Application Research on the Closed-Loop Heat-source-Tower Heat Pump Air Conditioning System in Hot-summer and Cold-winter Zone

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Abstract

The paper analyses merits and demerits of cooling and heating source schemes in hot-summer and cold-winter regions. Moreover, it investigates the working principles, category and utilization of closed heat source heat pump air conditioning system. Additionally, it introduces the developmental history and research reviews in this field. In this paper, a practical application of this system was tested and the operational characteristics were analyzed. It has been proposed that closed heat source heat pump has wide prospects with features of energy conservation, environmental protection and sustainable development in hot-summer and cold-winter regions.

Keywords: Closed-loop heat-source-tower; Air conditioning; Hot-summer and Cold-winter zone

1. Introduction

According to the national standard of Civil Building Thermal Design Code with annual average temperature as the main index, the hot-summer and cold-winter regions involve the Yangtze river basin and the surrounding zone at present in our country, including 16 provinces, autonomous regions and municipalities directly under the central government. The distinctive features of the regional climate is that the summer is hot and wet, while the winter is
cold with high humidity, and small temperature difference between day and night, the annual rainfall is great with less sunshine. Due to historical and economic reasons, the region's average residential building has no heating air conditioning, and the general thermodynamic performance of retaining structure is very poor, and indoor thermal environment and living conditions are very bad. Along with the region's economic development and people's better living standards, people have higher requirements for heating air conditioning. For the region, the conventional air conditioning heat and cold source schemes usually set respectively cold sources (refrigerator) and heat source (boiler). Due to the efficiency and environmental pollution problems, air conditioning heat source mode has gradually turned from the boiler to heat pump units with higher efficiency and more environmental protection. Currently, using air-cooled heat pump and ground source, water source heat pump and ground source heat pump for heating in winter and summer air conditioning, due to poor weather conditions in the region, all kinds of problems of the building itself appear, such as high energy consumption of air conditioning and heating, serious waste. The laws and regulations about energy saving of building air conditioning and heating have been enacted and the air conditioning and heating systems energy saving researches focus on the existing evaluation indexes, such as energy-saving reform policy, existing buildings, a variety of air conditioning system for air conditioning and heating, etc. Air conditioning system, as a heat source tower after the new air conditioning system, due to its low temperature heat taken from the high humidity environment and the characteristics of the design, can save energy in hot summer and cold winter region efficiently. As the heat source tower, heat pump air conditioning system is widely used in hot summer and cold winter region, and more and more scholars begin to study this system at home and abroad.

2. Methods

The heat source tower heat pump air conditioning system uses the heat source to transfer, gets heat from the low temperature heat source pump units in winter-hot and summer-cool regions, so as to realize the building heating, cooling. Heat source tower is used as cooling and heat sources, whose technology can be traced back to Japan in the 1980s, called heated or heating towers. After the introduction into domestic market, some manufacturers also call it energy tower. Modified [1] and promoted, it is officially named as the heat source tower.

In the process of heat transfer, the carrier medium lower than 0°C will be used in winter, efficiently extracting the low grade heat energy under low temperature environment with relative higher humidity, thus achieving the heat source of heat pump units; because of the special design, the heat source tower plays an efficient cooling effect in summer, cooling by heat pump units.

Heat source heat pump is designed according to the specific conditions in south China, the "very hot" summer and winter with "low temperature and humidity", which can run under low thermal heat pump system efficiently. The system is mainly composed of the heat source tower, heat pump and water pump and pipeline switching equipment. Given that the circulation medium in the form of contact with the atmospheric heat source tower is different, the heat source towers are divided into open and closed-loop heat source towers. And the corresponding air conditioning system is divided into open and closed-loop heat source heat pump air conditioning system.

2.1. Heat pump system of open heat source tower

In the open heat source tower, tower inside the working condition of circulates with cooling tower, and tower circulation medium fluid is always the heat in contact with the outside world, and the atmosphere with the outside world has qualitative phenomenon. In summer, the circulation medium is water; while it is alcohol or aqueous solution of salts with lower freezing point in winter, which can absorb heat from the winter cold air in the case of below freezing, providing to the low temperature heat pump units as the heat source.

