 1 describes the building and the facility. This office building has typically 1,000 m² of floor area per floor and rises 14 stories above the ground with one underground storey. The first floor has an exhibition galley, and the second floor contains consultation areas and meeting rooms. Offices occupy the third to the thirteenth floor. The fourteenth floor has a multi-purpose studio. Gross floor area is 20,000 m². An AHU (Air Handling Unit) and VAV (Variable Air Volume) system is installed in the interior. External blinds and multi-pane heating glass take the place of the perimeter air-conditioning. System controls for intensive energy saving are intricately integrated, including VAV, low temperature, out air minimize and out air control.

2.2 Perimeter basic concept

Figure 2 shows the perimeter basic concept. An important component of the facade system is "New External Blinds". In Japan, external blinds were in the past often damaged by typhoons. We developed strong hollow aluminium slats with a chain drive system. A wind speed sensor can trigger folding of the slats when a typhoon arrives.

In summer, the external blinds block off direct sunshine except for reflected visible light; this assists office lighting. In winter, the double-glazed windows block cold radiation and prevent cold drafts and condensation. In addition, the multi-pane heating film assists the balance of the indoor thermal environment on extremely cold days.

2.3 Automatic facade control system

Figure 3 shows the automatic facade control system. External blinds, lights, VAV and the multi-pane heating glass are connected to the "Floor Integrate Icont" via LonWorks. These controllers on each floor are connected via the BACnet data communications protocol. The exterior environment measurement meters on the building's roof are also connected via BACnet and the realtime data is used for the

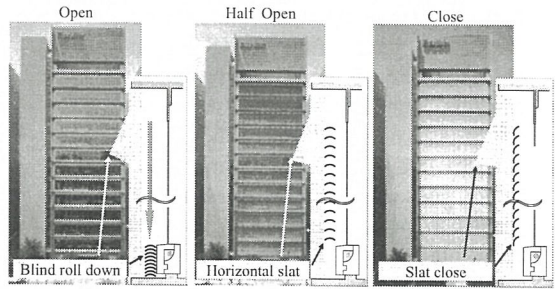


Figure 1: West-facing side of the building.

Table 1: Building & Facility outline.

Building outline		Facility outline	
Use	Office	Heat source system	Ice storage system [20GJ]
Completion	Mar. 2003	AC system	Air-source heat pump brine chiller / heater * 3 Absorption chiller/heater * 1
Floor	14 stories + 1 under ground	Piping	Interior : AHU □ VAV Perimeter : External blind + Multi-pane heating glass
Gross floor area	20,580m ²		4 piping [Cooling&Heating]
Air conditioning area	13,000m ²		Temperature difference : 10 °C [design]
Controls			
AC	VAV, Low temperature blow, Load reset, Out air minimize control, Out air cooling		
Pumps	VWV, Piping end pressure control		

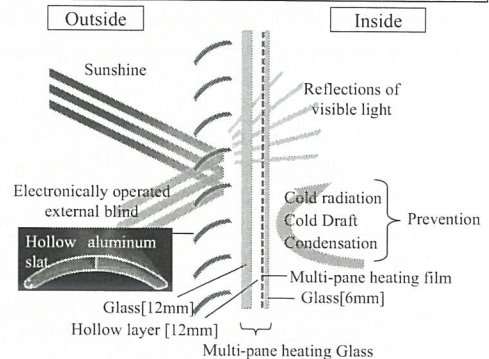


Figure 2: Perimeter basic concept.

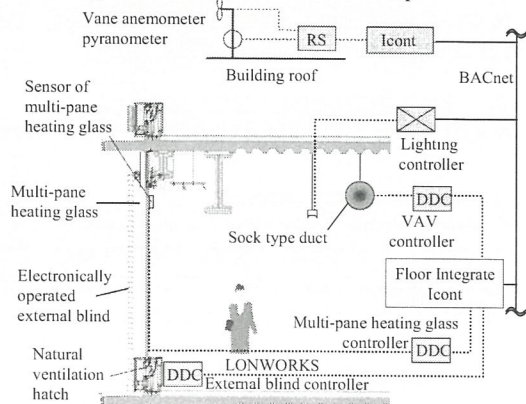


Figure 3: Automatic facade control system.

facade and interior environment controls.

