

# ENERGY SAVINGS AND ECONOMIC ANALYSIS OF SURFACE-WATER HEAT PUMPS IN THE HEATING SEASON IN HUNAN, CHINA

*Tingting Liu, Master, College of Civil Engineering,  
Jianguo Peng, Associate Professor, College of Civil Engineering,  
Guoqiang Zhang, Professor, College of Civil Engineering,  
University of Hunan, Changsha, China*

*Xuanjun Lin, Manager, Hunan Over Sky Technology Co., Ltd, Xiangtan, China*

## ABSTRACT

A new simplified procedure to calculate the heating seasonal performance factor (HSPF) of a surface water heat pump (SWHP) system was proposed in this paper, based on the temperature frequency method. This method permits one to evaluate heating energy requirement of buildings by a calculation with daily average water temperatures and ambient air temperatures, thus the energy consumption of a SWHP system can be analyzed. The economic analysis was also made using the calculating formula of annual cost approach. Besides, based on the energy consumption and costs comparison of SWHP system with air source heat pump (ASHP) system, it was concluded that SWHP heating system can save 31.5% of energy, and the annual cost per unit area of structure of SWHP system is 2.87 yuan/ ( $\text{m}^2 \cdot \text{year}$ ) less than that of ASHP system, which indicated the SWHP system is superior to the ASHP system evidently in the energy saving and economic respects.

**Key Words:** *SWHPs, HSPF, energy saving, annual cost, economic.*

## 1 INTRODUCTION

Due to limited availability of natural resources exploited for heating, people should strive to use renewable energy sources. Heat pumps allow the conversion of ambient heat, available in almost unlimited quantities, to heating energy. In recent years, because high temperature of geothermal allows the heat pump to operate at a high coefficient of performance (COP) throughout the winter, regardless of the ambient air temperature, ground source heat pump (GSHP) systems have become a popular heating system for buildings and the number of installations is expanding rapidly. As one system type of GSHP systems, surface water systems use a network of polyethylene pipe submerged in a body of surface water to provide for heat exchange (Kevin 2003).

There have been many experimental and theoretical studies of surface water heat pumps (SWHPs). Kavanaugh investigated the operation of water-to-air heat pumps using lake water as the heat source-sink for southern lakes of USA (Kavanaugh 1989). Several performance improvement possibilities with unitary water-to-air heat pumps were discussed by the same researcher in Ref. (Kavanaugh 1991). Kavanaugh et al. reported the performance of two water-to-air heat pumps that were designed primarily for southern installations in USA (Kavanaugh et al. 1991). O. Büyükalaca

made an experimental investigation of Seyhan River and dam lake as heat source–sink for a heat pump (O.Büyükalaca et al. 2003). Surface-tank-type ground couplings have been investigated experimentally by Johnson et al. (Johnson et al. 1988) and theoretically by Mohammed-Zadeh et al. (Mohammed-Zadeh et al. 1989). A disadvantage of these theoretical predictions is the requirement of considerable computational CPU times. Ünsal applied the complex finite Fourier transform technique to obtain exact annual periodic solutions of transient heat conduction problems for underground spherical and cylindrical seasonal thermal energy storage which may be utilized in energy storage system simulation studies (Ünsal 1990). Utilization of such analytic solutions in modeling can decrease the required computer CPU time considerably. R. Yumrutas et al. have made an extension of the work Ünsal did to predict annual periodic performance of residential heat pump systems with large hemispherically shaped surface tanks used as the ground heat source (R. Yumrutas and M. Ünsal. 2000). They introduced a new hybrid analytical-computational method and developed a Fortran computer code to determine the annual periodic transient temperature distribution in earth, the transient temperature in the surface tank and the thermal performance of the heat pump system. Various heat sources for heat pumps in buildings as well as in industry were discussed by Berntsson (Berntsson 2002).

