RESEARCH OF SOLAR HEATING SYSTEM DESIGN SOFTWARE

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1. Abstract

Solar domestic hot water systems are very popular in China, and millions of square meters of collectors were sold every year. However, most of the collectors were used for making hot water, only a few collectors are used for space heating. By the implement of Chinese national standard "*Technical code for solar heating system*"[1], more and more solar heating systems will be built. At present, engineers in China are not so familiar with solar heating system, they need some convenient tools for design. According to the standard and research of solar heating systems, we developed a software for solar heating system design. This software will be of great use for extending solar heating utilization in China.

Other commercially available software such as Trnsys, Polysun etc. was designed for simulating a given solar systems that the parameters were set up. They don't have the function of economic analysis and haven't considered so much about Chinese national standards. Solar heating design software could be used for designing a new project and have the function of economic analysis, and was designed closely in accordance with Chinese relative national standard.

2. Software design procedure

The software (see Fig. 1) is developed for design of solar hot water system, solar heating system, solar hot water and heating system and seasonal heat storage solar heating system. It includes more than 70 cities' hourly weather data of China, hundreds of manufacturers' information. The weather data and products parameters in this software can be changed manually. When designing a system, user can optimize the design by changing the heat load, collector's azimuth, solar fraction, volume of storage tank.etc.

Fig. 1: Main interface of the software

Especially, for seasonal heat storage system, the tank volume is a very important parameter. We can use the

software for calculating hourly temperature of the water temperature of the storage tank.

The solar flow chart (see Fig. 2) was introduced as follows：

（1） Begin

Start a new project, set up the location and building type.

（2） System information

Set up system type：Hot water supply system, Hot water supply + space heating system, Hot water + space heating + air conditioning system or Seasonal heat storage system. The hot water supply way should be chosen from full-time supply or fixed time supply.

（3） Load calculation

Hot water load is calculated according to Chinese national standards. Space heating and air conditioning load calculation need inputting building area, heat consumption index, air conditioning load, start time and end time of space heating. Software also support uploading hourly load file calculated by other software.

（4） Collector / SDHW type

According to the value of energy load, collectors or SDHWs can be chosen for the system.

（5） Solar irradiation calculation

The horizontal radiation is read from the database [2], with the input tilt angle and azimuth, the irradiation can be calculated.

（6） Collector area

Input solar fraction, the collector area of direct system can be calculated. The heat exchanger parameters should be confirmed in the indirect system

（7） Heat storage tank volume

Choose the tank type, and volume is calculated.

（8） Maximum water temperature of heat storage tank

For seasonal storage tank, the maximum water temperature of heat storage tank will be simulated and checked to insure the safety.

（9） Supplementary heat source

Confirm type of supplementary heat source and calculate the energy consumption of supplementary heat source.

（10） Hydraulic calculation

Choose pipes, working medium and calculate the parameters of pipes and pumps.

（11） Benefit analysis

The results include cost saving, invest recovery period, energy saving and carbon dioxide saving.

If the result is dissatisfied, recycle the calculation.

