POTENTIAL CAPACITY RESEARCH ON APPLICATION OF SEWAGE- SOURCE HEAT PUMP SYSTEM IN BATH CENTERS

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ABSTRACT

In bath centers，the most prominent characteristics is that great amount of hot water（35~60℃）is needed and consumed. At the same time, almost equal amount of warm water（30~35℃）is discharge directly to the drain (becoming to useless sewage). Great amount of low temperature thermal energy is included in the sewage. Sewage with this temperature has the great advantage and very suit for being as the low temperature heat source of heat pump systems. Thermal energy within the sewage should be fully utilized, otherwise, undue waste will be caused.

Heat pump system has its superiority on high energy conversion performance, but it is often restricted by the existing of low temperature sources. Such as the utilization of air source heat pump systems has the worse energy conversion performance in severe cold area even in cold area. Warm sewage from bath centers provides a valuable low temperature heat source for heat pump systems which has no regional restriction. Even in severe cold area, bath center sewage can provide an abundant, advantage and stable low temperature heat source for room heating and water heating by water source heat pump systems.

In this paper, a typical building of bath center is set, thermal (including air heating and water heating) end users are enumerated in detail. Amount of hot water and warm sewage, amount of thermal energy needed in hot water and included in sewage, building cooling load and condenser heat in summer, building heating load in winter etc. are counted up by calculation or simulation work. A unique independent sewage tank (for heat extraction) and a multiple purpose sewage source heat pump system (either for air heating or for water heating) are suggested and established. The whole research work is mainly based on simulation, such as building thermal load simulation (Energyplus software), characteristic simulation of the sewage source heat pump system (Transys software), optimal dimensions and thermal characteristic simulation of the sewage (thermal storage) tank, etc.. Based on the research work, an optimal analytical approach is presented, by this approach potential capacity and the optimal dimensions of the sewage tank for sewage heat pump systems can be obtained under the certain service allocation of the bath center. The optimal operation mode and the

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corresponding technical and economic analysis of the whole paradigm system have been also presented.

Keywords：potential capacity, sewage source, heat pump, bath center, sewage tank

INTRODUCTION

In bath centers，the most prominent characteristics is that great amount of hot water（35~60℃）is needed and consumed. At the same time, almost equal amount of warm water（30~35℃）is discharge directly to the drain (becoming to useless sewage). Great amount of low temperature thermal energy is included in the sewage. Sewage with this temperature has the great advantage and very suit for being as the low temperature heat source of heat pump systems. Thermal energy within the sewage should be fully utilized, otherwise, undue waste will be caused.

Heat pump system has its superiority on high energy conversion performance, but it is often restricted by the existing of low temperature sources. Such as the utilization of air source heat pump systems has the worse energy conversion performance in severe cold area even in cold area. Warm sewage from bath centers provides a valuable low temperature heat source for heat pump systems which has no regional restriction. Even in severe cold area, bath center sewage can provide an abundant, advantage and stable low temperature heat source for room heating and water heating by water source heat pump systems.

THE MODEL BUILDING OF A BATH CENTER

The model building is located in Beijing, it has 7-storeys with the total floor area about 5805.6 m^2. Parameters of the building envelope is illustrated in *Table 1*. The basement 1 and the second floor are bathing area, the first floor is the reception hall and changing area, the third floor is the compartment rest area, the fourth floor is the Leisure & Entertainment area, the fifth floor is the massage room, the sixth floor is guest room. Energyplus was used for the simulation of annual hourly load of the model building. *Table 2* shows the design parameters of the HVAC system. The system of sewage source heat pump was simulated by TRNSYS.

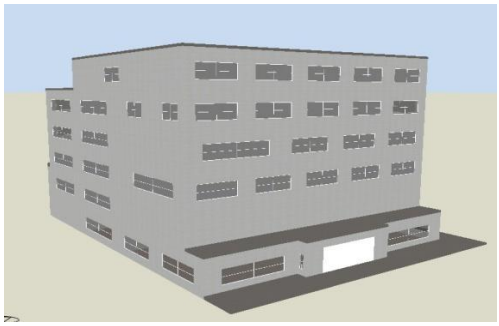
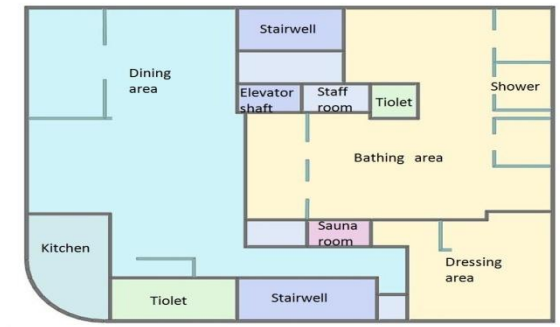


Figure 1 . *Outlook of the building*

Sewage (waste water from sauna, public bath, etc.) is used as the low temperature heat source, so sewage source heat pump can be effectively applied not only for water heating but also for room heating and cooling.



