Optimal operation of HVAC systems of a laboratory building based on Cx.

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ABSTRACT

Tokyo Electric Power Company R&D Center was completed in September 1994. The buildings constructed in Phase I (hereinafter just called “the buildings") were conferred the 35th Annual Awards by the Society of Heating, Air-Conditioning, and Sanitary Engineers of Japan (SHASE). The award was given to commend the 30% (approx.) energy savings attained by the adoption of the cold air distribution system and various other techniques and technologies for energy conservation and operation management. Tokyo Electric Power Company R&D Center has undertaken a wide range of building commissioning including building management since the completion of the construction. Now that a decade has passed since the completion, the R&D Center has enhanced the energy-saving performance well beyond the levels previously awarded.

1. INTRODUCTION

Tokyo Electric Power Company R&D Center launched the project for the construction of the central research facilities in 1992, hoping to re-energize our R&D through interaction enhanced by assembling the researchers who had worked the laboratories for various fields in four dispersed sites in the Tokyo Metropolitan area. The Phase I Project for the construction of the "Main Research Building (the former Research Building and Entrance Lobby) and Exhibition Building (the former Conference Building)" (within the red-bordered rectangle in Fig. 1). The following objectives were carefully considered at this planning.

1) To provide the surrounding communities with comfortable environments and to minimize potential impacts on the urban and global environment; and,
2) To establish a creative research environment and conserve energy.

Table 1 Overview of air-conditioning system

Heat source equipment	Double-Bundle Air-source Heat-Pump (DBAHP) 400 kW × 1 unit Double-Bundle Water-source Heat-Pump (DBWHP) 315 kW × 1 unit		
	Heat storage tank	Ice storage tank: 680 m^3, IPF 40% (Ice-on-coil system)	
		Hot water storage tank: 730 m^3	
	Exhaust heat utilization	Supplying of chilled/hot water using fuel cells (withdrawn in 2002)	
Air-conditioning equipment	Piping system	Main Research Bldg. upper floors	Variable water volume 4-pipe system
		Others	Variable water volume 2-pipe system
	Air conditioner	Main Research Bldg.	Cold air distribution Variable air volume
		Computer Room	Under floor air distribu
		Others	Constant air volume o Variable air volume

