Nested Energy-saving Water Boiler Based On Air-source Heat Pump

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1. Introduction

The nested energy-saving water boiler based on air-source heat pump is a kind of multifunctional water boilers which can provide washing water in 60°C and drinking water in different temperatures. It use air-source heat pump as a major heating mode, and electric heating as a minor mode. It combines respective advantages of different heating modes, therefore, this water boiler can use power efficiently.

This boiler's key technology is the following aspects. Firstly, the use of multi-layer design and mutually nested structure in this boiler can achieve efficiently use of energy and reduce energy loss. Secondly, heat pump and electric heating are reasonably controlled so that water temperature in each tank will be maintained at a preset temperature range. Thirdly, the appropriate heat-preservation materials can reduce heat dissipation. Fourthly, the single chip circuit and various sensors can control solenoid valve opening and closing, thus the water level is maintained at the proper range.

Furthermore, we have conducted a survey of the boiler consumer market, there are several problems found in the current boiler. Such as high energy consumption, no temperature choice, unreasonable working control, etc. This nested energy-saving water boiler can solve such problems and meet the needs of customers.

The nested energy-saving water boiler based on air-source heat pump can be mainly used instead of the traditional electric heating water boiler in occasions with large-scale flow of people, its economy and energy efficiency is very significant and should be popularized widely.

2. Designing scheme

2.1 Mechanical part

2.1.1 Basic structure

This nested energy-saving water boiler uses a multi-layer structure design, and forms a nested structure. Side section of each tank has rectangular configuration with 45° chamfer, which is beneficial to forming a flow loop after heated. So that it can improve the heating efficiency.

This nested energy-saving water boiler is made up of drinking-water tank, washing-water tank, ice-water tank and heat pump accessories box. Covering the water tanks with polyurethane heat-preservation materials is beneficial to minimize heat dissipation, so as to achieve energy-saving.

