

## ENERGY EVALUATION BY SIMULATION FOR EFFECTIVE USE OF SEWAGE HEAT

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### ABSTRACT

An effective means for greenhouse gas reduction is to use sewage heat, an unused energy resource, for air conditioning. This study conducts energy evaluation of the utilization of treated sewage, heretofore discarded from the sewage disposal plant adjacent to a developing area, as a heat source of air-conditioning for that developing area by simulation. The result estimates 12.2% reduction in annual equivalent primary energy consumption (6.4% for cooling; 36.1% for heating) with a system using a heat pump. It also predicts 16.8% of reduction in annual greenhouse gas emissions, which verifies the efficacy of sewage heat utilization.

### INTRODUCTION

Today, deterioration of the global environment, with phenomena such as global warming, air pollution, and a rise in the sea level, is worsening. The necessity for mitigation of environmental impacts from sources such as CO<sub>2</sub> emissions is increasing. In addition, reduced consumption of fossil fuels, of which depletion is especially worrisome, is an important subject in Japan, which is poorly endowed with energy resources. Consequently, development of unused energy resources such as solar heat and sewage heat is a pressing need.

Sewage heat is an unused urban energy resource. It is characteristic in its constant temperature through a year compared with ambient air, and its energy-saving effect is expected if used as a heat source of air-conditioning. However, most sewage brought to the sewage disposal plant is treated and subsequently discharged to the sea. The heat created by sewage has not been recycled effectively. This study addresses the efficacy of employing sewage heat as a heat

source for air-conditioning system, and conducts a simulation of energy consumption in annual operation in the scale of city development.

Moreover, a simulation was conducted to elucidate annual operations with and without sewage heat with the same conditions and air-conditioning system. The results are compared and discussed. This simulation uses the Life Cycle Energy Management Tool (LCEM tool)<sup>1)</sup> distributed from the Ministry of Land, Infrastructure and Transport, Japan.

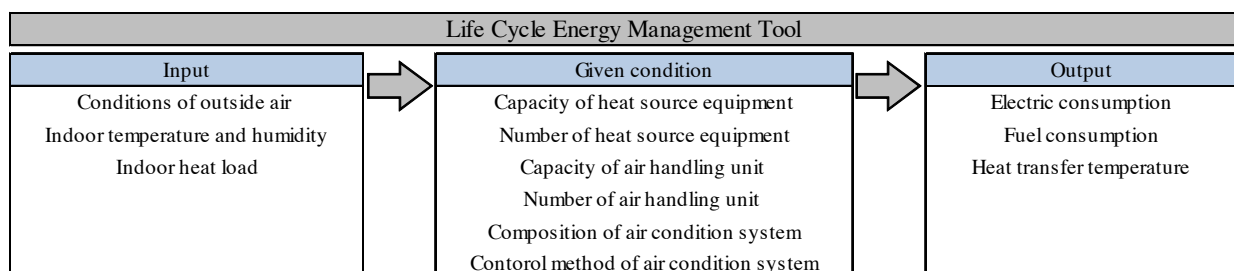
### SIMULATION

#### **Guideline of the LCEM Tool**

The Life Cycle Energy Management tool (LCEM tool) has been developed so that a simulation can be conducted using highly general-purpose spreadsheet software. It enables us to estimate the operational state of an instrument numerically, and to evaluate power consumption, fuel consumption, etc., by computation with spreadsheet software converting the service conditions of an instrument into input conditions and inputting a characteristic equation that is intrinsic for an instrument. Figure 1 presents a schematic view of the LCEM tool. Figure 2 presents operating characteristic example of a centrifugal chiller.

#### **Guideline of Sewage Heat Utilization and Supply Facilities**

Heat supply to a development area is assumed, considering the development area under planning in Tokyo in the future, and regarding an urban sewage plant adjacent to them as sewage heat supply facilities. Treated sewage discharged to the river is subjected to advanced wastewater treatment, and is thereafter used as a heat source for air conditioning.