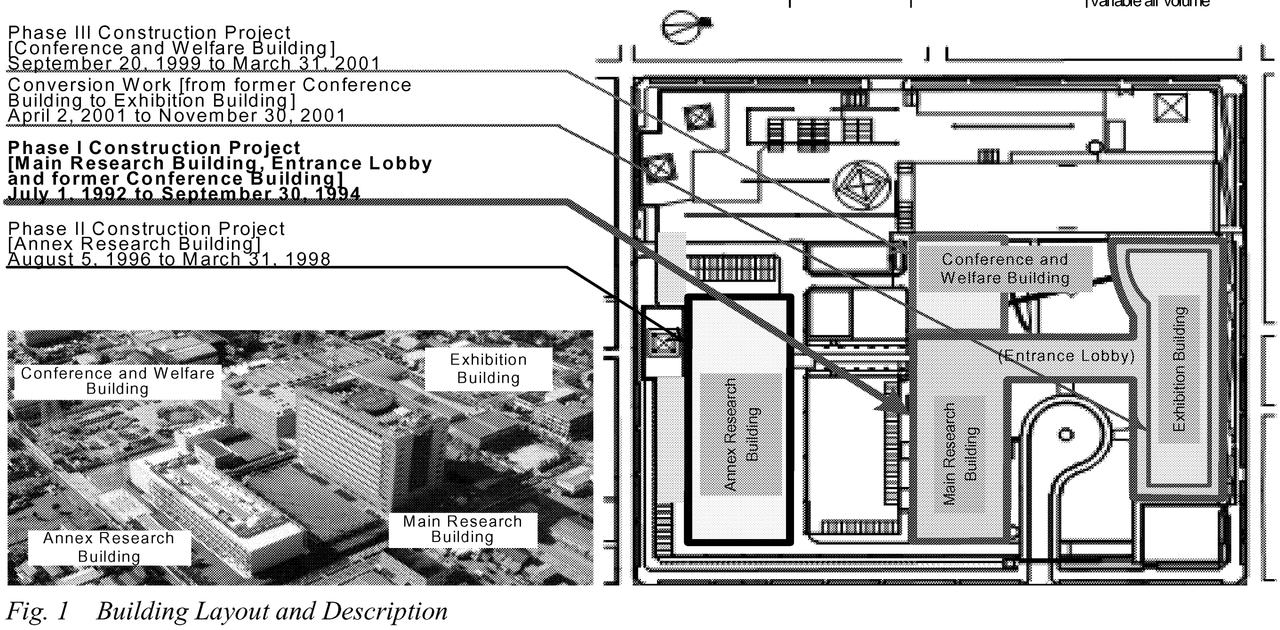

Fig. 1 Building Layout and Description

Phase I was followed by the construction of more buildings (the Phase II and Phase III Construction Projects) and the conversion of the "former Conference Building" to the "Exhibition Building (Electric Power Historical Museum)." Since the completion of these phases, the pattern of building usage and the structure of energy consumption at the project buildings have gradually changed. Table 1 gives the overview of the air-conditioning system adopted. A brief summary of the enhancements achieved follows.

1.1 Optimized operation based on data presented in visual forms.

・ A 30% enhancement in overall air-conditioning efficiency of the cold air distribution system (ice thermal storage system) achieved by feeding back findings into the designers and the operation managers
・Comfort and environmental performance maintained without interruption for ten years [Stably good indoor environments have been available since the award was conferred]
・ Load matching and equipment efficiency improved by tuning operation of the heat source equipment and control of the thermal storage system [10% enhancement in COP (coefficient of performance) of the whole heat source system]
・ Further improved heat transport factor by tuning minimum airflows in the cold air distribution system [40% enhancement]
・ Substantially reduced electric energy for lighting through turning off most of the lights together automatically according to schedules (the simultaneous lights-out function) [10% energy savings]

1.2 Ongoing implementation of pioneering commissioning

・ A Working Group (WG) formed to take charge of the operation management of the buildings; energy conservation meetings held at two-week intervals [providing solutions to about 1,800 types of problems]
・ Commissioning implemented to cover not only equipment operations but also building management based on measurement data through the BEMS (Building Energy Management System) [covering about 15,000 cases]

Figure 2 gives the overview of developments of the new R&D facilities from the completion of the Phase I Construction Project to the present, based on various data.

Changes of electric energy consumption in the buildings (Phase I Construction Project) prove that the energy conservation performance has been consistently maintained. Total loads (sum of heating and cooling) have gradually enhancement as the following buildings were completed; however, those of the buildings have changed little. Moreover, the enhancement of measures to energy saving has been implemented since fiscal 2002; as a result, energy consumption has been also decreasing.

