THE ACTUAL OPERATIONAL SITUATION OF HEAT SOURCE FACILITIES THAT UTILIZED HIGH EFFICIENCY HEAT PUMPS AND THERMAL STORAGE

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Abstract: The Tokyo Electric Power Company's thermal storage contract service, using high-efficiency heat pumps and thermal storage, provides for the construction, operation, management and maintenance of heat source facilities of customer-owned thermal storage air-conditioning systems. To operate a thermal storage air-conditioning system properly, data measurement and monitoring are critical for the accurate assessment of operational situations which will change on a daily basis. Our thermal storage contract service uses information technology (IT) to acquire operational data, which is subsequently used for analysis from various perspectives and visualization through graphic representation. Based on information acquired from analysis and visualization processes, the validity of heat source facilities is checked daily, and if required, collective measures are taken to achieve optimal operation. There are many advantages in combining high efficiency heat pumps and thermal storage, which, when maximized and combined with optimal operation and maintenance based on operation data, are an essential and effective means of realizing a "Low-Carbon World" in future.

Key Words: Thermal Storage Contract Service, Heat pumps, Data measurement and monitoring

1 INTRODUCTION

The Tokyo Electric Power Company (TEPCO) provides the "Thermal Storage Contract Service" using high-efficiency heat pumps and thermal storage air-conditioning systems. In this service, TEPCO is responsible for the construction (design and installation) of heat source facilities for customer-owned thermal storage air-conditioning systems, and undertakes the operation and maintenance for an extended period. To operate thermal storage air-conditioning systems properly for a long time, accurate assessments of operational situations which will change on a daily basis is critical. To achieve this, the thermal storage contract service utilizes IT for collecting data and managing operations. This report covers part of TEPCO's activities for deploying the thermal storage contract service, and assessments of currently operating heat source facilities based on their operation data.

2 THERMAL STORAGE CONTRACT SERVICE

2.1 Overview

In thermal storage air-conditioning systems, heat source equipment such as a centrifugal chiller or air-cooled heat pump chiller is operated overnight to store chilled/hot water or ice in thermal storage tanks, and the heat in the thermal storage tanks is then used for air conditioning in daytime.

A thermal storage air-conditioning system, which contains additional components, i.e. thermal storage tanks, which make structures slightly more complex compared with a non-thermal storage system, enables the capacity of the heat source equipment to be reduced because the thermal storage tanks absorb fluctuations and level off the air-conditioning load. The heat in thermal storage tanks is used as a priority in daytime for air conditioning, reducing the frequency of operation of the heat source equipment which is mainly operated overnight via an inexpensive overnight electricity service for storing heat into thermal storage tanks. Accordingly, the thermal storage air-conditioning system is characterized by flexibility to adjust to the fluctuating air-conditioning load, which is a significant advantage from an economic perspective.

So, TEPCO provides the "Thermal Storage Contract Service" offering total support for building owners planning to introduce such systems. This service includes the construction (design and installation), operation and maintenance of heat source facilities for an efficient supply of chilled or hot water required for air-conditioning. Figure 1 illustrates the scope of service. In principle, the heat source equipment uses a combination of a high efficiency electric heat pump, top-rated in its field at the time, and water or ice thermal storage tanks. None of our personnel resides on-site for operating the heat source facilities as a rule, and it is operated remotely, via automatic control, with the status also remotely monitored.