*Figure 1 Overview of LCEM tool.*

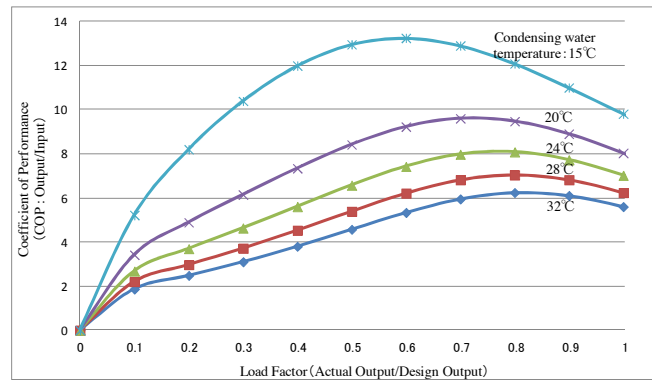


Figure 2 Operating characteristic example of a centrifugal chiller (With inverter control / Mitsubishi Heavy Industries / included in LCEM Tool)

Figure 3 presents the monthly temperature variation of treated sewage and ambient air. The ambient air temperature was determined from AMEDAS data of the average in 1971–2000 in Tokyo, and the sewage temperature was set after the case of the Koraku 1-chome District Heating and Cooling (DHC) system in Tokyo<sup>3)</sup> as a reference.

**Guideline of Development Area Using Sewage Heat and Thermal Load**

Table 1 presents the approximate building scale and thermal loads of the development area adjacent to the sewage disposal plant. Table 1 also presents the hourly maximum air-conditioning thermal load computed using a thermal load basic unit for each use. Figure 4 shows the cooling and heating loads on a representative day of each month. Figure 5 presents annual cooling and heating load each month. The principal building use is assumed as office and retail buildings. Only the air-conditioning load is considered, but the domestic hot water load is not included.

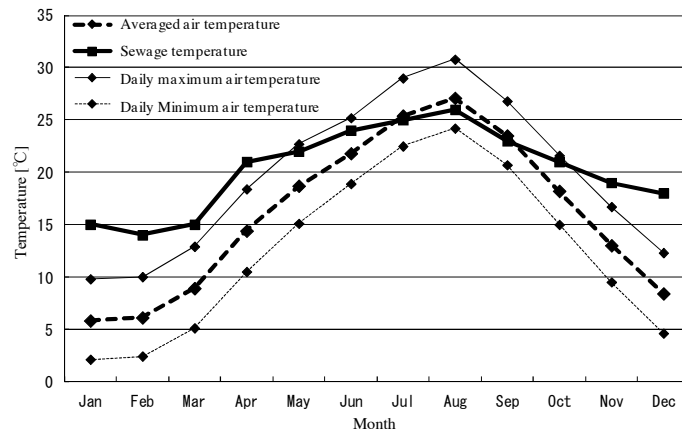


Figure 3 Monthly temperature of treated sewage and ambient air

Table 1 Building scale and thermal loads of redevelopment area

Building use	Office	Retail	Total
Gross floor space [m <sup>2</sup> ]	550,000	123,000	673,000
Cooling load [W/m <sup>2</sup> ]	93	140	-
[MJ/h]	184,000	62,000	246,000
Heating load [W/m <sup>2</sup> ]	58	70	-
[MJ/h]	115,000	31,000	146,000