According to experiences, the accessorial initial investment of water source heat pump (WSHP) system can be reclaimed within 3~7 years because its operation cost is much lower than the conventional air conditioners (Bose et al. 1985) . So WSHP system is a viable and relatively low-cost GSHP option. Moreover, lakes, streams, ponds, man-made lakes and bays can be very good heat sources and sinks for WSHP systems if properly utilized. Many successful systems are currently in operation. Hence, if the building is located adjacent to a suitable body of water, the SWHP system may be the most energy and cost effective heating system in warmer climates.

However, a great deal of information needs to be assembled and published including the minimum lake size and depth required to avoid poor performance (i.e., ice buildup on coils) and prevent unwanted changes (excessive evaporation, heat buildup, etc.) to smaller bodies of water (Stephen and Kevin 1997). Furthermore, from the SWHP system design standpoint, it is very difficult to estimate the actual energy consumption and running costs, thus in order to prove the SWHPs are the optimal heating solution for the given climatic area, the energy consumption and annual costs in winter have to be estimated. This paper presented an energy consumption and economic analysis method of SWHP systems and proposed the optimal heating mode according to the calculating results that reduces design risks. A Visual Basic code was developed and used to determine the thermal performance of SWHP system. Results obtained from execution of the code for a group of buildings located in Xiangtan, Hunan, China with a man-made lake adjacent to them were reported.

## 2 ENERGY SAVING ANALYSIS OF SWHP SYSTEMS IN HEATING SEASON

### 2.1 Heating Seasonal Performance Factor (HSPF) of SWHP Systems

The definition of HSPF is given by the following equation.

$$HSPF = \text{total heating load} / \text{total input power} = \text{heat load of the buildings} / (\text{operating energy consumption of heat pumps} + \text{auxiliary heat}) \quad (1)$$

When the required inside design air temperature is given, the HSPF of SWHP systems is varying not only with the design and fabricate of heat pumps, but with local climate, local water temperature and SWHPs COP. Therefore, HSPF can be used to analysis the energy saving of a SWHP system in heating season in given climatic district (Nengzhao 1997).

## 2.2 A New Day-to-Day Accumulation Calculation Method for HSPF of SWHP Systems

Department of Energy (DOE) and Institute of Air-conditioning & Refrigerating (ARI) have advanced the temperature frequency method to calculate the HSPF (Weiding and Cunyang 1995). HSPF can be calculated using formula (2).

$$HSPF = \frac{\sum_{i=1}^m (Q_{li} \times M_i)}{\sum_{i=1}^m (P_i \times D_i \times M_i) + \sum_{i=1}^m (Q_{ai} \times M_i)} \quad (2)$$

where

- $m$  = number of temperature frequencies in heating season,
- $Q_{li}$  = buildings' heat load in  $i$ th temperature frequency, kW,
- $P_i$  = heat pumps' input power in  $i$ th temperature frequency, kW,
- $D_i$  = partial load coefficient in  $i$ th temperature frequency,
- $Q_{ai}$  = quantity of auxiliary heat in  $i$ th temperature frequency, and
- $M_i$  = number of hours in  $i$ th temperature frequency, h.

Now we extend this approach into SWHP systems. Since the water temperature is a primary factor that affects the HSPF and it is much more stable than ambient air temperature, the above method can be simplified by replacing hourly temperature with daily temperature. Thus, the number of hours in each temperature frequency can be replaced by that of days. We have to compute the HSPF according to formula (1) day by day because it is difficult to describe the dependence relation between water temperature and ambient air temperature quantificationally.

Firstly, suppose that the manufacture's stylebook data agreed with actual operation, auxiliary heat resource was electricity, and the electrothermal efficiency of electric heaters was 1.0. Secondly, calculate the heat load of the buildings ( $Q_1$ ) according to intraday average ambient air temperature and the heating output of SWHPs ( $Q_2$ ) according to intraday average water temperature. Thirdly, compare  $Q_1$  with  $Q_2$ , if  $Q_1 > Q_2$ , then the quantity of auxiliary heat ( $Q_a$ ) equals their difference; if  $Q_1 < Q_2$ , then the partial load coefficient ( $D$ ) equals their ratio; if  $Q_1 = Q_2$ , then  $Q_a = 0$  while  $D = 1$ . Finally, calculate the HSPF according to formula (2).