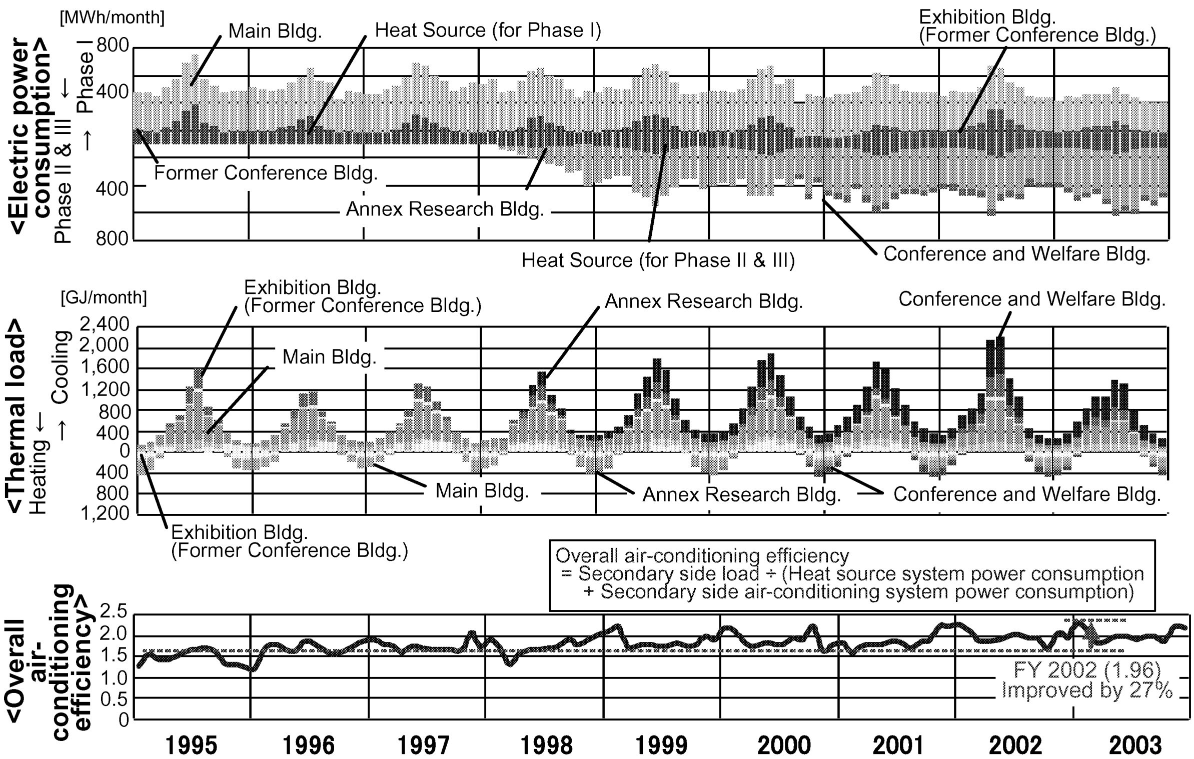

Fig.2 Transition of Building and Changes in Various Data

2. MAIN POINTS

2.1 Optimized operation based on data presented in visual form

Recognizing measuring operation data to be important, we have measured as many as 9,000 points for the buildings. Clearly understandable visual presentation should be essential for the effective use of high-volume data in practical applications; in recognition of this, a BEMS incorporating various capabilities for graphical presentation with aids of graphs through off-line PCs has been built and applied in the operation management WG, etc. Examples of several practical outcomes of these achievements are described below.

2.1.1 Changes in basic units for the buildings and effects of tuning of operation

The Main Research Building, having two-thirds of the total floor area of the buildings constructed in Phase I, was targeted for evaluation of the basic units for comparison with other standard buildings .

Figure 3 shows changes in the basic unit of primary energy consumption and the amount of CO_2 emissions by fiscal year.

The primary energy consumption has remained below the standard value specified by SHASE in every fiscal year. The value rose in fiscal 1998 and 1999 since fuel cells as experimental equipment had deteriorated with their efficiency low. The value rapidly fell in 2002 when the experimental fuel cells were removed and all of the buildings equipments were electrified. The primary energy consumption in fiscal 2003 decreased further as a result of the record-breaking low temperatures in the summer of that year. The data in fiscal 2003 are treated as reference and the year 2002 is defined as a standard year.

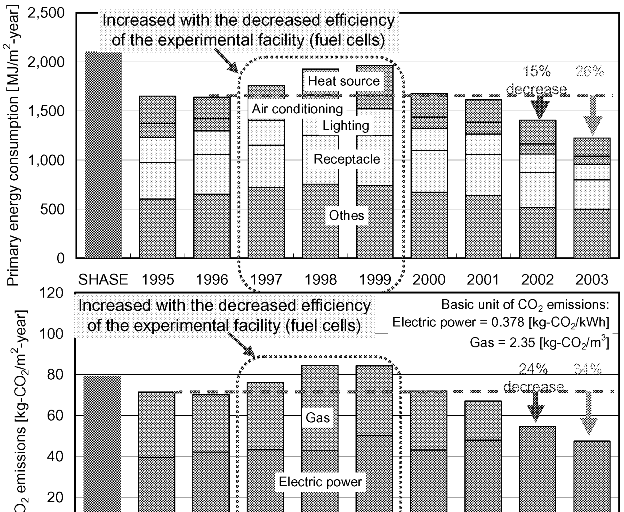

Fig.3 Changes in primary energy consumption and CO_2 emissions over time

Similarly to primary energy consumption, CO_2 emissions enhancement in fiscal 1998 and 1999 because of the fuel cells with low efficiency; however, emissions rapidly decreased after the electrification.

