Analysis and Evaluation For Equipment Performance by Surface Measurement

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Abstract: Many building owners and facility managers are deeply interested in both operation and maintenance costs related to a building's life cycle. Optimizing energy consumption and obtaining long equipment activity requires sophisticated management. If the data needed for this management are unavailable, then measures must be taken to augment them. We were able to lower power consumption in heat source equipment by approximately 12% by means of analysis and evaluations as well as using optimum measurement features that allow measuring operation data without stopping operation of surface measurement equipment. More cost-effective renewal plans and designs were achieved by proposing equipment specifications based on the cooling and heating load during operation.

Key words: building energy; measurement; analysis; evaluation; facility management; Energy saving

1.INTRODUCTION

We have been developing a "Measurement + Analysis + Evaluation Totalized System (we called MAT)"[1] as an engineering tool for the planning, design, installation, and operation of HVAC systems. Evaluating HVAC system performance is indispensable not only for assessing the installation technology but also for optimizing equipment performance and environmental conservation. It is essential that results from these performance evaluations are utilized in operation proposals designed to make customer equipment more sophisticated and as feedback to improve quality in the design, installation, and machine manufacture of HVAC systems.

In this paper, we describe the critical importance of measurement + analysis + evaluation in assessing the operating state of the equipment. We also report on a Case A that makes operating improvements in new equipment; and a Case B that designs and provides renewal planning of aging equipment. Both cases involve implementing that assessment process.

2. BASIC TECHNOLOGIES FOR MAT

We are developing basic technologies for MAT to allow providing operating proposals to optimize factors in the building life cycle such as operation control, energy utilization and renewal decisions. By integrating these technologies we aim to obtain a maximum effect for minimal (optimized) measurements.

2.1 Technology for Measurement

The basic functions of the Building Automation System (BAS) are only equipment monitoring, scheduling [2], and gathering and/or recording status values needed to operate and control equipment such as inlet / outlet temperatures and equipment starting / stopping, etc. The stored data is only the minimum required information so the information needed for analyzing and evaluating equipment performance is inadequate in most cases. Moreover, adding measurement points to the BAS is not easy, especially in terms of costs. However when there is not enough operating data for making an evaluation, then surface measurement will prove an effective tool for making measurements at a low cost without having to stop the equipment. Figure-1 shows an overview of the surface measurement setting points. Sensors were first of all installed on the outer surface of pipe / duct / electricity wiring, and conversion and compensation formulas then established to accurately understand the internal flow information from surface measurement data from the sensors. The temperature measurement accuracy was within a temperature differential of ±0.4°C.

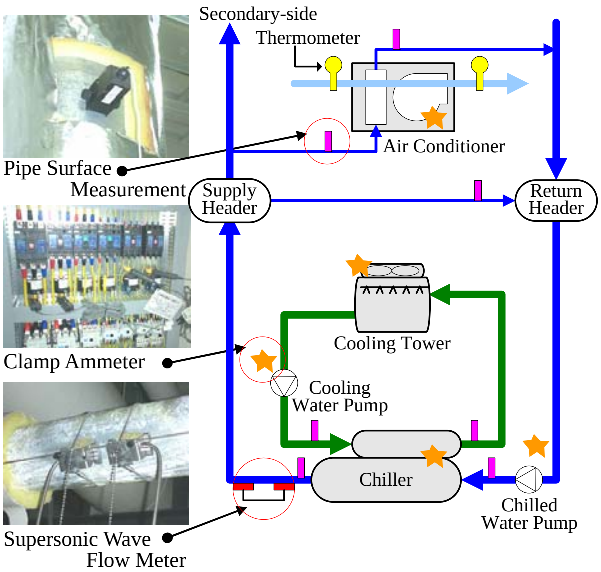

Fig. 1 Schematic diagram of Surface measurement setting points

2.2 Technology for Analysis

Operating data collected from the BAS was utilized in spreadsheets, making daily reports and graphs [3]. However MAT also uses the information for analyzing control actions and analyzing performance of equipment that has aged over time, in order to determine whether the control set points are suitable. Operating data measured in the machinery shown here was used to analyze performance of individual machines and to analyze the energy balance between generating and using to the entire building.