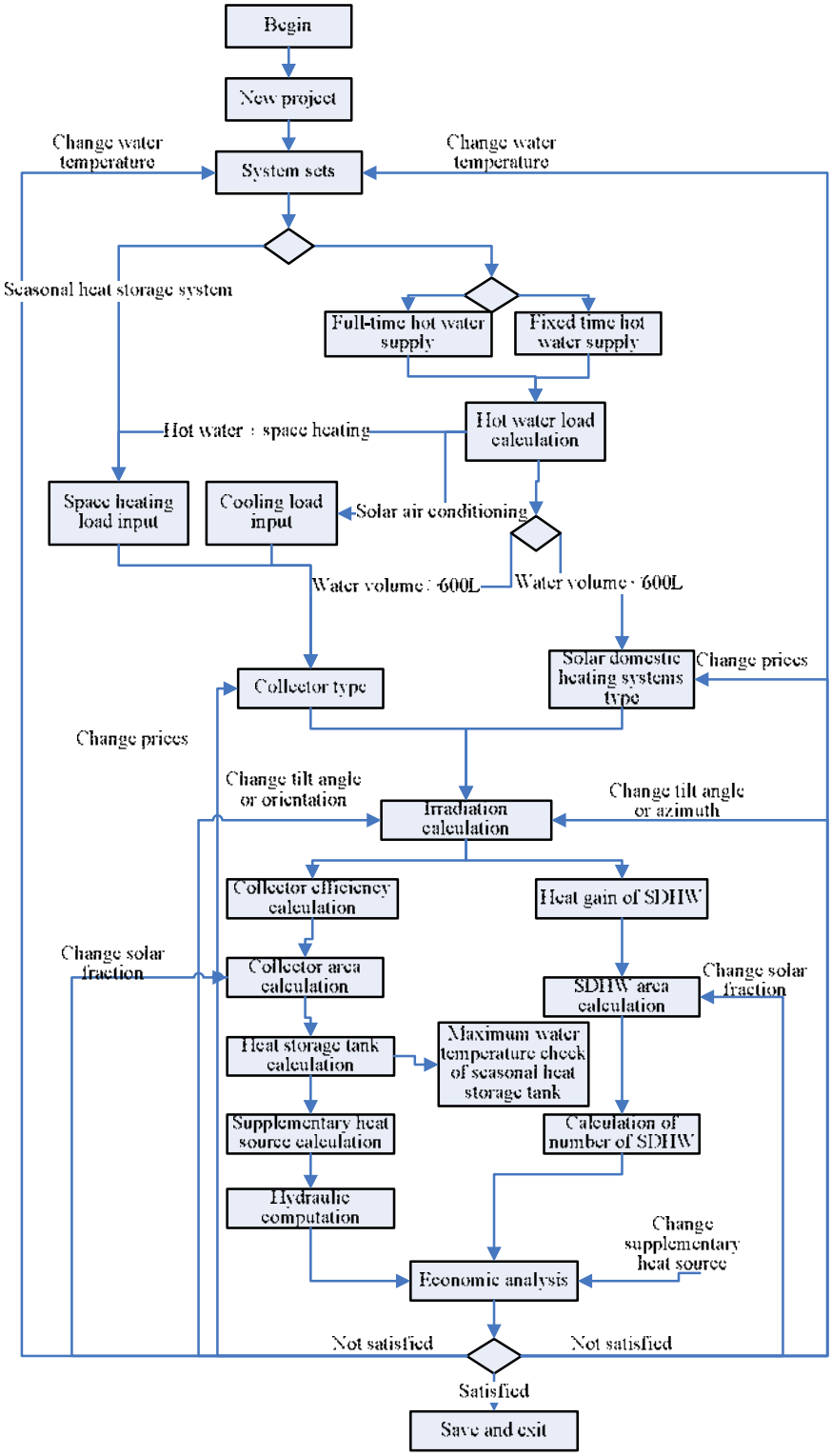

Fig. 2: Software flow chart

3. Main algorithm

3.1 Calculation of solar collector area

3.1.1 Direct solar collector area of the system

$$A_C = \frac{86400 Q_H f}{J_T \eta_{cd} (1-\eta_L)} \qquad \text{（eq. 1）}$$

Where： A_C —Collector area of direct solar heating system, m^2;

Q_H —Building heat consumption, W;

J_T —Daily solar irradiation per aperture area of solar collector, kJ/（m^2·d）;

f —Solar fraction, %;

η_{cd} —Efficiency of solar collector, %;

η_L —Heat loss ratio of pipe and heat storage, %.

3.1.1 Indirect solar collector area of the system

$$A_{IN} = A_C \cdot \left(1 + \frac{U_L \cdot A_C}{U_{hx} \cdot A_{hx}}\right) \qquad \text{（eq. 2）}$$

Where： A_{IN} —Collector area of indirect solar heating system, m^2;

A_C —Collector area of direct solar heating system, m^2;

U_L —Gross heat loss coefficient of solar collector, W/（m^2·℃）;

U_{hx} —Heat transfer coefficient of heat exchange, W/（m^2·℃）;

A_{hx} —Heat exchange area of indirect solar system, m^2.

3.2 Hourly temperature of seasonal heat storage tank

According to relative Chinese national standards, hourly temperature of seasonal heat storage tank should be simulated to insure the safety. The principle is shown in Fig. 3. The hourly heat gain, hourly heat consumption and heat loss are two important parameters for calculating the hourly temperature of the heat storage tank. The heat transfer process is considered steady state, and the water is well distributed in the tank.

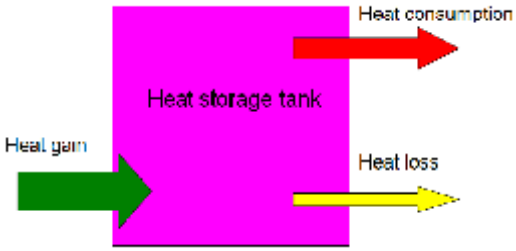

Fig. 3: Heat transfer principle of heat storage tank

（1） Hourly heat gain of heat storage tank is calculated by the equation below：

$$\Delta Q_{\mathrm{ak}} = J_{Tk} \cdot A_{\mathrm{c}} \cdot (1-\eta_c) \cdot \eta_{ck} \qquad \text{（eq. 3）}$$

Where： ΔQ_{ak} —Hourly heat gain of solar collector system, kJ；

$A\mathrm{c}$ —Collector area of solar collector system, m^2；

J_{Tk} —Hourly solar irradiation on aperture area of solar collector, kJ/㎡；

η_{ck} —Hourly collector efficiency of solar collector（based on aperture area）, %；

η_c —Heat loss ratio of pipes, %.

