Evaluation on Energy Performance of Heating Plant System Installed Energy Saving Technologies

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ABSTRACT

This paper is concerned with energy performance of building heating plant system installed energy saving technologies. The energy performance from design to operation phase is evaluated by actual measurements and model-based simulation analysis, and the fault on the system operation are detected and was solved through the evaluation is also reported in this paper.

The building and the heating plant system were built in Japan in September 2001, and the operation data have been measured for last about two years. The model-based simulation using heat load data is also carried out. The effectiveness of energy saving technologies is clarified by means of that each technology is considered in the simulation models on a step-by-step basis.

Some faults were actually detected in the last season through these evaluations by measured data and simulation analysis. This fact can show the importance of fault detection and diagnosis and optimization in a system operation phase.

INTRODUCTION

Recently, the topics of environmental destruction and the efficient use of fossil fuels have become prominent; studies on energy conservation in the all field of architecture have been raised in Japan, too. And most of these studies are about commercial buildings, although the energy consumption of industrial facilities is very large. Usually, industrial facilities require strict management for HVAC control relatively because it is deeply related to directly affect production. Therefore, larger energy consumption is demanded compared with other buildings. On the other hand, large energy consumption means that unit price cost is increased. In view of this, energy conservation is very important to a company's economical operation. Generally, the heating plant systems of buildings are intended to reduce energy consumption from the design phase. And to increase the efficiency of a heating plant system and/or reduce energy consumption, it is necessary to adopt some methods in buildings. Therefore, it is valuable to clarify and estimate the effectiveness of heating plant system from the design phase. And the heating plant systems of industrial facilities are equal to

