Energy Consumption Simulation and Analysis of Heat Pump Air Conditioning System in Wuhan by the BIN Method

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Abstract: Based on the weather data of a standard year in Wuhan, derived from the data of the latest 15 years, the data for the BIN (temperature and humidity frequency) method of an annual and 8-hour system were calculated. Then the BIN method was adopted to simulate the annual energy consumption of groundwater heat pump systems (GWHPS) for an office building in Wuhan. Its annual energy consumption was obtained and compared with the partner of the air source heat pump systems (ASHPS). The results show that the energy consumption of the former was approximately less 23.3% than that of the latter in summer and 19.1% in winter.

Key words: heat Pump , air conditioning, energy consumption simulation , BIN method.

1. INTRODUCTION

In recent years, building energy consumption is increasing year after year. It is investigated that the energy consumption of air conditioning system in total energy consumption of a public building usually takes 22.33%～79.41% in Wuhan, the average energy consumption of air conditioning system 42.90%[1].

There are different methods of analyzing building energy consumption[2]. These methods can roughly be classified into two classifications: one is accurate simulation calculation method, including DOE-2, BLAST, ASCESS, Energy Plus, DEST software etc, which this kind of softwares are generally comparatively complicated; Another is simplified simulation method, including degree-day method, equivalent operation hour method, effective coefficient of heat transfer, Bin (temperature frequency) Method, etc, which this kind of methods have been simplified in theory. For convenience, Bin Method is used to perform the simulation of energy consumption of air conditioning system here.

2. ANALYSIS OF METEOROLOGICAL DATA FOR BIN METHOD

2.1 Meteorological Data of Wuhan

The ambient meteorological condition is a main factor influencing indoor thermal environment of a building and energy consumption of heating and air conditioning. Annual meteorological parameters are widely different, therefore many researchers devoted to studying the typical meteorological year that represents the typical meteorological condition for multi-years. The typical meteorological year files attempt to represent average weather conditions for a location over many years. These are often a synthetic year made up of 12 actual but typical months. In this research, the meteorological data of Wuhan (North latitude 30°37’, East longitude 114°08’, Elevation 23.3m) are from the standard meteorological data that Zhang QingYuan studied, which originated from International Surface Weather Observations[3].

2.2 Data Process

Bin meteorological data are the number of hours that the outdoor air temperature was in each of a set of equally intervals of outdoor air temperature. The hourly meteorological data are needed in which BIN method is adopted to simulate the energy consumption of heating and air conditioning system. These data include the outdoor dry ball temperature, outdoor relative humidity or humidity ratio. Details of the method see ASHRAE handbook[2] .

Taking 2℃ as a temperature frequency interval, 24 hours of a day are divided into 6 periods, the calculated data are presented in six daily 4-hour shifts for the entire year and for each month for a better part-load analysis. Then taking the place with the middle point temperature of each temperature frequency interval, calculate the average wet ball temperatures according to the procedure in references [2][4][5]. From the data analysis it can be known that the bin with the higher frequency during January, February and December is 5-7℃, during March it is 7- 9℃, during November it is 9- 11℃, during April it is 13- 15℃, during October it is 17-19℃, during May, June and September it is 23~25℃, during July and August it is 27- 29℃ in Wuhan.

Table 1 provides the Bin data of one shift over an entire year (from 8:00~18:00). Figure 1 gives Temperature frequency over an entire year. Results show that the temperature bins with the higher frequency annually are 25- 27 ℃ (frequency 7.83%),23- 25 ℃ (frequency 7.48%) and 5- 7 ℃ (frequency 7.23%). If heating starts when the outdoor temperature is lower than 10C, the number of the heating hour over the whole year is 2476 hours. If cooling begins when the outdoor temperature is higher than 23℃, the hour number for refrigeration over the whole year is 2781 hours. The heating period in Wuhan mainly concentrates on January, February, March and December. The cooling period mainly concentrates on June, July, August and September.