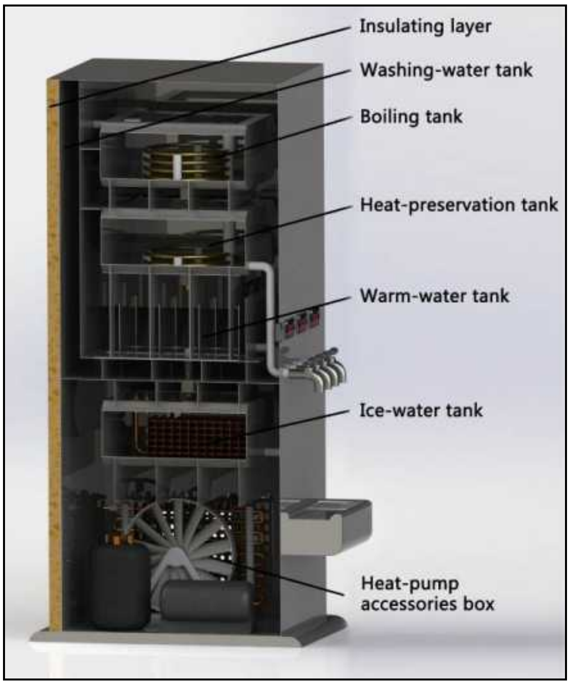

Figure 2.1 Front view and section view of the nested energy-saving water boiler

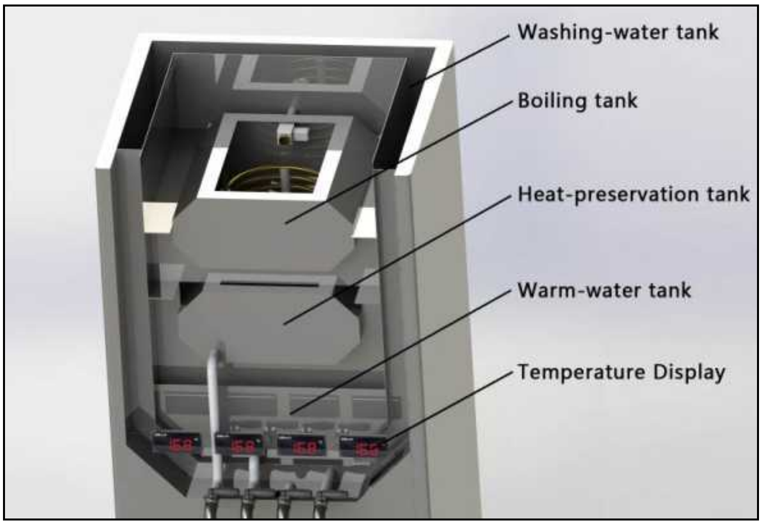

Figure 2.2 The internal structure feature without head cover

Washing-water tank surrounds the outside of the drinking-water tank, equipped with a heat pump condenser tube. It has comparatively large volume and is preheated by the heat pump to about 55°C. In this working temperature condition, the heat pump can work efficiently and its COP is higher than 4.3. This tank can provide a relatively lot of warm washing-water and provide drinking-water tank with preheated water. Meanwhile washing-water tank will absorb the lost heat of inside drinking-water tank and reduce the temperature difference between the outside environment and the water boiler, so that it can reduce heat release to the outside environment.

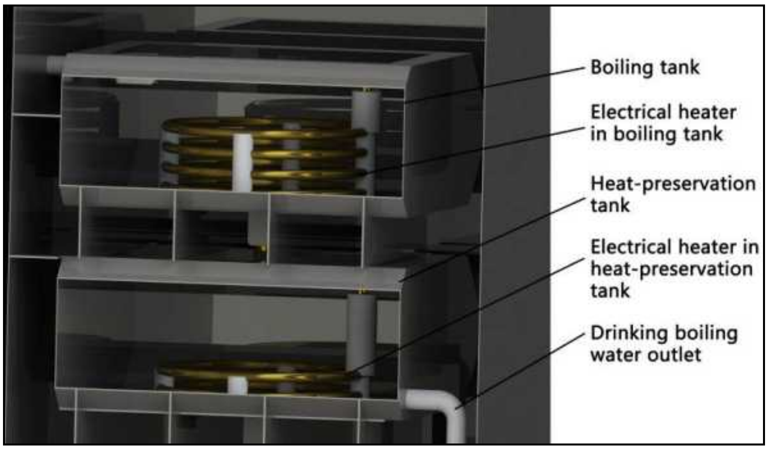

Figure 2.3 Internal structure of the boiling tank and the heat-preservation tank

Drinking-water tank is divided into three-tier structure. The upper part is the boiling tank, in which preheated water from the washing-water tank can be heated to boil by an electric heating pipe, so it can achieve a drinkable condition. The middle part is the heat-preservation tank, in which boiled water can be maintained at 95°C by an electric heating pipe, this tank can provide drinking boiling water and avoid unhealthy repeated boiling. The bottom part is the warm-water tank, in which water reduce temperature from 95°C to about 60°C by a heat exchange with the outside washing-water tank, thus it provide users with drinkable warm water by means of the heat dissipation.

Ice-water tank is located under the washing-water tank, equipped with a heat pump evaporation tube, drinkable warm water can be cooled by heat pump, the desired effect is providing water in about 15°C. It can be directly consumed at high temperatures or mixed with warm water.

The heat pump accessories box is located at the bottom of the boiler, including heat pump compressor, electromagnetic expansion valve, shell and tube heat exchangers, heat pump evaporator tubes, exhaust fan, boiler’s microcontroller, etc. There are openings on both sides of the tank, which form an air duct, so it can bring plenty of air for air-source heat pump. Boiler’s microcontroller controls each electrical device automatically and efficiently.

2.1.2 Machine dimensions

Machine dimensions and volume of each tank are shown in the following table:

Name	Dimensions (mm)	Volume (L)
Boiling tank	350*350*150	11.33
Heat-preservation tank	350*350*150	11.33
Warm-water tank	450*400*150	15.44
Washing-water tank	550*450*700	49.99

Ice-water tank	350*350*150	11.33

External dimensions of the nested energy-saving water boiler is 710*760*1340mm, and thickness of polyurethane heat-preservation materials is 30mm.

