Reuse of heat energy in wastewater: implementation examples in Japan

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Abstract Sewage and treated water can be a heat source in urban area due to large heat capacity, thus recovery and reuse of its energy is one of the most desirable plans for the sewerage system. In this paper, characteristics of heat energy in wastewater, reuse plans, and some experiences in Japan are presented. Full-scale reuse projects for heating and cooling in the Tokyo Metropolitan Districts and project for melting snow in Sapporo City are discussed. The key factors found in experience of Tokyo were setting the heat pumps near the demand points and the technical developments of equipment to prevent system from clogging, corrosion, and decrease in the heat transfer efficiency. It was also found through the project for melting snow in Sapporo that the key factor in public acceptance was the multi-purpose use of the sewerage system both for melting snow in winter and retaining rain water in summer.

Keywords Air conditioning; melting snow; recovery and reuse of heat energy; Sapporo City; Tokyo Metropolitan Districts; wastewater

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Introduction

The effluent of wastewater treatment plant (WWTP) has been recognized as the dependable water resource created right at the doorstep of the urban area, and reclaimed water has been used for landscape irrigation, industrial cooling, toilet flushing in large buildings, and water for aesthetics and environmental purposes in many parts of world (Asano, 1998). This application is reusing the quantity of water. Sewage includes heat energy wasted by the urban activities. Recover and reuse of the heat energy from wastewater is desirable. The purpose of this paper is to present the current status of recovery and reuse of heat energy in wastewater in Japan which includes: characteristics of heat energy in wastewater; how to reuse recovered heat energy; two case studies on the reuse systems of heat energy implemented in the Tokyo Metropolitan Districts and Sapporo City.

Characteristics of heat energy in wastewater and its reuse

Figure 1 shows the heat energy flow through the water system in February 1998, Sapporo. The temperature of tap water was 3.8°C, then the water usage raised its temperature to 13.1°C. Finally, the effluent of Waste-water treatment plant (WWTP) had temperature of 13.8°C. The sensible heat energy in Figure 1 was evaluated on the basis of the atmospheric temperature. The 700MJ/s of sensible heat was released to the receiving water body. As shown in Figure 2, the heat energy in the wastewater or treated water occupied about 50% of the total wasted heat energy in Sapporo (Ochifuji *et al.*, 1992). The total amount of the heat energy in the effluent of WWTP was about 5,500 TJ/year (= 10^{12}J/year) comparable to about 26% of the annual consumption of domestic use in Sapporo (Narita *et al.*, 1995).

Figure 3 shows the monthly variation of the mean temperature of the effluent of WWTP as well as that of ambient air in Sapporo. Since the temperature fluctuation of the effluent is smaller than that of air, we can recognize the effluent as the stable heat source. The quality of energy is evaluated in terms of 'Exergy' defined as the energy that is able to convert to

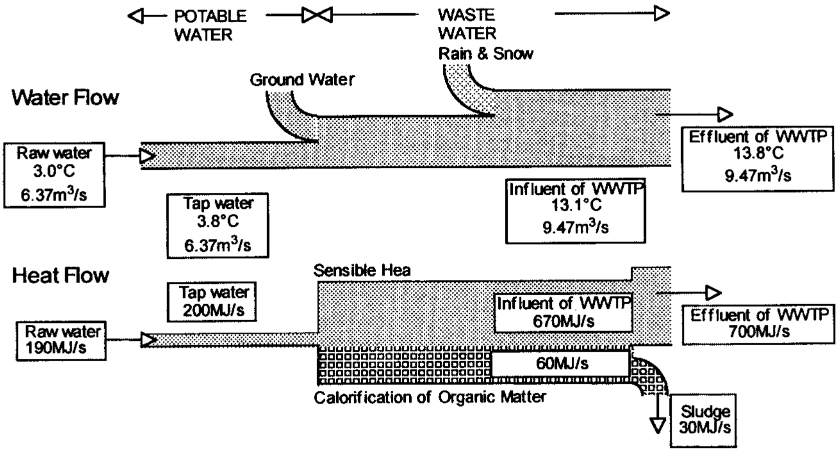

Figure 1 Heat energy flow through the water supply and sewage system of Sapporo in February, 1997

