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Drinking Water Heating Integrated Self-Contained Small Animal Shelter Manual

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Abstract

As human activities expand globally, ecological destruction has triggered extreme weather events like global warming, severely threatening small animals' habitats. Current conservation efforts rely on limited, spontaneous initiatives that lack geographical diversity and are vulnerable to human interference. To address these challenges, our team developed an integrated water-heating shelter for small animals. The PTC heating system maintains optimal indoor temperatures, high-voltage sterilization ensures water quality, while photovoltaic power generation and energy storage enable self-sufficiency. A mobile app allows real-time monitoring of equipment performance. This multifunctional solution meets the survival needs of outdoor animals, providing a clean, safe, and comfortable sanctuary. By working continuously in harsh environments, this device contributes significantly to China's animal welfare initiatives.

Keywords

Animal protection; drinking water safety; public welfare; photovoltaic energy storage; PTC heating.

1. Introduction

With the acceleration of urbanization and intensifying global warming, habitats suitable for stray animals and wildlife in both urban and rural areas are being progressively squeezed, posing serious threats to small animals' health and biodiversity. This innovative shelter not only addresses water access issues but also provides emergency refuge with built-in heating and water purification systems, ensuring survival support. The self-sufficient energy supply through photovoltaic power generation enables renewable energy utilization, while air-powered water collection reduces dependence on natural water resources, significantly cutting energy and labor costs. To address these challenges, the multifunctional animal sanctuary has emerged as a practical solution.

In developed countries, there are numerous national animal rescue organizations dedicated to public welfare, along with private and welfare-based animal shelters. These institutions play a vital role in protecting and housing stray animals, supported by relevant laws and regulations that safeguard their survival. However, China's domestic situation presents a stark contrast: an enormous population of stray animals, limited animal protection organizations, and management challenges indicate a concerning state of affairs. Essentially, the concept of animal welfare has yet to gain substantial traction nationwide. We must therefore intensify efforts to protect and raise awareness about small animals in China.

2. Feasibility Analysis

2.1. Energy Supply

The cooling fan, various sensors and high-voltage electrostatic field generation equipment used in this equipment are all powered by low-voltage power supply. Photovoltaic power generation and energy storage technology are ideal choices, and batteries are set up to store excessive energy. Energy is selected from nature to meet the power supply conditions of the system, which is clean, low-carbon, safe, efficient and pollution-free.

2.2. Structural Advantages

The structure adopts a log cabin design, primarily divided into two sections: a modular storage area and an animal shelter. The solar panel roof provides ample space for photovoltaic power generation to generate sufficient electricity. Additionally, the cabin's design offers animals shelter from wind and rain. Through integrated condensation water collection and PTC electric heaters, the system achieves dual functionality of water extraction and heating, effectively serving as an animal sanctuary.

2.3. Water Production Conditions

The atmosphere contains abundant water resources, with approximately 98% of the water remaining in vapor form.Even in the Sahara Desert region, where the annual average temperature is 30°C°C and average humidity reaches 25%, each cubic meter of air contains 8 grams of water. This demonstrates that the air possesses the necessary moisture conditions for water extraction. The utilization of renewable energy aligns with the original purpose of water conservation.

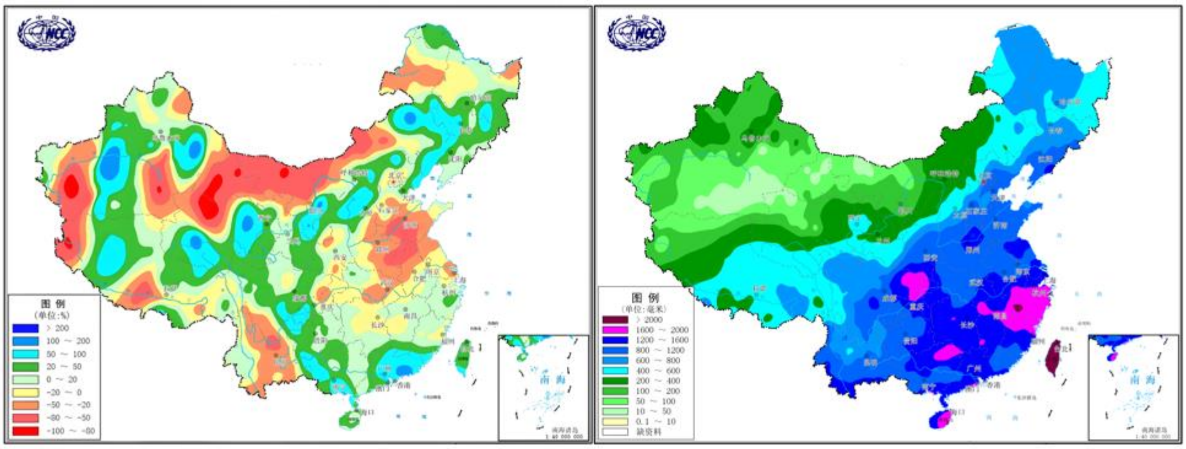

Fig. 1 Annual Precipitation Range Percentage Distribution in China

2.4. Heating and Heating

The PTC heater is currently the most efficient, cleanest, and safest electric heating solution. It primarily consists of two components: a PTC heating element and a heat dissipation structure. By heating the air, it creates a warm and comfortable environment for small animals. Thanks to the temperature-sensitive resistance characteristics of the PTC heating element, the heater functions like a thermostat, significantly improving energy efficiency.