2.3 Technology for Evaluation

A hierarchical display graph was drafted as a guide for devising improvements and for evaluating equipment performance from actual measurements of equipment operating states and analysis results. A typical hierarchy graph is shown in Figure-2. Current problem points detected to the macro level are shown at the topmost level of the graph display. The next lower level is results from cause-and-effect analysis used for finding the operating states in detail. The following lower level is results from cost analysis for evaluating in advance, the effects obtained after making improvements and countermeasures. The finally level is a graph for verifying countermeasure results by making a before and after comparison. The order that one views the graph differs according to the user's job and occupational specialty so that it can serve as an interface between human and machine by means of separate layered graph menus that allow the user to easily find the needed graph.

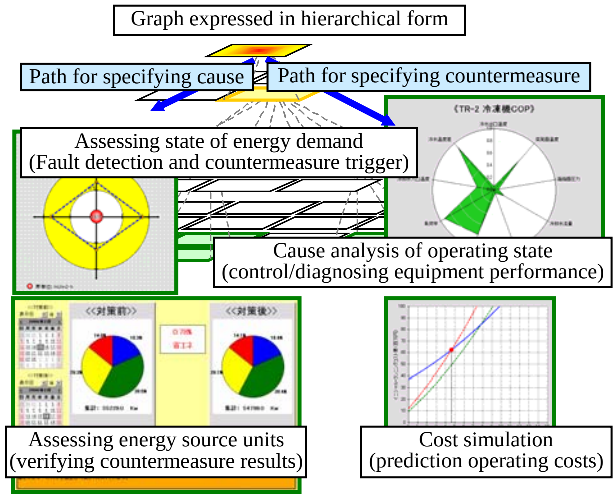

Fig. 2 Hierarchical construction of graphic to use MAT

3. MAT APPLIED TO INITIAL USE FACILITY (CASE A)

This case shows operation planning changes that take into account the actual performance and performance assessment of chiller (turbo type) after installation of new facility (industrial plant applications) was completed.

3.1 Need for Finding the Actual Performance

Recently built facilities include many energy-saving devices such as high-efficiency chiller [4]. These were incorporated at the planning design stage as an investment giving priority to effects on the equipment life cycle. The correct type of operation and sophisticated management is needed to make this type of equipment exhibit its full performance. If the operating data needed for this sophisticated management is not recorded at the BAS, then measurements must be made within a short time to find the current performance.

3.2 Collecting Operation Data

Equipment operation status values are constantly fluctuating to make the deviation versus the control set points smaller. The daily report (hourly and daily average values, maximum values and minimum values) printed out by the BAS is sufficient if the facility manager is merely comparing the control set points with the operation states. However, evaluating equipment performance requires that detailed operating data such as input quantities and output quantities for each piece of equipment be collected within a short period. The BAS data was supplemented with surface measurement data. Figure-3 shows the measurement points. The previously constructed BAS makes more detailed measurements such as the heat value on the secondary-side than many other facilities. However, the facility manager cannot find the chiller performance because no measurements are made of chilled water flow rate data. We therefore made surface measurements while changing the operating combinations on 2 chillers and found the flow rates and temperatures on each chiller. No changes were made in the valve openings before and after measurement so that a fixed flow rate was obtained in the performance analysis made after making the measurements.