Figre 2. *The plan of the second floor*

Table 1. *Parameters of the building envelope*

NAME	Material				U-Value (W/m^2 ·k)
Layer (from outside to inside)	Layer1	Layer2	Layer3	Layer4	
External WALL	Basalt 30mm	Aerated Concrete slab 200mm	Mortar 10mm	___	0.69
External Window	Generic PYRB CLEAR 3mm	AIR 13mm	Generic CLEAR 3mm	___	1.978
Flat Roof	Asphalt 10mm	MW Glass wool 145mm	Air gap 200mm	Plasterboard 13mm	0.25

Table 2. *Indoor settings*

Room type	Saunas room	Waiting room	Changing room	Bath room （shower、bath）	Guest room
temperature	60～80℃	20℃	25℃	30℃	20℃
Relative humidity	60%	60%	60%	<90%	60%

Bath center are high grade spaces that require high standard service quality and comfort standard, indoor environment (both comfort and air quality) is highly restricted, so that the operation and control of its HVAC system is particularly required. Compare with other commercial buildings, the consumption of water and energy is larger, the operation time is longer, variation of customer flow is large, the cooling load and condenser heat in summer, the heating load in winter, the low grade warm thermal energy within the sewage and the heat required for water heating are considerable. In this case, sewage source heat pump system is the best choice to be employed for the service.

Hourly thermal load of the bath center in the whole year has been simulated and is illustrated in *Figure 3*, the maximum cooling load in summer is 1173.58kW, and the maximum heating

load in winter is 634.77kW.

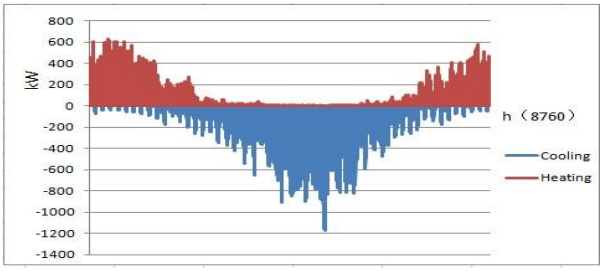


Figure 3. *Hourly thermal load of the Bath center in the whole year*

THE MODEL OF THE SEWAGE SOURCE HEAT PUMP SYSTEM

The principal diagram of sewage source heat pump system is illustrated as follows，see *Figure 4* and *Figure 5* .

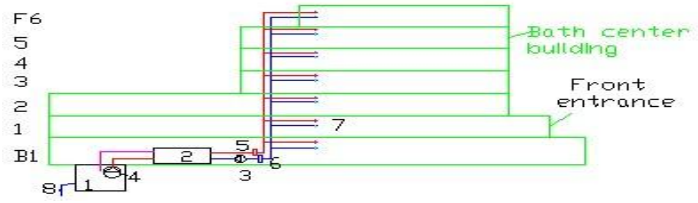


Figure 4. *For room cooling and heating*

1-Sewage tank，2-SSHP，3-Circulating water pump，4-Sewage pump，5-Water distributor，6-Water collector，7-Connected to FCU，8-Drain

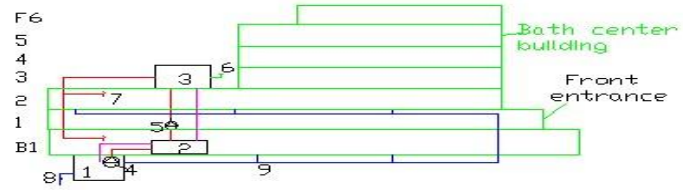
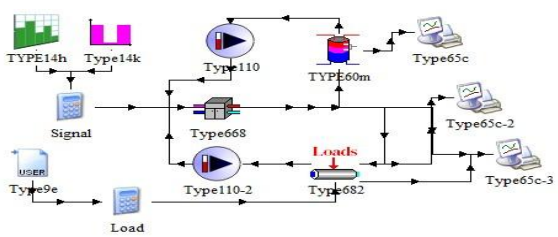


Figure 5 . *For hot water heating*

1-Sewage tank，2-SSHP，3-Themarl storage tank，4-Sewage pump，5-Circulating water pump，6-Connected to tap water，7-Connected to the bath system，8-Drain，9-Sewage collecting system.