2.1.2 Assurance of uninterrupted comfort

(1) Assurance of thermal and aerial environment

Results of environmental measurement in accordance with the Act for Maintenance of Sanitation in Buildings (Law for Securing Hygienic Environment for Buildings) are shown in Fig. 4. With the adoption of the cold air distribution system, the humidity could be reduced to a low level in summer; however, it has met the criteria as demonstrated by Fig. 4. The buildings need all year air-cooling; hence low humidity becomes a problem in winter. Ultimately it has been brought to a level that satisfies the criteria through tuning of the humidifiers, though the humidity actually dropped below 40% at one time. For the aerial environment, air change rate was set at 1.8 times per hour in expectation of possible effects from separation of smoking areas. As it turned out, airborne particles and CO_2 concentration met the standard values.

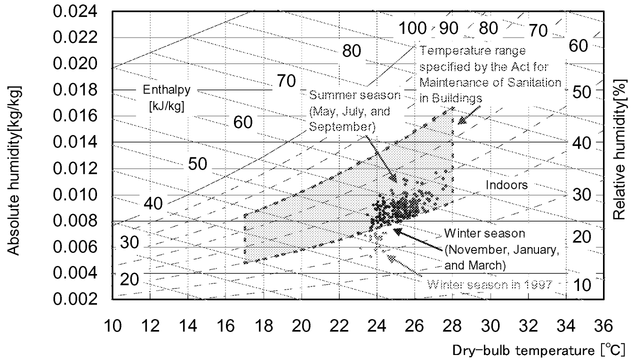

Fig. 4 Indoor temperature and humidity (FY 1997 through FY 2003)

(2) Assurance of radiational thermal environment at windows through perimeter-less air-conditioning

Since their completion, the buildings have adopted a perimeter-less form of air-conditioning with built-in ventilation windows equipped with an automatically controlled shading mechanism. The thermal environment at the windows is comfortably assured.

(3) Assurance of visual environment through lighting control

The illuminance on desks in the offices with optimal control of illuminance and daylight utilization almost meets the design value of 750 Lx. There have been no complaints from the people working in these offices.

2.1.3 Operation management of the heat source system and results obtained

Tokyo Electric Power Company R&D Center has tuned operation of the heat source systems in the buildings with an emphasis on the following points.

1) To maintain and improve the COP (coefficient of performance) of each individual heat source equipment.
2) To improve the COP of the entire heat source system (S-COP).
3) To level the electric power load.

As a result, S-COP was improved by 10% in fiscal 2002 compared to the early stages just after the completion of the buildings.

(1) Maintaining and improving efficiency of each individual heat source equipment

For all heat source equipments, their COPs have been maintained above the design value through consistent monitoring of the COPs and comparison with the design COP since the buildings were completed. Specific methods of tuning and changes in the COPs of the heat source equipment are described below.

a. Improvement of the COP by optimizing circulating water temperature
b. Improvement of the COP by tuning the control of fans
c. Maintaining high-efficiency operation by tuning various operation modes

(2) Improvement in S-COP of the entire heat source system

Based on comparisons of the COPs classified by operation mode and heat source equipment with each other, priority of operation order has been given to the DBWHP with higher efficiency throughout a year. The chiller has been tuned to operate in the exhaust heat recovery mode as much as possible whenever there is demand for heating. The results are illustrated below and in Fig. 5.