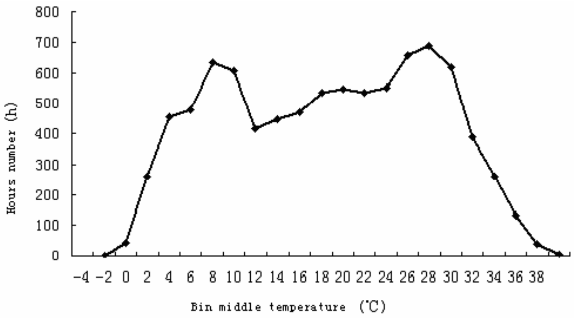

Fig.1 Bin data over an entire year

3. SIMULATION RESULTS AND DISCUSSION

As an instance, the annual energy consumption for the air conditioning system utilizing GWHP in an office building is made simulation and discussion.

Tab. 1 Bin data of one shift over an entire year (from 8:00~18:00)

Dry-bulb temp.(℃)	Temp. range(℃)	Hours number	Wet-bulb temp.(℃)
-2	-3/-1	8	-3.6
0	-1/1	76	-1.5
2	1/3	138	0.7
4	3/5	182	2.4
6	5/7	214	4.6
8	7/9	264	5.9
10	9/11	162	7.5
12	11/13	179	9.4
14	13/15	190	11.3
16	15/17	230	13.7
18	17/19	199	15.3
20	19/21	208	17.2
22	21/23	235	18.7
24	23/25	265	20.6
26	25/27	272	23.0
28	27/29	259	24.4
30	29/31	224	25.5
32	31/33	199	26.8
34	33/35	108	27.1
36	35/37	34	27.3
38	37/39	4	28.7

3.1 Instance of Building with Air-conditioning System

Taking an office building in Wuhan as an interest object, the air conditioning system begins operation when the ambient air dry bulb temperature reaches 23℃ in summer or when the ambient air dry bulb temperature reaches 10℃ in winter. The air conditioning area in the building is 5000m^2, and the air conditioning system only operates from 8:00~18:00, which amounts to 10 hours a day. The other characteristics of the building are as follows:

(1) The indoor design conditions for summer air conditioning are the indoor air temperature 26℃ and the relative humidity 60%; the indoor design conditions for winter air conditioning are the indoor air temperature 18℃ and the relative humidity 40%.

(2) The Heat transfer coefficient of the outer wall, which is made of 240mm brick wall, 20mm cement mortar outside and 20mm lime whitewashed inside, is 1.94W/(㎡.K).

(3) The Heat transfer coefficient of the roof, which is make of gasified concrete, is 0.79 W/(㎡.K).

(4) The outer windows are single layer ordinary glass plastic steel windows, thick 5mm, of which the heat transfer coefficient is 6.26W/(㎡ • k) and light-colored curtain is hung inside the windows, of which the shading coefficient is 0.55; All the north window area of the building is 464 ㎡, the south window area 395 ㎡, the west window area 54 ㎡, the east window area 13 ㎡, the window to wall ratio 35%.

(5) The occupants in the building are considered as 400 persons, and the fresh air requirement is 30m^3 per hour every person in summer or winter.

(6) Internal loads are considered as follows: The calorific capacity of office equipment such as computers is counted as 10w/㎡, lighting load as 5 w/㎡ , of which simultaneous coefficient is 0.5.3.2 Calculation of Air Conditioning Load

The bin method is the evolution in building energy calculations from the various degree-day methods. The underlying assumption of the bin method is that for a given temperature at the general time of day, the heating and cooling loads of a building should be almost the same. Therefore, one can derive a building's annual and cooling loads by calculating its loads for a set of "snapshots" defined by temperature "bins", multiplying the calculated loads by the number of hours represented by each bin, and then totaling the sums to derive the building's annual heating and cooling[4].