2.4 Building energy management system

Figure 4 shows the BEMS outline. Not only the facade and interior environment controls, but also all the floor controllers, which are operated by Windows CE, are able to accumulate all the data. The BEMS server goes around getting data and shows graphs to permit appropriate control. With this integrated system, the BEMS can provide flexible control to reply to multiple demands.

2.3 Heat source system

Figure 5 shows the heat source system outline. This heat source system consists of 3 ice storage units with an air heat source brine chiller/heater (HR-1~3) and an absorption chiller/heater (RA-1). In Japan, night-time electricity costs about 1/5 that of daytime electricity. Ice storage units are therefore adopted to reduce operation costs and installed capacity. On the other hand, gas for RA-1 is also cheaper in summer for day-time use. It is thus clearly necessary to achieve a good balance between electricity and gas consumption in this system.

The cold water supply temperature is 6 °C and return temperature is 16 °C. In spite of the RA-1 outlet temperature being 7 °C, ice storage units and heat exchangers cause this large temperature difference. VWV control is adopted for the cooling water pump and cold/hot water pumps. On the other side, the brine pumps are CWV-controlled, since HRs are controlled during rated operation. For the control and evaluation of this system, measurement equipment was installed appropriately and connected to BEMS.

3. EVALUATION OF EXTERNAL BLINDS AND INTEGRATED CONTROL

3.1 Perimeter environment

Figure 6 shows the result of a side-by-side test between external blinds and internal blinds in summer (5F). The thermal difference peak between the two came at

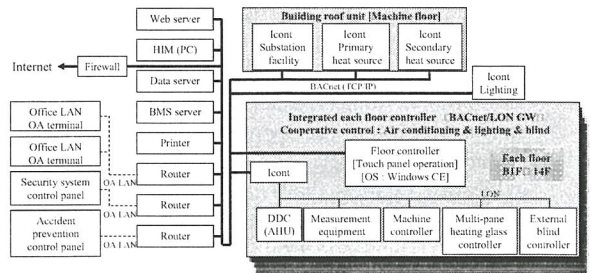


Figure 4: BEMS outline.

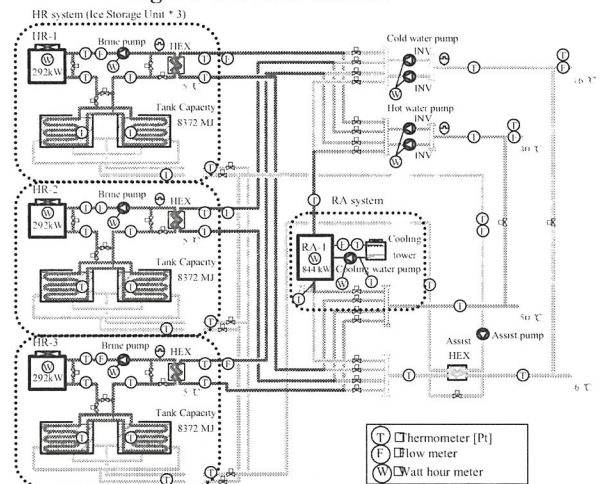


Figure 5: Heat source system outline.

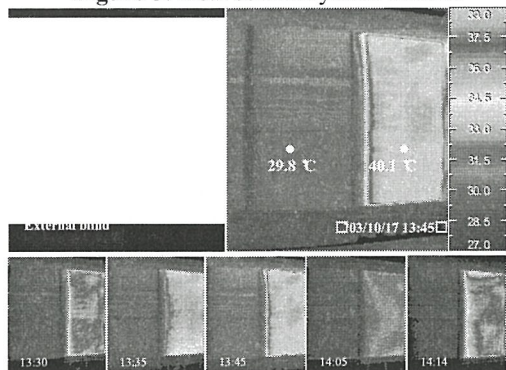


Figure 6: Side-by-side test between external blind and internal blind (5F).