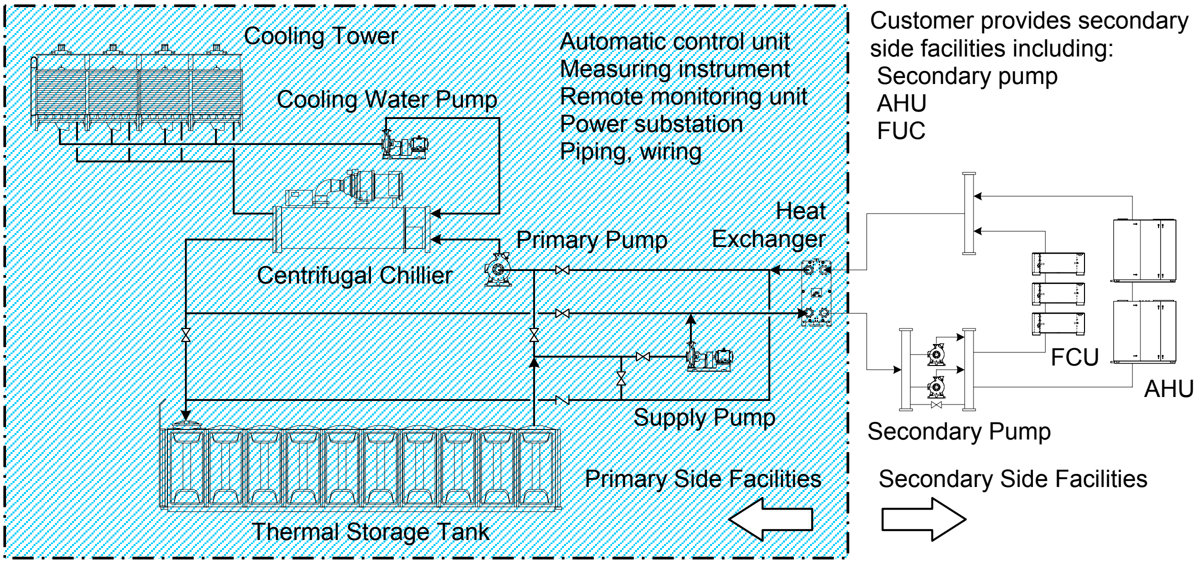

Figure 1: Scope of the Thermal Storage Contract Service

2.2 Customers of the Thermal Storage Contract Service

The current thermal storage contract service commenced in 1998, since which we have won 47 contracts till 2010, including those currently under construction. Table 1 shows the customers of the thermal storage contract service by industry. 26 contracts, representing about 55 percent of the total of 47 contracts, fall into commercial buildings, including large malls. In addition, various types of industry, including offices and hospitals, have selected our service for their air-conditioning systems, the structures of which differ depending on the air-conditioning load profiles and heat source facilities.

Table 1: Number of Contracts

	Commercial Building	Office	Hospital	Others	Total
No. of contracts	26	7	4	10	47

Table 2 lists the number of currently operating heat source units and their capacity. A total of 472 units or 66,915USRt are used as the heat or cold sources for air conditioning. There are 44 boilers or 55,573kW used as the heat source, for which TEPCO handles the operation and management. This suggests that the scale of service is relatively large.

Table 2: Number of Heat Source Units and Their Capacity

Unit	Type	Quantity	Capacity	
			kW	USRt
Centrifugal chiller	Cooling water	18	62,083	17,656
	Brine	57	142,652	40,569
Chilling unit	Air-cooled	183	22,008	6,259
Packaged air-conditioner	Ice thermal storage	31	1,291	367
	Ordinary type	183	7,257	2,064
Boiler	Steam	18	23,879	--
	Hot water	26	31,694	--

3 OPTIMAL OPERATION OF THERMAL STORAGE AIR-CONDITIONING SYSTEMS

3.1 Monitoring System and Allotment of Work

Operation data for heat source facilities and alarm signals emitted when an error is detected are transmitted from the remote monitoring system installed on-site to the maintenance service company we have contracted for field service, and the EsP (Energy Service Provider) Center, which is our remote monitoring center, via telephone line, etc. Various types of data are accumulated at these places. Figure 2 shows the heat source facilities monitoring system and the allotment of work to related parties.

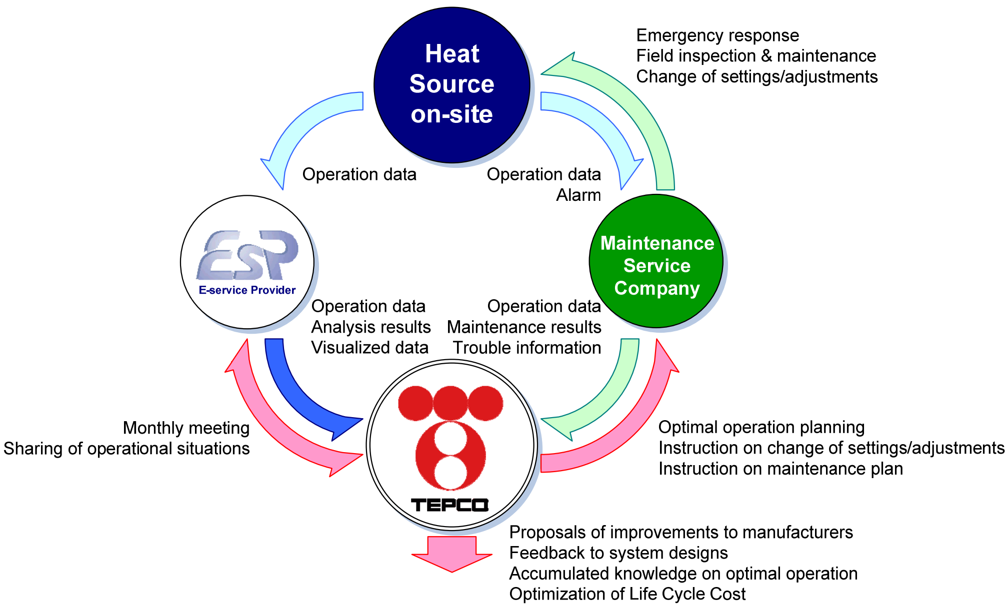

Figure 2: Monitoring System and Allotment of Work

TEPCO is responsible for checking the data transmitted from the EsP Center to determine any abnormalities in the operation of heat source facilities at each site, and accumulating various data, including inspection results and information on malfunctions delivered from the maintenance service company on a day-to-day basis, as well as performing various analyses based on the accumulated information, investigating and planning the optimal operation method for heat source facilities according to the actual air-conditioning load, and instructing the maintenance service company on specific corrective work. It is also responsible for proposing improvements to equipment manufacturers on the relevant operation data and trouble information, and providing feedback for such improvements in our system design in future. Another important role of TEPCO is to optimize the Life Cycle Costs (LCC) required for the operation and maintenance of heat source facilities.

