Research on the Solar Water Cooler

Chengyao Zhong
School of Physics and Electronic Engineering, Hainan Normal University, Haikou, Hainan, 571158, China
e-mail: 490086268@qq.com

Abstract: a solar water cooler that uses solar energy directly or indirectly to cool the water consists of a cool water storage tank, a condensing wall, an auxiliary refrigeration device, with an insulating board dividing the cool water storage tank into an upper water-cooling tank and a lower water freezing tank. The system provides a solar water cooler with a dual-temperature cool water tank that reduces the water temperature to the minimum temperature of the day via heat dissipation, and the obtained minimum-temperature water is delivered directly for cooling purposes or delivered onto the condensing device as cooling water to improve the cooling efficiency. The auxiliary refrigeration device helps reduce the water temperature when the cooling water does not reach the required temperature for the air conditioner for refrigeration purposes. The major tasks of this study are to reduce the temperature of the cooling water to lower than the minimum temperature of the day and increase the required temperature of the air conditioner for refrigeration to save energy. With these two challenges solved, most areas in the world can use air conditioners with solar water coolers for cooling purposes, thus alleviating global warming and benefiting the whole world population.

1. Introduction
In recent years, with fast economic growth, urban power demand surges, and the power consumption by air-conditioning systems in urban buildings take a large proportion – higher than 50% of the total power consumption of buildings. In the peak season in summer, the power consumption of air conditioning systems in northern China takes up 16% ~ 18% of total power consumption in cities, and that in developed cities in southern China (Guangzhou, Shenzhen, etc.) takes up a proportion of over 30%. Air conditioners consumes large amounts of power, and peak hours of cooling load coincide with the peak hours of urban power consumption, which exacerbates the supply-demand imbalance of power and aggravates the power shortage in peak hours. To relieve this grave situation, the Chinese government has taken a series of measures: in 1994, the State Development Planning Commission and the Ministry of Electric Power decided to differentiate the price of electric power in peak and valley seasons to “balance the peak and valley”. The Northern China Electric Power Group first stipulated that ratio of the power price in the peak season to that in the valley season is 4.5:1; after that, many electric power departments followed suit and released some preferential policies. Driven by these initiatives, the cool storage air-conditioning technology gained rapid progress [2].

Since the 1980s, cool storage air-conditioning technology has developed rapidly and improved in developed countries around the world. Given the experience of the US, Japan and Taiwan, one important solution to solve the power demand-supply imbalance is to develop cool storage air conditioners. Take Japan as an example: in this decade, Japan has built or renovated over 3000 cool storage systems, increasing the power utilization rate in valley seasons to 45%; South Korea issued laws that public buildings covering an area of over 3000 m2 must use cool storage air-conditioning
systems. In 1990s, cool storage air-conditioning technology began to gain momentum in China; large provinces and cities including Shenzhen, Beijing, Guangzhou, Zhejiang, Shanghai, Tianjin, Wuhan and Fujian initiated several large- or medium-scale cool storage central air-conditioning programs which achieved good economic efficiency and were promoted in more than 20 provinces across China. The current situation shows that the users and the electric power departments have provided positive feedback for these programs. The users need to pay less power fees, the performance of the new system was better than the traditional systems, and the goal of “balancing peak and valley” of power departments is reached [2].

The range of temperature of air-conditioning systems is 15~30 °C, which is within the range of natural temperatures in China, and thus can meet the needs for natural cooling and reach the goal of saving energy. The nature of cooling energy is: making use of the temporal and spatial difference of the natural temperatures to store energy and reach the goal of cooling [3].

2. Components and principle of the solar water cooler

2.1. Components of the solar water cooler
The solar water cooler consists of a cooling storage water tank, a condensing wall, heat dissipation pipes, heat dissipation sheets, an upper cooling water tank, a temperature-insulating board, a lower chilled water tank, a reflux pump, an auxiliary refrigeration device, intra-connected pipes, water inlets, water outlets and ports, as shown in Figure 1.

![Figure 1. Components of the solar water cooler](image)

