Economic analysis of a water source heat pump—direct surface water cooling hybrid system

Xudong Jiang 1,2, Jinhua Chen 1,2 *
1 School of civil engineering, Chongqing University, Chongqing, China
2 Key Laboratory of the Three Gorges Reservoir Region’s Eco-Environment, Chongqing University, Chongqing, China

*Corresponding author e-mail: c6657889@126.com

Abstract. IN order to realize the energy saving potential of natural water sources, a complex system of low temperature surface water cooling and water source heat pump is proposed. Taking the actual project as an example, a LCC calculation model for engineering evaluation was established. DeST-c was used to simulate the annual energy consumption of the engineering example. The relationship between load changes of FCU and AHU is analysed when the outdoor climate and the use of building changed. The calculation of LCC was based on performance curves of water source heat pump unit and variable frequency pump. Comparing the LCC components with the hybrid system, conventional system and water source heat pump, it was found that the LCC of hybrid system was 70% of conventional system and 83% of water source heat pump. The hybrid system of low temperature surface water cooling and water source heat pump has great energy saving potential and economic benefits.

1. Introduction
As a kind of renewable energy source, water source heat pump (WSHP) is widely used in the world since the 1970s due to its energy saving and carbon emission reduction [1]. China is rich in water resources especially in south china with a lot of lakes, rivers, oceans and many other water resources. There are many cities or buildings was built near water bodies. Thus, there are great potential to use water source heat pump as a heat source or heat sink. While, another way of using surface water for building cooling was called direct surface water cooling (DSWC) [2]. These systems use water from deep oceans or deep leaks where the temperature of water is as low as water from heat pump chillers. So the systems of DSWC don’t have heat pump and can save 90% energy comparing with conventional systems [3]. Although the energy saving effect of the DSWC is so excellent, there are many challenges to use it. The biggest challenge is that it’s hard to find surface water bodies with temperature under 10°C in China. With the truth that water source heat pump can use 26°C surface water with quite high COP, how to use water range from 10°C to 20°C remains a problem.

To solve this problem, we used temperature and humidity independent control systems. The system can overcome the problem of high surface water temperature in China. On the basis of the energy-saving advantages of water source heat pump, the DSWC is utilized and formed a new hybrid system, thereby fully exerting the energy-saving potential of surface water, a natural heat sink.
In this paper, the LCC calculation model is used to compare the hybrid system and the conventional system with the water source heat pump system. The performance of the hybrid system and other systems are different. Considering the occupancy rate of building and the influence of outdoor climate, the method for calculate energy consumption is improved, and the energy saving value of different systems is quantitatively calculated.

2. The WSHP-DSWC hybrid system

In hybrid system of WSHP and DSWC, temperature and humidity independent control system is required. In the hybrid system, two kinds of cold sources with different temperatures are used. High-temperature cooling water (16℃) handled most of the sensible heat load which was low-temperature chilled water (7℃) did in traditional air-conditioning systems. The low-temperature chilled water bears all the latent load and part of the sensible heat load.

The direct surface water is used as a high-temperature cold source. The temperature of the direct water supply is about 16 ℃. It needs to be determined according to the water source conditions. The direct surface water is supplied to the indoor devices such as a dry fan coil for removing sensible heat through a plate heat exchanger. It is responsible for the main sensible heat load. The WSHP is used as a low-temperature cold source to prepare low-temperature chilled water with a return water temperature of 7 ℃/12 ℃, which is supplied to the fresh air treatment unit, so that the fresh air bears all the wet load and a small part of the sensible heat load. In the winter, the direct water supply system is turned off, and the water source heat pump is used to prepare the hot water for HAVC systems. The schematic diagram of the system is shown in Figure 1:

![Figure 1. WSHP-DSWC hybrid system](image)

3. LCC calculation method

3.1. LCC calculation model

The LCC refers to the costs that the product has gone through research, design, construction, use, and retirement. It includes not only economic costs, but also environmental and social costs. Since this paper discusses the evaluation method of the specific object of the WSHP and DSWC, it can be simplified to consider only the economic costs of the equipment.

