POTENTIAL CAPACITY RESEARCH ON APPLICATION OF WATER-LOOP (TANK) HEAT PUMP SYSTEM IN CATERING BUILDINGS

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ABSTRACT

In catering buildings, there are variety of thermal end users, such as food cooking, hot water heating, air conditioning (both heating and cooling), etc.. To supply these thermal consumptions, certain amount of water and air accompanying with certain amount of heat load and cooling load is spent. Great amount of primary energy (or electricity) is consumed to generate corresponding amount of heat and cooling load to heat or cool the water or air which serves as the thermal media. Most of these operations are taken in separate line flow, with the obtaining of heating and cooling products from primary energy source, much of remaining low temperature thermal energy is discharged directly outside, such as hot flue gas, warm sewage water, condenser heat, etc. . These kinds of utilizations are manipulated in unreasonable way and cause much thermal energy wasted. To increase the utilizing efficiency of building energy, and decrease the total amount of building energy consumption, independent separate thermal systems should be integrated. With the system integration, coupling utilization of thermal energy will be possible, primary energy input the building will be utilized at the greatest extent. To incept this perspective, water-loop (tank) heat pump system is necessary and the most important content is the allocation of the thermal storage tank (served as the water-loop). In this paper, a typical catering building has been selected, building thermal services and systems are enumerated in detail. The amount and state of thermal energy utilization within each service system is analyzed. A specific integrated model thermal system is suggested. The whole research work is mainly based on simulation, such as building thermal load simulation (DesignBuilder software), characteristic simulation of the water-loop heat pump system (TRNSYS software), optimal dimensions and thermal characteristic simulation of the thermal storage tank, etc… The energy consumption characteristic analysis and the technical and economic analysis of the whole model system has been done, the optimal scheme of service allocation and optimal operation mode are also presented in this paper. Based on the analytical results, the advantages and superiorities of the model system are adequately demonstrated.

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KEYWORDS： potential capacity, water-loop, tank, heat pump, catering building

INTRODUCTION

Catering buildings belong to commercial buildings，and existing everywhere in our society. Its total area amount is not very large, but its energy consumption and water consumption is considerable. In catering buildings, there are variety of thermal end users, such as food cooking, hot water heating, air conditioning (both heating and cooling), etc.. To supply these thermal consumptions, certain amount of water and air accompanying with certain amount of heat load and cooling load is spent. Great amount of primary energy (or electricity) is consumed to generate corresponding amount of heat and cooling load to heat or cool the water or air which serves as the thermal media. Most of these operations are taken in separate line flow, with the obtaining of heating and cooling products from primary energy source, much of remaining low temperature thermal energy is discharged directly outside, such as hot flue gas, warm sewage water, condenser heat, etc. . These kinds of utilizations are manipulated in unreasonable way and cause much thermal energy wasted. To increase the utilizing efficiency of building energy, and decrease the total amount of building energy consumption, independent separate thermal systems should be integrated. With the system integration, coupling utilization of thermal energy will be possible, primary energy input the building will be utilized at the greatest extent.

THERMAL ENERGY AND MASS FLOW IN CATERING BUILDINGS

Main thermal energy flow and mass flow in catering buildings is illustrated in *Table 1*.

Table 1. *Main thermal energy flow and mass flow in catering buildings*

	Type			temperature
Thermal energy flow	Hot energy flow	heating	heating by heat pump	
			heating by hot water	
		condenser heat, sun light radiation		
		lighting heat, dissipative heat from electricity driven device		
		heat from hot flue gas	chimney flue gas	
			flue exhausting duct	
	Cold energy flow	cooling by air conditioning		
		waste cold energy discharged by heat pump		
Mass flow	Air flow	ventilation	inflow	-10～40℃
			outflow	14～30℃
	Water flow	running water intake		14～30℃
		Sewage water discharge	cold sewage	10～22℃
			hot sewage	20～80℃
	flue gas flow	chimney flue gas		150～200℃
		flue exhausting duct		60℃