In the bin method, the cooling (in winter) or heating (in summer) load of the air conditioning system can be considered to make up of four components, i.e. solar radiant cooling load, cooling load from heat conduction through building envelop, heating or cooling load from outdoor air, and internal cooling load from occupant, lighting, appliance and equipment. According to the procedure in references [2][5], these parameters can be calculated by following equations.

$$SCL=0.04T+8.33 \quad (1)$$

$$TCL=2.67T-69.36 \quad (2)$$

$$THL=2.67T-53.35 \quad (3)$$

$$TSCL=0.0085T+0.21 \quad (4)$$

Where SCL is the solar radiant cooling load, W/m^2; TCL is the cooling load from steady heat conduction through building envelop in summer, W/m^2; THL is the heating load from steady heat conduction through building envelop in winter, W/m^2; TSCL is the cooling load from unsteady heat conduction through building envelop in summer due to solar radiation, W/m^2; T is the ambient temperature, K.

The load from outdoor air consists of sensible load and Latent load. They can be calculated by following equations.

$$CLVS=1.02T-26.52 \quad (5)$$

$$HLVS=1.02T-20.4 \quad (6)$$

$$CLVL=1.19d-25.10 \quad (7)$$

$$HLVL=1.19d-11.55 \quad (8)$$

Where CLVS is the sensible cooling load from outdoor air; HLVS is the sensible heating load from outdoor air; CLVL is the Latent cooling load from outdoor air; HLVL is the Latent heating load from outdoor air;

Internal cooling load from occupant, lighting, appliance and equipment can be obtained through the given data of section 3.1.

CLI=5+10.72+10=25.72 W/m^2

3.3 Energy Consumption Analysis for Air-conditioning

3.3.1 The energy consumption for summer air conditioning

Summarizing equations (1), (2), (4), (5) and internal cooling load, total cooling load CL can be expressed as

$$CL=4.18T-64.30 \quad (9)$$

By using the Bin data of one shift over an entire year (from 8:00~18:00), calculate out the energy consumption for air conditioning of all temperature frequency, as shown in table 2. Figure 2 shows the percentage of the energy consumption of four load components for summer air conditioning.

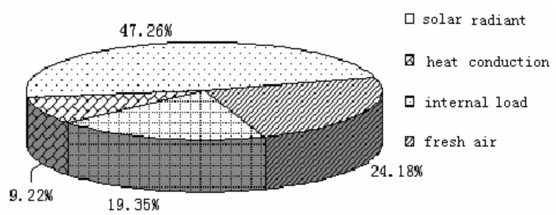

Fig.2 Percentage of the energy consumption of four load components for summer air conditioning

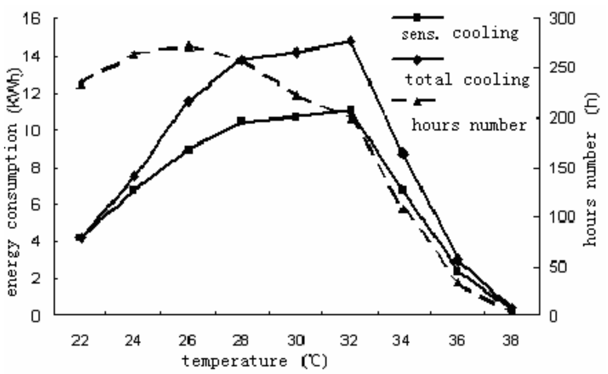

Fig.3 Relation among total cooling energy use and sensible cooling energy use with bin in summer

Table 2 and Figure 2 indicate that the cooling energy consumption for summer air conditioning of the building is 78.3(KWh/㎡), among which the internal cooling load accounts for the largest proportion (47.26%), the cooling load from outdoor air second (24.18%), the solar radiant cooling load third (19.35%), the cooling load from heat conduction through building envelop fourth (9.22%). According to the calculation process, it demonstrates that the load of the air conditioning system is mainly influenced by the indoor temperature, occupant density, fresh air requirement, building envelop characteristics, window to wall ratio, etc.