2.1.3 Design of heat pump

The nested energy-saving water boiler based on air-source heat pump has two evaporation tubes, which are distributed in the ice-water tank and the air duct. Two evaporation tubes are series structure. After through the expansion valve, heat pump refrigerant transits the evaporation tube in ice-water tank firstly, then transits the evaporation tube in air duct. After fully evaporated in evaporation tubes, heat pump refrigerant was pressurized in the compressor, then enters into heat pump condenser in the shell and tube heat exchangers. After pumped from washing-water tank, cold water get heat energy from heat pump refrigerant in the heat exchanger, thus the water boiler can achieve the function of heat pump heating.

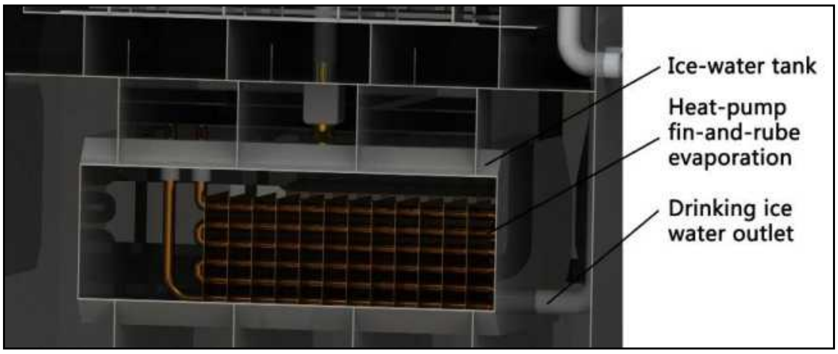

Figure 2.4 Internal structure of the ice-water tank

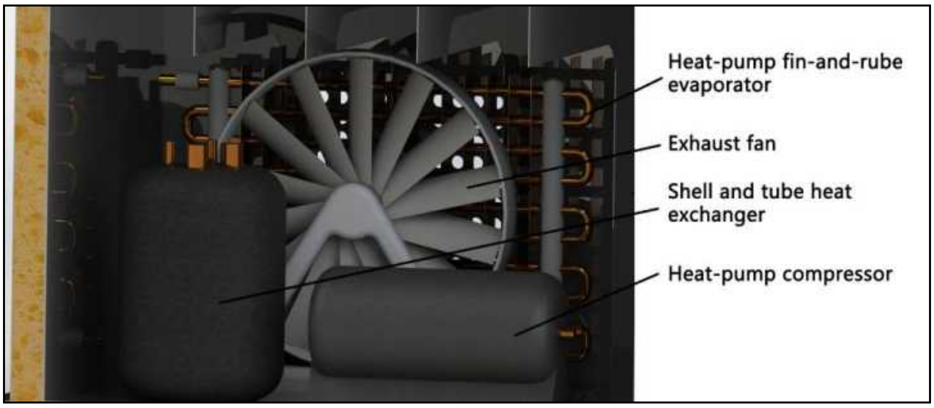

Figure 2.5 Internal structure of the heat pump accessories box

2.1.4 Material selection

2.1.4.1 Heat pump refrigerant

Heat pump working medium chosen R-417A refrigerant, of which toxicity and flammability rating are A1 level. R-417A is harmless to the atmospheric ozone layer, so it is accepted widely by the world as an environmentally friendly refrigerants.

2.1.4.2 Insulation materials

The nested energy-saving water boiler use high-density CFC-free polyurethane as insulation materials, of witch thermal conductivity value is less than 0.022 W/(m·K). The thermal conductivity value of conventional polyethylene foam is about 0.10 to 0.13 W/(m·K). So polyurethane can reduce the heat exchange, in order to achieve an energy-saving effect.

2.2 Control system design

2.2.1 Overall control

For the system to work efficiently and orderly, the control system need to monitor and control each tank water level and temperature in real time. We chose an 89C51 SCM as water boiler's control center, and use electrical heater, heat pump and solenoid valve as the executing units. In addition, we used DS18B20 temperature sensors and float-level switch to feedback level and temperature information to form a closed control loop.

2.2.2 Power section

Firstly, it use a transformer to reduce AC220V to 12V, then use a rectifier bridge to rectify in order to get DC12V. Through capacitor filter, the three-terminal regulator, it can provide relays and solenoid valve with DC+12V, which meanwhile provide MCU and other circuit with DC+5V. Electrical heaters and the heat pump compressor use AC220V as operating power supply.

