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Study on Water-Cooled Solar Semiconductor Air Conditioner

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Abstract: Aiming to compare the cooling effect, two types of solar-powered semiconductor air-conditioning devices were designed in different structures. According to the cooling load in an experimental room, the solar panels and battery capacity were determined for the development of a test system. In the same working condition, a comparison test was carried out to examine the cooling performance. Experimental results showed that the design of dual water-cooled cooling unit presented a higher ratio of energy efficiency, with its maximum value of 1.08. By observing the experimental data of the prototype, its comparative economic evaluation results indicated that the annualized cost of solar semiconductor air-conditioning was app. 2.7 times that of air-conditioning made from an ordinary compressor.

Keywords: Peltier effect, semiconductor air conditioner, solar energy.

1. INTRODUCTION

Utilization of solar energy includes two aspects: Thermal use and power generation. General solar thermal projects, such as heat collecting, supply of heating water, etc., are not fully consistent with the available solar energy on demand. In cold weather, the heat provided by the sun is often inadequate. While in the hot summer weather, a large proportion of power energy may be consumed in the cooling operation.

Solar cooling is highlighted in some advantages: 1) Well match to the seasons, that is, the hotter the weather, the stronger the solar radiation, the greater the cooling capacity of the system; 2) solar cooling system can be effective in combining the summer cooling and winter heating, plus the hot water supply in other seasons, significantly improving the utilization and economic benefits; 3) helpful to reduce the power load of the peak summer season, leading to a reduced pressure on the grid.

A solar semiconductor cooling system is based on the thermoelectric cooling effect of semiconductors, where solar cells are responsible for the DC supply required for semiconductor cooling chips, ensuring the effective cooling and heating operation [1-3]. As shown in Fig. (**1**), a solar semiconductor cooling system consists of 4 components: solar photoelectric converter, NC matcher, energy storage device and semiconductor cooling device. Photovoltaic inverter governs the DC output, part of which supplies the semiconductor cooling device, and the other part comes into the storage device for backup on cloudy days or at night. This makes it possible that the system runs around the clock.

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2. CALCULATION OF COOLING LOAD

The roof is type III, as shown in Fig. (**2**).

$K_1=1.16W/(m^2.K)$,

$F_1=8.4\times5.4=45.36\ m^2$

North window, all glass in single-layer, blue curtains, $F_2=6\times2.2=13.2\ m^2$

North wall, brick,

$K=1.55W/(m^2.K)$,

$F_3=8.4\times3.5-13.2=16.2\ m^2$

East window, all glass in single-layer, blue curtains, $F_4=2.7\times3=8.1m^2$

West wall, brick,

$K=1.55W/(m^2.K)$,

$F_5=5.4\times3.5=18.9\ m^2$

East wall, brick,

$K=1.55W/(m^2.K)$,

$F_6=5.4\times3.5-8.1=10.8\ m^2$

Indoor design temperature: $t_n=26\ °C$

4 people working indoors (8:00 to 5:00 pm)

Room pressure slightly higher than the atmospheric pressure outside

Here, tn - Indoor Design Temperature; F1 - Roof Area; F2 - North Window Area; F3 - North Wall Area; F4 - East Window Area; F5 - West Wall Area; F6 - East Wall Area; K - Heat Transfer Coefficient of Brick Wall; K1 - Heat Transfer Coefficient of Roof;

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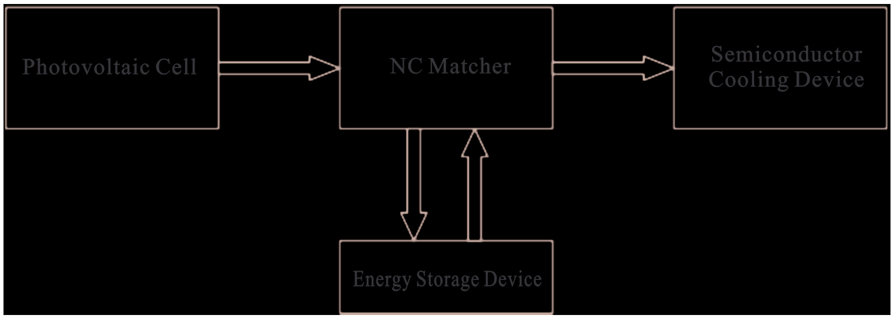


Fig. (1). Solar semiconductor cooling system.

Table 1. Calculation of cooling load.