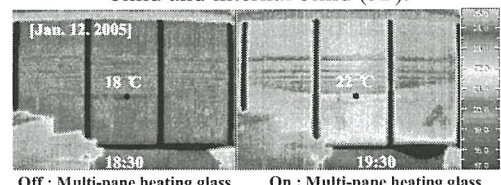


Figure 7: Window temperature of multi-pane heating glass on/off action (5F).

13:45. Internal blinds indicated more than 40 °C, and the temperature fluctuated over a short period of time. It was thus confirmed that external blinds have both the high performance and the stability needed for thermal shielding. Figure 7 shows on/off action test results of multi-pane heating glass. In the off state, although the outside temperature was below 5 °C, double glazing and the low-e response of the multi-pane heating film were together able to maintain an environment of 18 °C.

3.2 Advantage verification

We improved the HASP-L dynamic thermal load calculation program to simulate the effects of external blinds and multi-pane heating glass. The standard model has inner Venetian blinds and single 8-mm glass without lighting controls. The model for our building has automatic external blinds, multi-pane heating glass and optimized control of artificial lighting and day lighting. Table 1 shows the simulation conditions. The volume of expelled air is smaller than the normal setting, but was decided based on actual operational results. Table 2 shows the physical properties value of the window system. Figure 8 shows the results of the simulation. Total air-conditioning load of this floor is 15% lower (84.1%) than the standard model. This comparison demonstrates that external blinds effectively block solar radiation and the multi-pane heating glass has high insulation properties. In addition, control of daylight utilization is effective in reducing the lighting energy requirement.

4. OVERVIEW OF HEAT SOURCE SYSTEM OPERATION

4.1 Operation of heat source system

Figure 9 shows cold energy output details. Between May and September, RA-1 outputs cold energy as the main chiller. In other periods, cold energy was covered by operating the HRs during the night. This night-time operation of HRs averaged about

Table 2: Conditions for simulations.

Content	Value
Day□ of A.C. stop	National holidays & 12/30 □ 1/3
Running schedule	Weekday 8:00□22:00 Saturday□Sunday 8:00□20:00
Room air condition	□ 25.5□26.0 °C 40□60□RH □ 25.0□25.5 °C 40□60□RH □ 24.0□24.5 °C 40□60□RH
Out air (Average of running results)	AC-1(East)□3.5m ³ /m ² h AC-2(West)□2.8m ³ /m ² h
	□□□Jun□Sep □□Apr, May, Oct, Nov, Dec □□Jan, Feb, Mar

Table 3: Thermal performance of glass types.

Classification	Overall heat transfer coefficient [W/m ² K]	Shading coefficient	
		SCR	SCC
FL8mm+Internal white venetian blind	4.9	0.26	0.26
Multi-pane heating glass	2.0	0.60	0.09
External blind and multi-pane heating glass	2.0	0.07	0.07

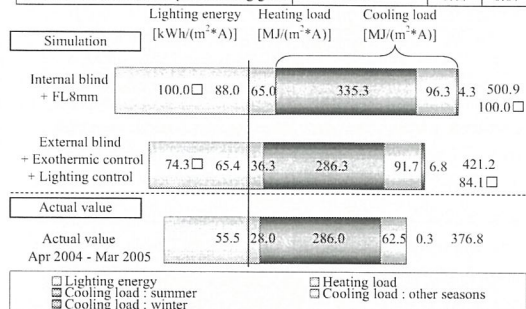


Figure 8: Simulation results with actual value (2004.04~2005.03) 5th floor (Area 1,000m²).

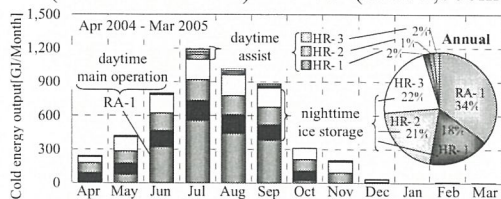


Figure 9: Cold energy output details.