Above calculation procedure is a new day-to-day accumulation calculation method for HSPF of SWHP systems proposed in this paper. Whereas, in order to compute the heating output of SWHPs ( $Q_2$ ) and the input power ( $P$ ) at a certain water temperatures ( $T_w$ ) which are not lined out on the catalog performance chart, curve fitting method have to be used to formulate the relation between  $Q_2$  and  $T_w$ , and between  $P$  and  $T_w$  using the least-squares procedure before starting the calculation.

For a given climatic area, when the characteristics of building envelop, the indoor design parameters, the ambient design air temperature, and the type and performance of chosen heat pumps

are determined, total heating output of heat pumps, power consumption of heat pumps, and quantity of auxiliary heat will vary only with the number of chosen heat pumps in winter which indicates that the HSPF is principally a function of the number of chosen heat pumps. The heating mode when the HSPF obtained by above procedure comes to a maximum will save the most energy and thus we can determine how many SWHPs and auxiliary heaters should be chosen, when the auxiliary heater should be operated, and how much the quantity of auxiliary heat is.

### 3 ECONOMIC ANALYSIS OF SWHP SYSTEMS IN HEATING SEASON

#### 3.1 First Cost of Heating Equipments

The first cost of SWHP systems includes the first investment of heating equipments ( $C_1$ ) and the energy source construction fee (see 2.2). The first investment of heating equipments includes chiller/heater plant construction cost; heat pumps and auxiliary heaters cost; water pumps and other auxiliary equipments cost; cool/hot water network materials and execution cost; installation cost; and inlet water pipe, inlet water pump station and water treatment investment.

#### 3.2 Energy Source Construction Fee

The government collects the energy source construction fee ( $C_z$ ) from all the thermal consumers according to some energy polices (Zhijiang 2004). The energy source construction fee can be calculated using formula (3).

$$C_z = P_{ez} (W_{hp} + W_{eh}) \quad (3)$$

where

$P_{ez}$  = electric construction fee per unit power, yuan/kW,

$W_{hp}$  = nameplate input power of heat pumps, kW, and

$W_{eh}$  = nameplate input power of electric heaters, kW.

#### 3.3 Operating Cost of SWHP Heating Systems

The operating cost of SWHP heating systems ( $C_r$ ) includes operating energy consumption cost, basic power rate, maintenance attendance cost, depreciation cost, and management cost (Yiqiang 2001).

##### 3.3.1 Operating energy consumption cost

The calculation of operating energy consumption cost is based on the calculation of energy consumption throughout the heating season. The daily energy consumption can be calculated using formula (4).

$$E_i = P_i \times D_i + Q_{ai} \quad (4)$$

where

$E_i$  = energy consumption of SWHP systems in  $i$ th day, kW.

Then the operating energy consumption cost can be calculated using formula (5).

$$C_{yx} = kP_e \times \sum_{i=1}^m E_i \quad (5)$$

where

$C_{xy}$  = operating energy consumption cost of SWHP systems, yuan,

$P_e$  = electrovalence, yuan/kW•h,

$k$  = number of hours of runtime per day, hour, and

$m$  = number of days in a heating season, day.

### 3.3.2 Basic power rate

The basic power rate is collected monthly according to the electric power (kW) or the transformer capacity (kV•A). It can be calculated using formula (6).

$$C_{jb} = 12P_{\text{fl}}(W_{hp} + W_{eh}) \quad (6)$$

where

$C_{jb}$  = basic power rate, yuan;

$P_{\text{fl}}$  = rate per unit installation power, yuan/ (month•kW);

### 3.3.3 Maintenance attendance cost, depreciation cost, and management cost

There is no quantized method yet to calculate maintenance attendance cost, depreciation cost, and management cost of HVAC&R systems at present in China. In order to simplify the calculation, assume the annual equipments maintenance attendance cost and depreciation cost equal 1% of the system first cost; and suppose the salary of the administrators is 40 yuan / (day•people) so as to estimate the annual management cost.