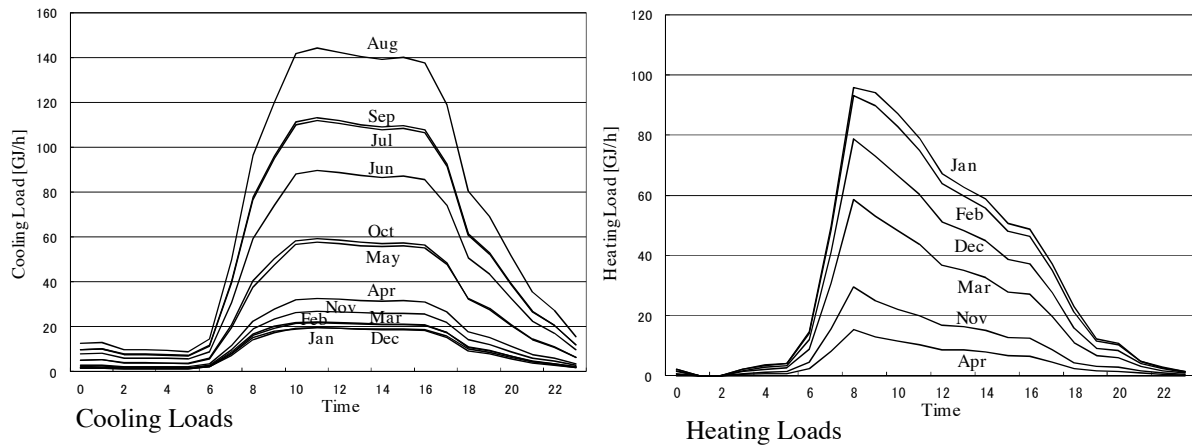


Figure 4 Cooling and heating loads on a representative day of each month (A result of the building thermal load simulation)

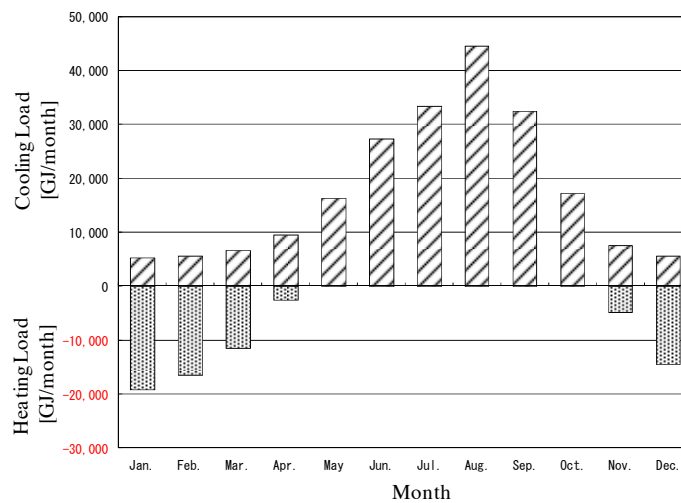
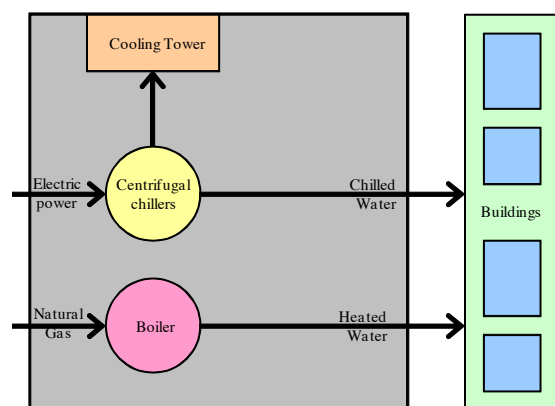


Figure 5 Annual cooling and heating load each month. (A result of the building thermal load simulation)

### Setting of Heat Source Systems

A District Heating and Cooling (DHC) system is assumed as a heat source, and an energy center is established in a development area. Heat source systems of the following three patterns are assumed, and the efficacy of sewage heat utilization is evaluated.

- (1) Standard system: this system is conventional heat source system, and the combined use of the electricity and natural gas energy.
- (2) Thermal storage system: a thermal storage system is with a heat storage water tank for cooling and heating. Thermal storage tank is same capacity of the sewage heat utilization system, for comparison and evaluation by simulation.
- (3) Sewage heat utilization system: The heat source of this system is all electrification energy and establishes the thermal storage tank for equalization of the sewage heat supply.



Equipment	Capacity
Centrifugal chillers	Cooling 22,000 Rt COP 5.5
Gas boilers	Heating 94,000 MJ/h

COP : Coefficient of Performance

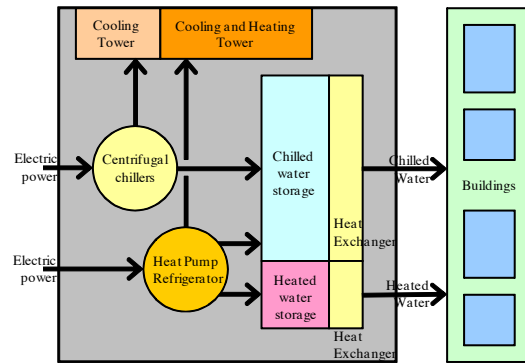
Figure 6 Standard System

### Standard System

It is a system adopting a centrifugal chiller and a fuel gas boiler, set as presented in Figure 6. The total refrigerating capacity for cooling of a centrifugal chiller is 22,000 Rt (without inverter control) on Coefficient of Performance (COP) 5.5, and total capacity for heating of fuel gas boilers is 94,000 MJ/h.