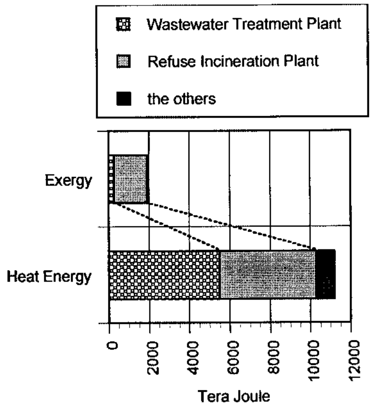

Figure 2 Heat energy and exergy of wasted heat in Sapporo (adapted from Ochifuji, 1992)

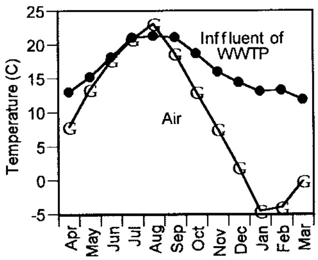

Figure 3 Comparison of sewage temperature with air temperature in Sapporo

the work by the Carnot cycle. The value of the exergy is also depicted in Figure 2. The exergy of the urban waste energy is far lower than the heat energy, and the reduction of its value is conspicuous in the heat energy of WWTP. This means that the quality of the heat energy in the effluent is very low in a thermodynamic sense because of its low temperature. It is difficult to use the heat energy for power supply, but it is easy to use it for heating and/or for melting snow.

Reuse of heat energy for heating and air conditioning

The required temperature of heat media is more than 40°C for heating and less than 15°C for cooling. Therefore a heat pump system is essential to increase or decrease the temperature of heat energy recovered from the wastewater or the effluent. Figure 4 gives the illustration of the heat pump system for heating purpose at the Ochiai WWTP in Tokyo. The refrigerant is circulating through four units in the heat pump. The evaporator makes use of the heat energy in the effluent of WWTP to vaporize the refrigerant. In this process, Q_1 J/s of heat energy is transferred from the effluent to the refrigerant. At the compressor, the vapor of the refrigerant is compressed and its pressure and temperature rise. This compressing process requires W_1 J/s of work which should be supplied by electricity. At the condenser, the compressed vapor of the refrigerant releases its heat energy and then becomes

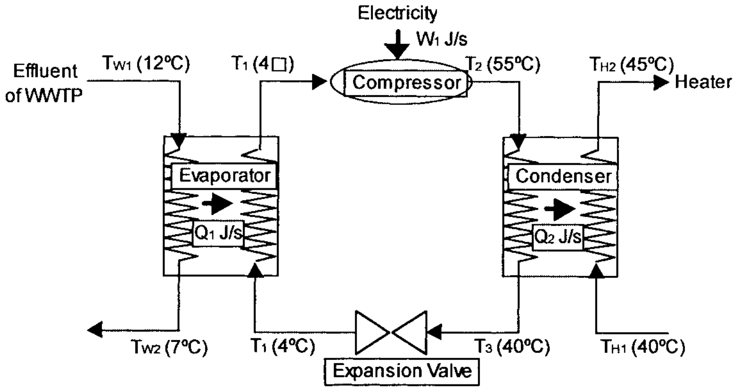

Figure 4 Block diagram of the heat pump system with sewage heat source in the Ochiai WWTP for heating

liquid. The heating media receives Q_2 J/s of heat energy. The final equipment is the expansion valve. The refrigerant is expanded by the throttling process and reduces its temperature. In the heat pump cycle described above, the temperature of the WWTP effluent changes from T_{w1} to T_{w2}; W_1 of work is consumed at the compressor, and Q_2 of heat energy with T_{H2} temperature is obtained. The performance of this heat pump is evaluated with the value of Q_2/W_1 which is called COP.