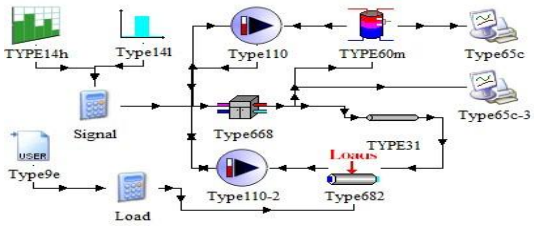
The TRNSYS model of the system is set as follows，see *Figure 6-8.*



Type14h---Time Dependent Forcing Function
Type14k---Heating Season Forcing Function
Signal---A signal equation
Type110 --- Variable Speed Pump

Figure 6. *For room heating*

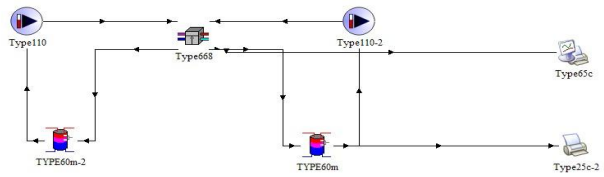
In winter, one sewage source heat pump unit is employed for room heating, the rated parameters of the high temperature side is 65℃/60℃, the rated parameters of the low temperature side (sewage)is 15℃/6℃, sewage is quite warm in winter, and make the operation of sewage source heat pump unit in an excellent status with a high system COP.



Type668--- Water to Water Heat Pump
Type682--- Heating and Cooling Loads Imposed on a Flow Stream
Type9e --- Data Reader For Generic Data Files
Load ---A load equation

Figure 7. *For room cooling*

In summer, running water(20℃) is taken as the cooling water for the condenser, at the outlet, this cooling water has the temperature great than 40℃, and directly be used as the bath water. The energy consumption for heating the bath water can be reduced to the greatest extent.



Type65c --- Online graphical plotter with output file
Type25c---Printer - No units printed to output file
Type31---Pipe

Figure 8. *For bath water heating*

In the TRNSYS simulation of hot water heating, the initial sewage temperature within the sewage tank is set as 30℃, high temperature sewage source heat pump unit is employed, its rating power is 32.7kW. The flow rate of the sewage (low temperature side) is 22m³/h, inlet and outlet sewage temperature is 30℃/20℃; The flow rate of the running water(high temperature side) is 9m³/h, inlet and outlet running water temperature is 15℃/40℃,when the volume of the sewage tank is set as 10m³, 1.2h preheating time(circle heating, 37℃→40℃) is required. COP variation of the sewage source heat pump is shown in *Figure 12*.

AMOUNT CALCULATION OF LOW GRADE THERMAL ENERGY WITHIN THE SEWAGE

Great amount of water is consumed in bath centers everyday, water requirement and consumption consist of four main parts: Shower, massage pool, steam room, domestic hot water, etc., all of them turn to sewage after be used.

Table 3. *Variable discriptions*

Variable	Variable discriptions
m	Number of shower room
q_1	Requirement of shower water for one person，take 200L/person
L	Guest number for each shower room，take 8～12 person
V	Volume of massage pool，13×10×1
N_1	The amount of the Massage pool
N_2	The amount of the Steam
N_3	The number of the bed in rest lounge
k	Water replenishing in massage pool，take 15%～20%
w	Guest number for each steam room，take 3～4 person
q_2	Requirement of water for one person in steam room，take 250L/person
q_3	Water consumption for one bed ,take120L～160L

Table 4. *Water consumption calculation*

Usage	Calculation	Water requirement
Shower room	$Q_1 = m \times q_1 \times L = 66 \times 200 \times 12 / 1000$	158.4m ³
Massage pool	$Q_{2P} = v_i \times N_1 = 13 \times 10 \times 1 \times 1$	130m ³
	$Q_{2s} = k \times v_i = 0.2 \times 130$	26m ³
Steam room	$Q_3 = N_2 \times w \times q_2 = 4 \times 4 \times 250 / 1000$	4m ³
Domestic hot water	$Q_4 = N_3 \times q_3 = 38 \times 140 / 1000$	5.32m ³
Total	$Q_Z = Q_1 + Q_{2P} + Q_{2s} + Q_3 + Q_4$	323.72m ³