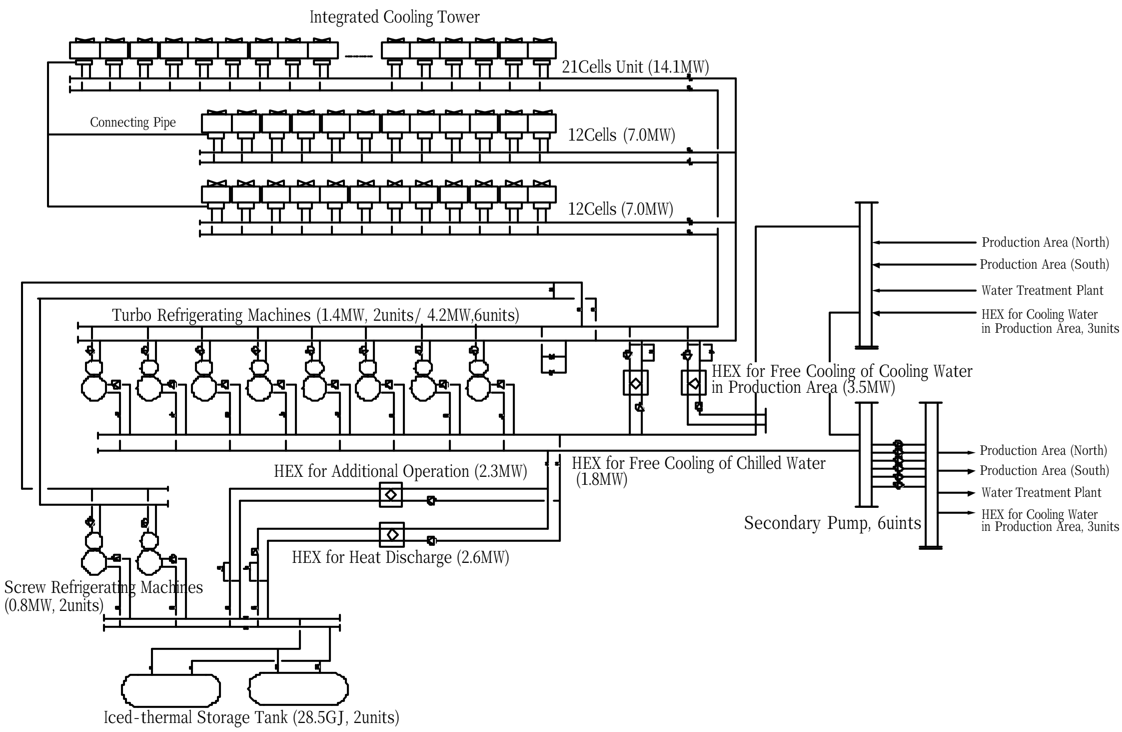

Figure1. Schematic of Heating Plant System

Table1. Design Parameters of Heating Plant System

Equipment	Design Parameters
Turbo Refrigerating Machine	Cooling Capacity: 1.41MW (4811KBtu/h), 2units and 4.22MW (14399KBtu/h), 6units
Screw Refrigerating Machine	Cooling Capacity: 0.8MW (2730KBtu/h), 2units
Integrated Cooling Tower	12Cells, 2units/ 21Cells, 1unit
Iced-thermal Storage Tank	Strorage Capacity: 28.5GJ (27MBtu), 2units
Heat Exchanger (HEX)	Free Cooling of Chilled Water: 1.8MW (6142KBtu/h), 1unit
	Free Cooling of Cooling Water in Production Area: 3.5MW (11942KBtu/h), 1unit
	Heat Discharge: 2.6MW (8872KBtu/h), 1unit
	Additional Operation with Screw Refrigeration Machine: 2.3MW (7847KBtu/h), 1unit
Pump for Chilled Water	Turbo Refrigerating Machine (1.41MW): 152m^3/h (5398mf^3/h), 2units
	Turbo Refrigerating Machine (4.22MW): 454m^3/h (16124mf^3/h), 6units
	Secondary Pump: 567m^3/h (20137mf^3/h), 6units
	Additional Operation: 242m^3/h (8595mf^3/h), 1unit
	Free Cooling of Chilled Water: 303m^3/h (10761mf^3/h), 1unit
	Heat Discharge Operation: 152m^3/h (5398mf^3/h), 1unit
Pump for Cooling Water	Turbo Refrigerating Machine (1.41MW, 4811KBtu/h): 285m^3/h (10122mf^3/h), 2units
	Turbo Refrigerating Machine (4.22MW, 14399KBtu/h): 852m^3/h (30258mf^3/h), 6units
	Free Cooling of Cooling Water in Production Area: 702m^3/h (24932mf^3/h), 1unit
	Free Cooling of Chilled Water: 433m^3/h (15377mf^3/h), 1unit
	Screw Refrigeration Machine: 176m^3/h (6251mf^3/h), 2units
Pump for Brine	Screw Refrigerating Machine: 250m^3/h (8878mf^3/h), 2units
	HEX for Heat Discharge: 334m^3/h (11862mf^3/h), 1unit

those of commercial buildings basically, therefore it goes to without saying that energy saving technologies and equipment used on this system can be adapted in commercialbuildings.

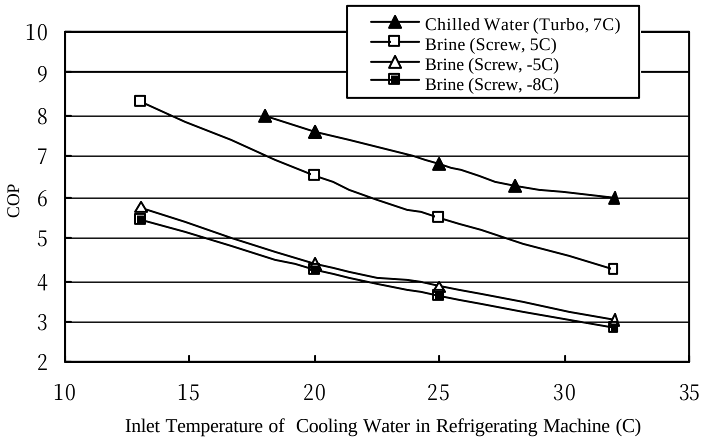

Figure2. Relation between the COP and Cooling Water Temperature in Refrigerating Machine

The mentioned industrial building is for producing semi-conductors and has a clean room facility. It was built in September 2001 and the official name is Kumamoto TEC of Sony Semiconductor Kyushu Ltd (Kumamoto TEC). A trial test was operated from completion of the plant to March 2002 and the actual operation of the plant began in April 2002. The heating plant system is separated from production are a.

OUTLINES OF THE HEATING PLANT SYSTEM

Figure1 shows the schematic of the heating plant system and Table1 shows the design parameters[1]. This system is operated 24 hours a day, 365 days a year. And it consists of turbo refrigerating machines, screw refrigerating machines, integrated cooling towers, iced-thermal storage tanks and some energy saving technologies are used to reduce energy and electricity consumption. The turbo and screw refrigerating machines mentioned in this paper are high efficiency compared with normal type of refrigerating machines. And we use the term, normal type of turbo and screw refrigerating machine, in order to distinguish high efficiency and normal refrigerating machines when it is needed. And this paper presents all of the heating plant system except steam heating as boilers.

Integrated Cooling Tower

In general, the traditional relations between cooling towers and refrigerating machines are on a one to one basis. But in the case of Kumamoto TEC, one refrigerating machine is connected to multiple cooling towers, thus the capacity of cooling tower is larger than that of a traditional one. Therefore, low temperature cooling water can be obtained. The integrated cooling tower consists of 2 groups of 12 cells and 1 group of 21 cells. The on/off set of each group is controlled by the quantity of the cooling water flow. Furthermore, the fan's operation in the cooling tower is changed with 4 steps on the condition of cooling water outlet temperature in cooling tower. When the quantity of the flow exceeds the default values, another group of unit cells goes stand by mode. And if the overflow state continues beyond a set time, another group of unit cells runs. In the case of a decreasing flow, it follows an opposite process. Figure2 shows the relation between the co-efficient of performance (COP) and cooling water temperature of refrigerating machines. As the cooling water temperature becomes lower, the COP value is raised. Each turbo and screw refrigerating machine has a lower limit of cooling water temperature; the limit of a turbo refrigerating machine is 18 degrees Celsius, and a screw refrigerating machine is 13 degrees Celsius.