In the case that the recovered heat energy is distributed for heating and/or cooling to the service area, the additional energy for transporting the heat media is required. Namely, the total required energy for the energy supply system with the heat pump is the sum of W_H (the energy for heat pump) and W_T (the energy for transporting heat media). The additional energy determines the adequate size of service area. This size is estimated by the following calculation. If the every building or house has an on-site air heat pump system and the required energy for the heat pump is W_a, then the sewage heat pump and transporting system has advantage within the area where the relationship of $W_a > W_H + W_T$ holds. The values of W_a-W_H and W_T are calculated by the following equations (Ochifuji *et al.*, 1992):

$$W_a - W_H = C_w \times G \times \left\{ \left(T_{w1} - T_{w2} \right) - T_{air} \ln \frac{T_{w1}}{T_{w2}} \right\} \qquad (1)$$

$$W_T = g \times G \times H \times \left(2 \times c \times L \right) \qquad (2)$$

where C_w is the specific heat of the effluent (=4.185kJ/kg/°C); G is the mass flow (kg/s); T_{w1} and T_{w2} are temperatures of the WWTP effluent at the inlet and outlet of the heat pump, respectively; T_{air} is the temperature of atmosphere; g is the acceleration of gravity; H is the head loss of 1 m of pipe for transporting heat media; c is the conversion factor of local friction loss to equivalent length of pipe; L is the distance of heat transportation.

Setting that $W_a = W_H + W_T$ yields the critical dimension, L_C of the service area for energy supply from the heat pump station. Figure 5 shows the computed results of L_C in the case that T_{W1}-T_{W2}=5°C ; H=6/1000. It can be seen in Figure 5 that under the typical summer condition: T_{air}=30°C; T_{w1}=20°C, the L_C is about 2000 m. In the guideline of Tokyo Metropolitan Districts, the recommended distance is 1000m (Nakamura, 1999).

Reuse of heat energy for melting snow

The heat energy in the wastewater and/or the effluent of WWTP can be used for melting snow by throwing snow directly into the combined sewer pipe and/or by diverting the

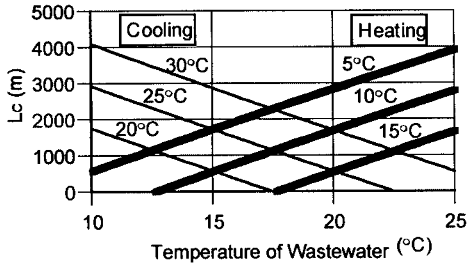

Figure 5 Critical distance for transporting heat from heat pump station. Parameters in the figure are air temperature

effluent of WWTP to the big basin for melting snow. The rate of melting snow is estimated roughly by the following relationship:

$$S = \frac{e \times Q_w \times r_w \times (T_w - T_0) \times C_w}{r_s \times (|T_s| \times C_s + J + T_0 \times C_w)} \quad (3)$$

where S is rate of melting snow (m^3/day); e is the efficiency; Q_w is the flow rate of the effluent of WWTP (m^3/day); r_w is the density of water (1000kg/m^3); T_w is the temperature of the effluent of WWTP (°C); T_0 is the temperature of the effluent of the basin for melting snow; C_w is the specific heat of the effluent (=4.185kJ/kg/°C); r_s is the density of snow (kg/m^3); T_s is the temperature of snow (°C); C_s is the specific heat of snow(kJ/kg/°C); J is the latent heat of fusion of snow (334.8kJ/kg).

In Equation (3), setting that T_w=10°C; T_0=0°C; r_s=500kg/m^3; T_s=–4°C (the average atmospheric temperature in a snow season); e=0.8 yields that 1m^3 of the WWTP effluent can melt 0.2m^3 of snow.