（2） Hourly heat loss of heat storage tank is calculated by the equation below：

$$\Delta Q_{lk} = \sum_{i=1}^{n} \lambda_i \cdot A_i (t_{wk} - t_{outk}) \qquad \text{（eq. 4）}$$

Where： ΔQ_{lk} —Hourly heat loss of heat storage tank, kJ；

λ_i —Heat transfer coefficient of the wall of heat storage tank, $\mathrm{kW/m^2.K}$；

A_{i} —Area of the wall of heat storage tank, m^2；

t_{wk} —Hourly temperature of inner surface of heat storage tank, ℃；

t_{outk} —Hourly temperature of external surface of heat storage tank, ℃.

（3） Hourly water temperature of heat storage tank is calculated by the equation below：

$$T_{K+1} = T_K + \frac{\Delta Q_{ak} - Q_k - \Delta Q_{lk}}{\rho V C_{\mathrm{W}}} \qquad \text{（eq. 5）}$$

Where： Q_k —Heat supply by solar system at time K, KJ；

T_{K+1} —Water temperature of heat storage tank at time K+1, ℃;

T_K —Water temperature of heat storage tank at time K, ℃;

ρ —Water density when water temperature is T_K, kg/m^3;

V —Water volume of heat storage tank, m^3;

C_w —Water heat capacity when water temperature is T_K, KJ/(kg.K).

（4） Initial soil temperature calculating method[3]:

According to meteorological data, the change of air and soil temperature is seasonal. The soil temperature calculation method can be seen in equation:

$$t_0 = t_d + A_d e^{-y\sqrt{\frac{\omega}{2a}}} \cos\left(\omega\tau - y\sqrt{\frac{\omega}{2a}}\right) \quad \text{（eq. 6）}$$

Where: t_d —Annual average ground temperature, ℃;

A_d —Range of ground temperature fluctuation, ℃;

y —Depth of the soil, m;

a —Temperature transfer coefficient of the soil, m^2/h;

τ —Time, h;

ω —Temperature wave frequency, rad/h;

For medium humidity soil, the temperature is postponed by 468 hours, when the calculate step of soil depth is 1 meter, the temperature calculating equation is as follows:

$$t_0 = t_d + A_d e^{-y\sqrt{\frac{\omega}{2a}}} \cos\left(\omega(\tau - (1+h)*468) - y\sqrt{\frac{\omega}{2a}}\right) \quad \text{（eq. 7）}$$

Where: h ——height of heat storage tank underground, m;

4. Example

For seasonal storage solar system, hourly temperature of seasonal heat storage tank must be checked for 5 degrees centigrade below the boiling point of water under the working pressure. One of the most important functions of the software is the hourly temperature calculation of seasonal heat storage tank.

There is a example of simulating the hourly temperature of heat storage tank in Beijing. The system is set as follows: The collector is heat-pipe solar collector that its instantaneous efficiency intercept is 0.554, and the gross heat loss coefficient is 1.562. The collector area are 100 m^2, tilt angle is 45 degrees. The initial

water temperature is 10 degrees centigrade.

By altering the heat storage tank volume, the maximum water temperature of heat storage tank is calculated. The results are shown in figure 4.

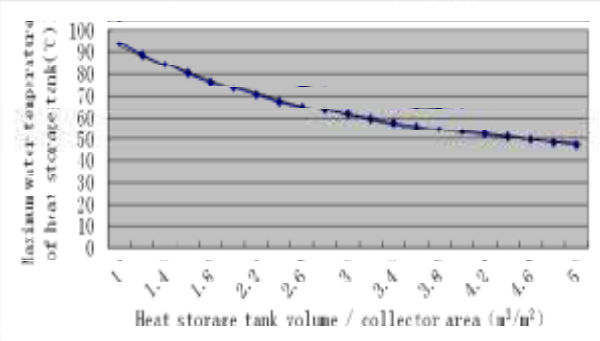

Fig. 4: water temperature of the storage tank against tank volume (software design example in Beijing)

From fig. 4, we can see that when the ratio of heat storage tank volume to collector area is less than 1 m^3 / m^2, the maximum water temperature of heat storage tank are more than 95 degrees centigrade, which couldn't meet the requirements of Chinese national standard. When the ratio of heat storage tank volume to collector area are more than 3 m^3 / m^2 and less than 5 m^3 / m^2, the maximum water temperature of heat storage tank are between 50 degrees centigrade and to 60 degrees centigrade, which is reasonable.

5. Conclusion

From above-mentioned views, we could summarize as follows：

- The software is fit for Chinese solar heating utilization and products, and the calculation function can be open-ended. The database is opened and can be synchronously updated with National Center for Quality Supervision and Testing of Solar Heating Systems (Beijing).
- The software can be used for solar heating system design and analysis, and is greatly helpful for development of solar heating systems in China.
- The calculation model should be continuously checked and modified according to relative national standards.

6. Reference

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2. China Meteorological Administration Meteorological Library Meteorological Information Center, Building Science of Tsinghua University, 2005. China building thermal environment analysis dedicated set of weather data, China Architecture & Building Press, Beijing.
3. Mou Lingquan, 1982. Calculation and application of wind tunnel cooling, China Architecture & Building Press, Beijing.