

Simulation and Analysis for Applying the Double-Stage Coupled Heat Pump System in the Villa of Cold Area

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Abstract: The conventional heating mode is a one-way circulation in cold areas, which causes abatement in the reserves of energy source and increases environmental pollution. An ecological cycle heating system, an air-to-water + apartment water-to-water double-stage coupled heat pump system, is presented in this paper based on analyzing the characteristics of the villa district heating. Prediction and analysis of the feasibility of the double-stage coupled heat pump system in cold areas were carried after the components and characteristics of the system are introduced. The lumped parameter method was used to establish a mathematical model of the whole system, and the system control methods and the volume of the heat storage tank were decided to get the best value of the heating seasonal performance factor (HSPF). Furthermore, the application of the double-stage coupled heat pump system in some representative cities of cold areas in China was analyzed. The results show that the novel heat pump system can be used for heating the villa district in cold areas. To make the HSPF of the system much better, the water circulations of the double-stage coupled heat pump system also were analyzed in this paper; some improvements are put forward, and single-double stages mixed heat pumps system for the villa districts heating are introduced.

Key words: The heating of the villa district, Double-stage coupled heat pump system, HSPF

1.INTRODUCTION

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Total energy consumption in the world reached 1086 Mtoe (million tonnes oil equivalent) in 2005, showing a 5.88% increase over 2004, total energy consumption in China reached 147.7 Mtoe (million tonnes oil equivalent) about 13.6% of the world, showing a 6.6% increase over 2004. The average concentration of CO₂ in the whole atmosphere was 378.9 ppm (parts per million) increasing 2 ppm over 2004. Energy shortage and environment pollution get more attention from the world.

Energy use in buildings is an important part, the ratio of the heating in cold area is even bigger. The conventional heating system, central heating by coal-fired boiler, is a one-way circulation in most cold areas of China, however, it abates the reserves of energy source and increases environment pollution.

In these situations, with the development of economy and the improvement of people's living level, the requirement for the comfort residential buildings is rising, the villas spring up increasingly. The heating of the villas has its own characters:

- 1) Independency: the villas are always built in some clean, grazioso places which are away from the city. It is difficult to use the central heating net, gas or the other large heat/cool source there.
- 2) Using time and the number of the residents are uncertain: a part of the residents don't stay in the house at all times, the occupying time may be the weekend, holiday or some special time. In this situation, the heating system has to adapt to the changes of the buildings' heat load, and circulate efficiently and reliably.

3) Higher requirement for comfort: the comfort requirement in villa is higher than that in the common buildings, so the heating system has to be controlled expediently as the residents' demand.

4) Higher requirement for environment protected: villas always are built in the area with pretty surroundings, so the environment quality must be protected during the heating season.

Due to the two former reasons, it is becoming focus how to realize the heating of villa on basis of reducing the energy consumption and the environment pollution. Therefore, an ecological cycle heating system, air-to-water + apartment water-to-water double-stage coupled heat pump system, is put forward in this paper. Simulation and analysis for the feasibility of its utilization in cold areas are also studied.

2.FORCAST AND ANALYSIS FOR CIRCULATING THE DOUBLE-STAGE COUPLED HEAT PUMP SYSTEM IN THE VILLA

The double-stage coupled heat pump system (DSCHP) is designed based on the heating characters of villa. It includes the centralized air-to-water units, heat storage tank, apartment water-to-water units and fan coil units.

The centralized air-to-water units produces low temperature water ($10 \sim 20$) to reduce the compression ratio in cold areas^[1-3]. The water is deposited in the heat storage tank, and then it is transported to the residential house as the low temperature heat source of the water-to-water units by the circulating pump and the pipeline net, at last, the water-to-water units raise the temperature to $45 \sim 55$, and supply to fan coil. The fan coil units transport the heat to every room of the house.

2.1 Characters of the Double-Stage Coupled Heat Pump System

Centralized machinery room: multiple air-to-water units are set on the basis of the building area and the heat load, so DSCHP can meet the residents' demand of the supply water temperature by changing the number of the units when the heat load vary, and thus save energy.