Time	12:00	14:00	15:00
Roof	420.94	636.67	773.48
North Wall	145.64	140.62	140.62
Temperature difference from the north window	456.16	520.49	538.03
Solar radiation from north window	501.30	516.97	493.47
East Wall	157.36	167.40	175.77
Temperature difference from the east window	228.08	260.24	269.02
Solar radiation from east window	307.62	317.23	302.81
West Wall	301.74	281.23	272.44
Human body	359.36	379.52	386.24
Other	560.00	665.00	679.00
Total load/W	3438.20	3885.38	4030.88

It was calculated that the room maximum load appeared at 3 pm, and amounted to 4,030.88W, as shown in Table **1**.

3. DESIGN OF COOLING UNITS

As the amount of heat dissipating from the semiconductor cooling device is equal to the sum of its cooling capacity and input power, solving the problem in heat dissipating therefore plays a crucial role in acquiring an enhanced cooling efficiency. Meanwhile, the structure of fins on the cold end for cold transfer is also viewed as a key factor on the cooling effect.

Regarding the cooling aspect, the hot end involved the use of the water cycle - air cooling structure: two outdoor units of 1.5P air conditioner with no compressors as the heat radiator at the hot end. The dissipating power was more than 4500W, capable of meeting the cooling requirements of the Project. At the hot end, the thermal grease was coated on the aluminum water-cooled tank, which was connected to the outdoor units through a copper pipe, with a 50W pump for water cycle to dissipate heat. As shown in Fig. (**3**).

At the cold end, two options were provided for cold transfer as a contrast:

In the Option I, the cold end of cooling fins was connected with the heat exchanger, taking away the cooling quantity of fins via fan to achieve indoor cooling. The cooler was linked to both the cold and heat exchangers via bolts, with thermal insulation gasket to reduce alternating heat and cold. Fig. (**3a**) shows the structure. This option features a simple structure and low cost, plus the use of only a pump, allowing a low power consumption of its indoor units.

Option II utilized the hot end and the same water circulation – an air-cooled heat exchanger structure, with the indoor unit of a 1.5P air conditioner as the air cooler. At the cold end, the thermal grease was coated on aluminum water-cooled tank, which was connected to the outdoor units through a copper pipe, with a 50W pump for water cycle to dissipate cold air. To reduce heat transfer between the troughs at the hot and cold ends, this option had the fins densely arranged, with a water-cooled trough in length only one half of that provided in Option 1. The structure is shown in Fig. (**3b**). This option took full advantage of the indoor

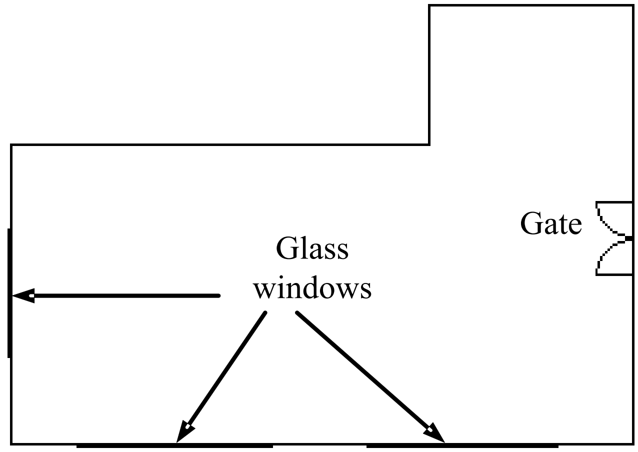


Fig. (2). Configuration of the experimental room.

and outdoor air-cooled radiators that were fine processed for commercial purposes, which, to some extent, were capable to avoid the impact of the processing precision on the cooling effect.

Semiconductor cooling chip followed the specification of TEC1-12708, 40mm × 40mm × 3.3mm, allowing the maximum allowable voltage 15.4V, and maximum current 8.5A. Placed in a refrigerator, there were a total of 48 pieces of semiconductor cooling chips, which were grouped in the operation, and switched between 12, 24, 36 and 48 depending on a given temperature.

4. COMPUTING CAPACITY OF PHOTOVOLTAIC CELLS AND BATTERIES

In Chongqing, the average peak sunshine in summer are considered as eight hours a day. DC48V was given to the DC voltage system in this work.

On the premise of ensuring the reliability of the load required, the combination of the minimum solar modules and battery capacity should be determined in order to optimize the design to achieve the best combination of reliability and economy. Loss of Load Probability, or LOLP, is commonly used at home and abroad to measure the reliability. It is defined as a ratio of the system outage time and the power time. LOLP is valued between 0 - 1. The smaller the value, the higher the reliability. There should be some limits to reliability requirements. Alternatively, the reasonable load reliability should come with the best economic benefits. In the design of a solar semiconductor air-conditioning system, the reliability expressed by a LOLP value of 0.5 may ensure the supply of 4 hours a day.