2.2 Working Principle of the solar water cooler
As shown in Figure 1, on the middle mid-section of the cooling storage water tank (1) is a temperature-insulating board (13) that divides the tank into an upper cooling water tank (12) and a lower water refrigeration tank (17); between these two tanks, there are connecting pipes (2 and 15) that connects these two tanks; inside the tank at the water inlet port of the chilled water tank, a reflux pump (18) is installed to recycle the chilled water; the condensing wall (7) is installed above the cooling storage water tank to dissipate heat, and at the water inlet of the heat dissipation pipe (8), there is an opening to the outside; between the condensing wall (7) and the chilled water tank (12), the pipe (6) connects the upper part with the upper part, and the pipe (10) connects the lower part with the lower part; above the chilled water tank (17) is installed the auxiliary refrigeration device (5) that
consists of a thermopile cooling component and a temperature monitor. The pipes (4 and 11) connect chilled water pipe of the auxiliary refrigeration device (5) and the chilled water tank (17). As the proportion of cool water is larger than the chilled water, the water of higher temperature in the upper part of the cool water tank (12) should be pumped upwards to the condensing wall (7) for natural heat dissipation, and then flows back to the lower part of the chilled water tank. Through repeated circulation, the water temperature can be reduced to the minimum temperature of the day to obtain the chilled water that is then delivered to the refrigeration device via the water outlet (14) to chill the condenser in the refrigeration device to improve the refrigeration rate; the chilled water after being heated flows back to the upper part of the cool water tank (12) through the water inlet (3); as between the cool water tank (12) and the chilled water tank (17) are installed intra-connected pipes (2 and 15), the water temperature in the chilled water tank (15) also reduces to the minimum temperature of the day. If the water temperature in the chilled water tank does not meet the requirements, the temperature monitor in the auxiliary refrigeration device (5) starts the thermopile condensing component to further reduce the water temperature in the chilled water tank; in this way, the required chilled water is obtained, which absorbs heat and reduces the temperature in the pipes via the water outlet (16), and then flows automatically via the water inlet (19) or is driven by a reflux pump back to the upper part of the chilled water tank. If the water temperature is higher than the chilled water, then the chilled water flows upwards to the upper part of the chilled water tank via the pipe (2), and the chilled water in the lower part of the cool water tank flows back to the lower part of the chilled water tank via the intra-connected pipe. The storage cooling water tank consists of the liner made of stain-less steel, the thermo-protective layer made of poly-foam, and a surface made of aluminum sheet.

3. Analysis of energy saving performance of the solar water cooler

3.1. Natural cold energy cooling

Natural cool energy is defined as “low temperature difference-caused low-temperature energy that exists in the natural environment”, also termed “cool energy”. In fact, “hot” and “cool” are comparative concepts; regardless of the temperature, whenever there is temperature difference, there is energy. As the nature has infinite capacity in maintaining the temperature of the environment, and the temperature difference is ubiquitous. Thus, the cool energy is infinite and a type of massive low-grade energy. Most areas of China have a continental climate, with large diurnal temperature difference and seasonal temperature difference; compared with those in marine climates, these areas have larger cool energy and a lower cost for using such energy. Cool energy has the same economic value as wind energy and solar energy, and its utilization will not incur any pollution [4]. There are already many cases where the cool energy is used for refrigeration in air-conditioning systems.

The central air-conditioning system in Liyujiang Power Plant is a self-developed system that takes the river water as the cooling source. The system serves the residences and offices in the plant, with a designed total cooling load of 4350 kW, and a total heat load of 3970 kW. In summer, the system uses the discharged water from Dongjiang Reservoir as the cooling source for cooling purposes in the plant, without need to use the refrigeration engine; in winter, the plant uses the electricity-driven steam engine to heat the river water to supply heat for residents and workers. The system was designed in 1997, troubleshot in 199 and put to use in May, 2000. The system works well and all indicators meet the requirements after put to use in the first two years. The overall investment reaches 7.45 million yuan which is 10 million yuan less than other traditional central air-conditioning systems of the same scale; the annual operation fee is over 1 million yuan less, which shows good energy-saving performance and discharges no pollutants [5].

3.2. Radiant cooling

Radiant cooling is to reduce the temperature of one or several surfaces inside the surrounding support structure to create a cooling radiant surface and reduce the temperature through heat exchange
between the radiant cooling surface, the human body, the furniture and the other surfaces of the surrounding support structure. As the radiant heat transfer in the radiant cooling system takes up 50% of the total heat transfer, and the indoor temperature cooled by the radiant cooling system is 1 ~ 2 °C than that cooled by traditional air-conditioning system. The radiant cooling system has advantages of saving energy, strong comfortability and little pollution [6]. The tradition of using radiant cooling technology could be dated back to the 1980s in Europe. So far, it has already been widely used in malls, banks, supermarkets throughout the Europe, especially in Germany and Switzerland [7].

In radiant cooling systems, the water temperature is higher than that in traditional air-conditioning systems, and the cool water temperature is 16 ~ 18 °C. For this temperature range, in northwestern China, the natural cooling sources like evaporation and cooling, deep-well water, ground cooling energy, and indirect evaporation cooling machine to provide the cooling water temperature required by the radiant cooling system [8]. The radiant cooling ground could reduce the surface temperature of the surrounding support structure, thus increasing the transferred radiant heat of the human body and improving the indoor comfort. To minimize the energy consumption, the floor radiant exchange ventilation system can increase the indoor temperature by 2.5~3°C compared with traditional air-conditioning system in a given comfort condition [9].

Analyses above show that the chilled water temperature of the radiant cooling system is 21~22°C. In most areas in China, the minimum temperature at night approaches 20 °C; for areas with a minimum temperature higher than 20 °C, the solar water cooler can obtain chilled water of the minimum temperature of the day without consumption of any form of energy.

