Evaluation on the Availability of Treated Sewage Water as an Unused Energy Source in a Super High-rise Complex Building

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Abstract

Because the super high-rise complex building would be designed vertically with a mixed-use space, a large amount of unpurified domestic sewage could be discharged continuously outside the building site. The waste heat from the sewage water can be used for low temperature heating and high temperature cooling sources for HVAC system such as radiant heating and cooling system, and domestic hot water services. This study aims to evaluate the availability of treated sewage water as an unused energy source in a super high-rise complex building. For this purpose, current sewage treatment methods were analyzed to clarify the alternatives of heat source, and thermal energy potentials were evaluated according to the quantity of treated water and seasonal temperature variation. In conclusion, it was forecasted that the treated sewage water could be more effective for using the heating sources rather than the cooling sources because the temperature differences in spring and winter between treated sewage water and outdoor air was larger than those in summer. Also the thermal energy potentials were estimated from 20,900 MJ/day to 62,700 MJ/day according to the building use patterns.

Keywords: Super High-rise Complex Building, Unused Energy Source, Treated Sewage Water, Heat pump, Low Temperature Heating and High Temperature Cooling

Introduction

Because the super high-rise complex building would be designed vertically with a mixed-use space, a large amount of unpurified domestic sewage could be discharged continuously outside the building site. Sewage water from baths and showers, washing machines in buildings has a various temperature ranges between about 13 and 30 ℃. Because the temperature of sewage water is relatively higher than outside air temperature with the seasons and is changed little, which is usually in less than 10℃, the sewage water has been regarded as suitable heat sources for HVAC system. Especially, the waste heat from the sewage water can be used for heat sources for low temperature heating and high temperature cooling system such as radiant heating and cooling, and domestic hot water services. Also with the recent advancement of heat pump technology, it has been considered as rational use of unused energy sources in buildings. This type of energy source has been considered as green energy sources and mainly used for district heating, heating and cooling energy for the building located near the sewage disposal plant.

This study aims to evaluate the availability of treated sewage water as an unused energy source in a super high-rise complex building. For this purpose, current sewage treatment methods were analyzed to clarify the alternatives of heat source, and thermal energy potentials were evaluated according to the quantity of treated water and seasonal temperature variation.

Application of treated sewage water in super high-rise complex building

Normally the sewage water has been discharged in every building stock. And the sewage water was moved through the drain pipe in city and finally to the sewage disposal plant. As sewage entered the plant, large solid bodies such as wood and gravel were screened out. Grit and sand were then removed by settling or screening with finer mesh. The remaining sewage passed into primary sedimentation tanks that suspended solid-type sludge settles out. The remaining sewage was aerated and mixed with microorganisms to decompose organic matter. A secondary sedimentation tank allowed any remaining solids to settle out. The remaining liquid effluent was discharged into a body of water. Sludge from the sedimentation tanks may be disposed of in landfills, dumped at sea, used as fertilizer, or decomposed further in heated tanks (digestion tanks) to produce methane gas to power the treatment plant.

The thermal energy from sewage water could be obtained by three methods depending on where the energy is extracted, i.e the in-house energy recuperation, energy recovery from raw sewers, energy recovery from treated wastewater after the sewage treatment plant. The energy potential of treated sewage water was much higher than that of raw sewage water. Unfortunately, the large energy potential of treated sewage water could not be used in many locations because the sewage treatment plants were located outside building stock, where no consumers for the heat were available.

Treated sewage water could be used for domestic hot water supply and heating and cooling for building HVAC system. As numerous pilot examples have shown, the combined use of treated sewage water for heating and cooling with thermal storage system and conventional heat sources such as chillers and boilers normally provides an extremely economical supply of energy. Generally, sewage water heat pump can use the treated water in winter of the temperature 11-15 ℃, in summer of the temperature 17-21℃. This makes the sewage water heat pump to operate efficiently by 20% in comparison of conventional air-conditioning heat pump system. Commercially available heat pump systems usually use heat from the ambient air or from the discharge of an air conditioner to heat water for household use. These systems are impractical or infeasible in cold winter season of Korea. Because conservation is particularly important in the colder climates, an alternative system is desirable.