Implementation examples in Japan

Reuse of heat energy in wastewater for heating and cooling in Tokyo Metropolitan Districts

The 38,000 TJ of heat energy is wasted to the sewage system annually in Tokyo Metropolitan Districts, which is equivalent to the energy consumed by 0.4 million houses for heating and cooling. The Sewerage Bureau of Tokyo Metropolitan Government has started the project for recovering the heat energy from sewage since 1987. Eleven heat pump systems are operating now and using 70,000m^3 of the effluent or raw wastewater daily. Four facilities are set at the pump station and they use the raw sewage as the heat source. The remaining eight facilities use the secondary or tertiary effluent of WWTP. The total capacity of energy supply is 32,200 MJ/hr for heating and 41,900 MJ/hr for cooling. The recovered energy is used mainly for air conditioning of the administration buildings of WWTP. Especially, the Kohraku system supplies the energy to the district heating and cooling.

Ochiai wastewater treatment plant. The heat pump system was constructed for heating and cooling of the administration buildings in 1987, which uses 1450m^3 out of 315,000m^3 of the secondary effluent as a heat source. The heat pump capacity is 2,090MJ/hr for heating and 2,220 MJ/hr for cooling. Table 1 gives the comparison of the running cost of the Ochiai heat pump system in March 1987 with that of the conventional boiler system used in Ochiai WWTP in March 1986, showing that the operation cost of the heat pump system is about 25% lower than that of conventional boiler system.

Kohraku pump station. The heat pump system as shown in Figure 6 for supplying heat energy to the district heating and cooling system is set at the Kohraku pump station. Raw

Table 1 Comparison of running cost of the heat pump system with Boiler system in the Ochiai WWTP*

	Heat Pump March, 1987	Boiler March, 1987	Boiler March, 1986
Energy consumption	256kWh/day of Electricity COP:5.26	147L/day of Oil (estimated value from heat demand)	313L/day of Oil
Running cost index	100	25	267

*adapted from Nakazato, 1987

wastewater is introduced to the heat exchanger instead of heat pump, and then heat energy is transferred to the heat pump. Part of recovered energy is stored in the heat storage tank. This heat storage tank is installed in the system to balance the heat demand variation and to make use of electricity at a night rate. The system has two heat exchangers; three heat pumps; three heat storage tanks and it distributes heat energy to five buildings with 175,400m^2 of floor area in the 21.6 ha of service district. The heat distribution lines consist of four pipes; supply and return pipes for hot and cold water. Ductile iron pipes are laid underground and their extension is approximately 500m. Figure 7 gives results of heat supply in 1997, showing that more than 60% of energy was distributed for cooling from July to September. The total electricity consumed in 1997 was 4.1×10^6 kWh: 74% was used by the heat pumps; 15% was spent for transporting hot and cold water. The COP value of heat pump was 3.80, and if we include the electricity for transporting, COP of the total system was 2.81.The price of heat energy consists of basic charge and specific tariff. The basic charge is 3.5 US$ for cooling or 3.1 US$ for heating per 1 MJ of contracted capacity. The specific tariff is 0.038US$/MJ for cooling or 0.031 US$/MJ for heating.

Technologies which can recover heat energy from sewage. Since many kinds of suspended solids and salts are included in sewage, the cleaning technology is the key factor of the energy recovery from sewage. The following technologies have been developed: (1) to prevent clogging by suspended solids, automatic strainers are installed at the inlet of the system; (2) to prevent corrosion, durable materials such as copper and titanium of the heat exchanger were selected; (3) to prevent the fouling in the resistance of heat transfer, automatic cleaning devices are installed. In addition to the above cleaning devices, cleaning by the high pressure jet water is applied periodically to the strainer and heat exchanger in the Kohraku system where raw wastewater is used as a heat source.

