Study on energy saving of solar hot water system

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Abstract. On account of the limited non-renewable energy and enlarging energy consumption, solar seems to be an alternative, because it is free, clean and extensive, and can be changed into different energy forms, such as electricity and heat. Heat captured by solar hot water system in buildings can be the energy source of space heating and cooling system. This report attended to conduct a survey and acquire an understanding of the Solar Hot Water system in the CSET building (mainly collection device) and provide suggestions on energy reduction by solar hot water system.

1. Introduction
The energy consumption problem nowadays is needed to be resolved and hundreds of solutions are springing up. Solar hot water system can be one alternative, which mainly reduce the heating and cooling consumption in buildings. The Centre of Sustainable and Environmental Technologies (CSET) Building in the University of Nottingham Ningbo, China processes a solar hot water system, which mainly generates electricity to support cooling system in summer and is seldom combined with geothermal heating system for heating section in winter. To get access to this, the survey of solar hot water system in the CSET building will provide the basic knowledge of fittings, explain the working principles and come up with some suggestions for improving its efficiency.

2. Basic survey
Generally, the solar hot water system consists of three main parts: a collection device, a storage facility and a distribution system [5]. Figure 1 merely demonstrates the simplest components, which does not show the circulation of liquid.

Figure 1. Main parts of solar hot water system (active or passive).
The system is located on the grassland without tall buildings surrounded, which engage for the optimized solar reception. In order to capture more solar energy, the collectors equipped with evacuated tubes are sited to the south of the CSET building and face south, since Ningbo is in the Northern Hemisphere. Observationally, these collectors are all tilted at a same angle, not kept flat along the ground, because the optimum condition for absorbing sunlight is that the collectors are perpendicular to it. As a consequence, in common cases, the best angle tilted from horizontal line is usually equivalent to the latitude of the place [5]. Specifically the angle of the collectors is about 24 degree measured and calculated roughly, then add the approximately angle of the ground slope 4 degree by eyeballing, the total is 28 degree, which is close to 29 degree, the latitude of Ningbo.

Table 1 below shows the quantities and functions of fittings with the aid of photos and Figure 2 is the sketch of the structure and connections within various joints of the heat collector system in the CSET building on the grass (some tiny parts may be not described in details in the text, but can be seen clearly in the picture). The collectors, each installing 30 evacuated tubes, grouped in 3 matrixes. The individual matrix has 4 collectors in a line and the 6 lines are paralleled to each other. The whole system possesses only one main inlet pipe and one outlet pipe. The sub-pipes, linking four collectors in series, are parallel connection to the main pipes by T-joints and elbow-joints.

| Fittings of Solar Hot Water System | Quantities | Functions | Photos |
|----------------------------------|------------|-----------|--------|
| Heat collectors                  | 72         | Capture heat | ![Heat collectors photo](image) |
| Pressure relief valve            | 23         | Vent air  | ![Pressure relief valve photo](image) |
| Expansion vessel                | 1          | A buffer for pressure fluctuation | ![Expansion vessel photo](image) |
| Temperature sensor              | 36         | Provide temperature information | ![Temperature sensor photo](image) |
| Equipment                           | Quantity | Function                  |
|------------------------------------|----------|---------------------------|
| Small gate valve                   | 38       | Control the liquid flow rate |
| Large gate valve                   | 7        |                           |
| Valve connected with meter         | 3        | No information            |
| Flow rate meter                    | 3        | Indicate flow rate        |
| Pressure meter                     | 3        | Indicate pressure         |
| Thermometer                        | 2        | Indicate temperature      |

Besides, the distance between 2 collectors in parallel is 1 meter and in series is 0.3 meter. This design can avoid shadow caused by the front collector and the side collector. Otherwise, some parts of the evacuated tubes shaded by the hind (or side) collector cannot receive sunlight, which decreases the efficiency.

Each matrix has a volume flow rate meter and two large gate valves, one is installed in the sub-inlet pipe and the other sub-outlet pipe. The smaller valves, helping to control the water volume flow rate, and the pressure relief valves, venting air when workers do the maintenance repair, are set in proper position of the system. Two pressure meters and two thermometers are necessary to provide the information about the temperature of water flowing in main pipes. A temperature sensor in each line end is also required to offer data at all times when the system is functioning and make the water temperature easily controlled. Apart from these fittings, there is an expansion vessel (300 litres) with a
pressure meter at the top in the main inlet pipe to avoid cracking because of the heat expansion and cold contract property and the evaporation of flowing liquid mixture. In other words, the expansion vessel can sustain the pressure fluctuation during the operation period.

Pipe 2 in Figure 2 is supposed to be the main outlet pipe; the other is main inlet pipe. It is easily perceived from the image that Pipe 1 is much longer than Pipe 2. If the heated fluid returns in Pipe 1, there will be more heat loss in the relatively long flowing distance.

3. Analysis and Discussions

3.1. Working principle

The collection device is the most indispensable section. The pictures in Figure 3 are drawn simply. According to the Solar Collector Purchase Contract of the UNNC with Jiangsu Sunrain Solar Energy Company in 2008 in Asset Office of the UNNC, the devices are manufactured by Jiangsu Sunrain Solar Energy Company and the detail information of the collectors is presented in Table 2 [7, 8].