### Thermal Storage System

Figure 7 presents the heat source flow chart of a heat pump system using a heating tower. This is an all-electric system, so off-peak (nighttime) power is used preferentially to suppress increases in running costs. It has centrifugal chillers with total capacity of 12,000Rt (with inverter control) on COP 5.5, a heat-pump refrigerator with total capacity of 4,500Rt (with inverter control) on COP 4.5 for cooling, and a heat pump refrigerator with total capacity of 68,400 MJ/h on COP 3.5 for heating. Its heat storage volume is 322 GJ (water volume of 9,600 m<sup>3</sup>), which is as much as the sewage heat utilization system, for comparison. Thermal storage system is using night power.

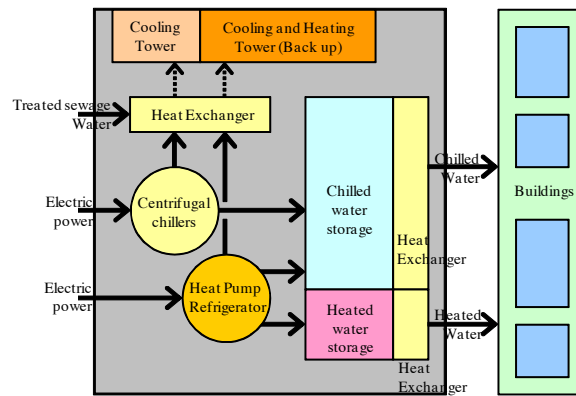


Equipment	Capacity		
Centrifugal chillers (with inverter control)	Cooling	12,000Rt	COP 5.5
Heat-pump refrigerator (with inverter control)	Cooling	4,500Rt	COP 4.5
	Heating	68,400 MJ/h	COP 3.5
Heat storage (water)	Volume	9,600 m <sup>3</sup>	Δt 8 °C

Figure 7 Thermal Storage System

### Sewage Heat Utilization System

Sewage heat retrieved at the sewage disposal plant is supplied to buildings that need heat as chilled water and heated water. Treated sewage water for heat utilization is pressure-fed by a water pump in the sewage disposal plant. However, it is difficult to supply it in accordance with the variation of building thermal load of consumers because the sewage treatment quantity fluctuates with time, as presents Figure 11. It is therefore decided that treated sewage water be fed at a predetermined constant quantity. Because consumers using heat from treated sewage water feed the heat according to the thermal load of their own buildings, a heat storage tank is indispensable. Figure 8 presents the instrument capacity and heat source flow chart of the sewage heat utilization system. The total capacity of a centrifugal chillers and a heat pump refrigerator for cooling, and another heat pump refrigerator for heating, are set respectively as 12,000 Rt (with inverter control) on COP 5.5, 4,500 Rt (with inverter control) on COP 4.5, and 91,700 MJ/h (with inverter control) on COP 4.6 based on the heat demand and supply balance of a summer and winter representative days in Figure 9 and 10. The minimum of the daytime supplied quantity of treated sewage water is set as the predetermined supplied quantity. It is assumed that there is no treated sewage water feed at dawn of the day when sewage treatment is less than the above quantities (see Figure 8), and the heat storage quantity was 322 GJ (9,600 m<sup>3</sup> of chilled water) so that treated sewage water is used effectively to the greatest degree possible. Figure 9 presents the balance of thermal load and heat storage quantity on a summer weekday. The refrigerators are