Research on the open tower heat source air conditioning system is conducted mainly through a series of theoretical analysis, numerical simulation and experimental contrast, focusing on the open heat source tower and mass transfer characteristics in the process of analysis for internal heat and mass transfer [2], the influence of gas liquid ratio on the heat source tower [3], heat exchanger in the phase change, the performance of the heat source tower [4], the regeneration of the circulation medium [5], the application of heat source tower heat pump system [6], etc.
Due to the applications of open type heat pump air conditioning system, the heat source tower in the winter circulation medium suffers a larger amount of drift and the surrounding environment corrosion, antifreeze, concentrated and diluted concentration, and the unit stability and poor security, antifreeze, and complicated situations. For reasons of environmental protection, safety and energy efficiency, the application of closed-loop heat source tower develops fast.

2.2. Air conditioning system of closed-loop heat source heat pump

In the closed-loop heat source tower, the circulation medium flows in the heat exchanger pipe, exchange heat with the outside world through the heat exchanger, thus eliminating the phenomenon of the circulation medium flowing; the circulation medium has always remained the same solution concentration, and the solution freezing point does not change, so that the heat pump host is in a stable working status, running efficiently. By the heat source tower and the heat pump host, it can be divided into the heat source heat pump and distributed heat pump.

2.2.1. Integrated heat source heat pump

The integrated heat source heat pump unites the heat pump host into one whole, which can supply users directly to the summer air conditioning freezing water and heating hot water in winter, and its structure is mainly composed by the vortex compressor, heat and cold source side broadband finned heat exchanger, the load side plate heat exchanger, accumulator, four-way reversing valve, refrigeration and heating expansion valve, the heat storage defrosting pilot valve, cooling system (including circulation pump, the anti-scaling alga induction meter, spray water segregator, etc.), variable speed fan, etc.

In summer, the fan will be integrated within the tower heat sources outside air into the body inside, and the spray system is running at the same time, the water spray evaporative cooling in the broadband fin heat exchanger surface, strengthen heat transfer effect. As shown in Fig. 1a, the refrigerating agent circulates in the heat exchanger, expansion valve, economizer, load side plate heat exchanger, four-way reversing valve, and compressor. In this tower the heat sources have played an important role in closed-loop cooling tower and water chillers, at the same time the spray water evaporation with heat transfer and its stable runs better than air-cooled heat pump with better cooling effect.
In winter, the spraying system will be part of the antifreeze solution intermittent spray in broadband fin heat exchanger surface to prevent frost, as shown in Fig. 1b, the refrigerating compressor compresses into the accumulator, which will be part of the heat storage to storage box; after reversing valve into the load side of the plate heat exchanger heat exchanger, it is cooled by expansion valve into the broadband finned heat exchanger, absorbing heat from the air into the compressor after completing the whole process. It is not easy to frost on the surface of heat exchanger, and the mechanism of the thermal efficiency is higher. The climate is relatively poor, under the condition of low temperature and humidity is higher; the tower heat sources need to enter the defrosting conditions. In defrosting conditions, as shown in Fig. 1c, the refrigerating compressor compresses into the accumulator, after reversing valve directly into the broadband finned heat exchanger heat exchanger, the heat exchange economizer stores after absorbing the heat. Part of heat in the heating and defrosting conditions enters the storage box providing heat for the defrosting process. The whole compressor is running smoothly in the process of heating and defrosting with higher heating efficiency.

Due to the limitation of the compressor and heat exchanger specifications, the integrated tower heat sources is only applicable to small civil buildings temporarily; at the same time due to items within the heat pump cycle control substance, and more complex energy storage, the performance is not stable, and the integrated temporarily tower heat sources in the experimental application stage has not been a large-scale promotion use.

2.2.2. Distributed heat source heat pump

The distributed heat source heat pump system refers to the heat source tower and heat pump host by reversing stand pipe connection, and the two do not become a whole. Such equipment is flexible, convenient, and easy to design, and the construction, installation and operation maintenance stage is easy most widely used at present.

From the image below, it can be seen that a distributed heat source heat pump system in the process of the winter heating mode can antifreeze, reversing the closed-loop heat source tower standing valve group, circulating between heat pump units, water pumps, absorbing heat transfer in the closed-loop heat source tower. The heat pump units in heating will store thermal energy, and the storage material is heated in the oven at the same time, and the surface of heat exchanger in the heat source tower can be extracted from the thermal storage tank. In the defrosting process, it only needs to turn off the heat source tower fan to open defrosting pump, and the heat exchanger cycle can be on the surface of the heat exchange coil defrosting. The defrosting process is simple and fast to avoid the heat pump host, which can save operating costs, improve the system efficiency. Distributed heat source heat pump system of the conversion of the summer and winter conditions also is very simple, which only needs reversing valve in the open position, no need to host tower and heat sources, water pump, etc.