Centralized machinery room also includes the circulating pump (first-stage pump and second-stage pump) and the heat storage tank, the functions of the tank are listed as follows:

- 1) It can conserve the extra heat from the air-to-water units when the outdoor temperature is high, and supply to water-to-water units when the outdoor temperature is low.
- 2) It can enhance the water capacity of the DSCHP, so the circulating of DSCHP is more stable.
- 3) It can supply heat to the defrosting of the air-to-water units, and improve the reliability and stability of the defrosting process.
- 4) It can improve the adjustment stability of the first-stage and decrease the on-off times of compressor.

The machinery room in the villa: water-to-water unit is set in the house based on the house heat load, so the residents can adjust it at any time they want. Then, the fan coil units distribute heat which is supplied by the water-to-water units to

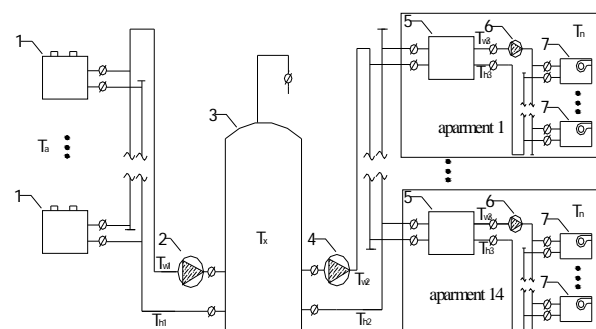


Fig. 1 Schematic diagram of double-stage coupled heat pump

1-air-to-water unit; 2-first-stage pump; 3-heat storage tank; 4-second-stage pump; 5-apartment water-to-water unit; 6-third-stage pump; 7-fan coil unit

the different room. The residents can adjust and control the fan coil units according to the purpose of the room or thermal comfort.

The different requirements of the residents are adequately considered by DSCHP, it can be adjusted expediently, convenient for the fees charging and management.

2.2 Research Methodology

Tab.1 The results of the simulation in representative cities

Area	Heating Season	Air-to-Water Units		Best Volume of The Tank (m ³ /m ²)	Heat Input (MJ)	Power (MJ)	HSPF During The Heating Season*
		Type	Number				
Beijing	149	FWRM020	3	0.003	146476.9	71382.49	2.052
Shijiazhuang	140	FWRM020	3	0.003	127597.6	60905.81	2.095
Jinan	124	FWRM020	3	0.003	107828.3	49943.63	2.159
Xian	127	FWRM020	3	0.003	114338	54394.85	2.102
Lanzhou	160	FWRM020	3	0.003	158379.2	79150	2.001
Taiyuan	162	FWRM020	4	0.003	169656.6	85083.55	1.994
Huhehaote	188	FWRM020	4	0.003	210552.1	105539.9	1.995
Yinchuan	170	FWRM020	4	0.002	175290.6	89754.55	1.953
Xining	191	FWRM020	4	0.003	194034.7	98896.39	1.962
Shenyang	177	FWRM020	4	0.003	198021.7	100213.4	1.976

On the basis of these analyses, forecast and analysis for applying the double-stage coupled heat pump system in the villa of Beijing is studied in this paper. A villa with 14 houses, 4536m² building areas, is

*—the power consumed by the circulating pumps is not included.

chosen as a model, whose schematic diagram is shown in Fig.1. The lumped parameter method is employed to establish a mathematical mode of the whole system, the time step of the simulating system is 6 minutes according to the experience principles of System Dynamics. Scroll type air-to-water units, which are better for the cold areas, is used in the centralized machinery room, R22 is used as refrigerant in the units. The low temperature source of water-to-water units in the house are between 10 and 20 from the air-to-water units, so it is not special requirements to the water-to-water units selection. The fan coil units use the 42CMX004 units.

3.RESULTS OF THE SIMULATION

The volume of the heat storage tank plays an important role in the circulating stability and the HSPF of the system, so it is an important part in the DSCHP system design to select the volume of the tank logically. This paper calculates it for the

purpose of obtaining the optimal value of HSPF in the heating season. After the former theory analysis, the simulation results are shown in Tab.1^[4].

Beijing is taken as example, the simulating details of the DSCHP system circulation in Beijing are shown in Fig. 2 to Fig. 6.