(Heat source for cooling)

1)Exhaust heat from fuel cells － 2)Heat from DBWHP － 3)Heat from DBAHP

(Heat source for heating)

1)Exhaust heat from fuel cells－2)Recovered exhaust heat from DBWHP－3)Recovered exhaust heat from DBAHP－4)Heat from DBAHP

[* The fuel cells were removed in 2002 since it had been installed on an experimental basis.]

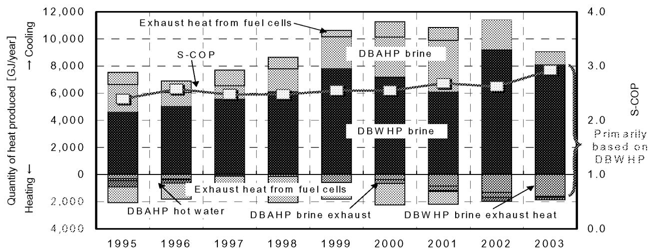

Fig. 5 Load sharing rates of each individual heat source and S-COP

(3) Continual operation management for matching of electric power load

If heat source equipment is to be used effectively for the enhancement of heat storage operation, accurate forecasts for quantities in thermal load and residual heat storage should be of importance. Details are given below.

a. Tuning of the thermal load forecast
b. Effects of tuning of the residual heat storage prediction

Figure 6 presents the heat storage balance on the day when maximum power demand was recorded. As the figure shows, the improved accuracy in assuming the load, the produced heat and the stored heat ensures that both of the thermal storage and the follow-up operation work properly in the heat source equipment.

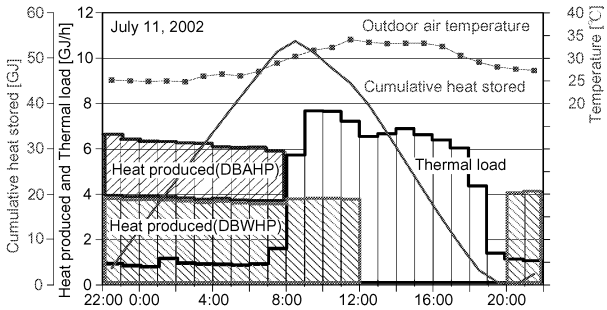

Fig. 6 Heat storage balance on the day of maximum electrical power demand

c. Effects of the tunings evaluated from a point of view of load shift

The ratio of load shift on heat provides very high values, 93% for cooling and 96% for heating.

Figure 7 depicts changes in the ratio of electric power load shift. It has consistently exceeded 90% in every stage except the stage early after building completion.

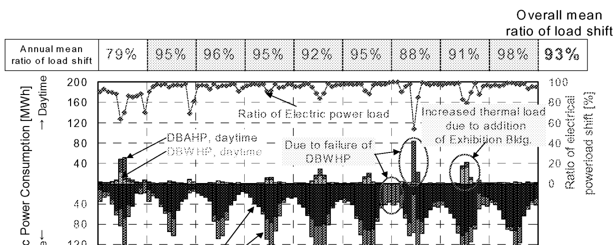

Fig 7Changes in the ratio of electric power load shift

Figure 8 shows the efficiency of thermal storage (ratio of quantity of heat produced to quantity of heat consumed). As the figure indicates, the efficiency is also maintained stably in 2003 (94% for cooling and 90% for heating), and loss of heat from the heat storage tank and the piping system is relatively low. This confirms that the insulation performance does not decline.