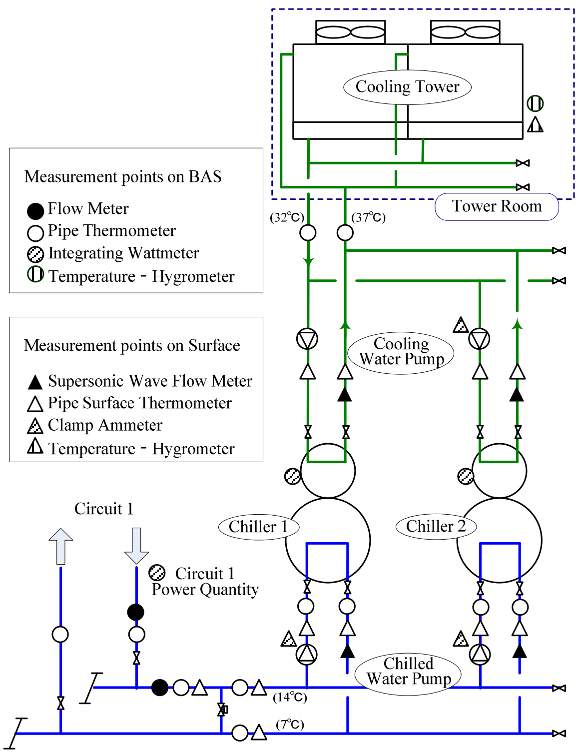

Fig. 3 Points on surface measurement and the BAS

3.3 Evaluating Performance

Flow rate expenditures and control operation stability such as with and without hunting were evaluated using surface measurement data from short periods. Figure-4 shows fluctuations over time in the chilled water temperature. The BAS data in the figure was taken in 10-minute periods and surface measurement data in 1-minute periods. Fluctuations became hunting around 17:25 as shown in the figure. This hunting fluctuation was due to a transient response in the bypass flow rate due to shutting down a portion of the air conditioning system. Operation as viewed from the BAS data appears extremely stable however sudden load fluctuations can be detected in response to hunting phenomenon can be found in the surface measurement data. Hunting not only shortens the control valve service life but also causes wasted energy consumption. As one countermeasure, we re-adjusted the Proportion Integral Differential (PID) constant of the two-way valve, effect to smooth enough changes in the bypass flow rate to follow the chiller's capacity control.

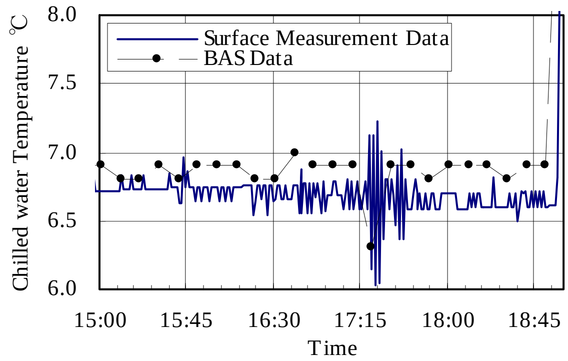

Fig. 4 Differences due to measurement periods for chilled water temperature

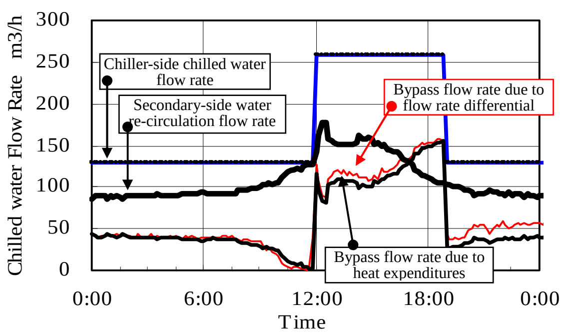

Fig. 5 Fluctuations in bypass flow rate

Figure-5 shows fluctuations in the chilled water flow rate. The chilled water flow rate in this figure is surface measurement data measured by a supersonic wave flow meter. The re-circulating waterflow rate from the secondary-side is the BAS data measured by a magnetic flow meter. Fluctuations in the bypass flow rate due to the flow rate differential between the chiller-side flow rate and the secondary-side re-circulating flow rate can be observed from fluctuations occurring on the secondary-side load and the multiple units control of chiller in operation. Moreover, the bypass flow rate occurring due to the flow rate differential closely matches the bypass flow rate found from the heat expenditure due to the approximate bypass valve temperature. The bypass flow rate required for analyzing / evaluating by regulating the multiple units control of chiller can be calculated from the approximate bypass valve temperature data collected by the BAS..