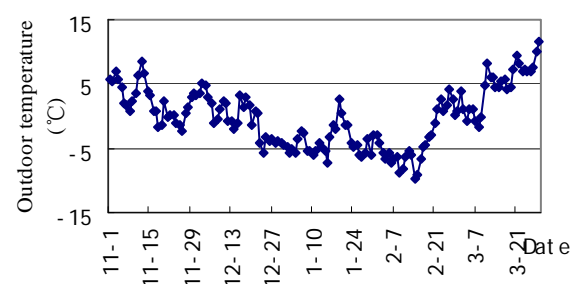


Fig. 2 The averaged daily outdoor temperature during the heating season

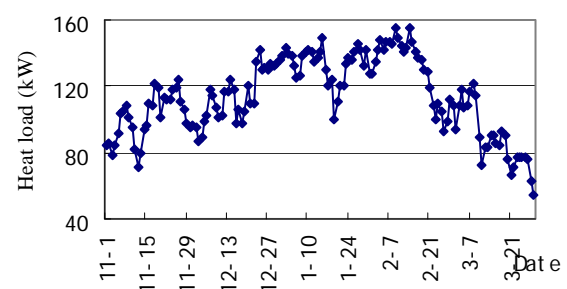
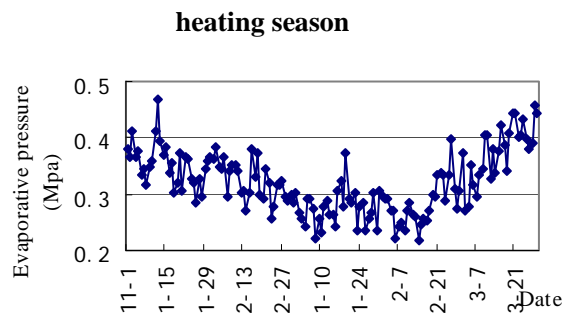
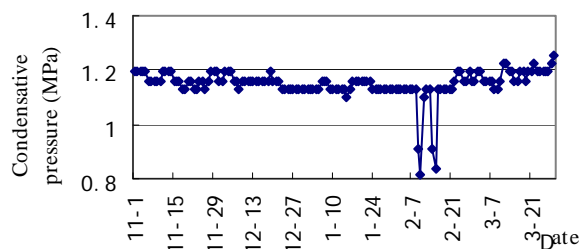


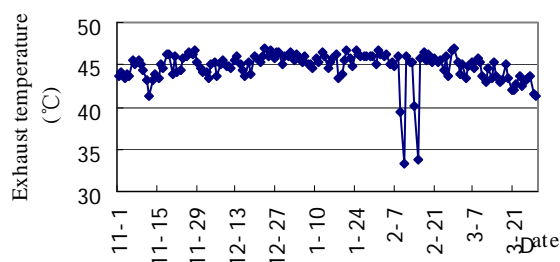
Fig. 3 The averaged daily heat load during the



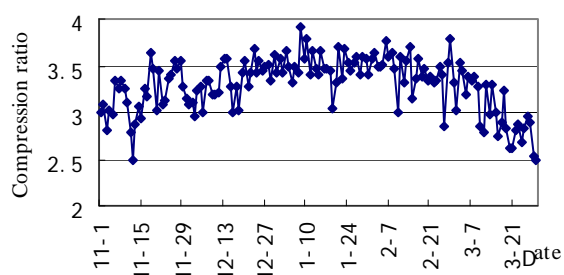
(a) The minimum of daily evaporative pressure