Now in addition to using heat storage tank for defrosting, when the outside air temperature is less than 1°C, there are three kinds of defrosting ways to be adopted: 1. automatic startup antifreeze solution spray pump, reduce frost freezing heat exchanger; 2. under the condition of conditions permit, certain heat transfer capability of the underground fire pool, start automatically spray defrosting system; 3. a certain match to the underground soil source with heat exchange capacity, starting automatically. The defrosting ways to choose convenient, flexible layout should be according to the geographical conditions, construction conditions of project.

Currently, the research on the closed-loop heat source tower system mainly focus on the analysis as a source of heat and cold [7] heat source tower [8] the basis of theoretical and experimental analysis, because of the heat source tower structure characteristic of heat pump system and operation mechanism, the winter can work long time under the condition of low temperature and humidity climate, it can keep the working condition of frost-free run efficiently, producing air conditioning and hot water for users’ living at the same time, and its decorate covers a small zone, convenient and flexible, no need to bury pipe drilling with simple operation and management, so in the hot summer and cold winter region in China, it is widely used and developed.
3. Results

3.1. Project profile

Taking a certain office building’s air conditioning system in Hunan as an example, the closed-loop heat source heat pump air conditioning system is studied. The total construction zone is 32819.5 m², building height of 60.60 m, the first class high building. It is divided into two secondary floor of a building, the main, 1 basement floor for an underground garage and equipment room, the floor 16th floor for office, conference room and multimedia projection booth, etc. Summer air conditioning outdoor is calculated dry bulb temperature of 35.0°C, the summer air-conditioning outdoor calculated wet bulb temperature of 26.8°C; winter outdoor calculated dry bulb temperature of air conditioning for -2°C, the winter air conditioning outdoor relative humidity of 72%. Building a year-round comfort of central air conditioning system, and the summer air conditioning cooling load is 3740 kW; the winter air conditioning heat load is 1800 kW. The summer air conditioning cooling has the load of 2515.4 kW, the main winter air conditioning heat load of 1130.7 kW. Building 1, 2, the summer air conditioning cooling load of 612.3 kW, winter air conditioning heat load of 334.6 kW. Building needed in winter and summer heat and cold source provided by the basement of refrigerating machine room air conditioning host, consider using coefficient of 0.90 at the same time. Summer chilled water for the return water temperature to satisfy the requirement of 7/12°C, temperature of hot water for back water in winter need to meet the requirements of 45/40°C.

3.2. Air conditioning system options

In hot-summer and cold-winter zone, the most commonly used air conditioning systems for ground source (water source) heat pump system and air source heat pump system (or air source heat pump plus gas boiler). Ground source heat pump (water source) system can make use of groundwater, surface water, or soil buried pipe technology to extract low heat source, the conditional region is an effective way to use renewable energy, but the more restrictive
conditions. In hot summer and cold winter zone, groundwater, surface water rich zone are mostly in the rural zone rather than the city, large-scale popularization and application in the city water source heat pump has some limitations. In ground source heat pump exchanger, due to poor heat transfer properties of the soil, need large heat transfer zone, covers an zone of large, affected by geological conditions and construction technology at the same time, also need to consider the problem of heat accumulation, thus has certain difficulty in promotion. Air source heat pump system from the extraction of low heat source in the air, flexible, widely used, but its shortcomings are obvious: one is as the outdoor air temperature is reduced, the efficiency of the heat pump also reduce accordingly; low temperature and high relative humidity in the environment can be easily absorbed in the evaporator surface, the air conditioning heat pump use the heat generated by the defrosting, not only influencing the user comfort, but also responsible for a large number of energy consumption.

In hot-summer and cold-winter region, the heat source heat pump system, compared with the traditional central air conditioning system, only changes part of the cooling tower; in winter you just need to add other equipment heating; compared to the ground source heat pump system, the heat source tower is generally installed on the top of the building, from the ground zone of restriction, which can save a lot of valuable floor space, at the same time the heat source tower heat pump system is not affected by geography, geology and water environment of the heat pump system for heat source tower operation. At the same time, the heat source heat pump units are with the method of water-water heat exchanger, the efficiency of the unit itself is higher than the air-water heat exchange, and the system efficiency is higher than air source heat pump system. Air conditioning system is relatively opening more than closed-loop heat source tower heat source tower for the air conditioning system. No gas supply in this project is located, poor geological conditions, choose to use in the building closed-loop heat source heat pump air conditioning system.