3.4 Evaluating Performance and Operation Planning

It is essential that the multiple units control of chiller in operation be planned as needed according to the secondary-side heat consumption. The process for evaluating changes in the operation planning based on results from the performance evaluation is described next.

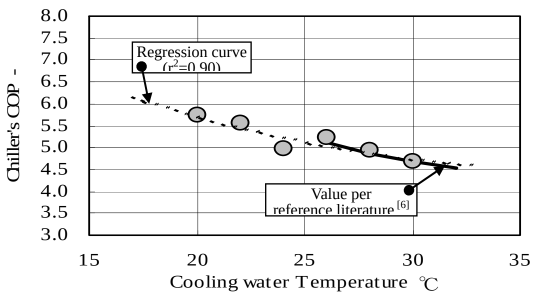

Fig. 7 Chiller's COP per cooling water temperature

(1) Machine performance

The chiller partial load characteristics are con-

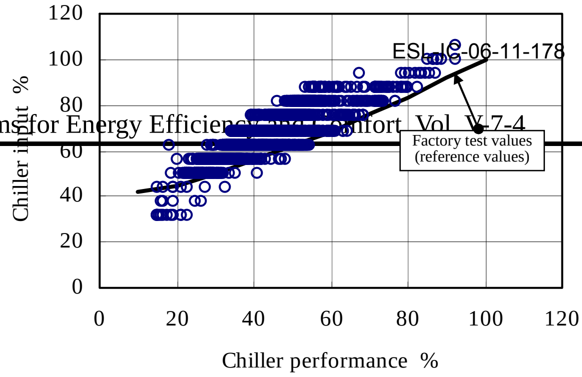

Fig. 6 Chiller's partial load characteristics

firmed in performance tests before being shipped from the factory. However, the operating conditions of the actual equipment are different from those during factory testing so whether the actual performance matches the listed specifications is not known [5]. Figure-6 shows the initial period performance in the 3-month period from the start of operation as well as the partial load characteristics. The chiller performance in the figure was found from the chilled water flow rate obtained by surface measurement over a short period, and the chilled water inlet / outlet temperature differential collected by the BAS. The time differential for the quantity measured by the BAS using an integrating wattmeter was utilized as the chiller input. The rating listed in the machine specifications was subtracted from both figures. Values shown in the figure as factory test results are reference values for the same chiller model. The fact that the equipment delivered the specified performance was demonstrated at the initial start of operation since performance was approximately 95 % versus a rated chiller input power of 100 %.

Figure-7 shows the correlation between the cooling water temperature and the chiller coefficient of performance (COP: thermal output [kW] / energy input [kW]). Values closely matched reference literature values in the figure, and showed a high correlation with the chiller COP up to the low cooling water inlet temperature.