Figure 3 shows the relation among total cooling energy use, sensible cooling energy use with bin in summer. It demonstrates that the maximums of the total energy consumption and latent energy consumption for air conditioning system in summer occur at 32℃ bin, not at 36℃ bin in which the cooling load reaches maximum. Although the maximum of bin hours number occur at 26℃, the cooling load and the energy consumption for summer air conditioning are not maximum. Therefore, the cooling energy consumption for air conditioning system doesn't have direct proportion with the bin hours number or the outdoor temperature.

3.3.2 Energy consumption for winter heating

Under ignoring internal cooling load, summarizing equations (1),(3),(4),(6) and (8), total heating load HL can be expressed as

$$HL=3.74T-65.21 \quad (10)$$

By using the bin data of one shift in Table 1, calculate out the energy consumption for winter heating, as shown in Table 3. It can be known from Table 3 that the heating energy consumption for winter air conditioning of the building is 351.79W/㎡. The heating load from heat conduction through building envelop is the main factor influencing the load in winter. The total energy consumption for heating in winter is 46.52KWh/㎡. When the outdoor dry bulb temperature is 8℃, the energy consumption for heating of the system reaches maximum in winter. As the temperature is - 2℃, the energy consumption for heating of the system is only 0.58KWh/㎡.

3.3.3 Energy consumption analysis for the air conditioning system over an entire year.

The air conditioning system operates 2644 hours over an entire year, among which the number of the cooling hours in summer is 1600 hours and The number of the heating hours in winter is 1044 hours. The energy consumption annually is 123.92 KWh/㎡, among which the energy consumption for summer air conditioning is 78.3 KWh/㎡ and the

Tab. 2 The energy consumption for summer air conditioning system

Temp. (℃)	Hours number (h)	Sensible cooling load (W/m^2)	Sensible cooling energy use (KWh/m^2)	Humidity ratio (g/Kg dry air)	Latent cooling load (W/m^2)	Latent cooling energy use (KWh/m^2)	Cooling load (W/m^2)	Cooling energy use (KWh/m^2)
22	235	17.98	4.23	12.2	0.00	0.00	17.98	4.2
24	265	25.46	6.75	13.8	2.99	0.79	28.45	7.5
26	272	32.94	8.96	16.5	9.72	2.64	42.66	11.6
28	259	40.42	10.47	17.8	12.95	3.35	53.37	13.8
30	224	47.90	10.73	18.8	15.44	3.46	63.34	14.2
32	199	55.38	11.02	20.2	18.93	3.77	74.31	14.8
34	108	62.86	6.79	19.9	18.18	1.96	81.04	8.8
36	34	70.34	2.39	19.5	17.19	0.58	87.53	3.0
38	4	77.82	0.31	21.3	21.67	0.09	99.49	0.4
total	1600	431.10	61.64	------	117.06	16.65	548.16	78.30

Tab. 3 The energy consumption for winter heating

Temp.( )	Hours number(h)	Heating load(W/m^2)	energy consumption (KWh/m^2)
-2	8	72.69	0.58
0	76	65.21	4.96
2	138	57.73	7.97
4	182	50.26	9.15
6	214	42.78	9.15
8	264	35.30	9.32
10	162	27.83	4.51
Total	1044	351.79	45.62

energy consumption for heating is 45.62 KWh/㎡. Figure 4 provides the percentage of three energy consumption components of the air conditioning system over an entire year. The sensible cooling energy consumption for summer air conditioning accounts for 49.75%, the sensible heating energy consumption for heating in winter accounts for 36.82%, and the latent cooling energy consumption for summer air conditioning only accounts for 13.44% in the total energy consumption over an entire year.