The EsP Center mainly accumulates the operation data transmitted from the remote monitoring unit at each site, visualizes the information in the form of numerical data and graphs, and delivers them to the related parties via the Internet. The EsP Center also summarizes the operational status of the heat source facilities at all service sites for the most recent weekly period, and sends the results of any abnormality analysis to TEPCO as a weekly report. Similarly, it creates a monthly summary of the operational status of heat source facilities in terms of management criteria such as efficiency, and presents it at the monthly joint meeting held by TEPCO and the EsP Center. Here, both parties confirm efficiency of operation, abnormal status, and so on through comparison of all service sites.

The maintenance service company is responsible for visiting the service site as soon as it receives an alarm indicating the failure of heat source facilities from the site and taking necessary countermeasures. It is also responsible for conducting monthly field inspections, regular maintenance of equipment, and any on-site work, including adjustments to equipment settings and change of automatic control settings.

3.2 Data Collection

To accurately assess the operational status of heat source facilities, it is critical to measure operation data such as temperature, flow rate, energy consumption, and the start/stop and operating time of the equipment at appropriate measuring points. TEPCO determines a list of management items critical for operating heat source facilities in advance, according to which the measuring points are set. Major management items include the quantity of heat supplied, supply temperature, energy (electricity, Gas) and water used, night rate (percentage of electricity consumption overnight), individual equipment or system efficiency, and thermal storage capacity, etc. Typical measuring points and other information are listed in Table 3.

Table 3: Major Management Items of Heat Source Facilities

Category	Managed object	Management item
Measurement	System	Quantity of heat supplied
		Supply temperature and flow of hot/chilled water
		System efficiency (quantity of heat supplied / energy consumption)
	Equipment	Quantity of heat produced
		Inlet/outlet temperature and flow of hot/chilled water
		Energy consumption (electricity, gas)
		Efficiency of individual equipment
		Operation count, operating time
	Thermal storage tank	Inlet/outlet temperature and flow of hot/chilled water
		Temperature distribution in thermal storage tank
Information	Trouble	Failure of equipment
		Improper supply temperature
		Improper supply due to human error

The volume of collected operation data for heat source facilities is enormous, but every measuring point is managed on a priority basis. Proper analysis of the data collected, and feedback of the results are essential for optimizing the operation of heat source facilities.

In addition to numerical data, we think information on various types of problems arising during everyday operation is also important. Such problems at heat source facilities range from trivial to serious, possibly even leading to the system shutdown. When a problem occurs, regardless of severity, related data such as the generation status, emergency measures taken, the course of development, and root cause, etc. is collected and accumulated in the form of text and photos. Based on this data, the required software or hardware measures are taken, and the information is delivered to all service sites to prevent any recurrence.

3.3 Short-term Monitoring Scheme

The volume of operation data for heat source facilities is enormous, and it is very difficult, even for experienced engineers, to figure out the accurate operational status with numerical data alone. For this reason, visualized data such as graphs and tables is an effective means to facilitate and simplify assessments of the current situation, and the basic requirements for achieving optimal operation. In addition to the direct use of numerical data, this operational data can also be used for analyses using various indices to determine the actual operational status more accurately.

The operation data of heat source facilities is sampled every minute, and tabulated every hour for data management. The operation data acquired can be analyzed in hours, days, weeks, months, quarters, and years, but TEPCO mainly uses the “one-day or one-week” data and “one-month or one-year” data as the units of monitoring and operating heat source facilities. To adjust the system, ensure it achieves optimal operation promptly and prevent immediate trouble predicted through daily monitoring, one-day and one-week data is most frequently used. Figures 3 and 4 show the typical visualized data used by TEPCO for monitoring the system.