Free Cooling Operation of Chilled Water

The chilled water is free-cooled before entering a refrigerating machine to raise the COP. The heat exchange between cooling water and returned chilled water, which comes from the production area, occurs. When the cooling water temperature is below 13

Table2. Operation Modes of Iced-thermal Storage in Season

Operation Methods	Modes	Operation Conditions
Thermal Charge Operation	Normal Thermal Storage Operation	Weekday, 10pm-8am
	Extended Thermal Storage Operation	Weekend, 8pm-8am
Thermal Discharge Operation	High Load Discharge Operation	Summer
	Low Load Discharge Operation	Spring, Fall and Winter

Table3. Nighttime Shifting Ratios of Quantity of Heat

Season	Date	Discharge Operation Modes	Heat Load of Production area in Day Time [MJ (kBtu)]	Quantity of Discharged Heat [MJ (kBtu)]	Nighttime Shifting Ratios of Heat Quantity [%]
Summer	Jul. 10th (Wed) 2002	Normal	373938 (354426)	43296 (41037)	12
	Jul. 15th (Mon) 2002	Extended	379723 (359909)	53255 (50477)	14
Fall	Oct. 3rd (Thur) 2002	Normal	246285 (233434)	43386 (41122)	18
	Oct. 15th (Mon) 2002	Extended	243315 (230619)	53098 (50327)	22
Winter	Jan. 10th (Fri) 2003	Normal	266965 (253035)	46241 (43828)	17
	Jan. 20th (Mon) 2003	Extended	276745 (262304)	57338 (54346)	21
Spring	April 9th (Wed) 2003	Normal	352643 (334242)	46434 (44011)	13
	April 7th (Mon) 2003	Extended	348529 (330343)	56932 (53961)	16

degrees Celsius, the chilled water pump for heat exchanger (HEX) runs.

The Control of the Turbo Refrigerating machine

A turbo refrigerating machine group consists of 8 apparatuses and keeps the chilled water temperature stable. The on/off set of turbo refrigerating machine is controlled by the quantity of chilled water flow. And there are 16 steps of refrigerating machine control in spite of having 8 apparatuses, because each one has 2 steps of operation; a refrigerating machine runs at 50% load and at 100% load, as the case may be. Furthermore, operations switch if there is a sudden alteration of the chilled water temperature.

When multiple turbo refrigerating machines are run, one of them is chosen as the base apparatus based on operation timetable and load from production area. The chilled water temperature of this base apparatus is 1K lower than that of other operated turbo refrigerating machines, those are non-base ones. These non-base turbo refrigerating machines cover the load from the production area by running at 100% all the way. And the base apparatus covers the remained load by portion load running. The turbo refrigerating machines are controlled also by load alteration as seasons change. The chilled water temperature is 2K higher in winter because of the comparative low load. The chilled water temperature would be changed in spring, summer and fall. During the period, base turbo apparatus makes chilled water of 7 degrees Celsius, and non-base turbo refrigerating machines makes 6 degrees Celsius. On the other hand, base turbo apparatus makes chilled water of 8 degrees Celsius, while non-base ones make 9 degrees Celsius in winter. This is the reason that the same ability can be obtained with less demand when the outlet temperature of chilled water gets higher.

Thermal Storage Operation

Mainly, the screw refrigerating machines are due to the iced-thermal storage operation during the night. And there are 2 methods of thermal storage. The operation modes of iced-thermal storage are shown in Table 2. The heat is charged during 10 hours in the night with brine (5 degrees Celsius below zero) in the case of normal thermal storage operation. However, the electric bill is cheaper on weekends and holidays because of a contract with the electric company. Therefore, an extended thermal storage operation is run and the heat is saved during 12 hours with brine (8

Table4. The COP of Iced-thermal Storage System

Date		Quantity of Electric Consumption [MWh (MBtu)]			Quantity of Discharged Heat [GJ (MBtu)]	COP of Iced-thermal Storage System
		Screw Refrigerating Machines	Pumps of Screw Refrigerating Machines	Pump of Discharge HEX		
2002	Jul.	130.5 (445.3)	30.6 (104.4)	11 (37.5)	1179 (1117)	1.90
	Aug.	96.4 (328.9)	23.4 (79.8)	9.1 (31.0)	927 (878)	2.00
	Sep.	85.8 (292.8)	22.8 (77.8)	9.0 (30.7)	872 (826)	2.06
	Oct.	76.1 (259.7)	24.6 (83.9)	14.7 (50.2)	984 (933)	2.37
	Nov.	62.1 (211.9)	22.8 (77.8)	15.1 (51.5)	888 (841)	2.47
	Dec.	65.0 (221.8)	24.2 (82.6)	15.6 (53.2)	932 (883)	2.47
2003	Jan.	60.4 (206.1)	23.6 (80.5)	12.6 (43.0)	901 (854)	2.60
	Feb.	70.1 (239.2)	27.1 (92.5)	13.7 (46.7)	1042 (988)	2.62
	Mar.	66.1 (225.5)	25.3 (86.3)	11.5 (39.2)	963 (912)	2.61
	Apr.	66.7 (227.6)	22.0 (75.1)	8.7 (29.7)	860 (815)	2.46
	May	83.5 (284.9)	22.7 (77.5)	8.4 (28.7)	870 (824)	2.11
	Jun.	111.0 (378.7)	30.5 (104.1)	10.0 (34.1)	1138 (1079)	2.09

degrees Celsius below zero). The charged heat capacity is larger than a normal thermal storage operation and the nighttime shifting ratio of quantity of heat is raised.