Equipment	Capacity		
Centrifugal chillers (with inverter control)	Cooling	12,000Rt	COP 5.5
Heat-pump refrigerator (with inverter control)	Cooling	4,500Rt	COP 4.5
	Heating	91,700 MJ/h	COP 4.6
Heat Exchanger for treated sewage water	Heat exchange	26,000 kW	
Heat storage (water)	Volume	9,600 m <sup>3</sup>	Δt 8 °C
Treated sewage water pump	Volume	5,700 m <sup>3</sup> /h	520 kW

Figure 8 Sewage Heat Utilization System.

subject to scheduled operation so that night power is useful preferentially. Figure 10 presents the balance of thermal load and heat storage quantity on a winter weekday. Because buildings are used mostly for offices, thermal demand is low and treated sewage temperature reaches 10°C or higher, which is advantageous compared with ambient temperature for a heat pump. Consequently, there is less accumulated daily heat utilization quantity of treated sewage than cooling energy utilization in summer.

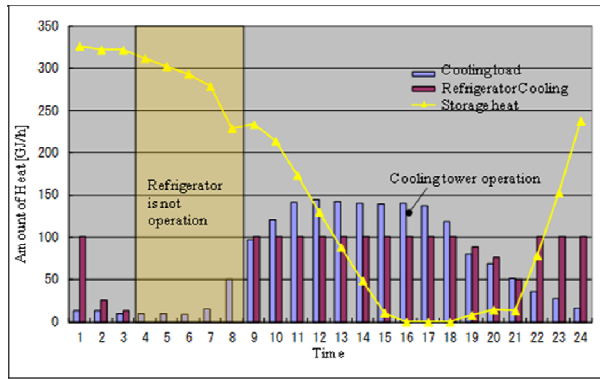


Figure 9 Thermal load and heat storage quantity on a summer weekday

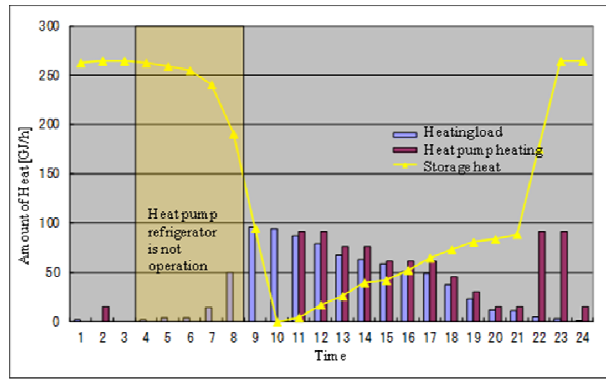


Figure 10 Thermal load and heat storage quantity on a winter weekday

( A schematic diagram for determining capacity of equipment from a result of the building thermal load simulation )

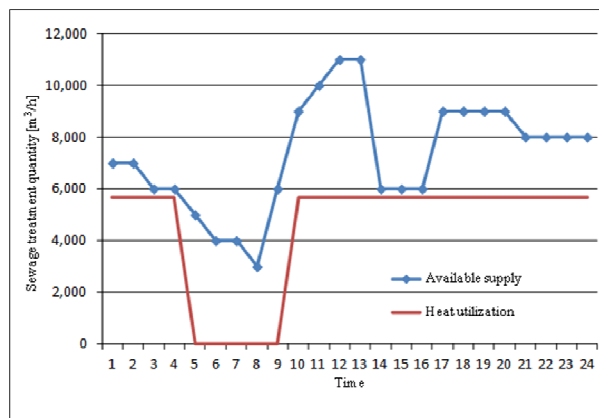


Figure 11 Sewage treatment quantity ( Actual value of one of the sewage disposal plant )

### SIMULATION RESULTS

The simulation of annual cooling and heating operations of each system was conducted using the LCEM tool. Energy consumption was converted using the basic units in Table 2 as a primary energy scale factor. It was assumed that heating operations are conducted for six months a year from November through April. The water temperature of treated sewage water used as refrigerator cooling water for the sewage heat utilization system and heat source water for the heat pump was set constant using the monthly average in Figure 3 for each month, and the efficiency of heat source was determined thereby. The inlet/outlet water temperature differential of each heat exchanger was set as 1 °C.