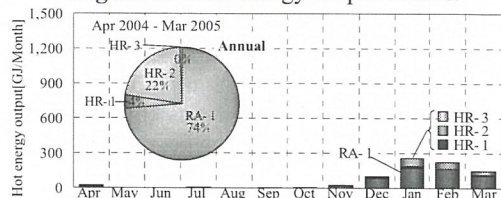


Figure 10: Hot energy output details.

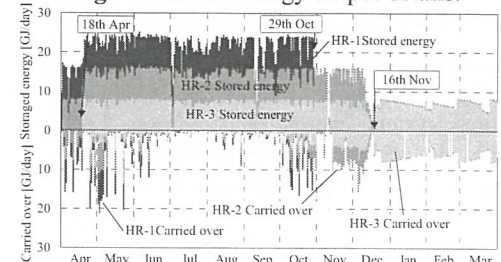


Figure 11: Results of operation of ice storage unit.

60% over the year. Figure 10 shows hot energy output details. 74% of hot energy was output by day-time operation of RA-1. The HRs heating mode was used for assisting RA-1.

4.2 Operation of ice storage tanks

From June to September, 3 HR units were operated at full storage without carry-over (Figure 11). This means that the cold energy of the ice which was generated during the night was fully used for day-time cooling. From the middle of December to March, only unit HR-3 maintained ice as cooling backup.

4.3 VWV control advantage verification

This heat source system adopted VWV control for the cooling water pumps. When the cooling water temperature falls sufficiently, the cooling water volume is decreased by VWV control. However, excessively decreased cooling water causes a loss of chiller input energy. For this reason, a confirmation was carried out using a simulation (Figure 12). Cooling water pump energy was reduced 58% by VWV control. Chiller energy (RA-1 + auxiliary) is increased with VWV control; however, overall effectiveness is reduced by 9%.

4.4 Operation of heat source system

To evaluate the efficient use of ice storage tanks, daily cold energy output is shown in Figure 13. This daily energy is divided into night-time (2200-0800) and day-time (0800-2200) and sorted in descending order. Considering the total storage capacity of 20 GJ, it was confirmed that more cold energy could be stored on some days. However, 60% of cold energy was output during the night, including these loss days. In addition, by focusing the HR units, 93% of energy was shifted to the night-time.

Figure 14 shows the details of the heat source system energy consumption. From June to September, the RA system supported the cold energy output of the HR

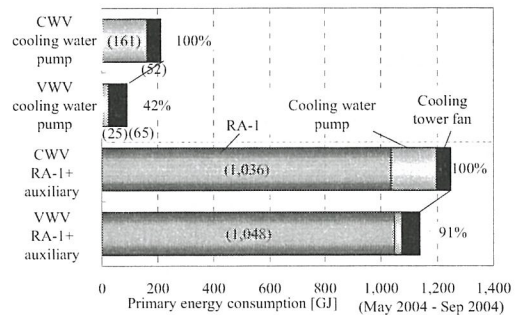


Figure 12: Effectiveness of cooling pump VWV control.

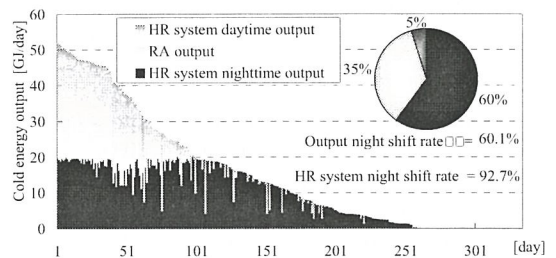


Figure 13: Daily cold energy sorted into descending order (divided into nighttime and daytime).