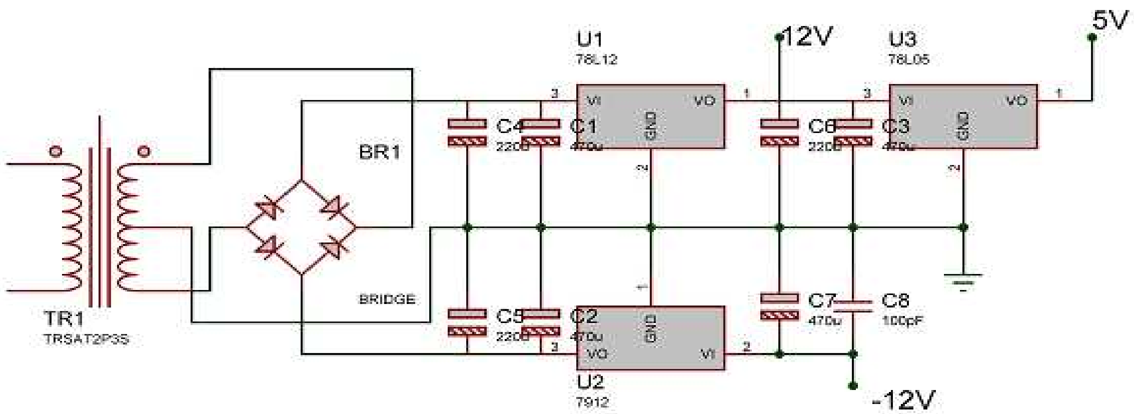

Figure 2.6 The circuit diagram of the power conversion section

2.2.3 Temperature control section

There are four units that need temperature control in the nested energy-saving water boiler. We use DS18B20 digital temperature sensor, 89C51 microcontroller, electrical heaters, air-source heat pump to measure temperature and control. SCM pickups temperature sensor information in fixed frequency. When the monitored temperature is below the temperature limit, SCM use optocoupler chip, transistors and high current relays as a driver circuit to drive electrical heaters or heat pump into heating. When the monitored temperature reaches the upper temperature limit, SCM control signals to the contrary, turn off the power of electrical heaters or heat pump.