### Standard System (Power – Fuel gas Combined Use)

Figure 12 presents the equivalent primary energy consumption for cooling and heating of the standard system (power – fuel gas combined use) for each month. Its cooling operations in August consumed 30,500 GJ, which was more than the sewage heat utilization system by 2,800 GJ (9%), whereas that in May, during comfortable seasons, consumed 12,100 GJ, which was greater than the sewage heat utilization system by 2,800 GJ (23%). Energy consumption for heating operation peaked in January at 23,900 GJ, which was greater than the sewage heat utilization system by 11,700 GJ.

Table 2 Sewage Heat Utilization System.

Electric power	Primary energy scale factor	9.97	MJ/kWh
	CO <sub>2</sub> emission factor	0.324	kg-CO <sub>2</sub> /kWh
Gas	Primary energy scale factor	45	MJ/Nm <sup>3</sup>
	CO <sub>2</sub> emission factor	2.11	kg-CO <sub>2</sub> /m <sup>3</sup>

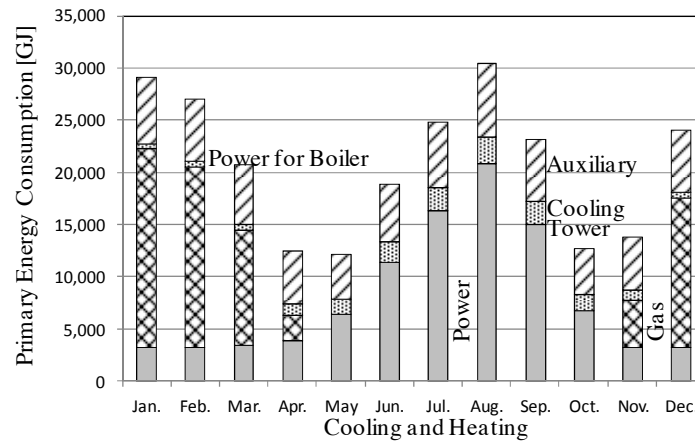


Figure 12 Primary energy consumption for cooling and heating of the standard system

**Thermal Storage System** (Heat Pump System with Cooling and Heating Tower)

Figure 13 presents the equivalent primary energy consumption for cooling and heating of the thermal storage system (heat pump system with cooling and heating tower). Its cooling operation in August consumed 28,400 GJ, a little more than the sewage heat utilization system by 700 GJ, whereas that in May during comfortable seasons consumed 9,200 GJ, less than the sewage

heat utilization system. Energy consumption for heating operation peaked in January at 20,200 GJ, which was greater than the sewage heat utilization system by 8,000 GJ. This difference is considered to arise because the refrigerator was operated at high COP; the water temperature of treated sewage was almost identical to the cooling water temperature in August, although it was higher than ambient temperature in January.

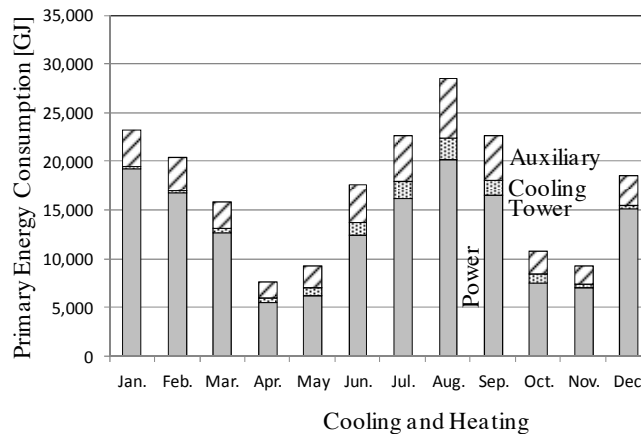


Figure 13 Primary energy consumption for cooling and heating of the thermal storage system.

**Sewage Heat Utilization System**

Figure 14 presents the equivalent primary energy consumption for cooling and heating of the sewage heat utilization system. The energy consumption of the sewage heat utilization system contains equivalent primary energy converted from power for conveyance for treated sewage water feed pump installed at the sewage disposal plant. Its consumption by cooling operations peaked in August at 27,700 GJ. Treated sewage water shortage took place during noon - 2 p.m. on weekdays of this month when the cooling load reached the maximum, and a cooling tower was used instead during this period. Energy consumption in May during comfortable seasons was 9,300 GJ, whereas that for heating peaked in January at 12,200 GJ.

