Scheme analysis of Bath modification in West Campus of Beijing University of Chemical Technology

Yuhua Yang\textsuperscript{1,a}, Fan Zhang\textsuperscript{2,b}, Shuya Yang\textsuperscript{1}

\textsuperscript{1} Logistics Support Department, Beijing University of Chemical Technology, Beijing, 100029, China
\textsuperscript{2} Infrastructure and Planning Department, Beijing Jiaotong University, Beijing, 100044, China
\textsuperscript{a}hyang@mail.buct.edu.cn, \textsuperscript{b}fanz@bjtu.edu.cn

Abstract. Air-resource heat pump, as a Green energy-saving equipment, which converts low potential energy into high potential energy, is commonly used as an auxiliary heat source of solar energy. Air-resource heat pump is driven by electric energy, makes heat (cold) quantity with ambient air as cold (hot) source. It can not only refrigerate in summer, but also heat in winter [1]. This article analyzes the current situation of the public bathroom in a university, updates and selects the equipment according to the new requirements, and reasonably adjusts and uses the original system device, and adds an automatic control system. After reconstruction, it meets the use requirement and achieves the purpose of energy conservation. Finally, the article also gives some advice of further modification.

1. Introduction
Student bathrooms in colleges and universities are energy-intensive consumers, which account for a large proportion of the total energy consumption and total water consumption in colleges and universities. In recent years, the government has required energy conservation and emission reduction, renewable energy utilization, air pollution prevention and control, electric energy replacement, clean heating, climate change, industrial transformation and upgrading, etc. Compared with other heating schemes, the carbon dioxide emissions of heat pumps are significantly reduced. Heat pump is a kind of green energy saving equipment, air source heat pump is driven by electric energy, with ambient air as cold (heat) source to make heat (cold) quantity of equipment, can not only in the summer cooling, but also in the winter heating.

2. Bath conditions before modification of Beijing University of Chemical Technology
The bathroom heating system in the West Campus of Beijing University of Chemical Technology was originally gas-fired heating system, but has been transformed into solar energy and air-resource heat pump combined heating system. In spring, summer and autumn, sufficient free heat can be obtained when there is sufficient sunshine, and the energy saving effect is obvious. However, after the increase of the operating life of the heat pump, by the end of 2019, the original 4 sets of air-resource heat pump with heating rate of 20KW, three of which have a longer service life, and in order to ensure the bathing effect, the electric auxiliary heat is added.

The number of students in the West Campus is about 600 in 2019. According to the school's arrangement, the number of students in the West Campus will increase to 1,030 after the summer
semester begins in 2020. The student bathroom on the West Campus can so far only meet the needs of 300 people per day, and the hot water supply capacity needs to be increased to at least 515 people per day to meet the needs of the bath. Considering the service life and operating conditions of the existing heat pump, it will not be able to meet the requirements after increasing the demand for bath, so the heat pump and the system should be updated and reformed. Existing solar equipment is in good condition and can continue to be used, which is not within the scope of this transformation.

3. the selection of air-resource heat pump water heater unit

After the number of students taking baths increases, the heat demand should be reassessed. The selection of air-resource heat pump unit mainly depends on the heat generating capacity of the heat pump unit under rated working conditions, and the heat generating capacity required of the student bath depends on the daily water consumption of the bath. The calculation of the selection of heat pump unit is as follows:

3.1. calculation of heating quantity

According to Table 1, we can see that the daily water quota of each student is 50L for calculation. The daily number of students taking baths is calculated as 50% of the total number of students, and the estimated daily number of users is 515, so the daily demand of hot water for bathing is 25,750 L.[2]

| Item | Unit | Maximum daily water quota (L) | Average daily consumption of water (L) | Usable time (h) |
|------|------|-------------------------------|----------------------------------------|----------------|
| shower | Per customer per time | 40~60 | 35~40 | 12 |
| shower, tub bath | Per customer per time | 60~80 | 55~70 | 12 |
| sauna (shower, massage pool) | Per customer per time | 70~100 | 60~70 | 12 |