(b) The maximum of daily condensing pressure



(c) The maximum of daily exhaust temperature



(d) The maximum of daily compress ratio

Fig. 4 The parameters of the air-to-water unit

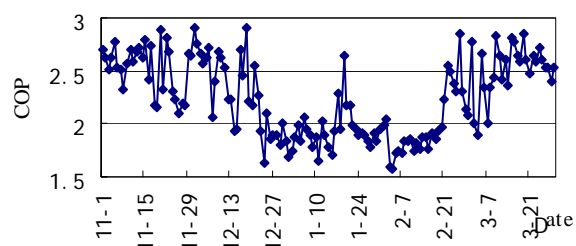


Fig. 5 The daily COP of system

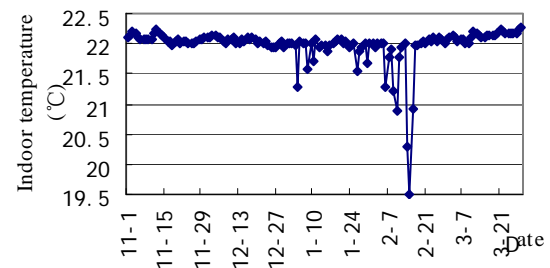


Fig. 6 The averaged daily indoor temperature

From Fig. 2 to 6, it can be seen that:

- 1) The compression ratio is between 2 and 4. The

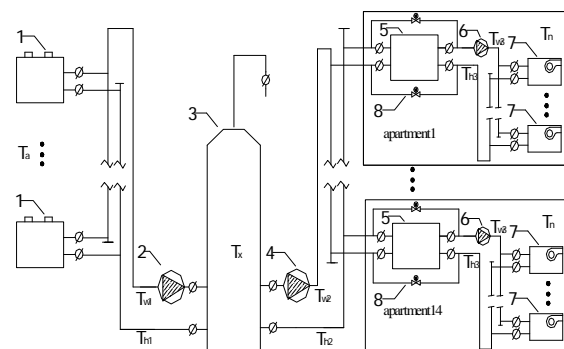


Fig 7 Schematic diagram of single-double stages mixed heat pump system using in villa district

1-air-to-water unit; 2-first-stage pump; 3-heat storage tank; 4-second-stage pump; 5-apartment water-to-water unit; 6-third-stage pump; 7-fan coil unit; 8-by-pass pipes

exhaust temperature is between 30 and 50 , much less than 150 which is the upper limit of compressor in air conditioner. Evaporative pressure is no less than 0.218 MPa. Condensing pressure is no more than 1.255 MPa, which is much less than the limit pressure 2.5 MPa of the compressor. The condensing pressure changes according to the water temperature in the heat storage tank, so there are some anomalous points of the daily max exhaust temperature and the condensing pressure in the colder days when the tank temperature is low. It is proved by the parameters of the air-to-water units that ordinary air-to-water heat pump units can be used in Beijing area normally.

- 2) The COP of the system is between 1.575 and 2.903, the HSPF during the heating season is 2.052, so the DSCHP is more efficient than electrical heating. The temperature of the indoor air is above 19.5 , it can meet the requirement of the residents.

4.SINGLE-DOUBLE STAGES MIXED HEAT PUMPS SYSTEM FOR VILLA

It is known that the HSPF of the DSCHP system is not good enough from the simulation results. To improve the COP of the system, the single-double stages heat pumps system is presented for villa. It is shown as Fig.7. It installs two by-pass pipes and valves, comparing with Fig.1. The air-to-water units directly supply hot water ($45 \sim 55$) to the fan coils when the outdoor temperature is more than -3 , the system is in DSCHP mode when the outdoor temperature is less than -3 . The energy consumption in single stage mode is less than it in double stage mode, so the COP of the single-double stages mixed heat pumps system is better than the DSCHP system.

5.CONCLUSIONS

The DSCHP system is presented in this paper based on analyzing the characteristics of the villa district heating. The simulation of the double-stage coupled heat pump system in cold areas is done after the components and characteristics of the system are introduced, it shows that the compression ratio of air-to-water units is between 2 and 4. The exhaust temperature is between 30 and 50 , much less than 150 which is the upper limit of compressor in air conditioner. Evaporative pressure is no less than 0.218 MPa. Condensing pressure is no more than 1.255 MPa, which is much less than the limit pressure 2.5 MPa of the compressor. It is proved by the parameters of the

air-to-water units that ordinary air-to-water heat pump units can be used in Beijing area normally. The COP of the system is between 1.575 and 2.903, the HSPF during the heating season is 2.052, so the DSCHP is more efficient than electrical heating. The temperature of the indoor air is above 19.5 , it can meet the requirement of the residents. The novel heat pump system can be used for heating the villa district in cold areas.

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