## 3.4 UTILIZING ANNUAL COST CALCULATING METHOD TO MAKE ECONOMIC ANALYSIS

The initial investment and running cost are different in nature, so they can not be added up directly. The annual cost calculating method is to convert the initial investment into a cost similar to the running cost using a coefficient of investment yields, then add them up and the sum is the annual cost (Zhijiang 2004). The annual cost per unit area of structure can be calculated using formula (7).

$$Z = (C_t \left| \frac{j(1+j)^n}{(1+j)^n - 1} \right| + C_r) / F \quad (7)$$

where

$Z$  = annual cost per unit area of structure, yuan / (m<sup>2</sup>•year) ,

$j$  = annual interest rate, we can use 10%,

$n$  = operational life of equipments, which generally is 15 years, and

$F$  = area of structure, m<sup>2</sup>.

Formula (7) shows that the objective function is a multi-variable function. But actually, it only depends on the number of chosen heat pumps if the annual interest rate, the operational life of equipments, and the price of equipments and energy sources are given. Obviously, the heating mode when the annual cost obtained by above approach falls a minimum will save the most money and thus

we can determine how many SWHPs and auxiliary heaters should be chosen, when the auxiliary heaters should be operated, and how much the quantity of auxiliary heat is.

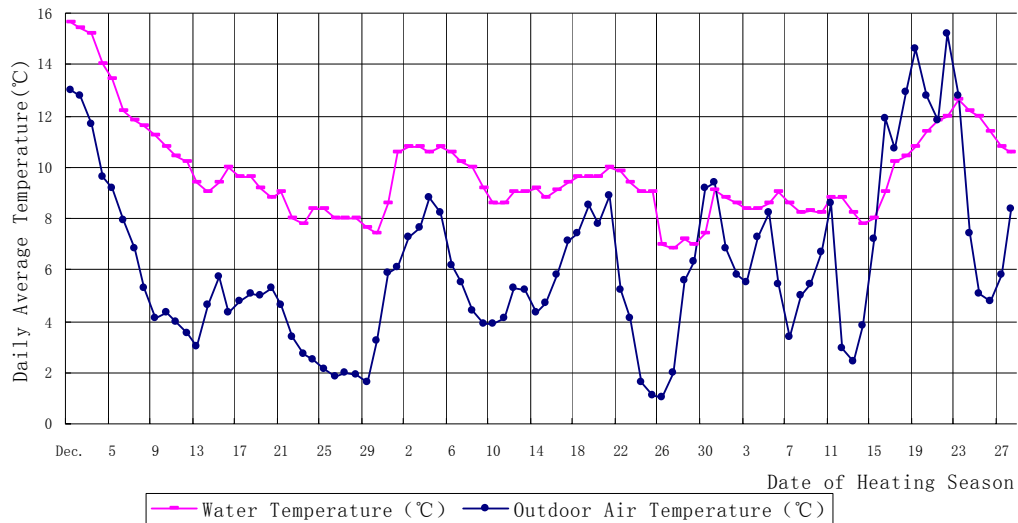
## 4 EXAMPLE APPLICATION – A SWHP PROJECT IN XIANGTAN, HUNAN, CHINA

### 4.1 Project Introduction

An example application is provided using actual buildings located in Xiangtan City, Hunan Province, a middle-southern city of China where it is hot in summer and relatively cold in winter, but much warmer than the northern districts of China. It is coldest in January when the monthly average ambient air temperature is  $4\sim 7^{\circ}\text{C}$ ; and hottest in July when it is  $27\sim 30^{\circ}\text{C}$ . The total area of structure of the buildings is  $124500\text{m}^2$ , the cooling load in summer is  $13200\text{kW}$ , and the heating load in winter is  $5786\text{kW}$ . A man-made  $80000\text{m}^2$  lake has been built in a park near the buildings as the heat source and sink of the SWHP system. LD-BL-1000 type module geothermal heat pumps have been chosen. The nominal refrigerating output of each heat pump is  $894\text{kW}$ , the nominal heating output is  $1002\text{kW}$ , the nominal refrigerating power is  $178.8\text{kW}$ , and the nominal heating power is  $222\text{kW}$ . Suppose there are 90 days in a heating season, the runtime is  $8\text{h/day}$ , the electrovalence is  $0.56\text{ yuan/kW}\cdot\text{h}$ , the electric construction fee per unit power is  $1000\text{ yuan/kW}$ , the rate per unit installation power is  $8\text{ yuan/}(\text{month}\cdot\text{kW})$ , and there are 10 administrators.

### 4.2 Surface Water Temperature and Ambient Air Temperature

Figure 1 describes the dependence relation between the daily average water temperature of Xiangjiang River and the daily average ambient air temperature in Xiangtan district in the heating season (December, January and February) in 2001.



**Fig. 1. Xiangjiang River's daily average water temperature and daily average ambient air temperature in Xiangtan district in the heating season in 2001**

It is evident from Fig. 1 that the water temperature change is much meeker than that of ambient air. The average water temperature throughout the winter is  $9.7^{\circ}\text{C}$ , which is  $3.5^{\circ}\text{C}$  higher than ambient air, indicating that heat resource contained in water body is much more abundant than in ambient air. Besides, the change of water temperature lags behind ambient air. Of course, the dependence relation