The specific design steps of the solar cell array are as follows:

(1) power consumption of air-conditioner

According to design requirements, each semiconductor air conditioner provided cooling capacity Qc = 2000W, where the cooling coefficient was assumed to be 1, so the power consumption of each air conditioner:

P=Qc/1=2000/1=2000 (W)

Operating current:

I=2000/48≈41.67(A)

(2) calculating the battery capacity

In cooling systems, the size of the load and working time are combined to determine the battery capacity. If the battery has a coefficient of 0.8 on the depth of discharge, the battery with self-discharge energy of 10% may have the self-discharge coefficient of 0.9. In engineering practice, the methodology of energy transfer is often used for computing the battery capacity.

$$C=\frac{P\cdot T}{D\cdot S\cdot V} \quad (1)$$

Here

C-----Battery Capacity

P------Load Power

T------Working Hours

D------Depth of Discharge

S-------Self-Discharge Coefficient

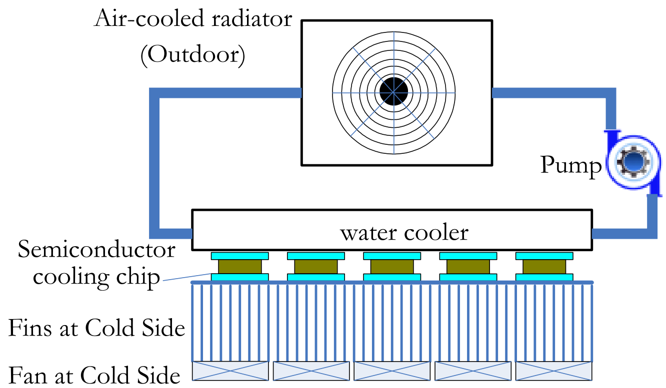
V--------Operating Voltage

According to the above formula, working time was selected as 4 hours, and the calculated battery capacity was app. 230 Ah.

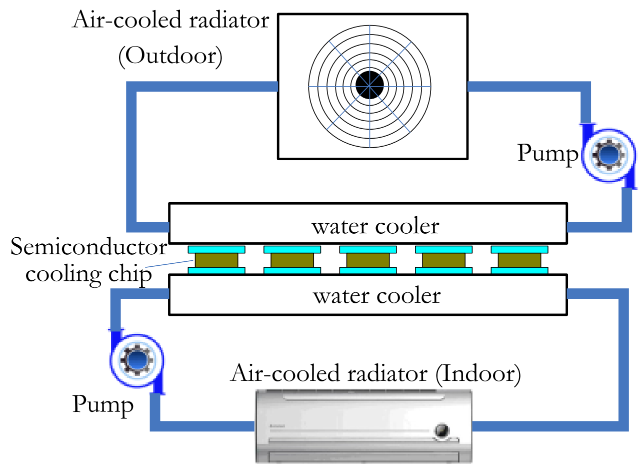
As a result, Fengfan Maintenance Series were applied by selecting eight 6-QW-120b-120AH/12V lead-acid batteries, two parallel branches, each connected with four batteries in series.

(3) Number of solar panels

In Chongqing, the peak sunshine time in summer is app. 7.5 hours, each of solar panels for 125W/12V. Similarly, energy transfer is applied to calculate the capacity of photovoltaic cells.



a. Structure of Indoor Air-Cooled System



b. Structure of Indoor Water- Cooled System

Fig. (3). Chart of Cooling Systems.

$$C' = \frac{C \cdot V}{T'} \tag{2}$$

Here:

C'------PV Capacity

C-------Battery Capacity

V-------Operating Voltage

T' -------Peak Sunshine Hours

As obtained from the above, the required capacity of the solar cell was 1472 W, tantamount to the required 12 photovoltaic cells. Each solar panel was given an output voltage of 12V, if all 12 panels in parallel, the controller might face too large a current. Due to this, the system initially had four solar panels in series, getting an output voltage of 48V, and then three groups in parallel.

By jointly considering the output voltage and current of the solar panel as well as the operating voltage of the semiconductor cooling components, one 65A/48V controller was selected accordingly.

5. TEST RESULTS

Some points were set in key parts of the air-conditioning systems for measuring indoor temperature, outdoor temperature, inlet and outlet air temperature of the air conditioner, inlet and outlet temperatures of cooling water, as well as the temperature of air-cooled cold transfer and the temperature of water-cooled heat radiator.