The LCC of the air conditioning system refers to the total cost paid during the life cycle of the air conditioning system, and is composed of the following parts: one investment cost IC; the operating cost OC; the scrapping cost RC. Therefore, the life cycle cost of an air conditioning system can be expressed by equation (1):
LCC = IC + OC + RC \tag{1}

Considering the construction cost and operating cost of the system, according to the initial investment cost, operating cost, maintenance cost and residual value of the system, and considering the correction of various economic factors, the mathematical model for obtaining the LCC calculation is as follows:

\[ LCC = IC + \sum_{k=1}^{n} OC(1 + i)^{-n} - RC (1 + i)^{-n} \tag{2} \]

- \( n \) — Economic life;
- \( i \) — Discount rate.

3.2. IC and RC

The IC is mainly for initial investment, including equipment purchase fee, material fee, installation fee, and distribution capacity fee. It is calculated with reference to the current supplier quotation and labor salary standard. RC takes 3% of the original value of the fixed assets.

3.3. OC and operation fee in summer

OC is the operating cost. In the air conditioning system, including maintenance management fees, on-duty staff salaries and equipment unit operating costs. OC have to parts, one cost does not change with changes in building load, the other varies with building load which is the hardest part to calculate. The main part of the changed cost is the summer operating fee.

In general, we use the load rate method to calculate energy consumption by dividing the load rate into several intervals. For the WSHP-DWSC hybrid system, the traditional calculation method can only calculate winter energy consumption, and there are two obvious problems for the calculation of summer energy consumption. The first problem is that the load ratio of sensible heat load and latent heat load varies with outdoor climate. Another problem is that even at the same load rate of building, the load ratio of the fresh air unit and the dry fan coil is different due to the influence of the simultaneous use coefficient of the building and the outdoor climate. The reason for the difference between hybrid system and traditional system calculations is that hybrid system, is the simultaneous operation of two systems rather than a single system.

To solve the first problem, first disassemble the building load and get the formula (3)–(6)

\[ Q = Q_{AHU} + Q_{FUC} \tag{3} \]

\[ Q_{AHU} = G \rho (i_w - i_l) \tag{4} \]

\[ d_s = d_N - \frac{W}{\rho \times \dot{G}} \tag{5} \]

\[ i_w = 1.01t + (2500 + 1.84t)d \tag{6} \]

- \( d_s \) — Air supply moisture, g/kg;
- \( d_N \) — Interior design state moisture content, g/kg;
- \( W \) — Indoor wet load, g/h;
- \( G \) — Fresh air volume, m³/h;
- \( \rho \) — Fresh air density, kg/m³

In order to solve the second problem, taking the hotel as an example, the simultaneous use factor can be simplified. First, the strength factor is considered when calculating the load for a single room. Secondly, the number of rooms used per day for the entire building is monthly or Quarterly study.

Establish the load model of the unit of the water source heat pump which is show in equation (7)
\[ P = \sum_{t=0}^{N} \frac{Q_t \cdot \text{COP}_t}{EER_t} \]  \hspace{1cm} (7)

4. Case introduction

4.1. Project introduction
Take a water source heat pump system project in a lake in Chongqing as an example. The project is located beside the Dashibao Reservoir in Daguan Town, Nanchuan District, Chongqing City. It is a mountainous tourist building with lower temperatures than other districts. The building is a hotel with a building area of 11979.17m² and a building height of 23.7m.

The building air conditioning load was simulated time-by-time using DeST software. The hourly load in summer is shown in Figure 2.

![Figure 2. The annual load distribution](image)

In September 2018, the water temperature of the Dashiba Reservoir was tested for several days. The water temperature data is shown in Figure 3. As can be seen from the figure, in the case of a temperature of 37 °C, the deep water temperature of 8 m depth is 11 °C, which can meet the requirements of direct water supply.

![Figure 3. Dashibao Reservoir water temperature data](image)

4.2. Air conditioning plans
Hybrid system we study is the scheme 1. Scheme 2 is the most common system. Scheme 3 is a water source heat pump system. We choose these scheme to study the energy efficiency of the hybrid system. The device is shown in table 1 to table 3.
Table 1. Device parameter list of scheme 1

| device    | parameter                                      | quantity |
|-----------|------------------------------------------------|----------|
| WSHP      | Cooling capacity 137kW, heating capacity 151kW, load 26/35kW | 2        |
| FCU pump  | Q=28m³/h, P=4kW, H=25m                          | 2        |
| AHU pump  | Q=28m³/h, P=4kW, H=25m                          | 2        |
| pump      | Q=56.3m³/h, P=11kW, H=33m                      | 2        |