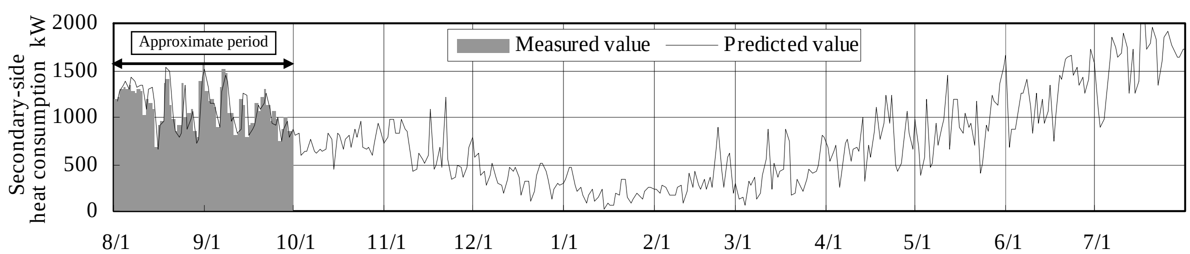

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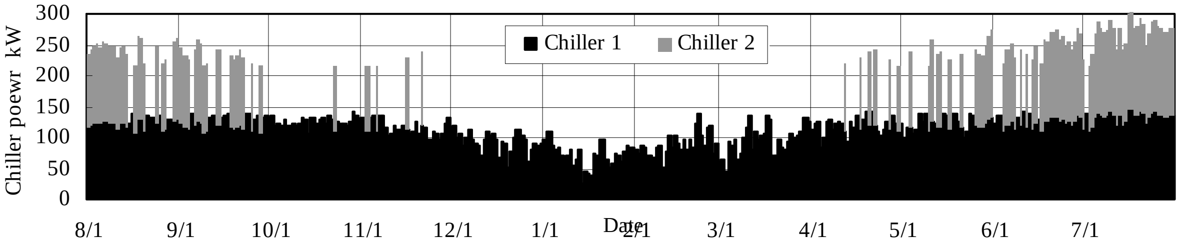
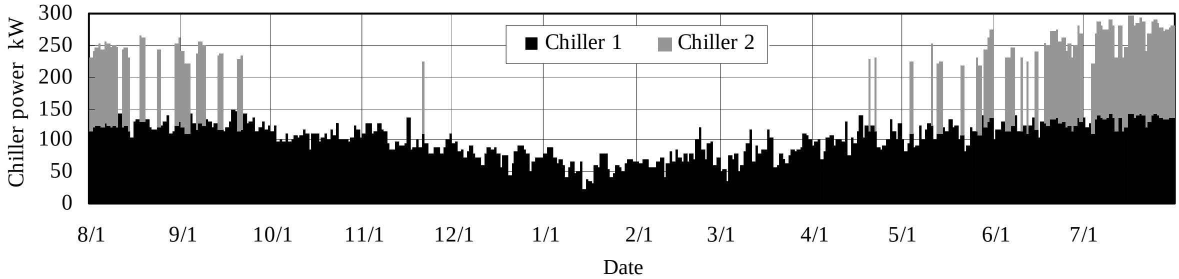
Fig. 8 Prediction results for secondary-side heat consumption



(1) Current status of multiple units control setting



(2) Multiple units control setting for boosting performance via cooling water temperature

Fig. 9 Differences in power due to changing the setting for multiple units control of chiller

Therefore specific values were obtained that are fully capable of predicting changes in performance when this chiller cooling water inlet temperature was changed.

(2) Secondary-side heat consumption

In this case, approximately 50 % of secondary-side heat consumption was from the outer air load due to special characteristics of building utilized as a factory. Here, regression analysis was performed to derive approximate values for outer air enthalpy, incoming power, and secondary-side heat consumption using typical daily values (2 p.m. value) for a 2month period from August 1st through September 30th. Secondary-side heat consumption was then predicted for October 1st and onward. Figure-8 shows the calculation results. The outer air enthalpy used in the prediction was a value found from outer air temperature and humidity values for adjacent metropolitan areas in 2004 from statistical information available from the weather bureau. The approximate accuracy for secondary-side heat consumption was within ±5 % so the predicted values were seen as offering the same accuracy.

(3) Chiller operation planning

Figure-9 shows the chiller power consumption calculated based on changes in performance due to the cooling water inlet temperature, partial load characteristics of the chiller, and the predicted value for secondary-side heat consumption. The efficiency of the fixed speed turbo refrigerating machine improves as the partial load rate rises so the operational planning must include as high a partial load rate as possible. The Multiple units control setting for boosting performance via the cooling water temperature (Figure 9-(2)), lowers the operating frequency of 2 chiller in the intermediate period and reduces the chiller power consumption compared to the current Multiple units control setting (Figure 9-(1)). A 12 % reduction was obtained when compared to the annual chiller power consumption so large energy savings are now possible. Based on results from these calculations, we are currently drafting operation planning while taking into account cooling water temperature control set point and more or fewer stages for multiple units control of chiller setting.

Operation planning that incorporates countermeasures such as changes in control set points and operating methods (mainly for large power consumption equipment) into the equipment from the start of initial operation is an effective means for making correct use of energy while maintaining the air conditioning load.

4. MAT APPLIED TO AGGED FACILITY (CASE B)

An example is described here of design and renewal planning that takes into account actual performance and performance assessment of heat source equipment comprised of 2 chillers (steam absorption type) for an aging equipment (Hotel) installed 23 years ago approaching its renewal period.

