Energy Consumption at the Aquamarine Fukushima

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ABSTRACT: Energy consumption at the Aquamarine Fukushima (AMF) has been monitored since the aquarium opened in 2000. Energy consumption at the AMF decreased after the Great East Japan Earthquake Disaster of 11th March 2011, resulting from reduced system infrastructure (e.g., system pumps). Following the Great East Japan Earthquake, it was difficult to replace damaged equipment due to transport stoppages, closure of pump factories, etc. Even though aquarium infrastructure was only partially restored, AMF was reopened on 15th July 2011. At this time, only three of six pumps were available for the largest exhibit, the Sea of Kuroshio. The volumetric turnover time for this exhibit rose from one hour to two hours (i.e., it dropped from 24 to 12 turnovers per day). Many other exhibits also were operated at slower turnover rates. An energy reduction ratio of over 20% was recorded by the AMF when operating at this reduced capacity. Complete infrastructure replacement was concluded two years after the AMF re-opened. At this time, the Sea of Kuroshio exhibit had a full complement of six operating pumps. However, only three pumps were used to operate the exhibit from that point forward, as water quality was deemed acceptable using the slower turnover rate, and electricity consumption and energy costs were correspondingly significantly decreased. Reduced energy consumption resulted in a secondary effect of reduced CO_2 emissions. This operating strategy has beneficial implications for the environmental mission of the AMF.

This paper describes variation of energy consumption from 2000, reason of the heat source system renovation, in addition to that energy consumption reduction after the Great Disaster, and perspective of environmental friendly aquarium.

Key Words: Great East Japan Disaster, Reduction of electricity consumption, Reduction of CO_2 emission

1 INTRODUCTION

The primary design concept of building services is reliability and environmentally friendly system. It is heavy duty for building services of aquarium to maintain the life of fishes, so the reliability is very important concept. Now a days global warming is one of the most important issue all of the world. But it was not serious in 1996. So it was effect to reduce the energy consumption not only for ecology but for economy.

Aquarium is a facility that consumes a lot of energy. So it has been big problem for AMF to reduce energy consumption since grand opening. The heat source system equipment must be carried out large scale maintenance after 10 years using. This maintenance cost was very high. Furthermore the natural gas price was very high in Onahama area. Because of these reason, the heat source system was changed from natural gas using system to electric heat pump system. That was very large scale construction, but the cost was near to the large scale maintenance of the heat source system, therefore heat source system renovation was chosen.

After large scale renovation of the heat source system, the energy cost was reduced and the environmental performance was good. But after only one year, the Great Disaster had come to the AMF.

2 DESCRIPTION OF HEAT SOURCE SYSTEM

2.1 Description of the heat source system from the grand opening

The concept of the heat source system (before heat source system renovation) was “high reliability”. So Co-Generation System (CGS) was chosen (co-generation system is called as Conbined Heat and Power (CHP) in Europe) as the main heat source system equipment. The CGS generates electricity and heat from natural gas. Therefore primary energy efficiency is high. The heat source system was composed of natural gas equipment and the electricity equipment. Natural gas equipment were CGS, Absorption Refrigeration and Heating Machine (RB) and Vacuum Boiler (B). Electricity equipment is Turbo Chiller (TR).

Table 1 shows the heat source equipment specification until heat source system renovation. Fig. 1 shows the schematic diagram of the heat source system. CGS generates the electricity and exhaust heat is collected from heat exchanger for heat source water in the same time. Exhaust heat from CGS is used to heating directly in the winter season. Exhaust heat is sent to the absorption refrigeration machine (AR) and AR makes cold water in the summer season. This is a basic CGS using.