The surface water temperature in Beijing is 4°C, so the inlet water temperature of the heat pump is 4°C for calculation. The calculation formula is as follows:

\[ Q_g = k_1 \frac{q_r c (t_r - t_1) \rho_r}{T_1} \]  

Among them:
- \( Q_g \) — Heat pump design quantity, kJ/h;
- \( k_1 \) — safety factor, 1.05-1.1;
- \( q_r \) — amount of hot water, L;
- \( c \) — specific heat capacity, \( 4.187 \text{kJ/ (kg·K)} \);
- \( t_r \) — Hot water temperature, 45°C;
- \( t_1 \) — cold water temperature, °C;
- \( \rho_r \) — Hot water density, kg/L;
- \( T_1 \) — Unit design working time, 18h/d.

According to formula (1), it can be calculated as follows:

\[ Q_g = 1.05 \times \frac{25750 \times 4.19 \times (45 - 4) \times 1}{18} = 258042.9 \text{ kJ/h} \]

3.2. Selection of air-resource heat pump unit

According to formula (1), the heat required by the bath is 258042.9kJ, namely 72kW. Solar-thermal are greatly influenced by environmental factors, selection of air-resource heat pump does not consider
solar energy collection heat. Brand in the market at present is more, and the quality is uneven. Finally we selected a Midea RSJ - 800 type heat pump, 80 kW of thermal measurement under the rated conditions, circulating water flow 15.5 m$^3$/h (unit heating capacity was obtained under the following conditions: in outdoor dry/wet bulb temperature of 20 °C /15 °C, unit initial water temperature 15 °C, terminate the water temperature of 55 °C environment with standard). COP of energy efficiency ratio is 3.95, and the relationship between energy efficiency ratio and ambient temperature is shown in the figure below:

![Variable condition curve](image)

**Figure 1. The variable condition curve**

4. system improvement

4.1. The system before the modification
The Bathhouse in the West Campus has a total of 5 water tanks. 4 tons of water storage tank is heated by solar energy and air-resource heat pump. When the water temperature reaches the setting temperature, it will be stored in the 14 tons of water tank and poured into the 12 tons of water tank when students take a bath. The system before modification is shown in Figure 2.

![Diagram of system before modification](image)

**Figure 2. The system before the modification**

Note: 4t, 14t and 12t are water tank capacities.

4.2. The system after the modification
The bathroom is open from 15:30 to 21:00 every day, and the heating and collection system is operating from 7:00 to 21:00.

The choice of the storage tank is not only related to the water production of the heat pump unit, but also related to the actual usage. The calculation showed that existing two 14 tons of water tanks as storage tanks can meet the use [3]. Two 4-ton water tanks will be changed into solar heating tanks, which will be heated by solar energy and then enter the 14-ton water tank, which will be heated by the
heat pump. The 14-ton water tank is heated directly by the heat pump and interconnected with the automatic control system to reduce the energy loss of the system water storage (Figure 3).

![Diagram of the system after modification]

Figure 3. The system after the modification

4.3. **Steel coil is added in the water tank**

Steel coil is added in the water tank for heat exchange to solve the problem of scale on the unit. The coil plays a role in heat exchange, and the thermal efficiency is higher than that of plate heat exchanger. The end of the system can continue to use the electric heating rod as auxiliary heat, with low cost and no impact on the unit which is caused by scale.

4.4. **Add automatic control system**

There is no automatic control of the system before modification, so the operator on duty need to operate the system manually. Control system is added after modification. The table below shows details:

| System               | Action condition                                      | Control mode                                                                                                                                 |
|----------------------|-------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------|
| **Supplement tank**  | Starting condition                                    | The liquid level controller controls the high and low water levels, stopping at the high level and starting at the low level                  |
|                      | When T1-T2 > Δt1, system startup, Δt1 should be used  | 5~8°C, This project takes 8°C                                                                                                                |
|                      | Stopping condition                                   | 1. When T1-T2 ≤ Δt2, system stopped, Δt2 should be used at 1~3°C, This project takes 3°C                                                 |
|                      |                                                       | 2. When T2 ≥ 42°C, system stopped                                                                                                         |
| **Solar heating system** |                                                        | When the solar system stops running, the heat pump system will be closed through the main contact signal,                                   |
|                      | Starting condition                                   | At this point, if T2 < T3, the heat pump system is started. This project takes T3=42°C                                                      |
|                      | Stopping condition                                   | 1. When the solar heat collecting system is running, the main contact is disconnected and the heat pump system stops                        |
|                      |                                                       | 2. When T3 ≥ 42°C, system stopped                                                                                                          |
|                      |                                                       | 3. When the water level in the water tank is lower than a set value, the heat pump system will be stopped to prevent dry heating of the equipment |
Note: The temperature of the measuring point on the solar heat collecting side is $T_1$, the temperature of the measuring point in the water tank is $T_2$, and the setting temperature of the heat pump is $T_3$. Circulating pumps in each system are linkage controlled with heat collecting and heating equipment.