The saved heat is discharged through discharge HEX and supplied to the production area during the daytime. There are 2 types of heat discharge operation in Table 2 and the completion of heat discharge is judged when the brine temperature exceeds set value. The purpose of the high load discharge operation is to shift the peak of energy consumption in the summer. The discharge HEX pump has an inverter, so the capacity of discharged heat is changed for the production area load. Therefore, it prevents the useless operation of turbo refrigerating machines and raises efficiency of turbo refrigerating machines. However, the normal heat discharge operation supplies constant heat capacity to the production area during the discharged heat time slot.

The screw refrigerating machines work additionally if the screw refrigerating machine's efficiency is better than the turbo refrigerating machine's that except storage operation time. The lower limit of screw refrigerating machine's cooling water is different from turbo refrigerating machine's cooling water. The Screw refrigerating machines produce 5 degrees Celsius brine, and then provide heat to the production area via additional HEX.

MEASUREMENT RESULTS

The actual operational data has been measured from April 2002 and each machine's efficiency and energy performance in the system was evaluated[2)].

Iced-thermal Storage Operation

The nighttime shifting ratios of the quantity of heat, efficiency of iced-thermal storage and the COP of iced-thermal storage system have been calculated for the evaluation.

The evaluations of iced-thermal storage are divided into normal thermal charge and extended thermal storage and also calculated. The nighttime shifting ratios of the heat quantity shown in Table3 is the ratio between the quantity of discharged heat and heat load of production area in daytime. It indicated 12% to 22% and the ratio values were smaller in summer compared with other seasons. The reason is that production area load had increased during the summer. And it is confirmed that there is an extended thermal storage effect and their values were increased a few percentage.

Table4 shows the COP values of the thermal storage system and values indicated 1.9 to 2.62 and the

Table5. Actual Operation Measurement And System Evaluation

Date		Temp. [C]	Humidity [%]	Load of Production Area [GJ (MBtu)]	Electric Consumption [MWh (MBtu)]			COP[-]			
					Refrigerating Machines	Pumps, Fans	System	Turbo	Screw	Iced-thermal System	Whole System
2002	July	27.3	75.4	20555 (19482)	1077 (3675)	544 (1856)	1621 (5531)	5.76	2.99	1.90	3.52
	Aug.	26.8	72.8	19736 (18706)	987 (3368)	533 (1819)	1520 (5186)	6.08	3.31	2.00	3.61
	Sep.	24.0	68.6	15839 (15013)	784 (2675)	514 (1754)	1298 (4429)	6.43	3.75	2.06	3.39
	Oct.	16.7	73.3	9123 (8647)	642 (2191)	537 (1832)	1179 (4023)	5.82	4.56	2.37	2.15
	Nov.	8.9	73.2	9703 (9197)	548 (1870)	504 (1720)	1052 (3589)	5.26	5.12	2.47	2.56
	Dec.	7.3	75.1	9968 (9448)	525 (1791)	503 (1716)	1028 (3508)	5.96	5.19	2.47	2.69
2003	Jan.	3.6	73.9	8339 (7904)	456 (1556)	459 (1566)	915 (3122)	6.86	5.39	2.60	2.53
	Feb.	6.8	74.9	8267 (7836)	445 (1518)	418 (1426)	863 (2945)	7.02	5.27	2.62	2.66
	Mar.	9.1	68.4	9896 (9380)	508 (1733)	448 (1529)	956 (3262)	7.34	5.12	2.61	2.88
	Apr.	16.0	72.0	12615 (11957)	670 (2286)	497 (1696)	1167 (3982)	6.99	4.42	2.46	3.00
	May	20.3	70.3	16156 (15313)	881 (3006)	544 (1856)	1425 (4862)	6.52	3.64	2.11	3.15
	Jun.	22.3	78.1	19623 (18599)	1083 (3695)	600 (2047)	1683 (5742)	6.33	3.59	2.09	3.24