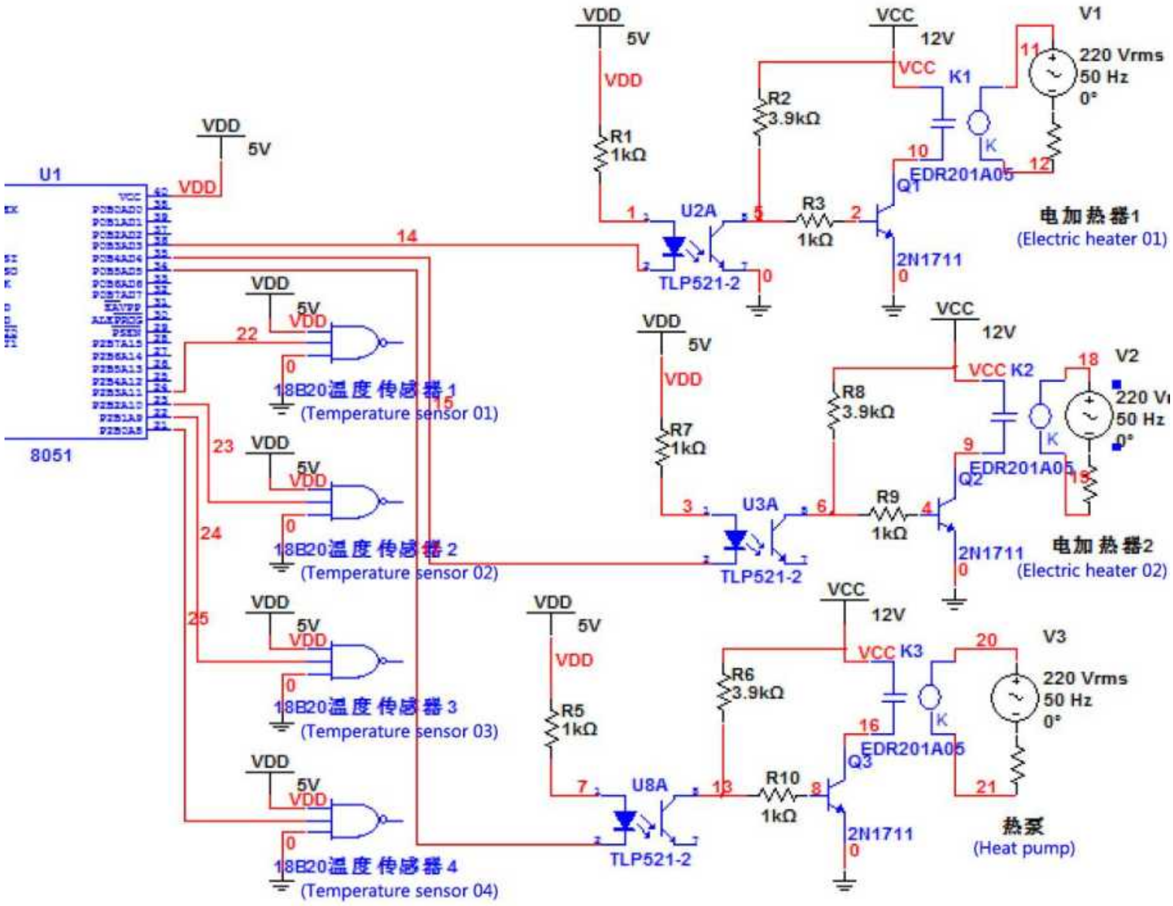

Figure 2.7 The circuit diagram of the temperature control section

2.2.4 Level control section

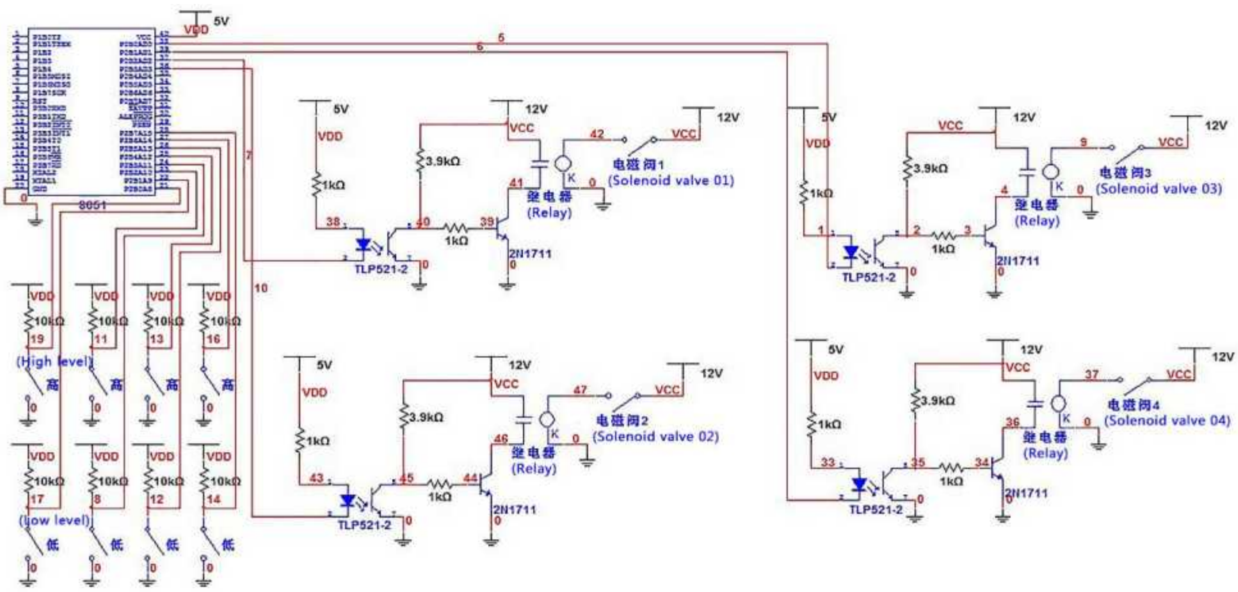

Figure 2.8 The circuit diagram of the level control section

Level control system uses the float switch as the water level sensor, and then add a small relay control to control solenoid valve, in order to keep the water level in a suitable range. For those five tanks have five similar control circuit. In order to avoid repeated boiling phenomenon, we use a double float switch scheme, so that the water level in the tank has a large level range.