THE MODEL OF A CATERING BUILDING

A model catering building is established which is supposed to be located in Beijing area. It is a two-storey Chinese style catering building, each floor has the area of 1652 m^2, floor height of the first floor is 4 m, floor height of the second floor is 3.5 m. Among the total 3304 m^2 floor area, dining-hall has the area of 1908 m^2, cookhouse has the area of 805 m^2, other sections(including corridors, toilets, storeroom, etc.) have the area of 591m^2. The outlook of the building, see *Figure 1*.

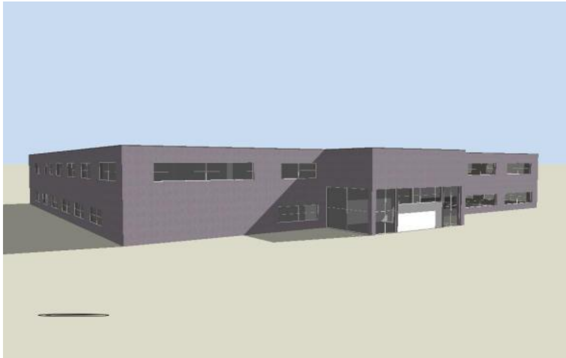

Figure 1. *Outlook of the building*

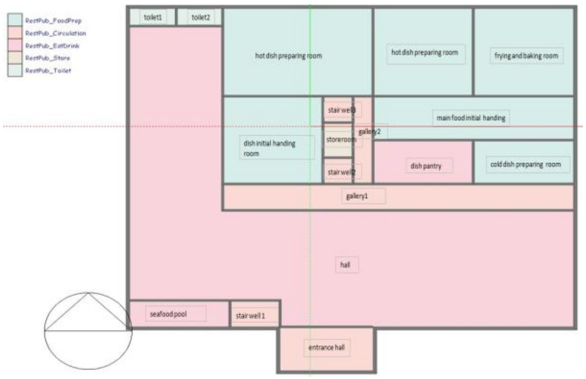

Figure 2 *.The plan of the first floor*

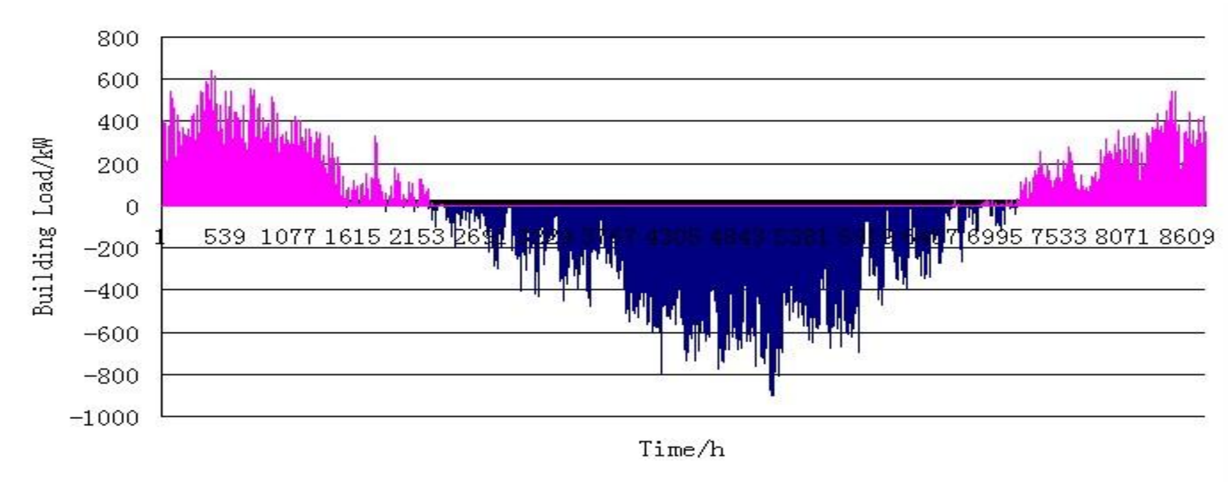

Figure 3. *Hourly thermal load of the building in the whole year (Simulated by DesignBuilder)*