between water and ambient air temperature is inconstant in different places because the area, shape, depth and surrounding of their water body vary with different districts. But anyway, water body can absorb a majority of radiant heat from the sun when it is strong enough and reserve it through inner heat exchange. Therefore, surface water of large thermal inertia is ideal heat source with stable temperatures.

### 4.3 Results and Discussion

**Table 1. Calculation result of day-to-day accumulation method and annual cost method**

| Number of<br>chosen<br>heat<br>pumps | Total energy<br>consumption of<br>SWHPs /kW | Total<br>auxiliary<br>heat /kW | HSPF | First cost<br>/thousan<br>d yuan | Annual<br>heating<br>operating cost<br>/ thousand<br>yuan | Annual heating<br>cost per unit area<br>of structure<br>/yuan/(m <sup>2</sup> •year) |
|--------------------------------------|---------------------------------------------|--------------------------------|------|----------------------------------|-----------------------------------------------------------|--------------------------------------------------------------------------------------|
| 8                                    | 110116                                      | 0                              | 3.71 | 17632.0                          | 876.1                                                     | 25.66                                                                                |
| 7                                    | 109504                                      | 1930                           | 3.67 | 17012.7                          | 903.5                                                     | 25.23                                                                                |
| 6                                    | 105629                                      | 16071                          | 3.36 | 16743.9                          | 1006.1                                                    | 25.77                                                                                |
| 5                                    | 94726                                       | 56251                          | 2.71 | 16432.5                          | 1189.7                                                    | 26.91                                                                                |
| 4                                    | 78843                                       | 114997                         | 2.11 | 16174.4                          | 1439.4                                                    | 28.65                                                                                |
| 3                                    | 60728                                       | 182183                         | 1.68 | 15863.0                          | 1711.6                                                    | 30.50                                                                                |
| 2                                    | 41130                                       | 255129                         | 1.38 | 15605.0                          | 2008.3                                                    | 32.61                                                                                |
| 1                                    | 20591                                       | 331772                         | 1.16 | 15293.6                          | 2312.0                                                    | 34.72                                                                                |

Note: yielding water temperature of SWHPs is 50℃, area thermal index (used to calculate the heat load of buildings) is 58W/m<sup>2</sup>, and inside design air temperature is 20℃.