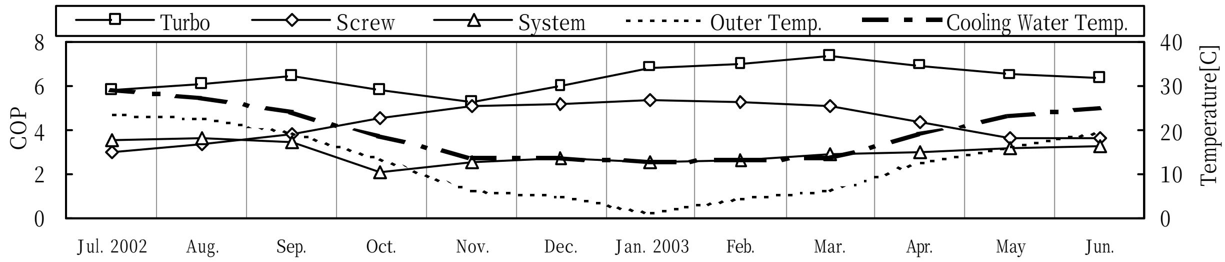

Figure3. Relation Between Cooling Water Temperature and the COP of Refrigerating machine and System

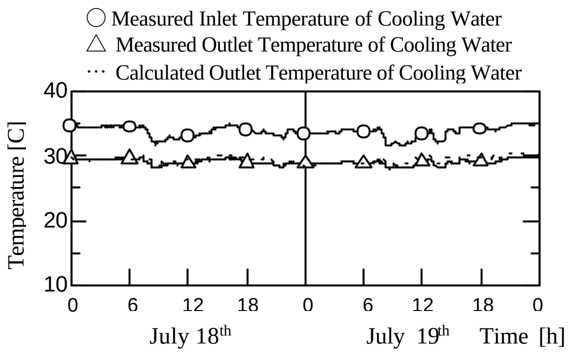

Figure4. Calculation for Simulation Accuracy in Cooling Tower

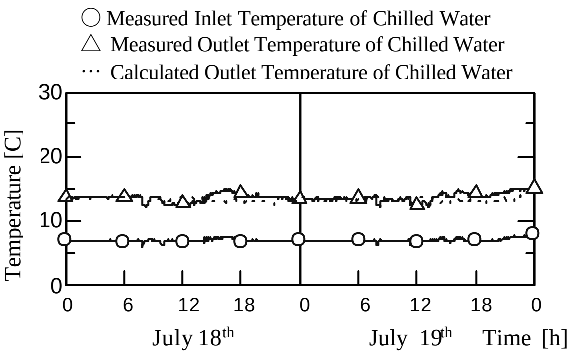

Figure5. Calculation for Simulation Accuracy in Turbo Refrigerating Machine

average was 2.31. The COP of fall, winter and early spring indicated high values relatively. It is considered that screw refrigerating machine's efficiency was improved because the low temperature of cooling water was closed to 13 degrees Celsius.

System Evaluation

Actual operation measurement and system evaluation and relation between cooling water and the COP of the refrigerating machine and the whole system are shown in Table5 and Figure3 respectively. The COP values of turbo refrigerating machines indicated around 6.0 in summer and 7.0 in winter. However, the COP values of October to December in 2002 dropped a little, it is considered that the portion load operation of refrigerating machines was decreased compared with

Table6. Considered Case and Description

Saving Technologies		Description
Case1	Traditional System	Operation of iced-thermal storage in night time with screw refrigerating machine/ High and low discharge operation of thermal storage/ The temperature of base turbo is 7C, and others are 6C/ A normal type cooling tower is adopted and set point of cooling water temperature is 32C/ None of addtional operation with screw refrigerating machine/ Normal type of turbo and screw refrigerating machine/ None of free cooling operation/ Distribution of production area load equally to operated refrigerating machines
Case2	Integrated Cooling Tower	Integrated cooling tower makes cooling water as lower as possible/ Others are equal to Case1
Case3	Free Cooling of Chilled Water	Free cooling of Chilled water is operated based on cooling water temperature/ Others are equal to Case2
Case4	Free Cooling of Cooling Water in Production Area	Free cooling of cooling water in production area is operated based on cooling water temperature/Others are equal to Case3
Case5	High Efficiency Refrigerating Machines	Adoption of high efficiency turbo (COP 6.0) and screw (COP 3.04) refrigerating machines/ Others are eqaul to Case4
Case6	Additional Operation	Additional operation with screw refrigerating machines based on cooling water temperature/ Others are equal to Case5
Case7	Control of Chilled Water Temperature	Control of chilled water temperature; 7C of base apparatus and 6C of others in April to October, 9C of base apparatus and 8C of others in November to March/ Others are equal to Case6
Case8	Control of Chilled Water Quantity	Whole operational ratio operation with none base turbo refrigerating machines and base turbo refrigerating machine covers remained production area load/ Others are eqaul to Case7

other periods. The ratio of portion load operation in screw refrigerating machines indicated around 1.0 and this is related to the fact that the screw refrigerating machines were only used for thermal storage operation. Especially, the COP of screw refrigerating machines is related to the cooling water temperature deeply. The system COP of summer indicated high values because the load of this season in the production area was large, and actually, the values of August indicated maximum values at 3.61 comparing of around 2.6 in winter.