Sewage water is collected from sinks, showers, and washing machines and is stored in an insulated storage tank. Particulates and other sediment, such as hair or lint, are filtered from the sewage water before the sewage water is circulated to an evaporator. In the evaporator, the sewage water transfers its heat to a refrigerant. The temperature of the refrigerant, which leaves the evaporator, is further increased in a compressor. Then, the heated refrigerant transfers its heat to household water in a condenser and the household water is stored. In application of treated sewage water in super high-rise complex building, an improved sewage water storage tank, including a conical mesh to treat the inlet sewage water to remove sediment, such as hair, lint, and other particulates is used in several cases. The treated sewage water is circulated to the evaporator by drawing warm sewage water from the top of the storage tank. After passing through the evaporator, the cooled sewage water is recycled to the storage tank, where it enters to displace warmer water upwardly in the tank. The conical mesh can be easily cleaned with a jet ejector nozzle which flushes the particulates from the mesh into the tank. In the evaporator, heat is exchanged between the sewage water and a refrigerant. The entering sewage water ordinarily has a temperature of about 35° C. while the refrigerant will be a liquid-gas mixture at about 4° C. The refrigerant gains heat so that it exits as a pressurized gas at about 4° C. In the compressor, saturated refrigerant vapor leaving the evaporator is superheated to achieve a high-pressure gas. This gas is passed through the condenser, where the refrigerant transfers its heat to inlet household water. The water exits via pump into an insulated storage tank. The refrigerant is re-circulated to the evaporator through a throttling valve, expansion valve, or capillary tube, completing its heat pump cycle.

Estimation of thermal energy potential in treated sewage water

Thermal energy potential is the theoretically estimated energy quantity in unused energy sources. So this is calculated with Eq.1.

$$\mathrm{E} = \mathrm{W} \times C_p \times \Delta T \qquad \text{(Eq. 1)}$$

Where E = Thermal energy potential [kJ/day]

W= mass [kg/day], i.e. mass flow rate of treated sewage water

C_p = specific heat of treated sewage water [kJ/kg·K] (approximately 4.18)

ΔT = available temperature drop [K or ℃], i.e. temperature difference between supply and return of treated sewage water

Available energy potential is the quantity of usable energy by considering the current physical and technical limitation. So this is calculated by assuming that the sewage water heat pump can be applied to the heating and cooling purposes. This is calculated with Eq.2 and Eq.3.

$$E_c = E \times \frac{COP_c}{(COP_c+1)} \qquad \text{(Eq. 2)}$$

$$E_h = E \times \frac{COP_h}{(COP_h-1)} \qquad \text{(Eq. 3)}$$

Where E_c = Available cooling energy potential [kJ/day]

COP_c= Coefficient of performance in cooling operation [-]

E_h = Available heating energy potential [kJ/day]

COP_h= Coefficient of performance in heating operation [-]

Results and Discussion

1. Analysis of sewage water temperatures

Because the performance of heat pump system can be affected by the part-load conditions and the temperature variations of treated sewage water, it is necessary to design the capacity of system appropriately according to the characteristics of building loads and temperature variation of sewage water. In this study, we have aimed at evaluating the energy potential of treated sewage water as an unused energy source, so at first the temperature variation of treated sewage water in real test building has been measured year-round. Test facility was composed of sewage water heat pump, submerged pump, indoor terminal units, control panel, and sewage disposal facility (See Fig.1). In measurement results, as shown in Table 1, the sewage water temperature has been changed according to variation of the outdoor air temperature. In summer seasons, the sewage water temperature was larger than the outside air temperature, but the temperature fluctuation of sewage water during the day was smaller than that of outside air. Also it was forecasted that the treated sewage water could be more effective for using the heating sources rather than the cooling sources because the temperature differences in winter between treated sewage water and outdoor air was larger than those in summer.