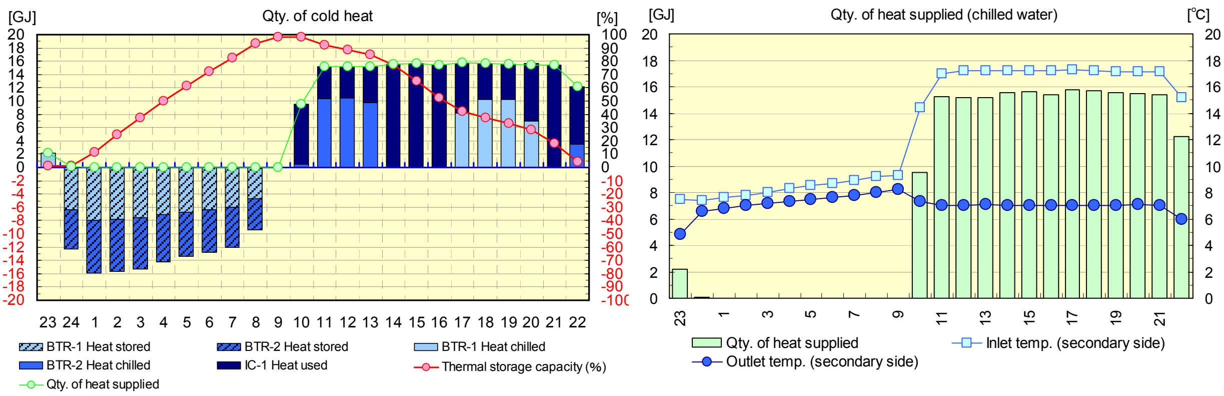

Figure 3: Operational Status in One Day

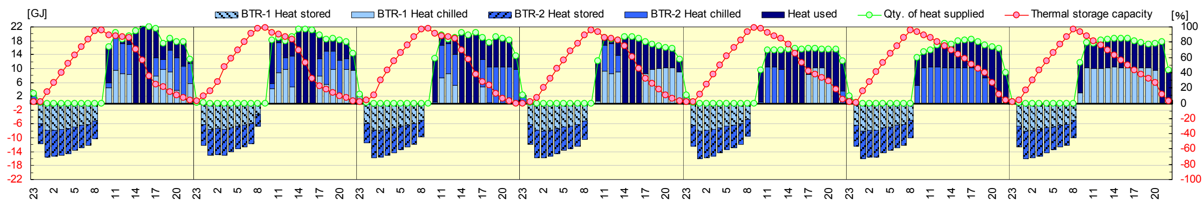

Figure 4: Operational Status in One Week

In Figure 3, the following six main items are monitored for daily operation:

(1) Suitability of thermal storage operation overnight (22:00 to 8:00)

(2) Sufficient quantity of stored heat at 8:00 in the morning.

(3) Coverage of full load only with stored heat during the peak time (13:00 to 16:00)
(4) Operation without the need for heat source facilities to operate during the peak time
(5) Depletion of stored heat during the period from 16:00 to 22:00.
(6) Changes of supply water temperature within a preset range.
* TEPCO sets "the peak time" between 13:00 and 16:00 during summer (June to September) in its Electricity Demand and Supply Clause.

If anything abnormal occurs, e.g. the deficient performance of the heat source equipment or incomplete thermal storage operation, TEPCO immediately sends an instruction to the maintenance service company to change the settings or make adjustments. In Figure 4 - Operational Status in One Week, the items to be monitored include the balanced use of heat source machines according to load conditions which usually fluctuate on a daily basis, or an appropriate transition between the storage and consumption of heat. The material reviewed in daily operations may also be found in this weekly operation.

3.4 Long-term Monitoring Scheme

For non-thermal storage air-conditioning systems, the heat source equipment often operates inefficiently with repeated starts and stops during the low load period. Thermal storage air-conditioning systems operate more efficiently by covering the load in daytime with stored heat alone. To achieve efficient year-round operation of heat source facilities, sufficient care is required for operation during periods of low as well as high loads.

Ever-changing air-conditioning loads and external temperatures cause the operation data to be varied accordingly, suggesting that getting an accurate picture of the actual operational status within a short span of time like a day or week is difficult. Therefore, to optimize the operation of thermal storage air-conditioning systems, analysis of the operation data over a longer period of one month or year may be required in addition to daily monitoring. In handling long-term data, momentary fluctuations need not be considered seriously, allowing analyses using operational efficiency for a certain period or values such as proportions based on certain indices.

Table 4: Monitoring Items for Long-term Operation Data

Monitored object	Monitoring item
System	Quantity of heat supplied within a specified period
	Energy consumption (electricity, gas) within a specified period
	Efficiency of system within a specified period
	Night rate
Equipment	Quantity of heat produced within a specified period
	Energy consumption (electricity, gas) within a specified period
	Efficiency of individual equipment
	Operation count, operating time
	Water supplied for producing heat (centrifugal chiller)
Thermal storage tank	Heat stored/supplied within a specified period
	Efficiency of thermal storage (supplied heat/stored heat)

Table 4 lists the main monitoring items for acquiring long-term operation data. Noting efficiencies in principle, monthly or yearly values are calculated, and the results are compared with the rated efficiencies provided by equipment manufacturers to check for unnatural variation. By comparing the results with data for recent years, specific status and age-related deterioration can be detected. Age-related deterioration can be useful information to determine when to overhaul the equipment, and largely influence the management environment, including the cost planning (LCC) required for maintaining heat source facilities.

4 ACTUAL OPERATIONAL STATUS OF HEAT SOURCE FACILITIES

4.1 Case with Commercial Buildings

In operating thermal storage air-conditioning systems, it is important to know the process of the load required for the building, and the operational status of thermal storage tanks and heat source equipment. In six typical commercial buildings selected from our service sites, the system operation was analyzed throughout the year in 2010, the results of which are partially shown in this section.