When the chilled water does not reach the required temperature, the water-cooling unit uses the low-price electric power of the valley period and produce cooling energy during the minimum-temperature period of the day. The cooling coefficient reaches above 10 [10], and can reduce the consumption of power and cut the electricity fee.

As Figure 2 shows, when the evaporation temperature T0 and the required cooling volume Q0 remains constant, and the compressor takes in saturated gas, the computer program computes the condensing temperature Tk within 25 ~ 40 °C, the cooling coefficient and the change ratio of the power consumption of the compressor. The experiment data and the computing result show that, for every 1 °C increase in the condensing temperature Tk, the condensing coefficient ε decreases by 2%, and the power consumption of the compressor increases by 2% [11].

![Figure 2. Correlation between the compression cycle performance and the condensing temperature.](image)

Analyses above show that to perform condensing during the period of minimum temperature of the day can save much electric power.

Moreover, if the air-conditioning system uses the electric power during the valley period, it can help achieve the goal of “balancing the peak and valley”. Table 1 shows the electric power price of industrial and commerce sectors and other fields of Hainan. As the table shows, to use electric power during the valley period for cooling can reduce the household electricity bill by 2/3, which indicates a good social and economic efficiency.

| Type | Compressor capacity | Voltage level | Power price | Valley price | price/peak |
|------|---------------------|---------------|-------------|--------------|------------|
|      | Peak              | Regular       |             |              |            |
|      |                   |               | Power price |              |            |
|      |                   |               | Peak        |              |            |
|      |                   |               | Regular     |              |            |
|      |                   |               | Valley      |              |            |

Table 1. Time-of-use power price for industry, commerce and other fields in Hainan

unit: yuan/kWh
Time-of-use power price division: peak period: 10:00 – 12:00; regular period: 7:00 – 10:00, 12:00-16:00; valley periods: 23:00 – 7:00 (next day)

4. Conclusions
In this study, we proposed a solar water cooler that directly or indirectly uses solar energy for cooling purposes and consists of a storage cooling water tank, a condensing wall, an auxiliary refrigeration device, with a thermos-insulation sheet separating the tank into an upper cooling water tank and a lower chilled water tank. The system provides a solar water cooler with a dual-temperature storage cooling water tank that reduces the water temperature to the minimum temperature of the day via heat dissipation; the obtained low-temperature water serves the cooling purpose via the pipes or flows into the condensing device as cooling water to improve the cooling efficiency. The auxiliary refrigeration device further reduces the water temperature when the cooling water does not reach the required temperature. The study aims to reduce the water temperature to lower than the minimum temperature of the day and increase the temperature of the chilled water required by the air conditioning system to save the energy. If these two challenges are overcome, most areas around the world can use solar water coolers for cooling purposes, alleviate global warming and benefit the whole population across the globe.

Acknowledgment
This work was supported by the project of Natural Science Foundation of Hainan Province (No.518MS053)

References
[1] Zhong C. Y., Yan S. S, Xing Y. C. Solar water cooler [P], ZL200410069513.4, Aug. 2009
[2] Liu Y., Zhou F. J. Current situation and prospect of use of natural cooling resources in northern China [J]. Journal of Agricultural Mechanization Research, 2007, 8: 190-192
[3] Zhang J. S., Fu R. Natural cooling energy: potential energy [J]. Environment Herald, 2003, 13:14
[4] Zhang J. S., Sun C. Q, Fu R., et al. Potential green energy in the 21st century – natural cooling energy [J]. World Sci-Tech R&D, 21 (1): 51- 54
[5] Jiang A. H., Mei Z. Research on use of reservoir water difference energy in cooling air conditioners [J]. Heating, Ventilating and Air Conditioning. 2004, 34(3):84-86
[6] Chen B. Brief analysis of radiant cooling supply system [J]. Refrigeration Air Conditioning & Electric Power Machinery, 2010,31 (2):69-72
[7] Miu A. G., Huo H. E. Brief analysis and design of radiant cooling systems [J]. Refrigeration and Air Conditioning, 2008,22(6):96-101,92
[8] Xuan Y. M., Huang X., Yan Z. H., et al. Application of evaporation and radiant cooling systems using dry air in northwestern regions [J]. Fluid Machinery, 2009,37(2) :82-85,68
[9] Zhang C. Y., Wang Z. J. Impact of radiant cooling ground on the surface temperature and indoor thermo-comfort in surrounding support structures [J]. Architecture Science, 2008,24(10): 79-84
[10] Jiang Y., Li Z., Chen X. Y., et al. Solution air conditioner and its application [J]. Heating, Ventilating, Air Conditioning, 2004, 34 (1): 88-97
[11] Huang X. Q. Design of household air source heat pump water heater (I) [J]. Domestic Technology, 2006,12: 48-49