According to the calculation results, the total heat load of the buildings is 408614.976kW. Table 1 indicates that in view of energy efficiency, the heating mode of selecting 8 SWHPs without an auxiliary heater will be optimum when the HSPF comes to a head; but in terms of cost efficiency, the heating mode of selecting 7 SWHPs and a 1930.11kW auxiliary heater will be optimum when the annual heating cost per unit area of structure touches bottom. The annual heating operating cost is 27.4 thousand yuan more than selecting 8 SWHPs, but the initial investment is 619.3 thousand yuan less. Therefore, the most economic heating mode is to choose 7 SWHPs and an 1930.11kW auxiliary heater, and operate the auxiliary heater once the daily average ambient air temperature drops below 2.1℃.

### 4.4 Influence of Some Factors on HSPF

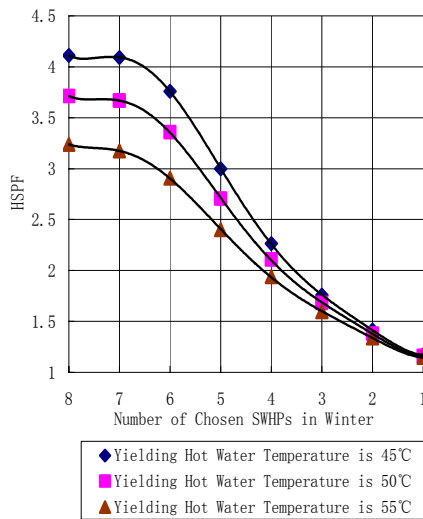
#### 4.4.1 Influence of the yielding hot water temperature of SWHPs on system's HSPF

Figure 2 shows that the maximal HSPF is falling with the rising of the yielding hot water temperature. The rising of yielding hot water temperature results in the increasing of system's energy consumption while the heat load of buildings is invariable, thus brings on the decreasing of HSPF.

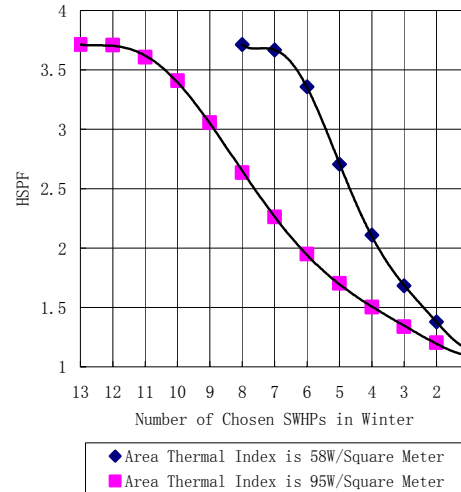
#### 4.4.2 Influence of the structure feature on system's HSPF

There are many structural factors affecting the running energy consumption of SWHP systems

including thermal characteristics of buildings' envelope, thermal storage capacity, volume of fresh air, density of occupants, and heat productivity of equipments et al. (Zuiliang and Yuan 1997). The area thermal index denotes the functions and characteristics of the buildings. Based on summarizing the theoretical studies and experimental data of heating load carried out by plenty of professionals in China, the recommended area thermal indexes are given by the book “Design Criterion of City Heat Supply Network” (Ping and Gang 1998). Figure 3 shows the effects of area thermal index on the maximal HSPF can be ignored while that on the number of chosen SWHPs are obvious. The Bigger is area thermal index, the more is chosen SWHPs and the greater is energy consumption at the maximal HSPF.



**Fig. 2 Influence of yielding hot water temperature on system's HSPF**



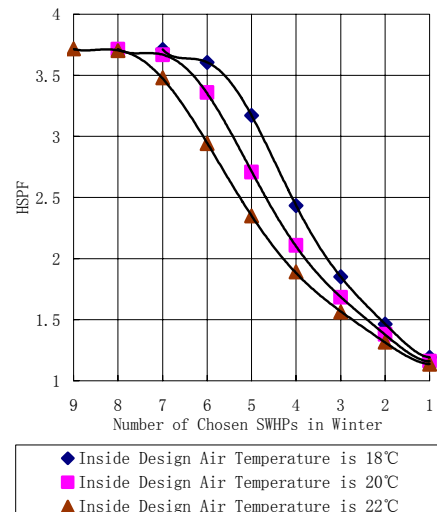
**Fig. 3 Influence of structure feature on system's HSPF**