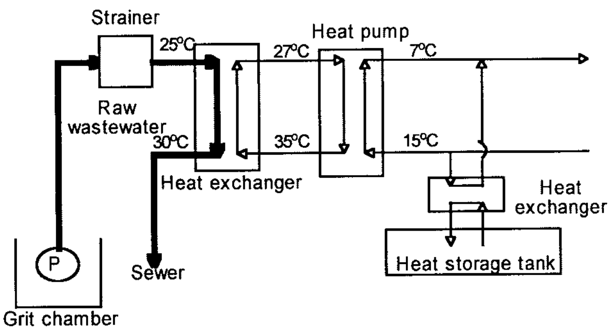

Figure 6 Schematic description of the Kohraku system. Numerical value shows the temperatures of input and outputs of each unit at the operation for cooling

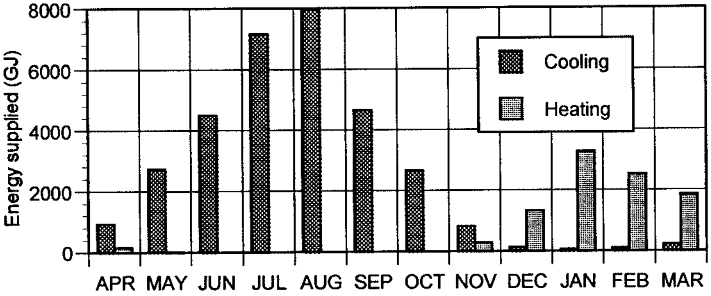

Figure 7 Monthly variation of heat supply from Kohraku Heat Pump system in 1997. (Adapted from Nakamura (1999))

Reuse of heat energy for melting snow in Sapporo City

Sapporo City has a so-called 'snow problem' such as removing snow from streets and dumping snow. This snow problem involves four issues. First, the public opinion survey in Sapporo has been showing that the citizens in Sapporo are not satisfied with the current service for removing snow from streets and residential area. Second, it becomes difficult to provide enough space to stock the transported snow. Third, snowmelt from stock yards causes water pollution problems. Fourth issue is related to energy consumption. Facilities for melting snow at on-site such as road heating system are used in many places. This causes the increase in consumption of high grade energy such as electricity and oil. The problem gives rise to a multi-purpose use of the existing sewerage system to transport and melt snow.

Facilities for controlling combined sewer overflow (CSO) and the basins for flow equalization of WWTP can be converted into a snow disposal system in winter. In a snowy-cold region there is no rain in winter and we can use their large storage capacity for melting snow. Figure 8 shows the new strategy of Sapporo City for combined sewer system. There are three projects depicted in Figure 8. The first project is a multi-purpose use of basin and reuse of heat energy of treated water for melting snow. Second project is construction of channels for transporting snow by supplying treated water. Third one is transporting snow by combined sewer. The facilities for throwing snow into the combined sewer were constructed in the central part of Sapporo. Dirty snow from downtown area is transported and melted in sewer then snowmelt is treated at WWTP.

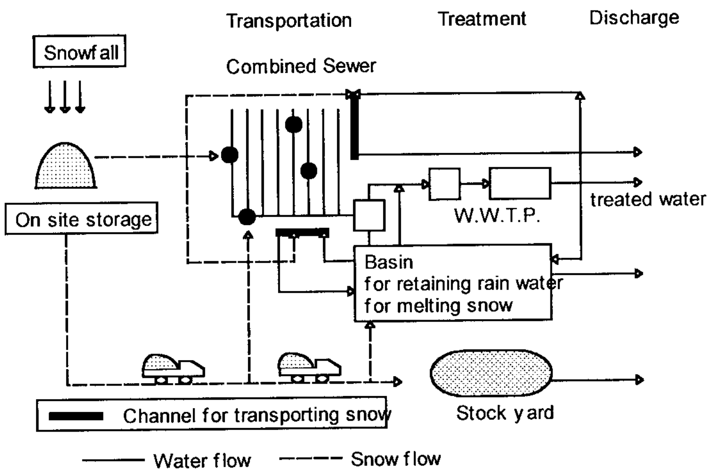

Figure 8 Sketch of the sewage system for its use to transport and melt snow in Sapporo