Table1 Heat Source Equipment Specification until 2010

Description	Qty.	Specification	Location
Turbo Chiller（TR）	1	Heating capacity:527kW	Main Machine Room
Absorption Refrigeration Machine (AR)	3	Cooling capacity ：334kW	Main Machine Room
Vacuum Boiler (B)	1	Heating capacity:930kW	Main Machine Room
Co-Generation System （CGS）	1	Heating capacity:512kW	Main machine Room
Absorption Refrigeration and Heating Machine （RB）	2	Cooling capacity:703kW Heating capacity:780kW	Main Machine Room

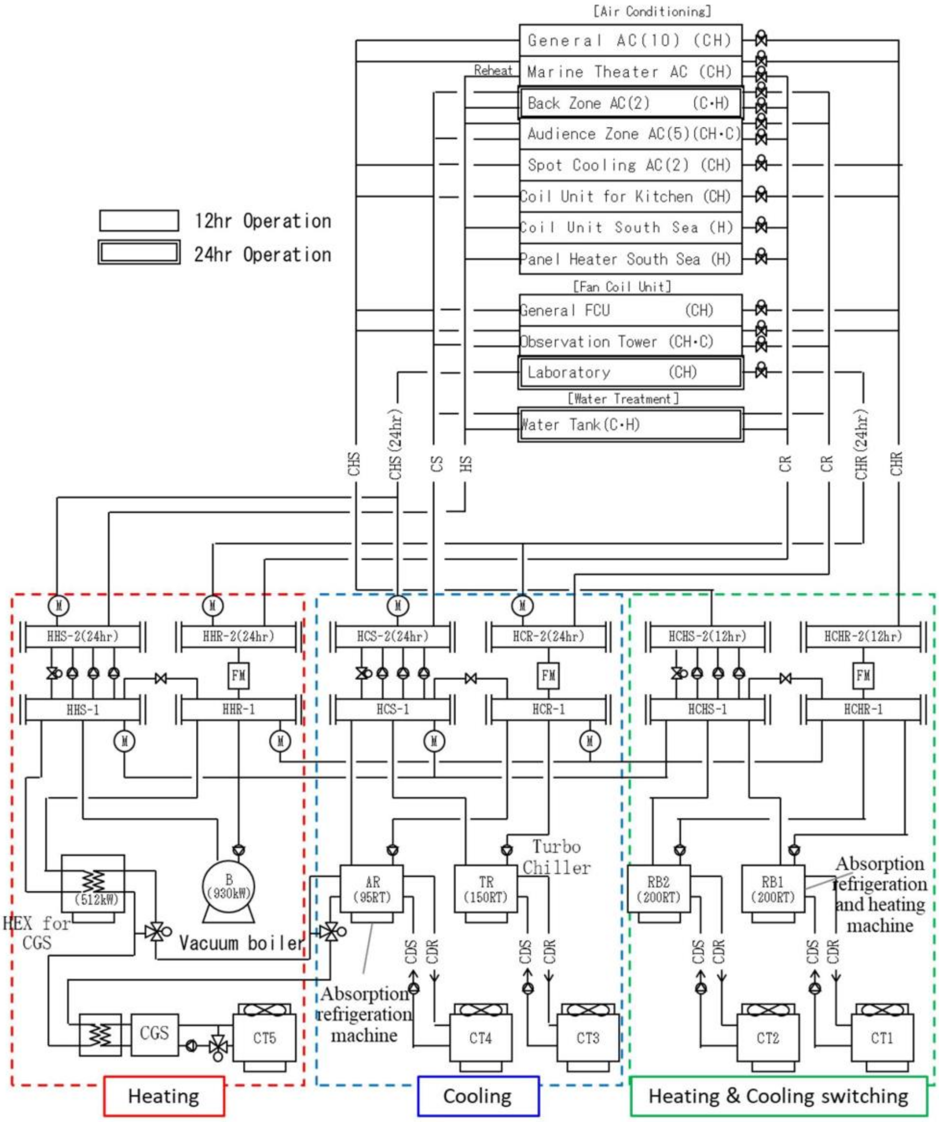

Fig.1 A schematic diagram of the heat source system until 2010

Electricity is sent from electric power company and generated in AMF. So the reliability of the electricity is higher than normal heat source system. This system is good energy performance and economical condition if energy price is low. But if the natural gas price is higher economical condition becomes disadvantageous.

The heat source system consists of a cooling system, a heating system and a cooling / heating switching system. A cooling / heating switching system supplies heating water in the winter season, supplies cooling water in the summer season. Cooling and heating is switched by season. A cooling / heating switching system supplies basically for air conditioning system. A heating system and a cooling system supplies for water treatment system and special air conditioning system.