**Annual Equivalent Primary Energy Consumption of Each System**

The annual primary energy consumption of each system is shown in Figure 15 and 16. The energy reduction quantity of the sewage heat utilization system was compared with each system. Energy reduction effects using sewage heat were anticipated as 6.4% for cooling, 36.1% for heating, and 12.2% annual in comparison with the thermal storage system, whereas they were assumed as 21.1% for cooling, 49.2% for heating period, and 27.5% annual in comparison with the standard system. The sewage heat utilization system was more effective than the thermal storage system with the same refrigerator in April and May during comfortable seasons.

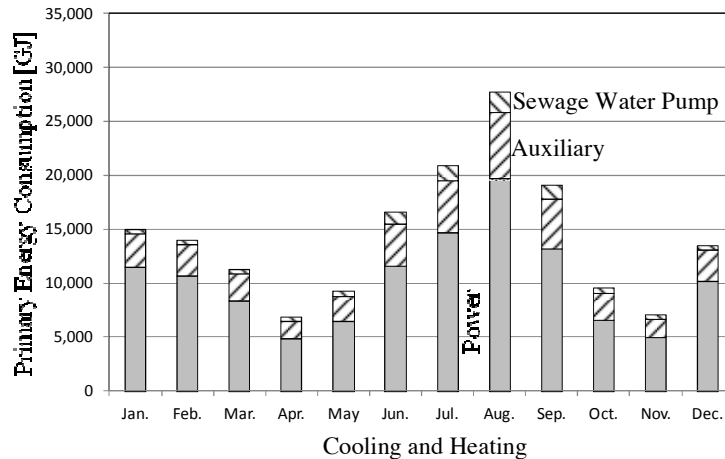


Figure 14 Primary energy consumption for cooling and heating of the sewage heat utilization system

This is presumably true because ambient temperatures lower than treated sewage water temperature allowed refrigerator operation at high efficiency.

The centrifugal chillers for cooling operation of the standard system was not inverter-controlled, but those of the sewage heat utilization system and thermal storage system were. It is therefore presumed that the great difference from the standard system results from performance factor at partial load

operation.

Energy consumption in heating operation of the sewage heat utilization system was smaller than that of the thermal storage system. Thereby the superiority of the heat pump system using sewage heat was verified. The standard system using fuel gas as an energy source consumed greater energy than the thermal storage system with an air-source heat pump. Consequently, the heat pump system efficacy was Confirmed.

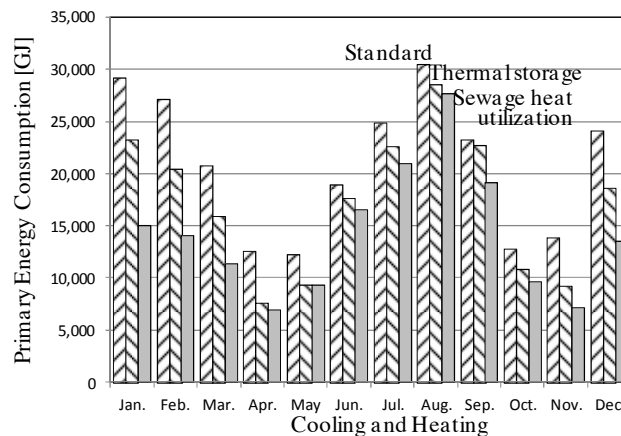


Figure 15 Primary energy consumption for cooling and heating of the sewage heat utilization system