The six commercial buildings are characterized by the significant cooling load and slight heating load required. All these building sites use ice thermal storage air-conditioning systems. Sites A to E use a set of centrifugal chillers and ice thermal storage tanks for their heat source facilities, while site F, where heating demand is expected to some degree, uses a set of air-cooled heat pump chillers and ice thermal storage tanks.

Figure 5 shows the heat balance of heat stored in the tank, the quantity of heat supplied from the tank, and the quantity of heat produced during a daytime chilling operation, arranged in order of date, and duration curves in which the heat balance components are arranged in descending order. These graphs also contain the maximum quantity of heat that can be produced by heat source facilities at the relevant sites based on the design and tank capacities.

The heat balance graphs in the figure reveal that chilling operations take place within the period May to October during which the cooling load climbs, and the air-conditioning load is covered only with the heat from the thermal storage tank for the period November to around April, during which the cooling load declines. The graphs reveal the year-round behavior of heat source facilities at a glance. To achieve the efficient operation of thermal storage air-conditioning systems throughout the year, it is important to deplete the entire heat stored in the tank.

In the duration curves in Figure 5, noting the period during which the chilling operation of the heat source equipment takes place, the quantity of heat supplied from the storage tank is near the tank capacity at sites A to C, E and F, indicating an efficient operation in which almost all the heat in the tank is consumed. In contract, at site D, the amount of heat supplied is less than the tank capacity, and the chilling operation, unnecessary under ordinary circumstances, was started, indicating the need for further operational adjustments. The proportion of the actual maximum load in one day relative to the calculated quantity of heat that can be supplied by the heat source facility is 67 to 80% in 2010.

Figure 6 shows, based on the operation data mentioned above, the ratio of the quantity of heat supplied from thermal storage tanks to the air-conditioning load, the efficiency of thermal storage, which is the ratio of the quantity of heat supplied to that of heat stored, and the annual supply system efficiency of heat source facilities.

The proportion of the quantity of heat supplied from the thermal storage tank to the annual air-conditioning load is an average of 69.8% at six sites. At site F, where the thermal storage tank capacity is intentionally reduced, the thermal storage air-conditioning system is capable of covering up to 70% of the air-conditioning load with only the heat from thermal storage tanks throughout the year. The thermal storage efficiency is 96.0% at six sites, suggesting that, even when considering heat loss from thermal storage tanks and pipes, almost all the heat stored is consumed for the air-conditioning load. However, the thermal storage efficiency drops slightly at sites D and F. To increase the efficiency, there is a room for improvement such as the adjustment of settings to determine when to complete the storage and supply cycle, or the operation of supply pumps during low load periods.