a) Front view of test building b) Sewage water heat pump c) Pipe inlet through the submerged pump

d) Indoor terminal unit e) Schematic diagram of sewage water heat pump system f) Control panel

g) Primary sedimentation and filter h) A/C filter i) Sewage water storage tank

Fig. 1 Photos of pilot project system in test building

Table 1 Comparison of outdoor air temperatures[1)] and sewage water temperatures

Date	Outdoor air temperature (°C) [1)]			Sewage water temperature (°C)		
	Average	Maximum	Minimum	Average	Maximum	Minimum
16 March (A)	1.9	6.0	-0.8	10.6	11.2	9.4
16 April (B)	8.2	15.4	0.2	18.3	22.5	12.0
16 May (C)	18.8	27.2	9.5	21.1	21.8	19.8
16 June (D)	22.8	27.9	17.3	28.1	28.4	25.8
16 July (E)	24.8	29.2	22.6	28.8	29.1	28.6

[1)] Outdoor air temperatures were obtained from the databases of Korea Meteorological Administration (KMA).

(http://www.kma.go.kr/weather)

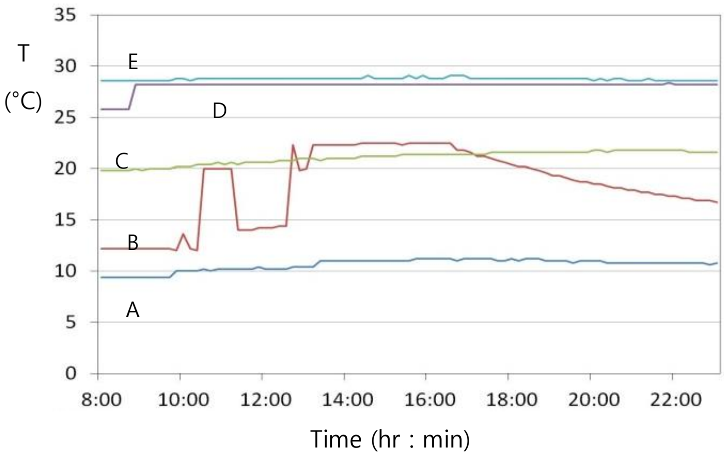

Fig. 2 Results of temperature fluctuation of treated sewage water

2. Analysis of sewage water flow rates

Sewage water flow rates in super high-rise complex building can be varied according to the total floor areas, use patterns, operation schedule, etc. Also it can affect the energy potential of treated sewage water. In the conceptual design stage, it is appropriate that the energy potential of treated sewage water and the capacity of system would be estimated according to the total floor areas because it is easy to understand the scale of overall system and communicate it with other experts. So we have used the basic estimation methods of discharge rates of sewage water according to the building usage pattern to evaluate the flow rates of treated sewage water. [1] As shown in Table 2, the discharge rates of sewage water were estimated according to the building usage, and that could be converted into the values for each floor area. In results, the discharge rate of sewage water in residential building was

10 L/m^2, that in office 15 L/ m^2, that in accommodation facility and restaurant 60 L/m^2, that in cultural facility 16 L/m^2.

Table 2 Discharge rates of sewage water according to the building usage[1)]

Building usage \ Discharge rates		Discharge rates of sewage water per day	Converted value according to the floor area
Residential building	Detached house	200 L/person	10 L/m^2
	Apartment building	200 L/person	10 L/m^2
Office building	Office	15 L/m^2	15 L/m^2
	Efficiency apartment	200 L/person	10 L/m^2
Accommodation facility (Hotel etc.)		250 L/person	60 L/m^2
Marketing facility (Shopping mall, store etc.)	Restaurant	60 L/m^2	60 L/m^2
	Department store	30 L/m^2	30 L/m^2
Cultural facility		16 L/m^2	16 L/m^2

[1)] Estimation methods of discharge rates of sewage water according to the building usage (Ministry of Environment, Notification No. 2007-178), Republic of Korea.