Building air conditioning heat and cold source adopts three heat source heat pump units; its single refrigerating capacity is 1120 kW, heating capacity of 809 kW. Chooses six closed-loop heat source tower with matching single heat source, and the rated water tower is 270m³/h, the rated air volume of 33000m³/h, heat absorption capacity of 380 kW, water side and user side adopts four 45 kW variable frequency pumps.

### 3.3. System operation performance

The parameters of heat pump host are recorded in the following table:

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Chilled water flow (m³/h)</th>
<th>Chilled water outlet temperature (°C)</th>
<th>Chilled water return temperature (°C)</th>
<th>Cooling water outlet temperature (°C)</th>
<th>Cooling water return temperature (°C)</th>
<th>host power (kW)</th>
<th>COP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>125.0</td>
<td>32.4</td>
<td>28.1</td>
<td>-6.2</td>
<td>-3.4</td>
<td>198.4</td>
<td>3.14</td>
</tr>
<tr>
<td>2</td>
<td>155.8</td>
<td>34.2</td>
<td>30.8</td>
<td>-6.3</td>
<td>-3.1</td>
<td>203.2</td>
<td>3.02</td>
</tr>
<tr>
<td>3</td>
<td>165.0</td>
<td>35.2</td>
<td>31.9</td>
<td>-6.6</td>
<td>-3.4</td>
<td>206.4</td>
<td>3.06</td>
</tr>
<tr>
<td>4</td>
<td>168.9</td>
<td>36.3</td>
<td>33.6</td>
<td>-6.1</td>
<td>-3.0</td>
<td>211.2</td>
<td>2.50</td>
</tr>
</tbody>
</table>

The parameters of air conditioning room are recorded in the following table:
Table 2. The parameters of air conditioning room.

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Temperature (°C)</th>
<th>Relative humidity (%)</th>
<th>Wind velocity (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Out Door</td>
<td>4.3</td>
<td>4.2</td>
<td>4.3</td>
</tr>
<tr>
<td>Room 12-8</td>
<td>18.5</td>
<td>18.7</td>
<td>18.8</td>
</tr>
<tr>
<td>Room 12-13</td>
<td>18.8</td>
<td>18.8</td>
<td>18.9</td>
</tr>
<tr>
<td>Room 4-2</td>
<td>19.6</td>
<td>21.2</td>
<td>20.6</td>
</tr>
<tr>
<td>Out Door</td>
<td>4.7</td>
<td>4.6</td>
<td>4.6</td>
</tr>
<tr>
<td>Room 6-1</td>
<td>19.3</td>
<td>19.3</td>
<td>19.3</td>
</tr>
<tr>
<td>Room 6-4</td>
<td>21.4</td>
<td>21.4</td>
<td>21.5</td>
</tr>
</tbody>
</table>

4. Discussion

As can be seen from the table
1) When the environment temperature is 4.3°C with the relative humidity of around 93.9%, the heat source tower in and out of the water temperature has reached -6.2°C~3.4°C, the whole system is stable and runs normally, and the heat pump host COP value can reach about 3.0; 2) With the reduction of the ambient temperature, the heat pump host COP also decreases; 3) When the heat source water temperature and the air wet bulb temperature different between 7~8°C, this is mainly due to the circulation medium with air and indirect heat transfer, and the heat exchanger performance needs to be improved.

5. Conclusions

The heat tower source heat pump is used later in the domestic market, and the closed-loop tower heat source heat pump air conditioning system, due to the higher initial investment, is not commonly promoted. The typical projects include the Sixth Affiliated Hospital of Zhongshan Hospital, and Changsha Shenghuoyijia Hotels, etc., most of which are located in the hot-summer and cold-winter regions in China. These projects have a few problems in the operation process, for example, the heat source tower heat exchanger fouling phenomenon is serious, the heat source tower import and export water temperature difference is small, there are some floating fluid phenomenon, for example, the heat source tower heat pump efficiency of the whole machine is not stable, now the heat pump air conditioning system for closed-loop heat source tower needs further in-depth study. But as people living standard rises, the heating requirements in hot-summer and cold-winter zone is also higher, and the closed-loop heat source tower with less restrictive conditions, comprehensive energy efficiency, saving energy and pollution-free will be more and more widely used.

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