Table2 Heat Source Equipment Specification after renovation

Description	Qty.	Specification	Location
Air cooled heat pump chiller for Cooling (CHP)	1	Total cooling capacity : 288kW	Outdoor Machine Area
Air cooled heat pump for Heating (HHP)	1	Total heating capacity : 215kW	Outdoor Machine Area
Air cooled heat pump chiller for Cooling and Heating 1(CHHP1)	1	Total cooling capacity : 710kW Total heating capacity : 574kW	Outdoor Machine Area
Air cooled heat pump chiller for Cooling and Heating 2(CHHP2)	1	Total cooling capacity : 355kW Total heating capacity : 287kW	Outdoor Machine Area
Turbo Chiller (TR)	1	Cooling capacity:527kW	Main Machine Room

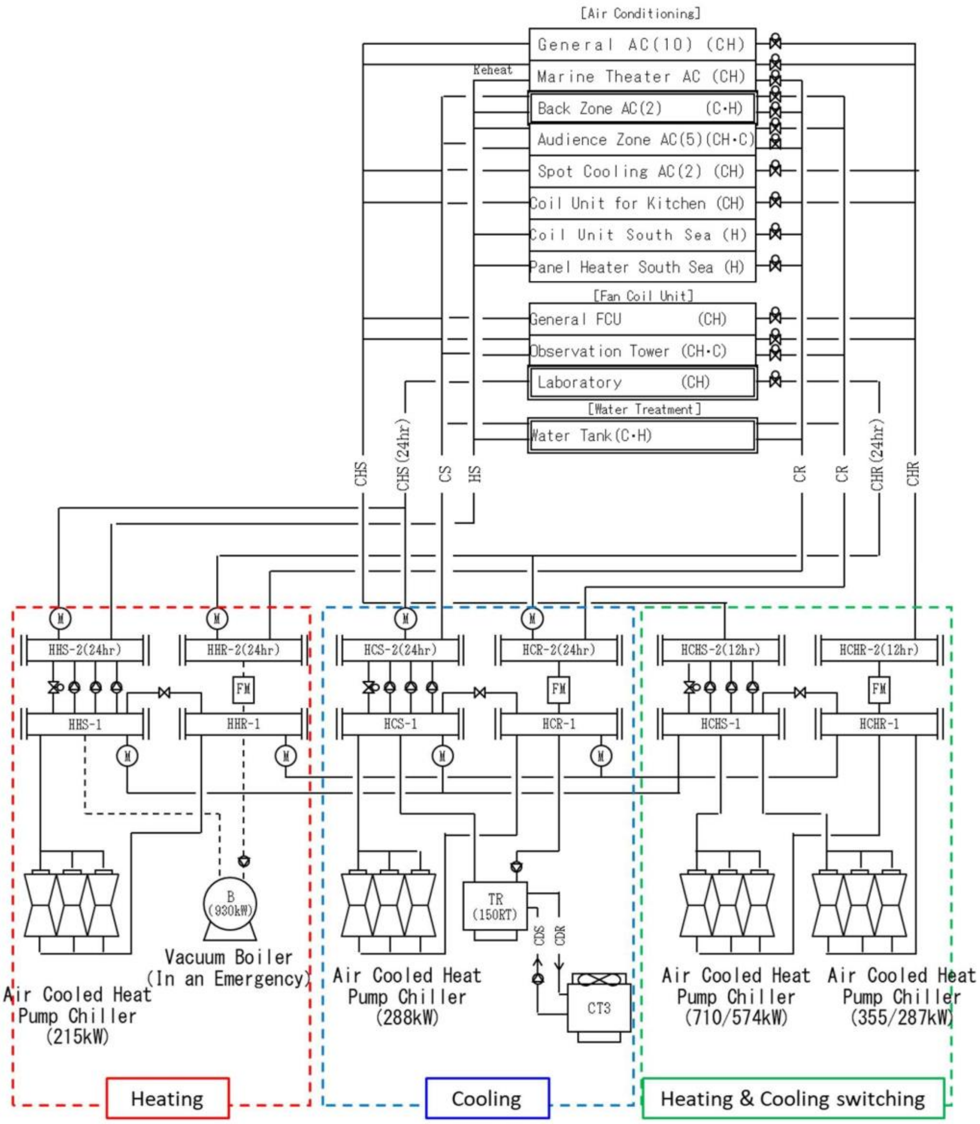

Fig.2 A schematic diagram of the heat source system after renovation

2.2 Description of the heat source system after heat source system renovation

The concept of the heat source system (after heat source system renovation) was "high Performance" and "simple system". So air cooled heat pump chiller was chosen. CGS and Vacuum Boiler were replaced by Air cooled heat pump (only heating). Absorption refrigeration machine was replaced by Air cooled heat pump chiller (only cooling). But Turbo chiller was not replaced, that chiller became a backup role. Absorption refrigeration and heating machine was replaced by Air cooled heat pump chiller (heating and cooling swiching).

Heat source system became very simple. Table 2 shows the Heat Source Equipment Specification after renovation. The grouping of heat supply is same as before. The composing of cooling system, heating system, cooling and heating switching system were same as before.

2.3 Variation of energy consumption tendency