Atsubetsu storage basin. Since 1993, Atsubetsu storage basin for flow equalization has been operated as a basin for melting snow. Half of the storage capacity (8,000m^3) is used for melting snow in winter. The heat source is the effluent of WWTP. Aeration is adapted in the basin for mixing snow. This aeration facility is equipped originally for mixing and pre-aeration of influent of WWTP. The operation results in the last three years are summarized in Table 3. In 1998, 0.3 million m^3 of snow was melted with 3.5 million m^3 of the effluent. This means that 0.085 m^3 of snow was melted by 1m^3 of effluent water. Table 4 shows the mean values of pH, SS, and BOD in the input water of the basin (the effluent of WWTP) and the output water of the basin. It should be noted that the SS and BOD values in the output are higer than the input water. The material balance of suspended solids around the basin in 1998 is summarized in Table 5. The values in Table 5 were estimated by the following way: 1) the mass of SS in the effluent of WWTP and the effluent of the basin for melting snow were calculated with data; 2) the mass of SS in the grit was estimated by the measured value of SS concentration of the grid, 1600 kg/m^3; 3) finally, the mass of SS in the snow was estimated by mass balance relationship. These estimated results showed that the solid removal performance of the basin was 69% approximately, and that snow contained about 1700mg/L of SS. It should be noted that melting snow in the basin improved the water quality of snowmelt.

Sosei retention pipe. The effluent of Sosei WWTP is distributed to the Sosei retention pipe for melting snow and channels for transporting snow. The distribution plan of the effluent is given in Figure 9. The Sosei retention pipe, 5 m in diameter and 2,495 m in length, can store 46,400 m^3 of water. This pipe has two functions: retaining storm water in a rain season and melting snow in winter. Snow is thrown into the retention pipe after reducing its size by a rotary grinder. Snowmelt is pumped up and discharged to the river. Table 6 gives the

Table 3 Summary of operational results of Atsubetsu storage basin

Operation period	Volume of snow melted, m^3	Volume of effluent used, m^3	Electricity kWh	Volume of grit m^3
Jan–Feb 1998, 39 days	285,796	3,450,900	102,280	131
Jan–Feb 1997, 6 days	6,370	663,980	22,140	25
Jan–Mar 1996, 55 days	536,578	6,245,590	197,270	179

Table 4 Water quality before and after melting snow

	PH	SS, mg/L	BOD mg/L	Temp. °C
Effluent after melting snow*	7.4	39	15	7.9–13.9
Effluent of WWTP*	7.5	13.5	4.6	12.9–14.5

* Mean value during operation period, Jan.–Feb., 1998.

Table 5 Water volume and suspended solid balance among the Atsubetsu basin

		Water Volume	Suspended Solid
In	Effluent of WWTP	3,450,900m^3	46,590 kg
	Snow	176,340m^3 (1)	209,600 kg(2)
Out	Grit	–	304,470 kg(3)
	Effluent of snow melt basin	3,627,240m^3	141,460 kg

(1) volume of snow times the density of the snow, 0.617, (2) estimated value by mass balance,
(3) suspended solid concentration of grid was about 1600kg/m^3

operation results in 1998 winter, and Table 7 shows the water quality of influent and effluent of the retention pipe.

Cost of melting snow in Sapporo. Cost of melting snow involves the expense of transporting snow, the operation cost of facilities for melting snow and the depreciation of the facilities. The cost for melting 1 m^3 of snow of three facilities ranged from 5.8 US$ to 7.5 US$ in 1998. Transporting and dumping snow in the stock yard was operated at the nearly same cost. The details of the total cost in 1998 are summarized in Figure 10. "Ohdori" is the facility for throwing snow directly into the combined sewer. Since this facility is located at the central part of Sapporo, the cost of transporting snow occupied about 50% of the total cost. On the other hand, the Atsubetsu basin is in the suburbs, the contribution of the expense for transporting snow exceeded the 80% of the total cost. In transporting and dumping snow to the stock yard, most of cost was for transporting snow, too. However, the initial and maintenance and operation cost are more expensive at the facilities located in the central part of Sapporo than that in the suburbs. It should be noted that it is becoming difficult to provide enough space to stock the transported snow and that the cost of transporting snow may become more expensive.