3. Analysis of thermal energy potential and available energy potential of treated sewage water

As previously mentioned, thermal energy potential and available energy potential of treated sewage water could be estimated by using the mass flow rate of treated sewage water, specific heat of treated sewage water, available temperature drop, and coefficient of performance in heating and cooling operation. Generally, the building usage pattern of international high-rise buildings over 150 meters has been changing as shown in Table 3. [2] In Table 3, we could see that the majority of high-rise buildings were destined for office use in 1980 and 1995. The current percentage in this use pattern was only 47.3%. Where buildings under construction were concerned, the figure drops to 26.8% of the total. At the same time we could see that the residential building was now becoming the most widely built pattern with 47.3% of the total currently under construction. Most of all, we also could find a steady rise of the mixed-use building, rising from 5.3% in 1980 to 11.0% today. With 17.7% currently under construction, we could anticipate a bright future for this building type. The mixed-use high-rise building would be more and more popular. So in this study, we have assumed the building use pattern in super high-rise complex building like the cases in Table 4 for estimating the discharge rates of sewage water.

Table 3 Percentages of Building usage of international high-rise buildings over 150 meters[1)]

Usage \ Year	1980	1995	2008 Plus those under construction	Those under construction only
Office	84.7 %	78.3 %	47.3 %	26.8 %
Mixed-use	5.2 %	6.6 %	11.0 %	17.7 %
Residential	5.2 %	9.6 %	35.3 %	47.3 %
Hotel	4.9 %	5.5 %	6.4 %	8.2 %

[1)] Georges Binder, The international Skyscraper: Observations, CTBUH Journal, 2008 Issue 1, pp. 20-30.

Table 4 Assumption of building usage in super high-rise complex building

Building usage	Case 1	Case 2	Case 3	Case 4
Residential	0.5	0.5	0.4	-
Office	0.5	-	0.3	0.5
Accommodation (Hotel)	-	0.5	0.3	0.5

Also we have assumed that the general coefficient of performance (COP) of heat pump system was 4 and the available temperature drop was 5°C to estimate the thermal energy potential and available energy potential of treated sewage water sources in super high-rise complex buildings. In results, when the total floor area is 800,000 m^2, the total discharge rate of sewage water was about from 10,000 Ton/day to 30,000 Ton/day. If we assumed that 10 percentage of this discharged sewage water would be treated for grey water in building, we could use the treated sewage water about from 1,000 Ton/day to 3,000 Ton/day for unused energy source. In this case, the thermal energy potentials were estimated from 20,900 MJ/day to 62,700 MJ/day according to the building use patterns.

Table 5 Thermal energy potential and available energy potential of treated sewage water sources in super high-rise complex building

Category		Assumption : Total floor area is 800,000 (m^2)			
		Case 1	Case 2	Case 3	Case 4
Discharge rate of sewage water (Ton/day)		10,000	28,000	21,200	30,000
Treated rate of sewage water (Ton/day)		1,000	2,800	2,120	3,000
Thermal energy potential (MJ/day)		20,900	58,520	44,308	62,700
Available energy potential (MJ/day)	Cooling	16,720	46,816	35,446	50,160
	Heating	27,867	78,026	59,077	83,600

Conclusions

This study aims to evaluate the availability of treated sewage water as an unused energy source in a super high-rise complex building. For this purpose, current sewage treatment methods were analyzed to clarify the alternatives of heat source, and thermal energy potentials were evaluated according to the quantity of treated water and seasonal temperature variation. In conclusion, it was forecasted that the treated sewage water could be more effective for using the heating sources rather than the cooling sources because the temperature differences in spring and winter between treated sewage water and outdoor air was larger than those in summer. Also the thermal energy potentials were estimated from 20,900 MJ/day to 62,700 MJ/day according to the building use patterns.

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