Because the float switch cannot directly control solenoid valve or high power relays, we chose Omron small relay HH54P to drive the solenoid valve which needs DC12V.

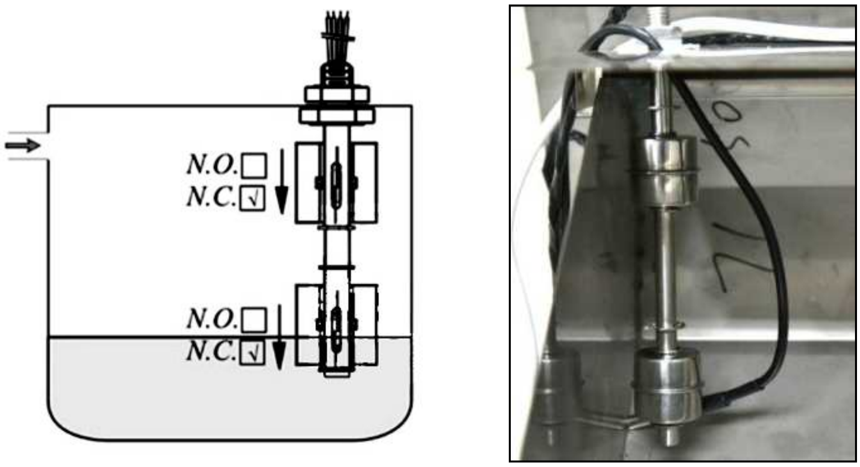

Figure 2.9 The Schematic and installation effect of double float switch

Figure 2.10 Omron small relay HH54P

3. Working principle

3.1 Heating principle

The nested energy-saving water boiler based on air-source heat pump use air-source heat pump as a major heating mode, and electric heating as a minor mode.

Because the technology of producing hot water around 55°C by air-source heat pump is quite mature and high efficiency, we use a two-stage heating method. First, tap water is heated by air-source heat pump in washing-water tank to about 55°C, which can provide users with live warm water. Then, part of warm water enter into the boiling tank, and it is heated by electrical heater to boiling in order to achieve drinkable condition. Next, boiled water enter into the heat-preservation tank, and it’s heated by electrical heater to keep upon 95°C, which can provide drinkable boiling water. Part of boiling water in heat-preservation tank will enter into the drinking warm-water tank. There will be heat exchange between the warm-water tank and washing-water tank, so the temperature of water in the warm-water tank will drop, therefore we can get drinkable warm water. Finally, some drinkable warm water will enter into ice-water tank, which is cooled by the heat pump principle to provide drinkable ice water.

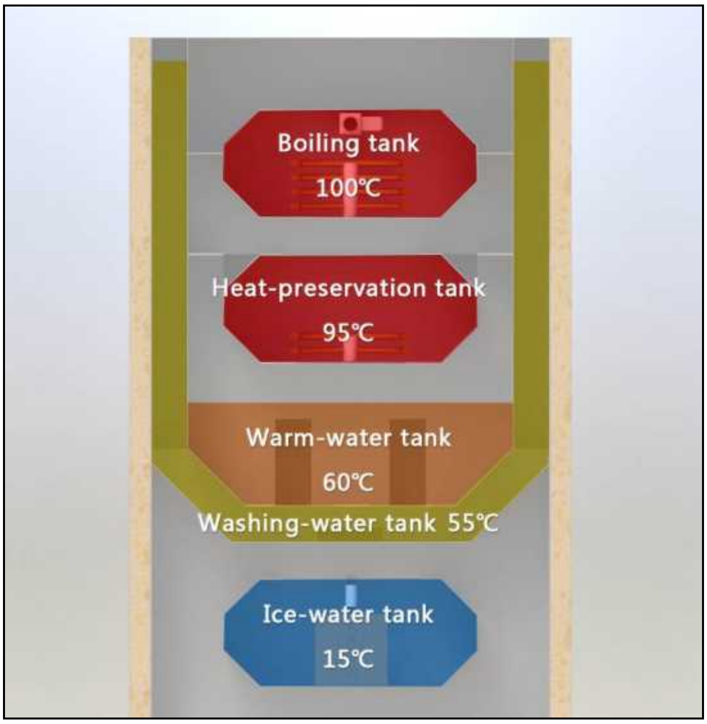

Figure 3.1 The temperature distributed diagram of tanks

The working principle of the heat pump is as follows.