Conclusions

Full-scale projects for reusing heat energy of sewage in the Tokyo Metropolitan Districts

Table 6 Summary of operational results of Sosei retention pipe for melting snow

Operation period	Volume of snow melted, m^3	Volume of effluent used, m^3	Electricity kWh	Volume of grit, m^3
Jan–Mar 1998, 3 days	55,300	1,584,320	395,930	20.7

Table 7 Water quality before and after melting snow

	pH	SS, mg/L	BOD mg/L	Temp. °C
Effluent after melting snow*	6.9	3	7.5	6.1–12.7
Effluent of WWTP*	6.7	3	6.9	7.9–14.3

* Mean value during operation period, Jan.–Mar., 1998

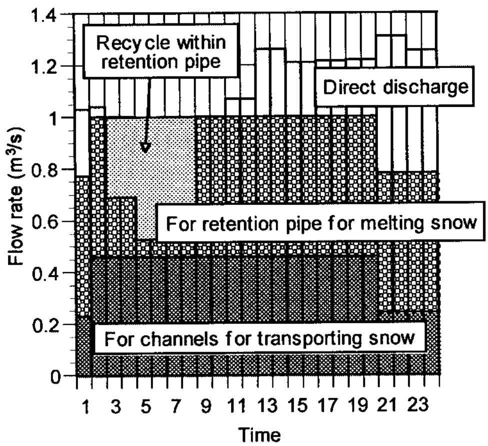

Figure 9 Distribution plan of treated water of Sosei WWTP for transporting and melting snow

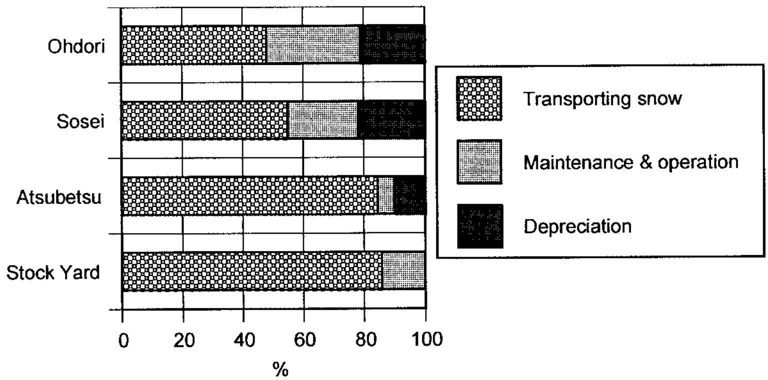

Figure 10 The percentage of constituents in the total cost of facilities of melting snow in Sapporo

and Sapporo City are discussed. The survey of heat energy flow in the Sapporo water system showed that huge amount of heat energy was wasted to sewage. Since the quality of the heat energy is poor in thermodynamic sense because of its low temperature, using the heat energy for heating and cooling or for melting snow is adequate. The energy consumption of two system was estimated and compared: the system with the sewage source heat pump and energy transportation, and the on-site air source heat system. The results showed that there is an appropriate size of service area for heat recovery and supply system. The successful implementation of heat energy recovery from raw wastewater for the district heating and cooling in Tokyo shows two key factors: location of heat pump and cleaning technology. First, the heat pump is located near the energy demand points. Second, the cleaning devices of heat recovery equipment have been developed to prevent systems from the trouble such as clogging, corrosion, and fouling. It was found through the project for melting snow with sewage that the key factor in public acceptance was the multi-purpose use of the sewerage system.

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