Fig.3 shows variation of monthly electricity consumption for 10 years. As a result of energy conversion, average consumption increased from 374MWh to 596MWh, peak load increased by 30%. Fig. 4 shows variation of monthly natural gas consumption for 10 years. After large scale renovation, natural gas consumption became 0.

Fig. 5 shows variation of monthly CO_2 emission for 10 years. CO_2 emission of AMF became from 359(T-CO_2/month) to 285(T-CO_2/month) after large scale renovation. That was 21% decreased.

3 DESCRIPTION OF THE ENERGY CONSUMPTION AFTER GREAT DISASTER

3.1 Introduction

After the Great East Japan Earthquake and Tsunami, AMF suffered excessive damage. But AMF was reopened 4 months after the disaster. Many hard work and idea made it possible to reopen.

Main theme is focused on energy consumption in this paper.

3.2 Variation of energy consumption from 2010

The energy conversion was completed after 2009. After one year operation of the new heat source system, the disaster occurred. There were so many difficulties to recover to the original AMF. However AMF reopened only 4 months after the disaster.

If the environmental effect of the building is evaluated the CO_2 emission is used. But almost nuclear power plant were stopped after the disaster, CO_2 emission factor of electricity was increased. So CO_2 emission of post disaster were compared with pre disaster, the result will be effected by variable factor. Therefore primary energy consumption was used for the evaluation of the environmental effect. Fig. 6 shows the variation of monthly electricity consumption after 2010. The electricity consumption disappeared at 11th March, the yearly average of electricity consumption decreased after reopening.

Fig. 7 shows the variation of monthly primary energy consumption after 2010. The average primary energy consumption since the renovation of heat source system until the Great disaster was 6,358[GJ/month]. But the primary energy consumption became