a) The working refrigerant, in its gaseous state, is pressurized and circulated through the system by a compressor.

b) On the discharge side of the compressor, now hot and highly pressurized vapor is cooled in a condenser and releasing heat, until it condenses into a high pressure, moderate temperature liquid.

c) The condensed refrigerant then passes through a pressure-lowering device, such as an expansion valve.

d) The low pressure liquid refrigerant then enters another heat exchanger, the evaporator, in which the fluid absorbs heat and boils.

e) The refrigerant then returns to the compressor and the cycle is repeated.

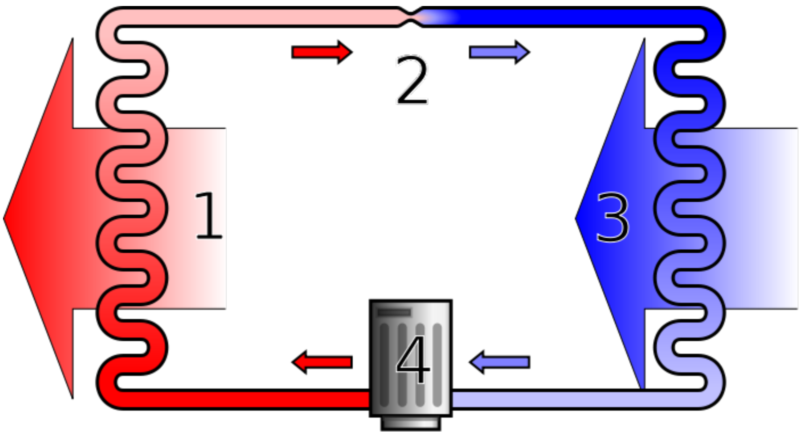

Figure 3.2 A simple stylized diagram of a heat pump's vapor-compression refrigeration cycle 1) Condenser, 2) Expansion valve, 3) Evaporator, 4) Compressor.

3.2 Work flow chart

The work flow chart of the nested energy-saving water boiler is shown below. As shown, we can got water in desired temperature from four outlets. Nested structure can maximize the recovery of the heat loss from the inside tank, while reducing the heat dissipation to the outside environment.