#### 4.4.3 Influence of the inside design air temperature on system's HSPF

Figure 3 shows the inside design air temperature has small impact on the maximal HSPF. However, the heat load of the buildings will be increasing along with the rising of enquired indoor design air temperature which results in consuming more energy and selecting more SWHPs. For example, if the inside design air temperature has raised 2°C (from 20°C to 22°C), one more SWHP have to be chosen, and contrarily, if it has decreased 2°C (from 20°C to 18°C), one less SWHP can be used.

#### 4.5 Energy Saving and Economic Comparison of SWHP System with ASHP System

If utilize ASHP system for heating, LSQWRF390 type module air source heat pumps can be chosen for example. The nominal refrigerating output of each heat pump is 390kW, the nominal heating output is 420kW, the nominal refrigerating power is 131.3kW, and the nominal heating power is 127.8kW. Its major drawback is that at ambient air temperatures below 0



**Fig. 4 Influence of inside design air temperature on system's HSPF**

°C its heating power and COP drop and the central heating system must be fitted with additional heaters to provide heating at outdoor air temperatures below 0°C (Milan 2003).

#### 4.5.1 Energy consumption comparison

Daily energy consumption of SWHP system and ASHP system can be calculated respectively using formula (4). The calculation results are described in Fig. 5.

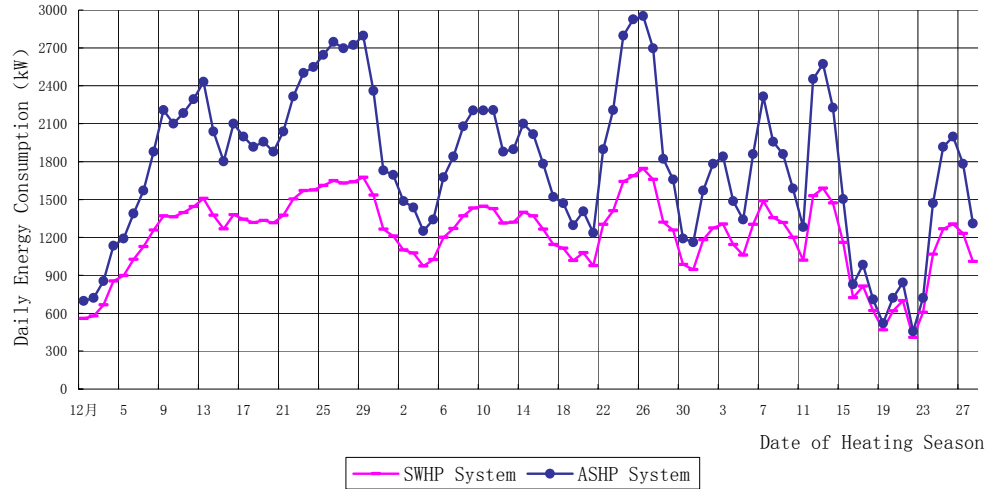


Fig. 5. Daily energy consumption comparison of SWHP system with ASHP system

The heat load of the buildings changes with ambient air temperature, and so does the number of heat pumps which have to be operated. The number of running heat pumps is reducing along with the rising of ambient air temperature. Table 2 gives the recommended number of running SWHPs or ASHPs which should be conditioned due to ambient air temperature.