4.1 Performance Assessment in Renewal Period

Renewal planning will start due to aging equipment in a facility more than 20 years old. Of course, renewal is not decided upon just by the number of years that have passed. Renewal may include making internal changes at Hotel, sales location changes at commercial facilities, or changes in the building application, etc [7]. However, the main factor in large scale renewal planning such as for heat source equipment is the number of years that have passed. In facilities which renewal period is approaching, it is essential that the renewal planning accurately grasp the current state of the operating equipment, provide the right capacity to cover the actual load, and provide the most effective equipment to yield benefits from the equipment investment. Here, we initiated renewal planning that offered correct equipment capacity after finding the state of current operating conditions and prior to selecting equipment.

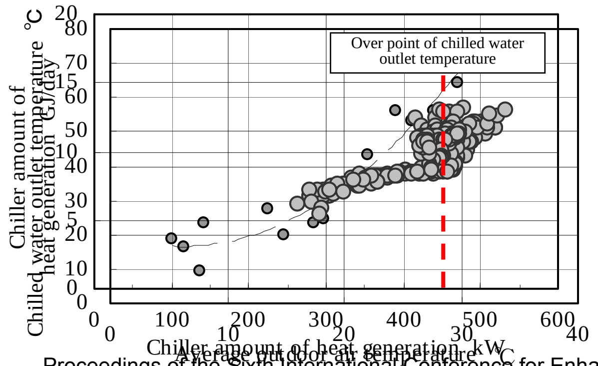


Fig. 12 Correlation between chiller's partial load characteristics and chilled water outlet temperature

Fig. 11 Correlation between outdoor air temperature and heat value emitted by chiller

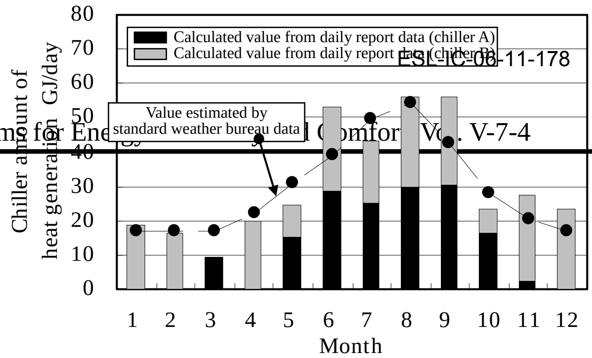


Fig. 10 Fluctuation in calculated value of chiller amount of heat generation

4.2 Surface Measurement and Daily Reports

Operation managers give painstaking consideration as to how utilize the daily report printouts. This is necessary because these reports do not contain enough measurement values for proper management. In energy management, the annual energy consumption figure per surface area unit can be calculated from recorded measurements of electrical power, gas quantities, and water supply quantities. However, whether energy utilization is suitable or not cannot be decided unless the actual load is known. Data in the daily report can be effective utilized if that data is supplemented with the equipment input and output quantities. The heat value for example can be calculated from the supply-return chilled water temperature differential in the daily report data and the flow rate measured over a short period by surface measurement. This does not require procuring all the daily report data, a general idea of fluctuations in quantities of heat generated from the heat source can be obtained by finding the heat value from the supply-return chilled water temperature differential from a typical week for each monthly period.

Figure-10 shows annual fluctuations in chiller amount of heat generation calculated from daily report data for fiscal 2003 and chilled water flow rate during surface measurements made in July of 2004. In this figure, a high correlation was obtained between the chiller amount of heat generation and the average outer air temperatures shown in Figure-11 so the amount of heat generation can be estimated from standard weather data.

Moreover, finding past amount of heat generation from daily report data and surface measurement data, and analyzing the correlation with secondary-side heat consumption allows obtaining information needed for finding the actual operation state such as due to changes in the equipment operating state, and the heat loss state, etc.

4.3 Renewal Planning Based on Equipment Performance Evaluations

The process for deciding on suitable renewal planning using performance evaluations of equipment based on daily report data and surface measurement data is described next.