Parameters of the building envelope, indoor settings and operation mode (For DesignBuilder simulation) are listed in *Table 2, Table 3* and *Figure 4.*

Table 2. *Thermal characteristics of the envelope (Construction template settings)*

Thermal characteristics of the envelope	External wall：Insulated concrete wall， *U-Value = 0.256 W/㎡k* External window：Double clear glazing，*U-Value = 2.708 W/㎡k* Flat roof：Insulated concrete roof， *U-Value = 0.15 W/㎡k* Ratio of window to wall：*30％*

__Table3.__ Descriptions of the set parameters within the building (Activity and Lighting template settings)

Indoor set temperature in winter	Dining hall：*20℃*； Washing room：*20℃*； Cookhouse（Cold preparing）：*16℃*；Storeroom：*10℃*； Cookhouse（Hot preparing）：*10℃*；
Indoor set parameters in summer	Temperature：*26℃*；Relative humidity：*≤65%*
Density of occupants	Dining hall：*0.75 people/㎡;* Cookhouse：*0.11 people/㎡* others(including corridors, toilets, storeroom, etc.) ：*0.11 people/㎡*
Average illumination	Dining hall：*150 Lx;* Cookhouse：*100 Lx;* others(including corridors, toilets, storeroom, etc.) ：*50 Lx*

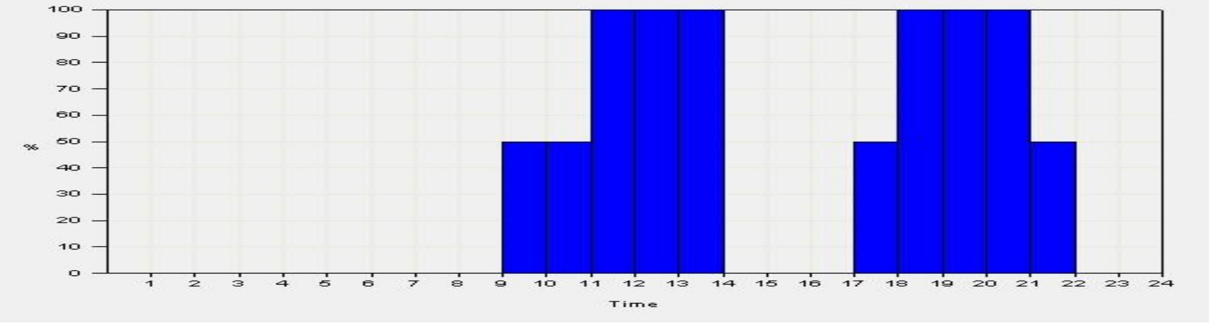

Figure 4. *Time schedule set for building operation and DesignBuilder simulation*

THE MODEL OF THE WATER-LOOP (TANK) HEAT PUMP SYSTEM

Water-loop heat pump system provide the opportunity of saving energy through heat recovery and thermal balancing when heating and cooling occur simultaneously, the principal diagram of water-loop heat pump system is usually described as follows，see *Figure 5*