MODEL-BASED SIMULATION ANALYSIS

Accuracy Confirmation of Subroutine Model

Before constructing the whole model in system simulation, a subroutine model was calculated to confirm accuracy. Figure4 and Figure5 show each calculated output in an integrated cooling tower[3)] and turbo refrigerating machine as examples. The input conditions are outdoor weather[4)] (temperature, relative humidity) and measured production area load on July 18th and 19th by every 1 minute because these days indicated typical load in summer.

Annual energy consumption of the whole heating system is 14707MWh (50180MBtu) during July 2002 to June 2003 and the outcome of simulation, which reflected actual operation of this system, is 14688MWh (50115MBtu) in the same period. Therefore, simulation program used in this paper was considered that each calculation output showed reasonable accuracy.

Case Study Model

Some case models have been prepared for verifying the effect of energy saving technologies with this heating plant system. Case1 is the assumption of the traditional type model and Case2 adds energy saving technology such as the integrated cooling tower to Case1. In the last case, Case8 includes all of the energy saving technologies in this system as described above and corresponds to Kumamoto TEC. However,

Table7. Results of Energy Consumption via Calculation

Classification	Design Phase Load			Actual Measured Load		
	Quatity of Energy Consumption [MWh (MBtu)]	Cut Rate Compared with Case1	COP	Quatity of Energy Consumption [MWh (MBtu)]	Cut Rate Compared with Case1	COP
	The whole System					
Case1	38955 (132914)		3.22	17107 (58369)		2.57
Case2	34996 (119406)	10.16	3.59	15533 (52999)	9.21	2.83
Case3	34436 (117486)	11.60	3.64	15715 (53620)	8.14	2.79
Case4	32544 (111040)	16.46	3.86	15305 (52221)	10.54	2.87
Case5	28012 (95577)	28.09	4.48	14539 (49607)	15.01	3.02
Case6	27488 (93789)	29.45	4.57	14168 (48341)	17.18	3.10
Case7	27076 (92383)	30.49	4.63	13680 (46676)	20.03	3.21
Case8	25385 (86614)	34.84	4.94	11837 (40387)	30.81	3.71
	Refrigerators					
Case1	29294 (99951)		4.28	12027 (41036)		3.65
Case2	24372 (83157)	16.80	5.15	9931 (33884)	17.42	4.42
Case3	23372 (79745)	20.22	5.37	9733 (33209)	19.07	4.51
Case4	21853 (74562)	25.40	5.74	9322 (31807)	22.49	4.71
Case5	17305 (59045)	40.92	7.25	8611 (29381)	28.40	5.10
Case6	16738 (57110)	42.86	7.50	8400 (28661)	30.15	5.23
Case7	16549 (56465)	43.51	7.58	8004 (27310)	33.45	5.49
Case8	14951 (51013)	48.96	8.39	6480 (22110)	46.12	6.78

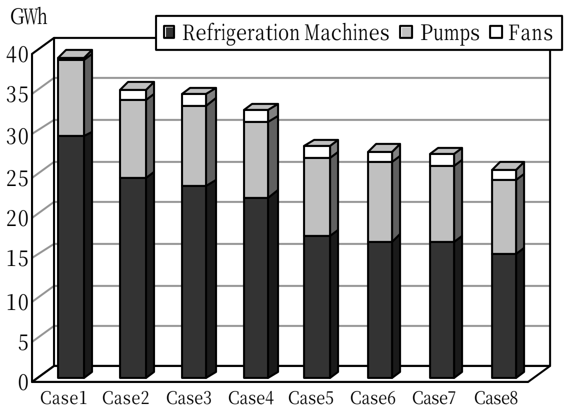

Figure6. Comparison with Each Case in The Quantity of Energy Consumption in Case of Design Phase Load

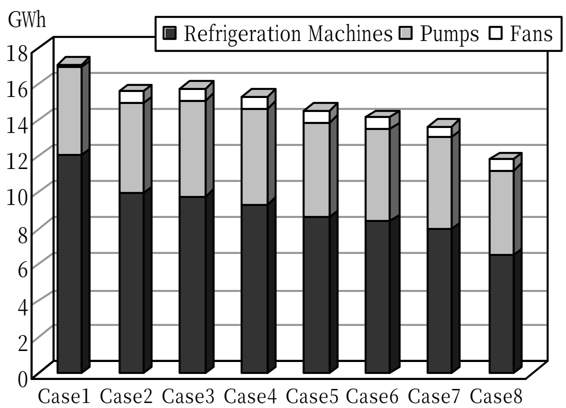

Figure 7. Comparison with Each Case in The Quantity of Energy Consumption in the Case of Actual Measured Load

all saving technologies, mentioned above, are not operated actually, for example free cooling and additional operations, to prevent portion load operations because there was not enough load in production area. The characteristics of each model are examined and shown in Table 6.