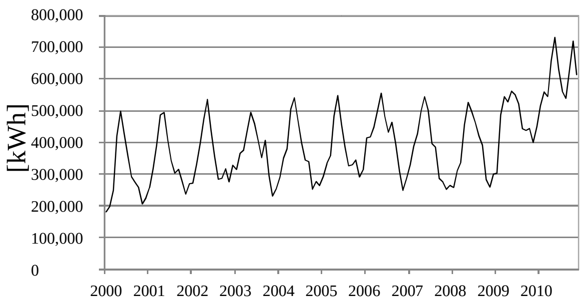

Fig.3 Variation of monthly electricity consumption for 10 years

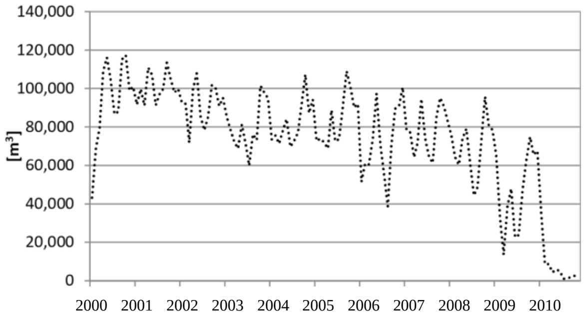

Fig.4 Variation of monthly natural gas consumption for 10 years

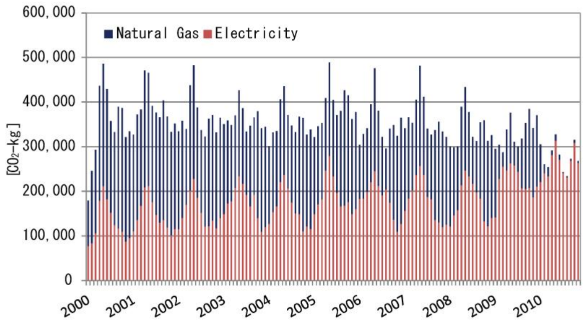

Fig.5 Variation of monthly CO_2 emission for 10 years

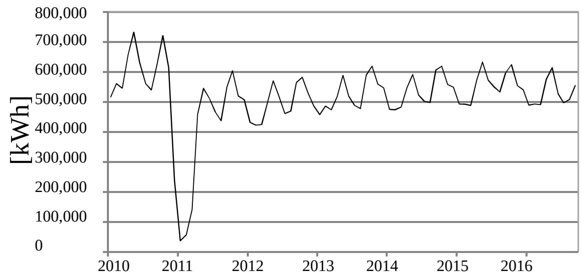

Fig.6 Variation of monthly electricity consumption after 2010

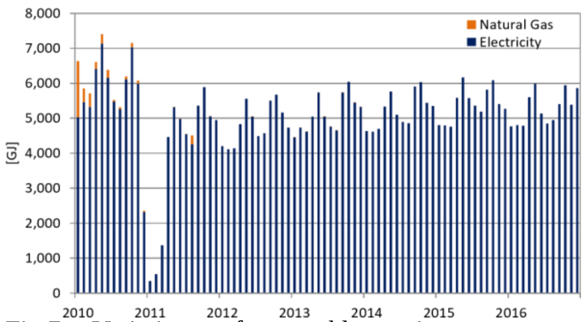

Fig.7 Variation of monthly primary energy consumption after 2010

4,935[GJ/month] after reopened, the average primary energy consumption decreased 22%. After great disaster the saving energy intention was spread throughout Japan, so it was assumed that these mind affected the reduction of energy consumption. But it was impossible to reduce over 20% of primary energy consumption by only saving energy intention.

Table 3 Operation pump and saving electricity after reopening in 2011

Name of exhibit	Qty of pump in operation	Pump power [kW]	Saving electricity [kW]
Exhibit 1	2→1	2.2	－2.2
Exhibit 2	2→1	3.7	－3.7
Sea of Kuroshio	6→3	30.0	－90.0
Sea of Oyashio	3→2	15.0	－15.0
Brackish fish	2→1	3.7	－3.7
Southern sea	2→1	7.5	－7.5
Sea lion	2→1	5.5	－5.5
Former sea otter	2→1	5.5	－5.5
Total saving electricity	―		－132.4
Remarks			

When AMF reopened, it was impossible to replace all damaged pump. Because of pump manufacturer, logistics and so on. Therefore the exhibit with multiplex pumps operated with half number of pumps. Table 3 shows the operation pump and saving electricity after reopening in 2011. The total electricity consumption of the pump of Sea of Kuroshio was reduced 90kW. Sea of Kuroshio is the largest exhibit of the AMF. And the electricity consumption of the pump of Sea of Oyashio was deduced 15kW.

This operation was effective for the power saving. But it was difficult to maintain the quality of exhibit water, minimum quality had been kept. All pumps were replaced new equipment in June 2013. But this operation method has been continued until today.

4 CONCLUSIONS

Large scale heat source system renovation succeeded to reduce energy cost and CO2 emission, approximately 30% of energy cost and 21% of CO2 emission was reduced. Hard work of all staffs and volunteers made early reopening after great disaster. The primary energy consumption was 33% reduced after great disaster. Total reduction of primary energy consumption was 32% before large scale heat source system renovation.

Many trial for reopening were good ideas for energy conservation and BCP (Business Continuity Plan).

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