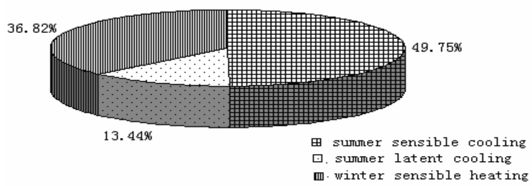

Fig.4 Percentage of three energy consumption components of air conditioning system over an entire year

3.3.4 Comparison with the results under the design conditions.

The outdoor design dry-bulb temperature for summer air conditioning in Wuhan is 35.2℃. Then calculate each load component of the building based on the design conditions. Table 4 gives the percentage of each load component of the building calculated by the bin method and the design parameters respectively. It can be known that under the design

Tab.4 Percentage of each load component of the building calculated by the bin and the design parameters respectively

	Bin method	Design conditions
solar radiant load	19.35	11.47
load from heat conduction	9.22	29.61
internal load	47.26	27.14
load from outdoor air	24.18	31.77

conditions, the cooling load from outdoor air accounts for the largest percentage (31.77%). But in summer air conditioning energy consumption calculated by the Bin Method, internal cooling load is largest (47.26%). Reducing internal load is effective energy saving in summer hot winter cold area.

3.5 Comparison between the energy consumptions of GWSHPS and ASHPS

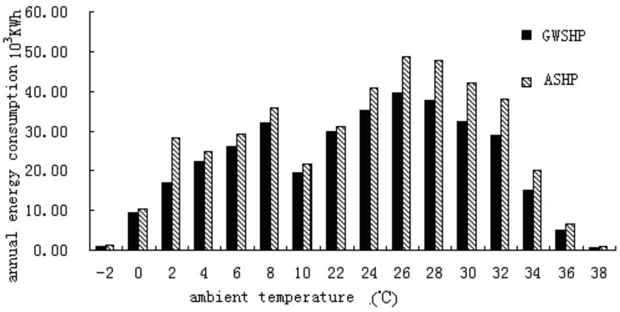

Fig.5 Comparison between the energy consumption of GWSHPS and ASHPS

Tab.5 The electricity consumption of GWSHPS and ASHPS over an entire year (10^3KWh)

	GWSHP	ASHP	Percentage,%
summer	223.93	276.01	23.26%
winter	127.11	151.37	19.09%
total	351.04	427.38	21.75%

The energy consumption of air source heat pump system (ASHPS) is calculated as that of groundwater source heat pump system (GWSHPS). The electricity consumption of each bin over the entire year is calculated out, and then make comparison between the energy consumptions of GWSHPS and ASHPS, as shown in Figure 5. In summer, with the rise of the outdoor temperature, and the electricity saving of the groundwater source heat pump increases compared to that of the air source heat pump. When the outdoor temperature reaches 35 ℃, the energy saving is up to 35%. In winter, with the outdoor temperature reducing, the electricity saving of the groundwater source heat pump system also increases.

Table 5 gives the comparison between the electricity consumptions of the groundwater source heat pump and the air source heat pump systems over an entire year. Compared to the air source heat pump air conditioning system, the energy saving effect of the air conditioning system used by the groundwater source heat pump is obvious in summer (refrigeration operation state), and the average energy saving is 23.26%. In winter (heating operation state), the average energy saving is 19.09%. The energy saving is 21.75% over an entire year. Therefore, in the summer hot winter cold area such as Wuhan, the energy saving of the groundwater source heat pump system is very useful to reduce energy consumption.

4. SUMMARY

The BIN method was adopted to simulate the annual energy-consumption of groundwater heat pump systems (GWSPS) for an office building in Wuhan. Its annual energy-consumption was obtained and compared with the partner of the air source heat pump systems. The results show that the energy consumption of the former was approximately less 23.3% than that of the latter in summer and 19.1% in winter.

In summer air conditioning energy consumption calculated by the Bin Method, internal cooling load is largest (47.26%), the cooling load from outdoor air second (24.18%). Under the design conditions, the cooling load from outdoor air accounts for 31.77%, the largest percentage, the cooling load from heat conduction through building envelop accounts for 29.61%, and the internal load accounts for 27.14%.

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