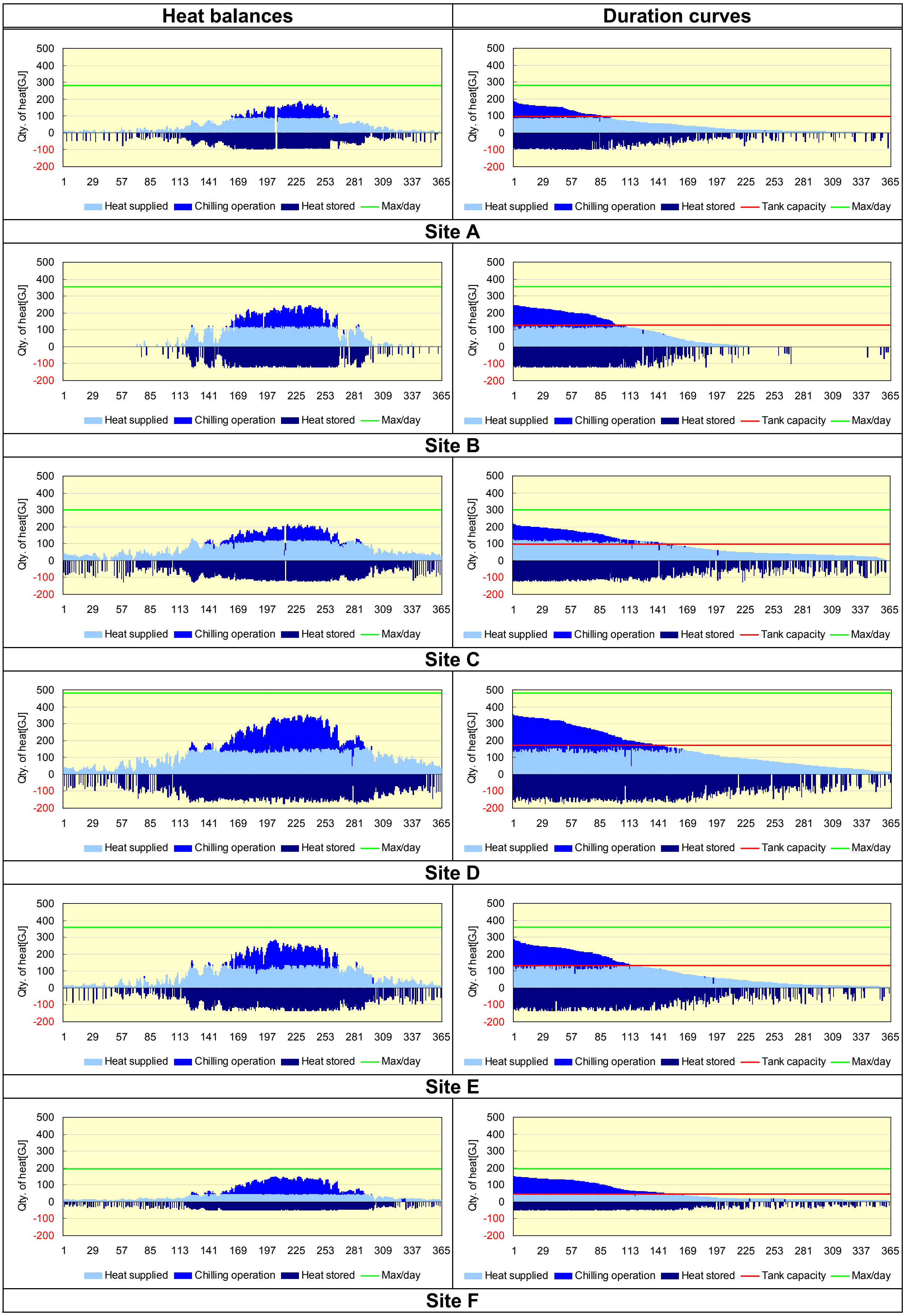

Figure 5: Heat Balances and Duration Curves (Commercial Buildings, 2010)

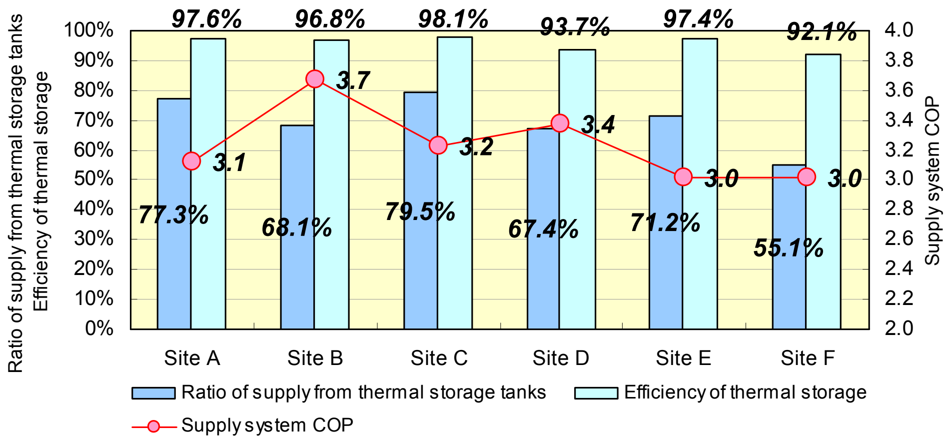

Figure 6: Ratio of Supply from Thermal Storage Tanks, Efficiency of thermal storage & Supply System COP (Commercial Buildings, 2010)

Finally, the annual supply system COP (Coefficient of Performance: energy consumption efficiency = quantity of heat supplied / energy consumption) in secondary energy equivalent of heat source facilities is 3.7 on-site B, and an average of 3.24 over all six sites. The efficiency of ice thermal storage air-conditioning systems at these sites still needs to be improved, but highly efficient operation has been generally achieved.

To operate thermal storage air-conditioning systems efficiently, it is important to design and operate supply pumps properly. Their operation, especially during low load periods, was found to be quite influential on overall system performance.

4.2 Optimal Operation Planning

4.2.1 Example of a Commercial Building

The owner of a commercial building, in which air-cooled heat pump chillers were used for ice thermal storage air-conditioning systems, requested improvements in operation efficiency and reduced electricity consumption for energy and cost savings.

TEPCO requested the owner to provide operational data for the secondary side air-conditioning facilities, which was subsequently analyzed to assess the load conditions of the building. Consequently, the flow balance was found to be poor on both the primary and secondary sides, while the plate type heat exchanger did not exchange heat at the predetermined temperatures. This made the inlet temperatures of the air-cooled heat pump chillers unstable, causing the heat source equipment to operate improperly. It was also found that the flow meter, which measures the quantity of heat supplied at the secondary side to determine the number of heat source units to be activated, was installed in the wrong place.

The solution was a review of the control scheme around the plate type heat exchanger, and a change in the quantity of heat to determine the number of heat source units activated from the secondary to primary side. The threshold to determine the highly efficient point operation of heat source units was also changed. Figures 7 show the results.