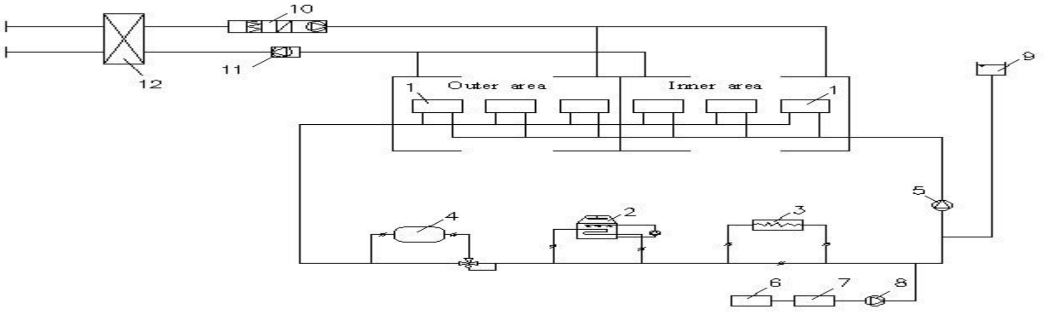

Figure 5. *Principal diagram of water-loop heat pump system*

1—water-source heat pump ; 2—closed cooling tower; 3—heating equipment; 4—thermal storage; 5—pump of water-loop; 6—water treating equipment; 7—make-up water tank; 8—make-up pump; 9—constant pressure arrangement; 10—fresh air unit; 11—exhaust air unit; 12—heat recovery device.

The simulation of the system is based on thermal load simulation which has been obtained by DesignBuilder software, and take the hourly thermal load, temperature, relative humidity of each room as the input data of TRNSYS Type9 module. The TRNSYS model of the system is set as follows，see *Figure 6*

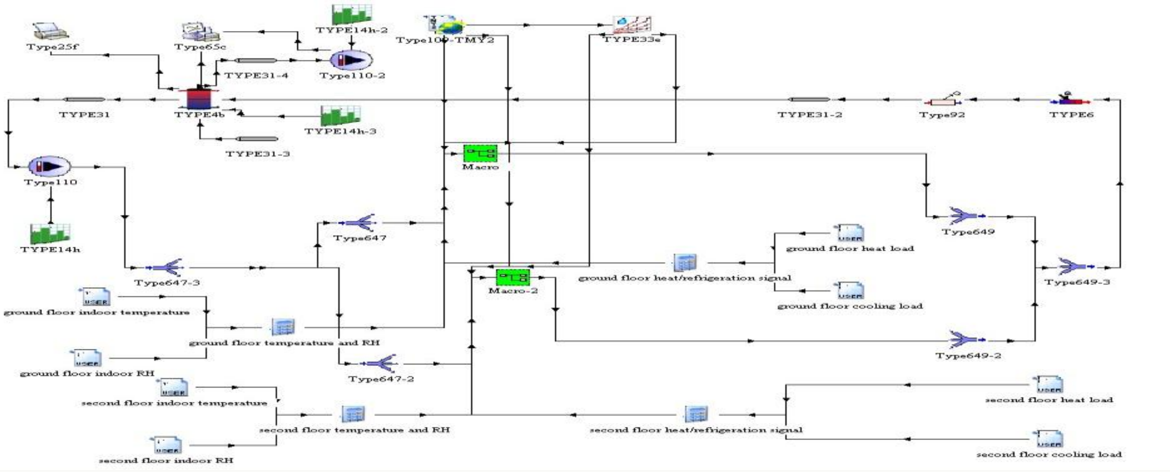

Figure 6. *Structure chart of Water-loop heat pump system in simulation studio*

Dimensions of the tube within the system are determined by the recommend water velocity within the tube, the recommend water velocity within the tube is listed in *Table 4*.

Table 4. *The recommended water velocity within the tube (For TRNSYS simulation)*

position	outlet of pump	inlet of pump	main tube	branch tube
velocity（m/s）	*2.4～3.6*	*1.2～2.1*	*1.2～4.5*	*1.5～3*

AMOUNT CALCULATION OF LOW GRADE THERMAL ENERGY WITHIN THE CATERING BUILDING

Variety of low grade thermal energy(usually taken as the waste) are enumerated and calculated, see *Table 5* and *Table 6.*

Table 5. *Variety of low grade thermal energy are enumerated and calculated in air flow*