(1) Evaluating chiller performance

Figure-12 shows chiller's single performance based on surface measurement data. Chiller's performance limits can be determined from the amount of heat generation (horizontal axis) and the chilled water outlet temperature (vertical axis) on this distribution chart. Up to an amount of heat generation of 450 kW, the chilled water outlet temperature gently rises from 7 to 8.5°C. When the amount of heat generation exceeds 450 kW, the chilled water outlet temperature suddenly rises to 12°C, where a maximum amount of heat generation of 530 kW was recorded. The chiller input at this time is a rating so the current chiller performance limit can be determined as 70 % for an amount of heat generation of 790 kW.

(2) Planning for equipment capacity

In currently used chiller, the chilled water outlet temperature climbs as the performance limit is reached, and the air conditioning load can no longer be maintained. Here, Figure-13 shows actual measured values for amount of heat generation during summer peak loads found by surface measurement and gives estimates values required for maintaining the required load. These estimates values were found from daily load patterns for separate equipment having the same application, and use the minimum daily amount of heat generation from actual measurements as reference values. These results allow assuming that the chilled water temperature will rise due to inadequate heat processing capacity in the current equipment in the period from 10:00 to 18:00. This also matches results from the actual measurements. If the maximum amount of heat generation is 1,400 kW, then the currently used secondary-side air conditioning system will be able to adequately support the load by maintaining a chilled water temperature differential of 5°C, even if the loss from amount of heat generation loss is projected as 10 %. The system capacity will also hold even for the estimated annual amount of heat generation in Figure-10. Using these results we planned for a capacity of 1,406 kW, which is approximately 10 % lower than the initial construction equipment capacity (1,582 kW). The actual renewal construction work has currently been completed and the cooling load is now being handled with no problems due to insufficient capacity.

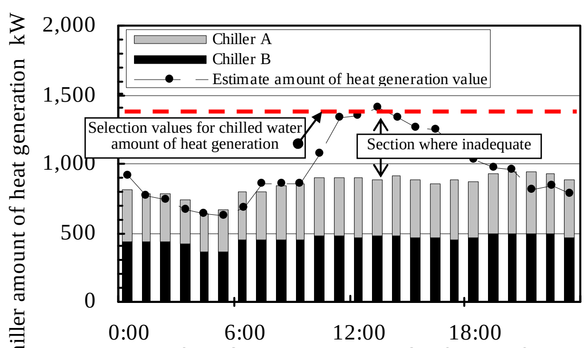


Fig. 13 Estimated chiller amount of heat generation during a summer peak day

Measuring the operating status of equipment assessed as deteriorating from age and whose renewal period is approaching, is usually judged as a waste of the equipment investment. However, if the current operating state is assessed when drafting renewal planning, and ample equipment capacity then planned, the resulting structure renewal will be highly suitable and effective without having to follow up on initial construction equipment performance figures or secondary-side heat consumption quantities. Moreover, a review of equipment capacity need not be restricted to the previous number of machine units so that there is more flexibility and energy consumption is lowered since operation can now take place at high partial load rates. One problem with renewal construction is that installation paths for new equipment are often restricted during renewal construction. However subdividing the equipment into smaller capacity machines can eliminate these installation problems.

5.CONCLUSION

Attaining both economic growth and 1 % per year reduction in carbon dioxide emissions requires planning measures to efficiently use energy and then implementing and verifying that planning. The MAT provides the actual technology needed to fulfill those tasks. This paper describes examples that utilize this technology for optimizing control from the initial startup of operation, and when drafting renewal planning.

The equipment operation data can be regarded as each building's precious asset. Results from analyzing that operating data transcend use for just that building. The essential value of that operating data is that it can be widely in the operation of our nation's building and equipment. In the near future, measurement-analysis information will be jointly shared, and in order to objectively assess equipment performance to device countermeasures to prevent global warming a lateral type of mutual cooperative effort will likely be required among owners, managers, manufacturers, and construction operators, etc.

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