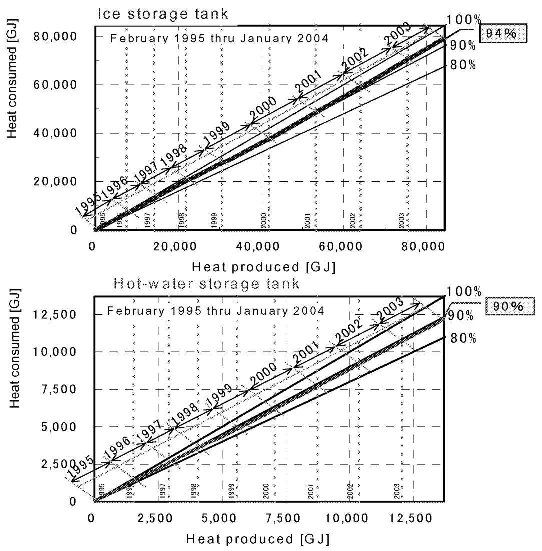

Fig. 8 Efficiency of thermal storage

2.1.4Operation management of the air-conditioning system and results obtained

Although cooling load factors fall below design values, cooling is needed predominantly throughout a year, so tuning was conducted as described in (1) and (2) below in order to improve heat transport factors. Figure 9 shows the change in mean efficiency TTF* by a fiscal year to demonstrate effects available from the tuning. It has been improved by 37% in fiscal 2002 and later, compared to that in the early stages after the completion

ATF*	Thermal load ÷ Fan power consumption
WTF*	Thermal load ÷ Pump power consumption
TTF*	Thermal load ÷ (Fan + Pump) Power consumption

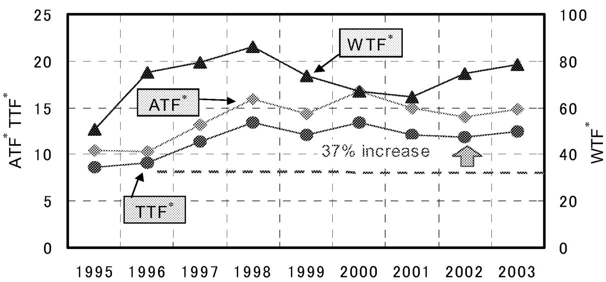

Fig. 9 Changes in TTF and other transport factors over time*

(1)Improved heat transport factors by tuning of the cold air distribution system

a. Tuning of the control of two-way valves for chilled water
b. Alteration of positions of thermostats
c. Tuning of minimum airflow rates

The separation of smoking areas ensures an acceptably low concentration of airborne particles in the buildings. Thus, minimum air change rates through VAV have been retuned to about 1.8 times per hour, although it was 3 before. As a result, the electric power consumption of the fans is reduced by 7%. Details are shown in Fig. 10.

This has helped to additionally facilitate the saving of electric power consumption for heat conveyance by cold air distribution since the VAV units regulating the zones with smaller interior heat can control temperature at lower air flow rate without resetting of the supply air temperature.

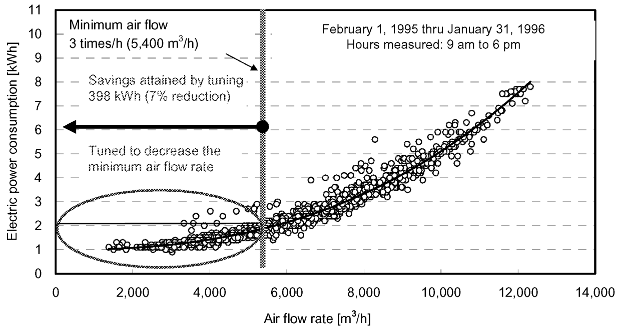

Fig. 10 Supply air flow rates and fan power consumption of an air conditioner

(2) Tuning of pumps for the air conditioning system

The water transport system in the buildings is based on a large temperature difference concept (design temperature difference 9 to 10°C), whose effects have been maximized by tuning the multiple units control and the speed control of pumps for the air conditioning system. Results of the tuning are described below.

a. Tuning of the multiple units control of pumps
b. Tuning of the speed control of pumps
c. A cleaning of heat exchangers

The timing for a cleaning of heat exchangers was determined based on changes in output power characteristics of secondary pumps for general chilled water system in upper-floor. Figure 11 shows changes in electric power energy before and after a cleaning. The characteristic curve is made gradual and the power consumption could be reduced by 78%.