Table 2. Device parameter list of scheme 2

| device                | parameter                                      | quantity |
|-----------------------|------------------------------------------------|----------|
| Screw chiller         | Cooling capacity 298kW, load 49.8kW            | 2        |
| Gas hot water boiler  | heating capacity 345kW, load 0.43kW, natural gas consumption 38.40Nm³/h | 1        |
| Cooling water pump    | Q=30.4m³/h, P=4kW, H=24m                       | 2        |
| Chilled water pump    | Q=25m³/h, P=3kW, H=20m                         | 2        |
| heating water pump    | Q=16.3m³/h, P=1.5kW, H=17.5m                   | 2        |
| Cooling Tower         | Q=31.2m³/h, 1.5kW                              | 2        |

Table 3. Device parameter list of scheme 3

| device            | parameter                                      | quantity |
|-------------------|------------------------------------------------|----------|
| WSHP              | Cooling capacity 297kW, heating capacity 337kW, load 58.5/73.7kW | 2        |
| Cooling water pump| Q=50m³/h, P=5.5kW, H=20m                       | 2        |
| Chilled water pumps| Q=31.3m³/h, P=4kW, H=17.5m                   | 2        |
| filter device     | 3kW                                           | 1        |

4.3. LCC of the 3 schemes

The LCC values of each scheme are calculated, and the service life of the equipment is calculated according to 20 years. The discount rate is 7%, taking 3% of the original value of the fixed assets. The results are shown in Table 8.

It can be seen from Table 4 that the LCC value of the scheme 1 is the smallest, the second is the scheme 2, and the scheme 3 has the largest LCC value. Although the initial investment of the scheme 1 is the highest, from the perspective of the entire life cycle, the efficiency of the scheme 1 is the best. The reasons for the higher initial investment in scheme 1 and 3 are the cost of water intake facilities and outdoor network management.

Table 4. Values of Scheme 1, 2, 3 LCC

|        | IC  | OC  | RC  | LCC  |
|--------|-----|-----|-----|------|
| Scheme 1 | 75.1| 10.5| 2.3 | 185.74|
| Scheme 2 | 48  | 20.7| 1.4 | 266.93|
| Scheme 3 | 74.8| 14.1| 2.2 | 223.60|
5. Conclusion
An evaluation method based on LCC is established, which can accurately evaluate and optimize WSHP-DSWC hybrid system. Through the analysis of the actual case, the following conclusions are obtained:

1. Establish a different method of calculating energy consumption from common system, consider the changes in outdoor climate and usage rate, and after reasonable simplification, can be applied in the evaluation and optimization of actual engineering.

2. Through LCC calculation, it is found that the annual operating cost of WSHP-DSWC hybrid system is only 51% of common system and 74% of WSHP. It fully exerts the energy saving potential of natural low temperature surface water.

3. WSHP-DSWC hybrid system has the highest initial investment, but its LCC is 70% of common system and 83% of WSHP. WSHP-DSWC hybrid system has great economic benefits.

This paper establishes the LCC calculation model of WSHP-DSWC hybrid system. Taking the actual project as an example. Three schemes’ LCC is compared and quantitatively analyzed for its energy conservation and economy. It is of great significance for the actual project design of guide WSHP-DSWC hybrid system.

Acknowledgments
This work was financially supported by the China National Key R&D Program “Solutions to heating and cooling of buildings in the Yangtze river region” (Grant No. 2016YFC070030*)

References
[1] Lin Baoyong, Dynamic Water Temperature in Surface Water Source Heatpump Systems Utilizing Stagnant Water, D. Chongqing university,2012.
[2] Mitchell, M.S., Spitler, J.D., Open-loop direct surface water cooling and surface waterheat pump systems -a review. HVAC&R Research 19 (2), 125-140.
[3] Davey Tom. Deep lake water cooling——a matter of degrees [J/OL],ronmental Science&Engineering. 2003, 9: 121-133.
[4] Fung,AlanS. Feasibility study of deep-lake water-cooling system at Ryerson University [J].ASHRAE Transactions, 2015,121(2):393-401.
[5] J.M. Cantrell, W.J. Wepfer, Shallow ponds for dissipation of buildingheat: a case study, ASHRAE Transactions Part 1 90 (1984) 239–246.
[6] Chen Jinhua,Yuan Juanjuan.Optimizsation analysis of open-loop surface water source heat pump system based on the life cycle cost evaluation method[J].Journal of hunan university(natural sciences).2013,40(5):24-30