A comparison of operation efficiency for one month in August 2008 and August 2010, during which the load conditions were similar, reveals that the COP of individual equipment for a month improved by about 7% from 3.08 to 3.28 on average. For electricity consumption in one day, as shown in Figure 7, the correlation between the external temperature and electricity consumption in 2008 and 2010 shows a reduction in electricity consumption of about 2,000kWh, even when the external temperatures are similar.

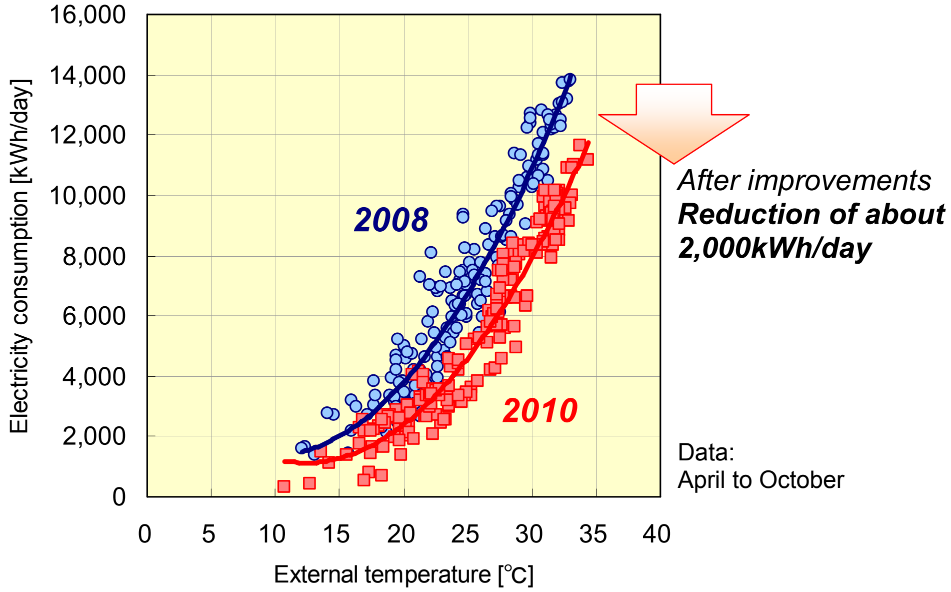

Figure 7: Correlation between External Temperature and Electricity Consumption

4.2.2 Example of a Factory

At a factory where the ice thermal storage air-conditioning system using centrifugal chillers is installed, the peak electricity demand of the entire facilities tends to be set between 13:00 and 15:00 during summer. The customer requested a reduction in electricity demand for energy and cost saving.

Analysis of the operation data of the factory suggested that one of the factors to increase electricity demand would be the timing of the chilling operation, whereupon the heat supply pattern was studied. The electricity demand of the entire facilities was likely to start rising at around 11:00, peak between 13:00 and 14:00, and decrease at around 15:00. During the summer peak in question, the heat supplied from the thermal storage tank was completed at around 13:30, whereupon two chillers were activated, raising the electricity demand of the whole facilities.

The initial countermeasure involved changing the operational schedule to prevent the activation of chillers immediately after the peak time zone by changing the time to supply heat between 8:00 and 12:00. When this change was made, the electricity demand between 12:00 and 15:00 declined, but two chillers started operating at 8:00 because the heat was retained until 12:00, resulting in the electricity demand peaking between 10:30 and 11:30, which had never been seen before. In addition, the heat supply started at 12:00, even on a holiday when the load was reduced. Consequently, the heat stored in the tank was not used up in a single day, and thermal energy tended to remain in the tank. Although changes in the heat supply timing solved the problem of daytime electricity demand, two further new issues arose.

The next countermeasure involved restoring the heat supply start time to the original setting of 8:00 to reduce the electricity demand between 10:30 and 11:30 which took place in the previous change, while at the same time, chiller settings were changed so that one of the two chillers was activated earlier than the other to prolong the duration of heat supply from the thermal storage tank, and prevent two chillers from operating at the same time until 15:00.

Figure 8 shows the results. The morning electricity demand was met by operating one of the chillers to cover the load and supplying heat from that in the thermal storage tank to compensate for the shortage of required heat. The simultaneous use of the heat from the thermal storage tank and the chilling operation with a chiller could be continued up until 16:00, which allowed a significant reduction in electricity demand, about 400kW, and simultaneously resolved the problem of eliminating surplus heat on holidays.