Results and Consideration

2 kinds of calculations have been carried out, one is for evaluation in case of considering design phase load and the other is actual measured load. The calculated results are shown in Table7, Figure6 and Figure7. The cut rate of energy consumption between both cases is like same, and the tendency is not different so much, either. Therefore the consideration of each case is described only about in the case of actual measured load in this paper. Case1 is a traditional heating plant system, in which cooling tower operation is stopped if cooling water temperature is lower than 32 degrees Celsius. Therefore, the quantity

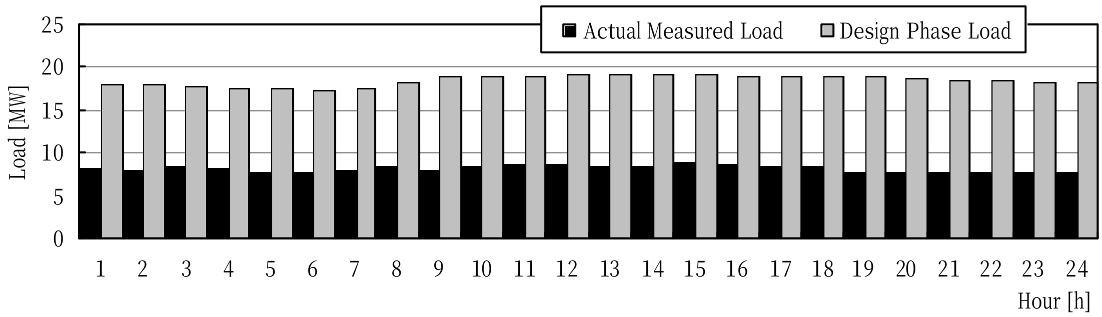

Figure8. Comparison of Actual Measured Load (August 13th 2002) and Design Phase Load (August)

of electric consumption in the cooling tower's fan is extremely small compared with other cases. However, the efficiency of refrigerating machines is bad because the cooling water temperature is high and the system and refrigerating machines COP values are the lowest in the examined cases.

The effects of energy saving technologies stand out in Case2, Case5 and Case8; each one adopts an integrated cooling tower and high-efficiency refrigerating machines, a quantity of chilled water control in the base apparatus. In Case2's adopted integrated cooling tower system, the quantity of electricity consumption in the cooling tower's fan increases much after this case, compared with Case 1. However, the cooling water can be controlled until 18 degrees (turbo refrigerating machine) and 13 degrees Celsius (screw refrigerating machine) in winter. Therefore, the COP values of refrigerating machines get improved compared with Case 1. As a result, the system and refrigerating machines' COP values indicate 2.83 and 4.42, and the rate of energy consumption is cut by 9.21 and 17.42 points, respectively. In Case5's adopted high-efficiency refrigerating machines, the COP values of the system and refrigerating machines indicate 3.02 and 5.10. Normal refrigerating machines are adopted until Case3 and the COP is 4.9 (turbo) and 2.65 (screw) when each one makes chilled water of 7 degrees Celsius and brine of 5 degrees Celsius below zero with cooling water of 32 degrees Celsius. However, after Case4, refrigerating machines are adopted and each COP is 6.0 (turbo) and 3.04 (screw) in the same situation. As a result, the rate of energy consumption in the system and refrigerating machines is cut by 4.47 and 5.91 points compared with former Case. The quantity of chilled water control operation is adopted in Case8, and the COP of the same items indicates 3.71 and 6.78. These values are the largest in the examined cases. Until Case7, in case of multi apparatuses operation, the production area load is provided with the same ratio of operation in the turbo refrigerating machine group. However, none of the base apparatuses had been operated at 100% output, prior to this, and the remaining load is handled with the base one in Case8. Of course, the operational ratio of base one is changed and it depends on the quantity of the remaining load. As a result, the whole operational ratio increases and the COP value is improved. The decrease in energy consumption in the system and refrigerating machines is 10.78 and 12.67 points respectively in Case8.

On the other hand, in Case3 and Case4; adopted free cooling operation for chilled water and cooling water of production area, the COP values of system and refrigerating machines are 2.79, 4.51 and 2.87, 4.71 respectively, and energy saving technology has little effect. The reason considered is that the quantity of chilled water flow in the HEX pump is not enough compared with the overall quantity. As a result, the decrease in energy consumption in the system and refrigerating machines is -1.07, 1.65 points and 2.4 and 3.42 points, respectively. In Case6's adopted additional operation with screw refrigerating machines in daytime, the COP of each item indicates 3.10 and 5.23 respectively, and the effect is also minimal. It is

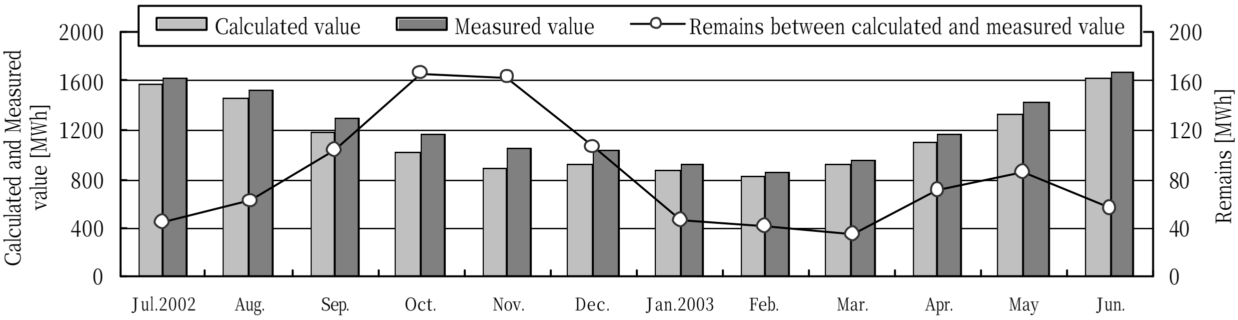

Figure9. The Remains Between Calculated and Measured Energy Consumption in Whole System