For the performance of the air conditioner, the cooling power was measured by cooling efficiency, or COP. The product of cooling power and COP, as a benchmark, was adopted for measuring the optimal conditions to balance the effect of these two parameters. Where the cooling power Q_c, heating power Q_h and input power P_1 are subject to a relation as $Q_h = Q_c + P_1$. Therefore, the cooling power can be obtained as

$$Q_c = Q_h - P_1 = C_{pw}\rho_w q_{vw}\Delta T_w - UI \tag{3}$$

Where: C_{pw} is the specific heat capacity of cooling water; q_{vw} is volume flow for cooling water; ρ_w is density of cooling water; ΔT_w is the temperature difference between inlet and

Table 2. Test data of the cooling system.

Test item	Test Results of Option I	Test Results of Option II
U	*7.8 V*	*8.5 V*
I	*4:00 AM*	*4.1 A*
ΔT_w	*10.9 K*	*12.2 K*
Q_c	*1.373kW*	*1.752 kW*
P_1	*1.593 kW*	*1.625 kW*
COP	*0.86*	*1.08*

Table 3. Costs on purchase and use of solar semiconductor air-conditioning.

Item	Expectancy (years)	Price (Yuan)	Annualized cost (Yuan)
Cooling chip	25	750	30
Water-cooled heat exchanger	＞30	400×2	27
Water pump	10	75×2	15
Air-cooled radiator (Outdoor)	15	800	53
Air-cooled radiator(Indoor)	15	700	47
PV (1000wp)	25	8000	320
Lead-acid battery 230AH	3	1500	500
Controller	25	200	8
Total		12900	1000

outlet of the cooling water; *U I* are voltage and current supplied to the semiconductor thermopile, respectively.

The COP is calculated as

$$COP = Qc/P_1 \tag{4}$$

The cooling water, the water temperature between inlet and outlet, work voltage and current and other parameters may directly affect the COP value of the system, so the above parameters in the experiment, and the temperature obtained by the test system were used to calculate the cooling power and COP [4-10].

The system was tested by Chongqing Municipal Academy of Metrology and Quality Inspection. In optimal conditions, the outdoor temperature was 35 degrees Celsius. The Table **2** shows the detection and calculation results:

Based on the experimental results, the use of a dual water cooling design significantly improved the COP value of the system. The main reason lies in the different design of the cooling structure at the cold end: the cold end of Option II counted on water circulation – air cooling mode to dissipate the cold, allowing the cold quantity produced at cold end to be quickly taken away by recycled water. Meanwhile, the use of the commercialized indoor air cooler is possible to avoid the influence of processing on the cooling effect. In a number of tests with Option I, fins at cold end were found with the presence of water condensation. This was mainly due to restrictions to the level of fin processing, resulting in the cold quantity at cold end failed to be discharged. Ultimately, this caused an effect on the cooling efficiency.

6. ECONOMIC ANALYSIS

For a semiconductor-based solar air-conditioning, its economic benefits can determine the scope of its application. By observing the test data in this experiment, a preliminary analysis was given to the economic benefits of the solar semiconductor air-conditioning system with a dual water-cooled structure designed in Option II. The annualized cost was obtained with the results shown in Table **3**. Table **4** shows the 23GW compression air-conditioning compared with this air-conditioning, where both operating costs were calculated at the same cooling power. The results showed that the solar semiconductor conditioning had annual running costs of app. 2.7 times that of the air-conditioning with a compressor.

Table 4. Comparison of operating costs.

Air-conditioning Type	Compressor 23GW	Solar Semiconductor
Initial cost (Yuan)	2000	12900×2
Expectancy (years)	15	25
Annual energy costs	600	0
Annualized Cost	733	2000

As can be seen from the cost structure, the best way of reducing the cost of solar semiconductor air-conditioning is to improve COP of the system, followed by reducing the costs of the main components with their life expectancy to be enhanced.

CONCLUSION

A low cooling efficiency is the biggest shortcoming of the Solar Semiconductor Cooling System. If its cooling performance aims to be paralleled to that of mechanical cooling, its dimensionless parameter ZT is required to reach 3 or more. At room temperature, the current value of ZT as the thermoelectric material most commonly used is approximately 1. Therefore, efforts should be made to improve the performance of the material and to find a more satisfied material [1, 7, 9].

Given the thermoelectric material properties, the performance of solar cooling system may be improved by way of heat dissipating and cold transfer and a better structural design. As the semiconductor cooling device provides the amount of heat dissipating that is equal to the sum of its cooling capacity and input power, focus on solving the problem of its thermal dissipating will play a crucial role in obtaining better cooling efficiency.

Semiconductor cooling device is characterized by a high heat density (up to 4 ~ 8W/cm^2). Further research should be made on how to expand such a high heat flux on a cooling area, having the heat dissipated sufficiently. After comparing experimental study, it was found that the water circulation approach for heat dissipating and cold transfer enables the semiconductor cooling system to have its performance greatly improved.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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