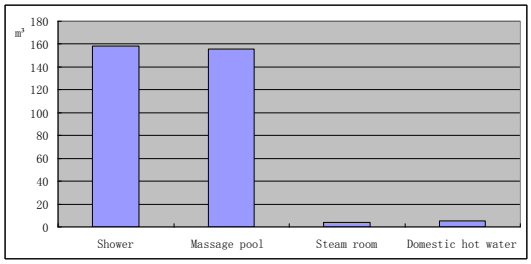


Figure 9. *Comparison of water consumption*

SIMULATION OF WATER TEMPERATURE VARIATION WITHIN THE SEWAGE TANK

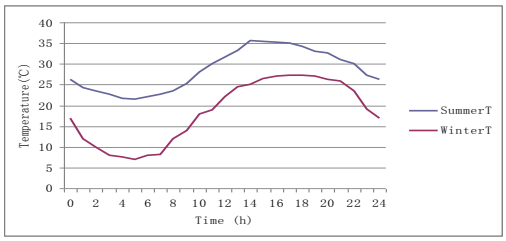


Figure 10 . *Sewage temperature within the sewage tank*

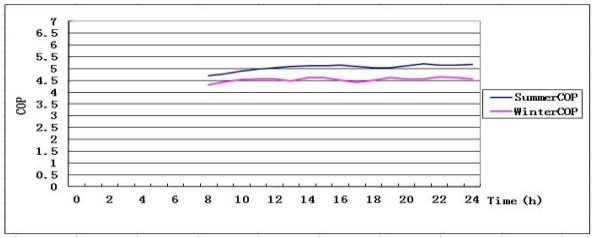


Figure 11. *The cop of heat pump for room heating and cooling*

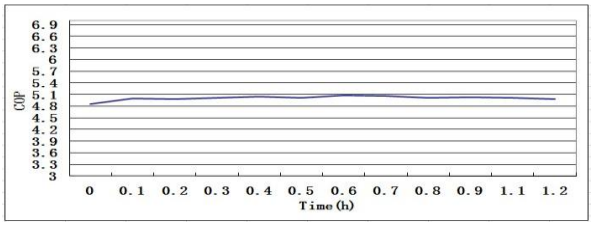


Figure 12. *The cop of heat pump for heating water*

ECONOMICAL ANALYSIS

The corresponding economical analysis of the sewage source heat pump system is illustrated in *Table 5*.

Table 5. *Economical analysis of the system*

Name	Usage	Equation of the energy consumption（Daily）	Energy Consump-tion	Fuel price	Cost (￥)
Gas-fired boiler	Heating	$V_q = \frac{Q_{Heating} \times h}{Q_V \times \eta} = \frac{634.7 \times 3600 \times 16}{35200 \times 0.9}$	1154 m^3	2.3 ￥/ m^3	2654.2
	Heating water	$V_q = \frac{Q_{Heating}}{Q_V \times \eta} = \frac{4.19 \times 323.72 \times 10^3 \times (40-20)}{35200 \times 0.9}$	856 m^3		1968.8
Single Air-Condition-ing	Cooling	$W = hP_{fz} = h \times Q_{Cooling} / cop = 16 \times 1173.58 / 2.5$	7510.88 kW • h		3755.4

Sewage source Heat pump	Heating water	$W=\frac{Q_r}{cop}=\frac{4.19\times323.72\times10^3\times(40-20)}{5\times3.6}$	1507.1 kW h	0.5 ￥/ kW • h	753.55
	Heating	$W=\frac{Q_{Heating}\times h}{cop}=\frac{634.7\times16}{4.5}$	2256.7 kW • h		1128.35
	Cooling	$P_{rb}=h\times Q_{Cooling}/cop=16\times1173.58/5$	3755.45 kW • h		1877.73
	Heating water	$W=\frac{Q_r}{cop}=\frac{4.19\times323.72\times10^3\times(40-20)}{5\times3.6}$	1507.1 kW • h		753.55
Auxiliary heater(used in winter)	Heating water	$P_A=Q_{HW}+Q_{Heating\max}-Q_{Sewage}=5963+4455.87-9416$	1003.72 kW • h		501.86

CONCLUSIONS

1. Great amount of water is consumed in the bath center(see Fig.9), great amount of low temperature thermal energy is included in the sewage(see Fig.10). Sewage with this temperature has the great advantage and very suit for being as the low temperature heat source of heat pump systems(see Fig.11, Fig.12).
2. Amount of sewage, size and capacity of the sewage tank, maximum heating load and maximum cooling load are the main factors that affect the characteristics of sewage source heat pump system. In bath center, with a proper size and capacity of the sewage tank, low grade thermal energy put into and extract from the sewage tank is roughly equivalent and make the sewage temperature proper for heat pump operation(see Fig.10).
3. COP of the sewage source heat pump system is a function of sewage temperature, because the variation of sewage temperature is not very large, so the systematic COP can almost keep constant around 5(simulation value, see Fig.11, Fig.12.)
4. Based on the technical and economical analysis(see Table 5), great potential capacity for the application of sewage source heat pump system in bath center is illustrated, the advantages and excellent characteristics of sewage source heat pump system on economy and environment effect should be sufficiently performed.

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