Figure 4. Bath monitoring system

5. **Modification effect**
After new semester beginning in September 2020, the number of students in the west campus will reach 1030. The effect of the bath modification is as follows:

- After the modification, the heat source capacity is stable and can meet the needs of students for bathing;
- The heating temperature of the heat pump is set at 42 degrees. The heating season of 2020-2021 is cold winter and the highest temperature in one-day was minus 10 degrees. The heat pump will stop heating when it reaches 39 degrees. In extreme weather, the electric heating of the end water tank can still meet the needs of students’ bath.

6. **Modification potential**
After the modification of the bathroom hot water system, the economical applicability and user experience have been greatly improved, but the system still has the potential of transformation and improvement, which can be considered from the following aspects in the future:

6.1. **Improving the heat insulation capacity of the water storage tank to reduce the temperature loss.**
The heating time of the hot water system is very long every day, and the storage time is more than ten hours, so the heat lost from the water storage tank cannot be ignored. As an important part of hot water system, the storage tank can be modified to reduce the temperature loss. For example, using double-layer stainless steel water tank, which is using polyurethane material in interlayer, can effectively reduce the temperature loss.

6.2. **Residual temperature utilization of wastewater**
According to the conclusion of relevant research literature [4][5] and actual bathroom measurement, the water temperature of the bathroom shower is 38–41 degrees, and the temperature in the wastewater pool is 30–33 degrees.

At present, the wastewater is discharged directly into the sewer network, and the temperature difference of at least 15 to 20 degrees can be used. If it is used for the pre-heating of bath, the heat of
waste water can be fully utilized. Higher water inlet temperature of heat pump can improve the energy efficiency ratio of heat pump and achieve the purpose of further energy saving.

7 Conclusions
After the bathroom modification of the West Campus, the updated heat pump equipment which has been reasonable calculated has solved the problem of insufficient heating capacity of the original heat source. So that the bathroom can meet the needs of more than one thousand students bath with a good user experience. The combined heating systems of Solar energy, air source heat pump and electricity-assisted heating have been added with automatic control to give full play to the efficiency of solar energy, minimize energy consumption and reduce human resource investment under the premise of normal operation.

This paper puts forward the idea of systematic improvement, which serves the teachers and students fundamentally, makes the energy technology get practical application, and points out the possibility for further reform.

References
[1] Zhu, X.W, Nie, X.L, Wang, X.C et al. (2012) Experimental Research of Air-Source Heat Pump Water Heater in Low Temperature. Research Journal of Applied Sciences, Engineering and Technology, 4(16):2740-2743.
[2] Ministry of Housing and Urban-Rural Development, PRC.(2019) Standard for design of building water supply and drainage GB 50015-2019. China Planning Press, Beijing.
[3] Yuan, Q.M. (2010) Determination of Effective Volume of Heat Storage Water Tank of Air Source Heat Pump Water Heater. Water Supply and Wastewater, 36 (S2) : 93-94.
[4] Jiang, Y.Z, Pan, J.G. (2020) Research on Energy Saving Reconstruction and Optimization of College Bathroom. Building Energy Saving, (4): 87-90.
[5] Feng, S.H, Li, D.Y.(2009) Analysis of recovery and utilization potential of waste heat from wastewater in public bathhouses of colleges in Beijing. In: The 16th Academic Exchange Conference of Building Thermal Power Branch of Architectural Society of China. Beijing. 226-228.