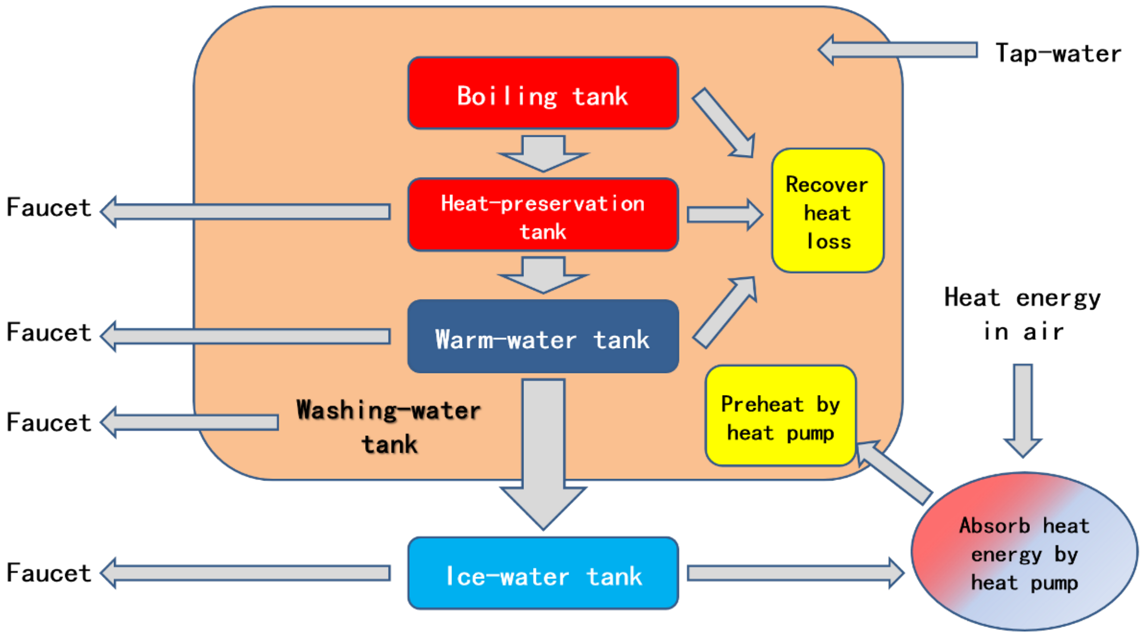

Figure 3.3 Work flow chart of the heat pump

4. Calculation of energy savings

The nested energy-saving water boiler use air-source heat pump principle, whenever and wherever it can absorb low-quality heat energy from the surrounding environment (low temperature heat source), and deliver refrigerant to the condenser by the compressor and releases heat in washing-water tank, of which the COP can be up to 4.3.

By referencing working data of current air-source heat pump water boiler on the market and experimental data of papers, we can calculate that per ton of water which is heated from 15°C to 55°C required 40195.2Kcal. Using electrical heating way needs ¥27.55, but using air-source heat pump water boiler only needs ¥4.81.

The consumption in student apartment environment, for example, can be calculated with reasonable assumptions. If we use ordinary electric heating water boilers, annual consumption of electricity was ¥ 826.5, while annual consumption of the nested energy-saving water boiler annual is ¥ 144.3. So each nested energy-saving water boiler can save ¥ 682.2, while reduce 1.395 ton of carbon dioxide emissions. In addition, the washing-water tank can recover plenty heat loss, which can be equal to save money ¥ 153.03. In a word, we can see its energy-saving effect is very significant.

5. Physical product and testing

We have completed calculation and design work of the nested energy-saving water boiler based on air-source heat pump, and machined a physical product to perform functional tests. The test result met the design requirements. Meanwhile, our team has completed the application process of a utility model patent, in order to protect the intellectual property rights of this design.

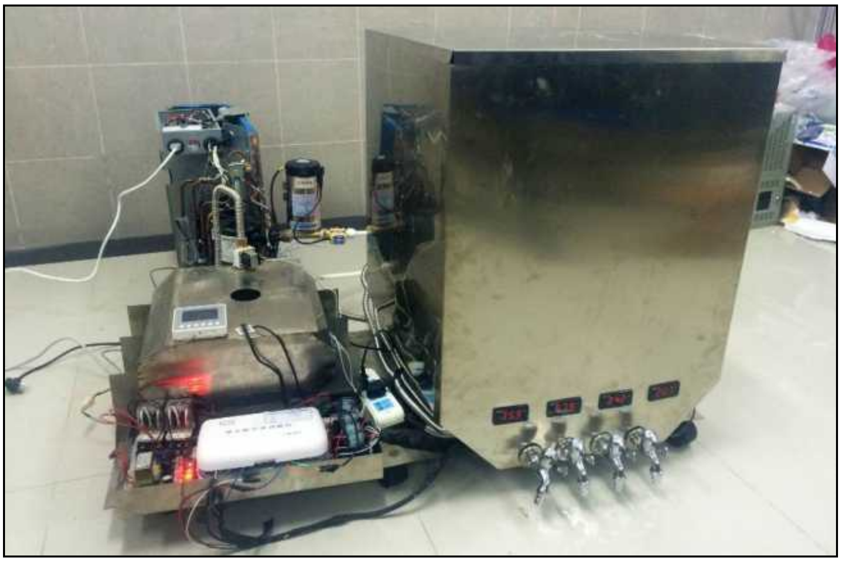

Figure 5.1 The nested energy-saving water boiler

Figure 5.2 Electronic control systems and electromagnetic relay

Figure 5.3 Air-source heat pump of the water boiler

6. Application environment

The nested energy-saving water boiler based on air-source heat pump can be mainly used in occasions that have large-scale flow of people, which can replace the traditional electrical heating water boilers, such as schools, apartments, office buildings, etc. For some occasions where people use it frequently, energy-saving effect of the product is more obvious and economic benefit is more prominent.