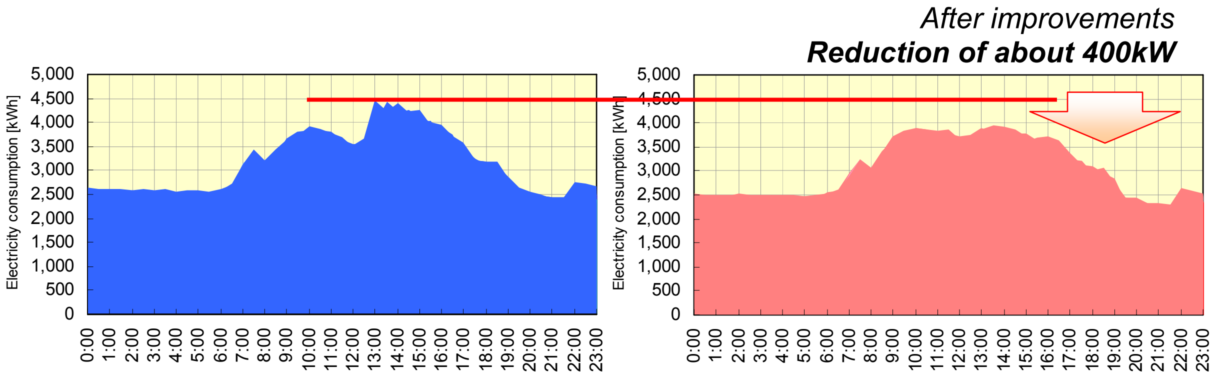

Figure 8: Electricity Demand Curves at a Factory
(Left: Before Improvements, Right: After Improvements)

By creating an operation scheme to use thermal storage tanks effectively, we can flexibly manage air-conditioning loads and reduce electricity demand appropriately.

When making an optimal operation plan, certain measures may solve existing problems immediately, but possibly trigger new problems. Operational improvements for energy and cost savings can be achieved only when we steadily continue our efforts to check daily operations and analyze data.

4.3 Insights about Operating Thermal Storage Air-Conditioning Systems

Features of Thermal Storage Air-conditioning Systems

An effective use of heat in thermal storage tanks is critical for energy-saving and the economical operation of thermal storage air-conditioning systems. In the examples given in 4.1, the proportion of air-conditioning loads covered by the heat from the thermal storage tank to the annual air-conditioning load is about 70%. By designing the thermal storage capacity and the system components properly, and making accurate assessments of the daily operational status, a highly efficient system that can effectively use the heat in thermal storage tanks can be implemented.

One of the notable features of the thermal storage air-conditioning systems is the fact that all loads can be covered by the heat from thermal storage tanks during low load periods. In general heat source equipment, air-conditioning loads of less than about 20% of equipment capacity cannot be controlled as required, and the equipment simply turns off. This is sub-optimal in terms of the efficiency and life of the equipment. In contrast, the thermal storage air-conditioning system allows the stable operation of the heat source equipment in a highly efficient way overnight or during low load periods, while covering the air-conditioning load using only the heat from thermal storage tanks in daytime, enabling year-round energy saving operation.

As shown in the optimization examples in commercial and factory facilities in 4.2, the thermal storage air-conditioning system can flexibly cover the air-conditioning load of relevant facilities when adjustments are correct, and meet the need of the customer's request requiring high technological skills for energy and cost saving operation.

Importance of Operation and Maintenance

Visualized operation data is critical for operating thermal storage air-conditioning systems. Analyzing this operation data from various perspectives, and visualizing the resulting data help clarify whether the operation of heat source facilities is maximized, or whether problems, etc. occur. The defects overlooked when an individual site is inspected may emerge in comparison with other sites.

Whereas, the information obtained from visualized operation data does, in fact, have limits. Field inspection and maintenance allow us to estimate the actual status of heat source facilities, and by analyzing it together with remote monitoring data, problems which may never surface on desk checks emerge for correction.

Appropriate remedial action on-site to cope with problems at different stages is essential for maintaining the optimal performance of heat source facilities as well as preventive maintenance and improvements. The heat source facilities installed under the thermal storage contract service are automatically operated in principle, but appropriate remote monitoring plus field inspection, and careful adjustments and changes in settings according to the status will promote further energy saving.

Life Cycle Cost Based Maintenance Plans

It is important to set an appropriate maintenance cycle for the equipment and systems in operating and maintaining heat source facilities. Equipment manufacturers indicate recommended maintenance cycles for maintaining the performance and function of their products, but these are often conservative. In most cases, constant and steady daily inspection and maintenance will prolong the maintenance cycle, and often reduce the maintenance cost.

A life cycle cost-based maintenance plan for the efficient operation and maintenance of heat source facilities can be set out only through accurate assessments of the operational status of equipment and systems, and conducting inspections, maintenance and other field work steadily.

5 CONCLUSION

Air-conditioning systems consume a significant proportion of energy used in buildings. When energy saving is the issue, the focus is often on the use of high efficiency equipment and inverters. This is critical as a matter of course, but energy saving in real terms requires full consideration of the operation of air-conditioning systems. Vast energy is consumed by air-conditioning systems installed in buildings while the latter are in use. To qualify as an energy saving building over an extended period, it is important to operate the air-conditioning system on a day-to-day basis according to its features.

The thermal storage contract service of TEPCO aims to optimally exploit the advantages of thermal storage air-conditioning systems, and achieve long-term practical energy saving operations by accurately assessing the daily operational status of heat source facilities based on data. We are certain this will lead to a “Low-Carbon World.”

6 REFERNCES

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