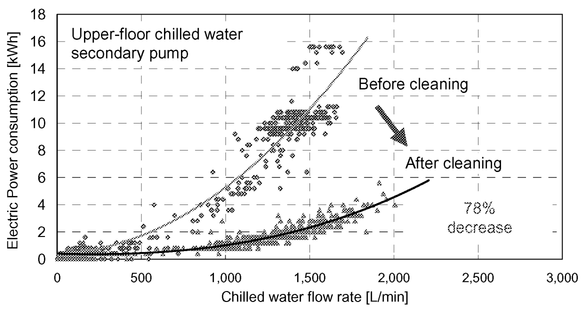

Fig. 11 Pump power consumption before and after cleaning of heat exchangers

2.1.5 Tuning of operation management of the lighting system and results obtained

The cutting-edge lighting control system composed of high-efficiency Hf lights and optimal illuminance control with daylight utilization, which are popular now, has been available in the offices faced on south.

The optimal illuminance control means once-a-month lowering excessive illuminance from new lamps using inverter. The daylight utilization means illumination control (2 to 100%) using the first two banks of the closest lamps to the south side window, which responds to varying daylight through window shades controlling its blade angels automatically. The operation management system employs a time-schedule control which implements simultaneous lights-out function at lunchtime (12:00 to 13:00) and during overtime hours (19:00 and 22:00). After lights-out the lighting system can be operated by remote controllers installed in each lighting zone (corresponding to an area enclosed by columns in the office), as enables to illuminate the particular zones requiring lighting.

Figure 12 presents the electric power of lighting saved by the simultaneous lights-out function. This operation management has helped the electric power reduction per year attain approximately 14%

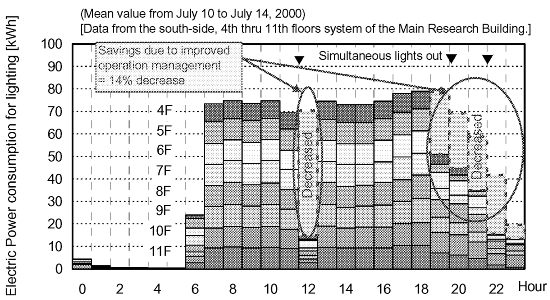

Fig. 12 Daily mean electric power consumption for lighting

2.2 Continual practice of the pioneering commissioning

2.2.1 Organization and system for commissioning

The Building Energy Management Working Group (the "EM-WG" hereafter) is composed of all parties who are involved in the energy management of buildings, including users, designers, operation managers, maintenance managers and contractors. The EM-WG was established just after the buildings were completed and now meets every other week. The EM-WG has implemented early detection and prompt repairs of problems and feedback to operation and maintenance, which are called "commissioning" now. The group members are able to handle these activities by making the most of the knowledge, experience and technical skills they have been developing and maintaining in their own fields, as well as by visualizing the performance management data, paying attentions to details in the building management including the operation of equipments.

2.2.2 Actual results of operation management and maintenance and feedback

(1) Solutions to problems and number of solutions implemented

The EM-WG has solved over 1,800 types of problems since the completion.1,137 types of problems were encountered in fiscal 1995(The first year). These account for about 61% of all of the problems reported in 9 years.

Among the many types of problem in that year, 764 (about 67%) were related to air-conditioning equipment. Among these problem types, retuning due to improper tuning of VAV and demand for improvement accounted for 575 (approx. 51%). In fiscal 1996 and later, the incidence of problems decreased substantially. This indicates that commissioning is more important in the first year after the completion.

The number of types of problems discussed in the EM-WG has been reduced sharply since the second year, while the total number of actual problems has not. This may prove the effectiveness of two factors: first, the application of the EM-WG's experience with tuning to similar cases; second, the contributions of effective functioning of PDCA as well as the definite network in which the EM-WG is central for the members.

3. CONCLUSUION

The buildings constructed in Phase I were conferred the 35th Annual Awards by the Society of Heating, Air-Conditioning, and Sanitary Engineers of Japan (SHASE). Now that a decade has passed since the completion, the R&D Center has enhanced the energy-saving performance well beyond the levels previously awarded.

- A 30% enhancement in overall air-conditioning efficiency of the cold air distribution system
- Comfort and environmental performance maintained without interruption for ten years
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REFERENCES

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