The material of the double tube outside is glass for that it is pervious to light and it holds vacuum better and longer [9]. During the sunny days, direct and diffuse light (including the light reflected by the aluminium layer below evacuated tubes) firstly strikes by glass tube and is converted into heat energy by dark selective coating, which absorbs mostly solar radiation with low reflection level [1]. Then the heat is transferred to the copper U-pipe through aluminium fin, which is pasted in inner tube inside. Figure 4 represents the sectional view of the evacuated tube. The structure of highly vacuum space between the outer tube and inner tube ensures excellent insulation and cut heat losses caused by conduction and convection [3, 5]. Therefore, the temperature of the fluid can rapidly increase, even exceeding 100°C [2]. However, the fluid will not be boiled so easily because the high pressure inside the pipes makes the boiling point higher than pure water. Despite the advantage of vacuum and glass allowing high absorption and low reflection, they make the evacuated tubes seem more fragile. However, the strong cylinder shape can be a feasible solution due to its high tolerance of pressure force [9, 10].
Figure 3. The size and structure of one collector viewed from side and top.

Table 2. Solar collector U-pipe.

| Model No.       | Collector Area (m²) | Vacuum Tube Quantity (piece) | Size Length/Width/Height (mm) | Gross Weight (kg) |
|-----------------|---------------------|-----------------------------|-------------------------------|-------------------|
| TZ47/1500-30U   | 2.91                | 30                          | 1660 × 2320 × 150             | 75                |

Remark: vacuum tube size: Ø47 × 1500

The U-pipe is made of copper, which features rather high heat conductivity. Thus, the cold liquid in the U-pipe is heated by the heat energy, especially the fluid in hot terminal facing the sun, which is stuck to the inner tube and with aluminium fin connected directly. The flowing direction and path in one collector through 30 U-tubes is illustrated in Figure 5. At one end of each main hot terminal or cold terminal in the collector, there is a plug to block the flowing and present opportunities to fluid to keep its pace through U-pipes.

The glycol-water antifreeze mixture flowing from inlet pipe to outlet pipe on Hot Water Supply that in the CSET’s system is circulated by pump. The pipes connecting the collectors and storage tanks are hidden in the earth. While being continually heated, the fluid carries the heat energy and transfers it to the water kept in the storage tank via heat exchanger, namely metallic spiral coils in this system. After that, the heated water in tanks can be utilized to generate electricity or assist geothermal system in building heating.
Figure 4. The structure of one evacuated tube.

Figure 5. U-tube solar collector.

3.2. Maintenance installation
The high vacuum cannot be kept perfect, because the entrance of tiny molecules and atoms, such as CO, CO2, N2, O2, H2O and H2, is inevitable after a certain time of running. By observing the model
of evacuated tube, the usage of gas absorbent or getter is introduced to solve the problem. It mainly absorbs air particles to guarantee a longer lifetime. When the getter turns white from silver, it means the space between inner and outer tubes vacuum any longer [6].

3.3. Safety consideration
High vacuum: The vacuum space has no liquid flowing inside. Therefore, the evacuated tube is not so fragile under the cold temperature condition [7, 8].
Reflective layer: four pieces of thin aluminium plates (each 1050 mm × 460 mm) in a solar collector are fixed as a reflective layer, configuration in one collector like ‘.’. The vacant space between the plates allows wind blowing through. Since the frequent occurrence of typhoon in Ningbo during summer and autumn, the vacancy can prevent solar collector falling down by the strong force of wind.
Holes: there are several holes excavated in concrete supporting device to drain away water in rainy days.

3.4. Suggestions for improving efficiency
Further efficiency can be improved by following methods.
First is the angle issue. As said before, the angle of the collector from horizon is around the latitude of Ningbo when it is fixed. Actually, this number is calculated by the formula: $90^\circ - \text{altitude} = \text{angle of collector}$. The altitude is changing over time and the sun path varies every day. With the assistance of Solar Radiation Monitoring Laboratory of University of Oregon, the sun path diagram of Ningbo is drawn as follows (Figure 6).

![Figure 6. The sun path diagram of Ningbo.](image)

Within given date and time, the altitude can be read by the intersection of them in the diagram. The result is often different. However, the average angle is approximately equivalent to the latitude of the place. To improve the absorption efficiency of evacuated, the metallic framework can be recommended to rotate automatically to alter the angle in accordance with the changing altitude controlled by computer system. Furthermore, the front side of collector can also automatically move to face the sun directly, just like sunflowers.
In spite of the advantage of maximum absorption efficiency, this system should require cutting-edge technologies and sums of funding. To be easier, it is seen obviously from the sun path diagram that the average altitude in summer is larger than it in winter, leading to the complementary angle is smaller. Since the solar collector is mainly used in summer and the Tropic of Cancer is 23.4° North of the equator, the angle is reasonably supposed to be adjusted smaller than 29°, perhaps around 23°, to achieve higher efficiency in hot days.

Then, using Compound Parabolic Concentrator (CPC) mirror (Figure 7) is another approach to increase the efficiency. It maximises light reflection to evacuated tubes at arbitrary angle. Moreover, it reflects both direct and diffuse solar rays. Hence, there is less weather limitation to the system applied CPC mirror, particularly in cloudy day, winter, dawn or dusk [4].

Finally, the absorption efficiency can be also improved by altering of internal tube structure. Currently, the aluminium fin only is connected with hot terminal of the copper U-pipe. To improve the transfer efficiency of heat, aluminium fin can be linked with cold terminal. In the same time, the position should be changed close to the inner tube, as indicated in Figure 8, which needs precision instrument and demands high accuracy of manufacture progress.

4. Conclusion
The solar hot water system is a valuable and favorable component of the sustainable building. A number of fittings, including meters, valves and pipes, are set up properly for controlling, detection and inspection. The core of system is the evacuated tubes. These tubes with copper U-pipe inside has predominant characteristic on absorption efficiency. By converting massive heat energy through
insulated pipes, the system can provide power source to heating and cooling actively and make the building in maximum comfort. Some secure and maintaining designs are brought into the system. However, in order to reach higher efficiency, the system can be promoted by modulate the angle, utilizing CPC mirror and change the inner structure of evacuated tube. Generally speaking, by doing these realistically, the solar hot water system in the CSET building can perform much better.

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