Air system		**Calculations**	**Air volume（m^3/h）**	**Temperature**
Cook house	flue exhausting（Q_{p1}）	$Q_{p1} = 1.4u \cdot P \cdot H \cdot K \cdot 3600$ where *u=0.25 m/s; P=23.6m;H=1.1m;K=1.1*	*35980*	*60*℃
	Indoor air flow（Q_{z1}）	$Q_{z1} = u \cdot A \cdot 3600 + Q_{S1}$ where *u=3m/s; A=1.8* ㎡*;* $Q_{S1}=3220\ m^3/h$	*22660*	*18～28*℃
	Fresh air（Q_{k1}）	Number of people: *89*，Fresh air requirement:*20* $m^3/h \cdot p$	*1780*	outdoor air dry-bulb temperature

	Outdoor air intake （Q_{x1}）	$Q_{x1} = Q_{p1} - Q_{z1} - Q_{k1}$	*11540*	outdoor air dry-bulb temperature
Dining hall	Fresh air （Q_{k2}）	Number of people: *1431*， Fresh air requirement:*20* $m^3/h \cdot p$	*28620*	outdoor air dry-bulb temperature
	Natural air exhausting （Q_{z2}）	$Q_{z2} = u \cdot A \cdot 3600$ where *u=3m/s; A=1.8* ㎡	*19440*	*18～28*℃
	Air infiltration in （Q_{S1}）	*0.5 times/h*	*3403*	outdoor air dry-bulb temperature
	Mechanical air exhausting （Q_{p2}）	$Q_{p2} = Q_{k2} - Q_{z2} - Q_{s1}$	*5777*	*18～28*℃

Table 5. *Variety of low grade thermal energy are enumerated and calculated in water flow*

Water system	Calculations	Water volume （m^3/h）	Temperature
Running water	$Q_P = Q_d / T$ $Q_d = m_1 \cdot q_0 + m_2 \cdot q_1$ Where *T =10 h* ； m_1*=1431*(number of people within the dining hall)； m_2*=89*(number of people within the cookhouse)； q_0 *=50 L/s* ; q_1*=50 L/s*	*7.6*	*10～20*℃
Domestic hot water	Washtub：number *4*, flow rate of each *0.14 L/s*；Staff shower：number *4*, flow rate of each *0.1 L/s*, Simultaneously factor：*0.7*	*2.45*	*40*℃
Boiling water	Boiling device：number *2*, water volume requirement of each *0.2 L/s*，Simultaneously factor：*0.5*	*0.72*	*100*℃

SIMULATION OF WATER TEMPERATURE VARIATION WITHIN THE WATER LOOP (TANK)

Quite a lot of research has been done on water temperature variations within tank. In catering buildings, with the variety of low grade thermal energy(usually taken as the waste) integrated and gathered in the water storage tank, water temperature variations within the tank (five different size and capacity,10m^3～50 m^3) are simulated by TRNSYS software and presented, see *Figure 8* and *Figure 10*.

In Summer

The low grade thermal energy flow within the water storage tank is illustrated in *Figure 7*.

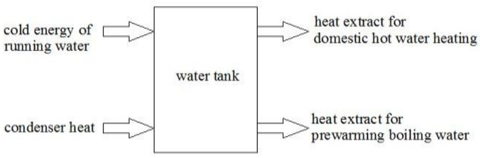

Figure7. *The low grade thermal energy flow within the water storage tank in summer*

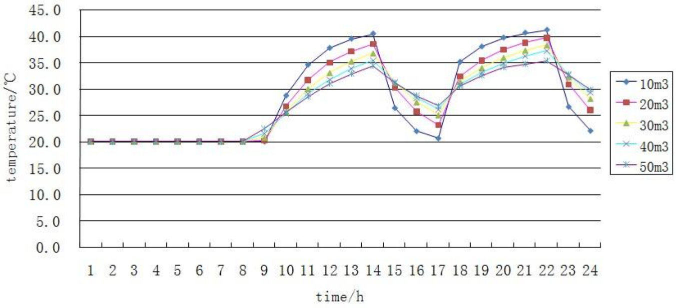

Figure 8. *Water temperature variations within the tank（Typical day in summer, 25th August）*