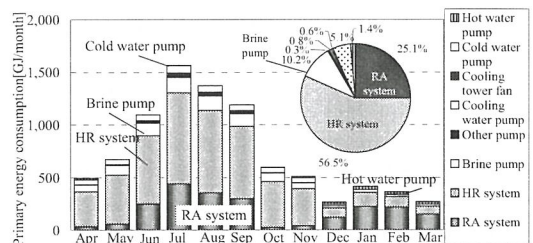


Figure 14: Details of heat source system energy consumption

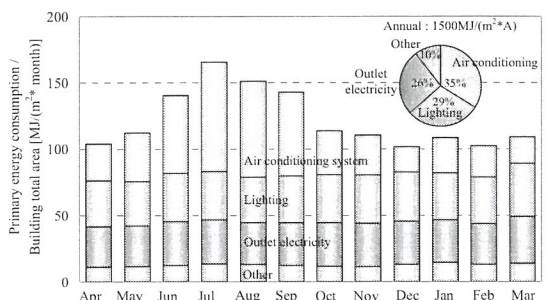


Figure 15: Details of primary energy consumption for the building total area.

system (ice storage units). From December to March, the HR system supported the hot energy output of the RA system. Primary energy conversion COP of heat source system became about 0.65 annually. This value is equal to the national average of DHC in Japan.

4. ENERGY EVALUATION OF THE BUILDING

Figure 15 shows the details of the primary energy consumption for the building's total area. Lighting, outlet output and other electrical consumption did not fluctuate during the year. Air conditioning accounted for 35% of the building's energy consumption.

This building is used by a variety of design workers who work overtime a great deal. Therefore, to study the energy utilization of the building, a study was carried out on office hours worked (Figure 16). It was observed that people often went entered and left the building. The average in-office ratio was 38%. At 10 pm, this ratio was still 20%, showing that this office is used for very long periods.

To gain a better understanding of the energy-saving effectiveness of the building, a comparison between our strategy and that previously applied is shown in Figure 17. For our design, annual primary energy consumption per building total area came to $1500 \text{ MJ/m}^2 \times \text{A}$, showing a 20% reduction over a conventional office, and a 35% reduction compared with the previous design.

An energy consumption comparison with business hours and non-business hours is shown in Figure 18. Concerning lighting and outlet energy, only half of energy consumption took place during business hours, and the extensive use of non-business hours was demonstrated. The long-hours use of this building increased lighting and outlet energy demand (Figure 17). However, energy saving was maintained as a result.

5. CONCLUSION

The combination of external blinds and the multi-pane heating glass is beneficial to the energy conservation of air conditioning in this building. Heat source system equipment, such as chillers, pumps and ice storage tanks *was controlled as design. In spite of installation of non high-end equipment, the well integrated facilities were operated efficiently, resulting in a 20 percent reduction in energy consumption compared with a typical office building in Japan.

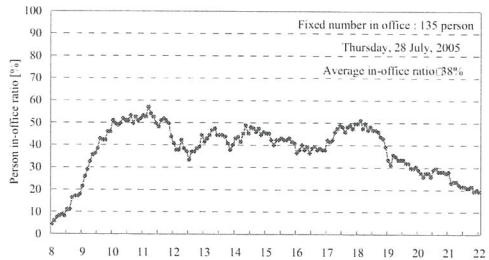


Figure 16: Person in-office ratio (5F).

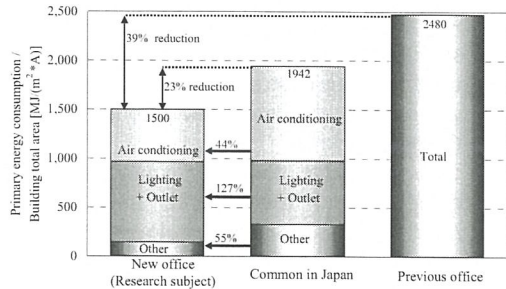


Figure 17: Effectiveness of the building.

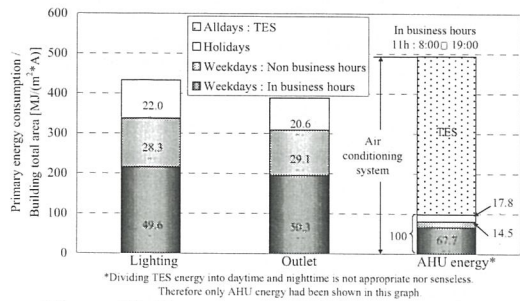


Figure 18: Energy consumption comparison with business hour and non business hour.