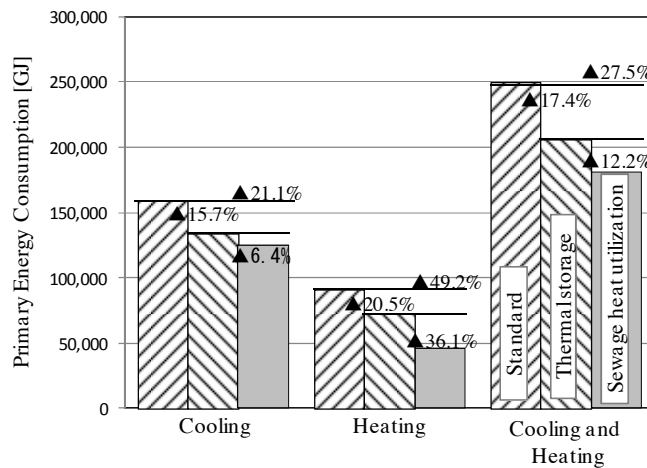


Figure 16 Primary energy consumption

## CO<sub>2</sub> Emissions

Figure 17 presents the annual CO<sub>2</sub> emissions of each system. CO<sub>2</sub> emissions from the sewage heat utilization system were expected to show 38.8% reduction compared with the standard system and 16.8% compared with the thermal storage system. CO<sub>2</sub> emissions with fuel gas as a heat source were estimated as significantly higher than those of the heat pump system using electric power.

## CONCLUSION

A case study was conducted assuming a sewage heat utilization system that supplies sewage heat from the sewage disposal plant to the development area. Treated sewage water quantity was predetermined based on the past records of the sewage disposal plant, and the reported values of the existing sewage heat utilization system were adopted as treated sewage water temperature. Object buildings were assumed based on the scale of the development area. The study results revealed a high energy reduction effect of the sewage heat utilization system, in particular during winter, and reduction effects by sewage heat were observed also in summer. However, little difference was observed in energy consumption for cooling between the sewage heat utilization system and the thermal storage system in comfortable seasons because of a lack of difference in the temperatures of treated sewage water and cooling water of the cooling tower.

The sewage heat utilization system marked the lowest values in annual primary energy consumption and CO<sub>2</sub> emissions among all systems. Thereby the superiority of the sewage heat utilization was verified. The heat utilization from treated sewage water is significantly effective from a viewpoint of the energy-saving effect and greenhouse gas emission inhibiting effect. However, the treated sewage quantity varies irrespective of the thermal load of a building in an actual scheme. It is necessary to construct a system considering this point, which enables us to use heat of treated sewage effectively. In the case of Tokyo, the cooling load occupies most of the thermal load of commercial buildings, and the efficacy of sewage heat utilization is smaller than in other areas with advanced heat utilization. Thermal load properties according to building use and the exhaust heat property of heat sources should be ascertained fully for effective utilization of unused energy such as sewage heat in Tokyo. Then simulation thereof for predicting its efficacy will engender its highly value-added industrialization considering future measures against global warming and environmental protection. Moreover, there are negative factors for using sewage heat for heat sink for air cooling, such as declining trends in treated sewage quantity that are expected to occur because of water-saving measures in recent years and sewage temperature rise through the years according to progress in urbanization.

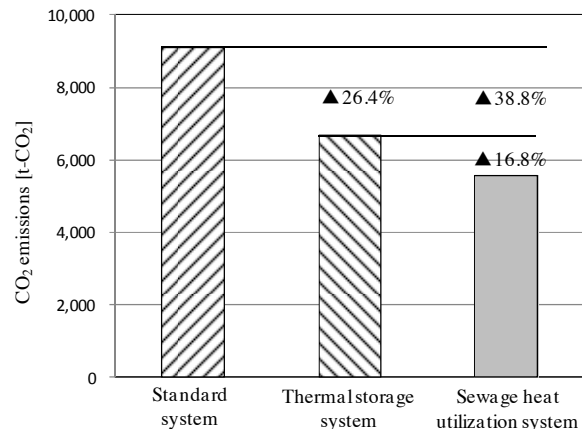


Figure 17 CO<sub>2</sub> emissions

Along with these issues, our future subjects include factors affecting the commercial potential of sewage heat utilization

## ACKNOWLEDGEMENTS

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## Additional notes : Economical evaluation

Shown in the results table 3 was estimated for investment and running costs. For the investment, Sewage heat utilization system will increase 34% for the standard system and the annual running costs will be reduced by 50%. Payback is calculated to be approximately 8 years.

Table 3 Financial implication

	Standard system	Thermal storage system	Sewage heat utilization system
Initial cost (As per the standard system)	1.00	1.29	1.34
Running cost (As per the standard system)	1.00	0.58	0.50