In winter

The low grade thermal energy flow within the water storage tank is illustrated in *Figure 9.*

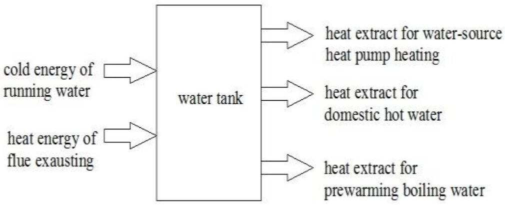

Figure 9. *The low grade thermal energy flow within the water storage tank in winter*

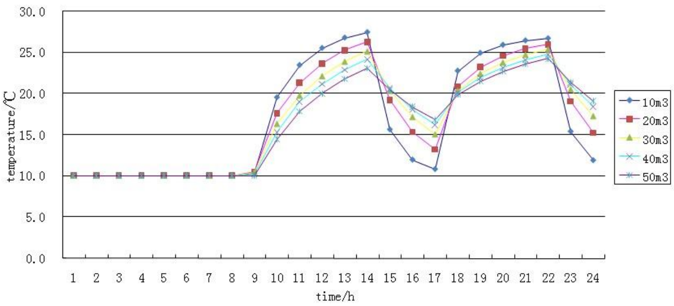

Figure 10. *Water temperature variations within the tank（Typical day in winter, 25th December）*

ECONOMICAL ANALYSIS

Because of great amount of the low grade thermal energy existing which recovered and collected in the water storage tank, water-loop (tank) heat pump system (with the integration characteristics) has the great potential to be applied in catering building. In this case, not only the system mode is reasonable, but also the significant economical effect can be obtained. Comparison of unit power consumption, the operation cost of water-cooled package is 30—40％ less than that of air-cooled one in china. The corresponding economical analysis is illustrated in *Table 6.*

Table 6. *The corresponding economical analysis*

	Kind of heat source	Thermal requirement	COP	Electricity consumption per year
Electricity consumption of AHU	Air source heat pump unit	Cooling load：*599479kW h/a* Heating load：*301929 kW h/a*	*3*	*300469 kW h/a*
	Water source heat pump unit		*5*	*180282 kW h/a*

Heating of domestic hot water	Electric boiler	Requirement of domestic hot water (*40 ℃*): *3.17* $m^3/h \cdot 10h \cdot 365d=11570\ m^3/a$	*1*	*336352 kW h/a*
	Water source heat pump unit		*5*	*67270 kW h/a*
Reduction of electricity consumption per year	*389269 kW h/a*			
Reduction of electricity cost per year	Commercial unit price in Beijing *0.75 Y*uan/ kW h，Reduction of electricity cost per year *291952* Yuan RMB			

CONCLUSIONS

1. Based on the theoretical analysis and simulation work, great amount of low grade thermal energy is existing in catering building and usually taken as the waste. Recovery and integrate utilization of these low grade thermal energy is necessary and possible.
2. Recovery and integrate utilization of the low grade thermal energy can gather great amount thermal energy and make a certain amount of water keep at proper temperature that make water loop heat pump system operation suitable and optimal.
3. Water tank is a main component of the water loop heat pump system, its size and capacity may affect the performance of the water loop heat pump system, comparative analysis on five tank schemes (with different tank size and capacity) has been made in order to find the optimal tank size for the system, tank of 50 m^3 is the best in this case.
4. Based on the technical and economical analysis, great potential capacity for the application of water loop heat pump system in catering building is illustrated, the advantages and excellent characteristics of water loop heat pump system on economy and environment effect should be sufficiently performed.

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