considered that the quantity of brine flow in the HEX pump is not as much as in Case3. And it is considered that operation of additional screw refrigerating machines in daytime makes the whole operational ratio of turbo refrigerating machines group drop, because the load covered by the turbo refrigerating machines group is reduced. As a result, the decrease of energy consumption of same items is 2.17 and 1.75 points compared with former case, respectively. Finally, in Case7's adopted control of chilled water temperature control, the COP values for the system and refrigerating machines are 3.21 and 5.49 respectively, and the effect is minimal, as in Case6. The reason considered is that small gap of chilled water temperature needs more the quantity of chilled water flow, therefore the quantity of pump electricity was increased. The decrease in energy consumption of the system and refrigerating machines is 2.85 and 3.3 points.

The whole cut rate of energy consumption was expected 32% when this heating system was designed[5)]. Actually, it was around 31% in the case of actual measured data and 35% in the case of design phase load. This gap is due to the difference of load, however it also shows that this heating system demonstrate the expected performance even if the low load period as like during the last years. Figure8 shows the comparison of between actual measured load and design phase load. The actual measured load was small compared with design phase load. Since only 2 years has passed after this system was completed, although the equipment capacity of this system was for 10-year-later's expected load, considering growth of market and demands increase etc. This is the reason why the actual measured load was so low.

FAULT DETECTION IN ACTUAL OPERATION

The quantity of system energy consumption was 14707MWh (50180MBtu) from July 2002 to June 2003 (Table5). However, it is different from the quantity of simulation results, 11837MWh (40387MBtu) of Case8. They are also some of the reasons that free cooling and additional operation were not occurred during considered period in actual, however the effects of those were not large so much. Therefore, such consideration is not enough to explain the whole gap of between actual and simulation results. There was other mistake while this system was run and it is considered that it was somewhat mistake of turbo refrigerating machines' operate order. The turbo refrigerating machine group consists of 8 apparatuses; 2 small capacity refrigerating machines and 6 large capacity refrigerating machines. Of course, the reason why the turbo refrigerating machines are divided into 2 types is that it is for the number control of refrigerating machines effectively. The running of turbo refrigerating machines has priority respectively according to load of the production area. But only large capacity refrigerating machines were operated in Oct. to Dec. 2002 in spite of low load. Therefore, the COP of refrigerating machines and the whole system dropped a little bit compared with other period.

The Way to Find Out Fault

The quantity of the whole energy consumption was examined to find out fault in the first phase but it was difficult to catch fault with only energy consumption because the alternation of consumption showed typical fact as annual fluctuation. Another way to find out fault was to use the COP. Definitely, the COP is the useful guideline to understand refrigerating machine's performance, however this heating plant system adopts the integrated cooling tower and uses low temperature-cooling water. So, it is difficult to judge the performance of refrigerating machine only by using the COP because it has deep relation with cooling water temperature.

Therefore we made another case of calculation that corresponds to Case8 except free cooling and additional operation as actual. This means that the number control of turbo refrigerating machines fallows the operate order that is supposed in design phase. Figure9 is the outcome and shows the remains between calculated and measured energy consumption in whole system. The remain values in Figure9 is large remarkably Oct. and Nov. 2002. The faults are detected by model-based simulation that calculates energy consumption. And this system's fault is different from normal kind of fault that is occurred in refrigerating machine as like leak, chilled water reduction, condenser fouling, furthermore it is very interesting fact that this system had been completed recently. Therefore the fault detection is the important fact even if the case of the new and renovated system.

CONCLUSIONS

The effect of energy saving technologies was clarified by actual measurement and model-based simulation analysis with a case study in this research. The measurements and actual data were taken from the period July 2002 to June 2003. The COP of the system indicated between 2.15 and 3.61, and it depends on the operational ratio of the refrigerating machines especially. The effect of energy saving technologies stands out in regard to energy conservation and electric consumption demands. Particularly, adopting an integrated cooling tower, high efficiency refrigerating machine and control of the quantity of chilled water in the base apparatus affect a lot. The decrease in energy consumption of the system and refrigerating machines is 30.8% and 46.1% in Case8, which corresponds to Kumamoto TEC compared with traditional type of heating plant system. And some kind of fault was occurred in turbo refrigerating machine group actually, and some methods were used to find out that, such as examine of energy consumption, the COP and the rated outcome of refrigerating machine.

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