Table 2. The recommended number of running SWHPs or ASHPs conditioned due to ambient air temperature and their comparison

| Range of ambient air temperature / | Recommended number of running SWHPs | Total energy consumption of SWHP system/kW | Recommended number of running ASHPs | Total energy consumption of ASHP system/kW | Fractional energy saving of SWHPs |
|------------------------------------|-------------------------------------|--------------------------------------------|-------------------------------------|--------------------------------------------|-----------------------------------|
| ≤2.3                               | 8                                   | 14936.58                                   | 22                                  | 24979.75                                   | 40.2%                             |
| 2.4~4.7                            | 7                                   | 33325.54                                   | 19                                  | 51708.73                                   | 35.6%                             |
| 4.8~7.3                            | 6                                   | 38975.10                                   | 15                                  | 55031.43                                   | 29.2%                             |
| 7.4~9.5                            | 5                                   | 15265.92                                   | 11                                  | 19779.45                                   | 22.8%                             |
| 9.6~12.7                           | 4                                   | 3757.63                                    | 8                                   | 4641.907                                   | 19.0%                             |
| 12.8~14.6                          | 3                                   | 3447.20                                    | 6                                   | 4090.042                                   | 15.7%                             |
| ≥14.7                              | 2                                   | 408.10                                     | 4                                   | 456.6896                                   | 10.6%                             |

Figure 5 and Table 2 show the heating energy consumption of SWHP system is much less than that of ASHP system, and the lower is ambient air temperature, the more energy can be saved by SWHP system. To sum up, utilizing SWHP system for heating in winter can save 31.5% of energy compared with ASHP system.

#### 4.5.2 Economic comparison

According to the calculation results, if utilizing ASHP system for heating in winter, the most economic heating mode is to select 21 ASHPs of LSQWRF390 type and 175.644kW auxiliary heaters, and operate the latter once the daily average ambient air temperature drops below 1.5℃.

**Table 3. Economic comparison of SWHP system with ASHP system at their most economic heating mode**

| Heating system | First cost of equipments/<br>thousand yuan | Energy source construction fee / thousand yuan | Annual heating operating cost / thousand yuan | Annual heating cost per unit area of structure /yuan/ (m <sup>2</sup> •year) | Number of chosen heat pumps |
|----------------|--------------------------------------------|------------------------------------------------|-----------------------------------------------|------------------------------------------------------------------------------|-----------------------------|
| SWHP           | 14948.7                                    | 2064                                           | 903.5                                         | 25.23                                                                        | 7                           |
| ASHP           | 14542.8                                    | 2883.8                                         | 1206.8                                        | 28.10                                                                        | 21                          |

Table 3 shows the annual heating cost per unit area of structure of SWHP system is 2.87 yuan/ (m<sup>2</sup>•year) less than that of ASHP system. Although the initial investment of SWHP equipments is 405.9 thousand yuan more than that of ASHP equipments, the total first cost of SWHP system is 413.9 thousand yuan less than that of ASHP system after reckoning in the energy source construction fee, in addition, annual heating operating cost of the former is 303.3 thousand yuan less than that of the latter. It can be concluded that SWHP systems have obvious economic superiority in heating season.

#### 4 CONCLUSIONS

1. In an actual SWHP air conditioning project, some theoretical indexes have to be employed to evaluate their energy and cost efficiency. Utilizing the HSPF as an energy conservation evaluating indicator and the annual heating cost per unit area of structure as an economic efficiency evaluating indicator can reveal intuitively the energy consumption and costs of SWHP system in a given climatic district in heating season.
2. The day-to-day accumulation calculation method for HSPF of SWHP systems developed in this paper is simple, visualized, convenient, and wieldy which has credible academic foundation. The heating mode when the HSPF comes to the maximum is the most energy effective. The example indicated utilizing SWHPs for heating without auxiliary heaters can save the most energy.
3. The annual heating cost calculating method was used here to make economic analysis and the results show the heating mode when the annual heating cost falls to the minimum can save the most money.
4. The designers can determine the number of SWHPs and auxiliary heaters conveniently according to the consumers' emphasis so as to reduce design risks.
5. The comparison results show that in terms of energy consumption and costs the SWHPs have a huge advantage over the ASHPs. In the climatic area where the buildings are located, the use of the SWHP heating system is fully justified. If an ASHP system had been used for heating instead of an SWHP system, 50571.9286 kW more energy or 357.315 thousand yuan more money would have been consumed per winter.

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