2.5. Safe Drinking Water

The dry-bonded condensation water production technology represents an innovative, eco-friendly and energy-efficient solution. By capturing water molecules from the air at the source, it significantly reduces impurities and harmful substances in raw water. The purified water is filtered, stored in tanks, and periodically treated with high-voltage electrostatic field sterilization. This process ensures complete compliance with national standards for livestock drinking water.

3. System Structure Block Diagram

This system integrates photovoltaic power generation with energy storage technology, utilizing a combined dry-wet condensation water production method. A high-voltage generator creates an electrostatic field for disinfection, while PTC heating technology maintains optimal temperature levels. Specifically designed for small animals, it delivers convenient and safe drinking water services. The system requires only initial equipment investment, eliminating complex maintenance needs and significantly reducing operational costs and maintenance challenges.

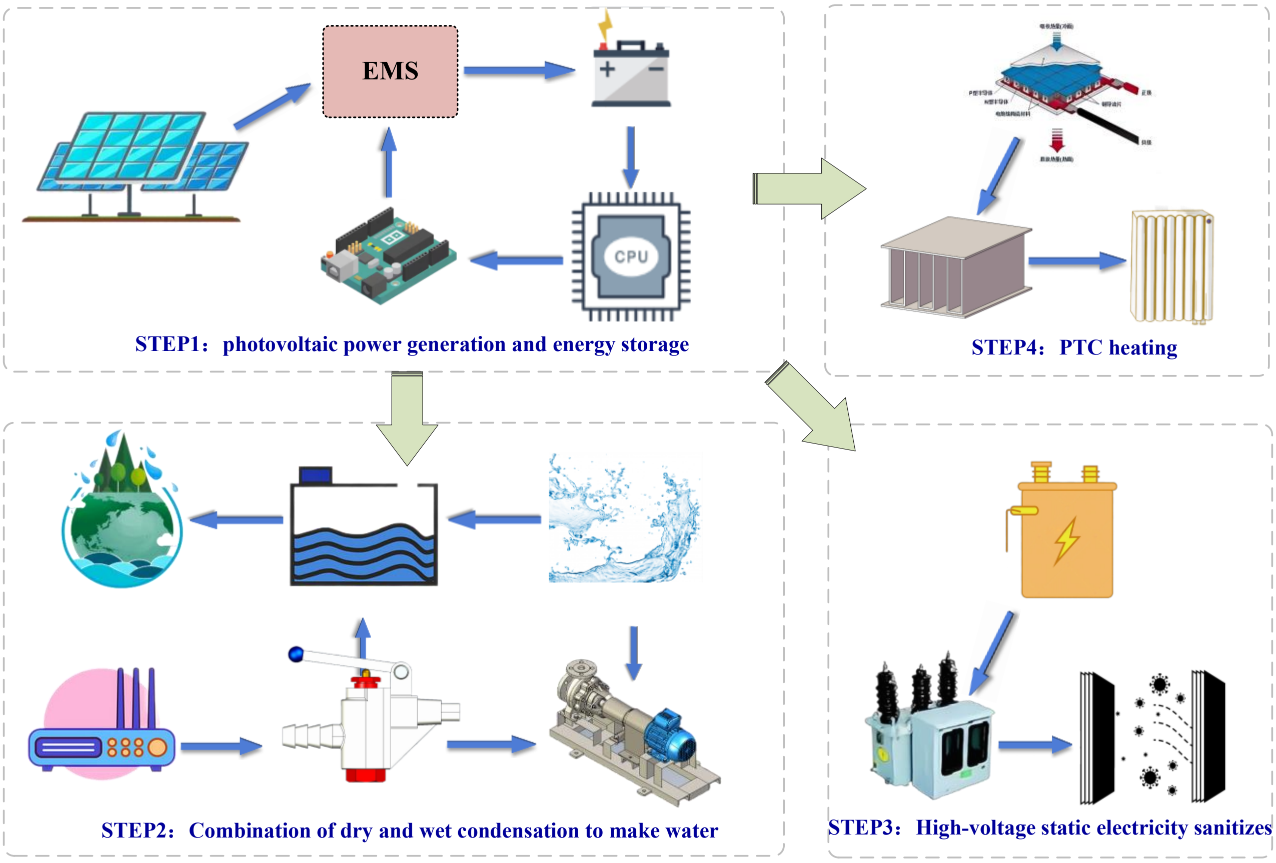

Fig. 2 System Overall System Block Diagram

4. Structural Design and Construction

The small animal shelter measures 80cm by 75cm in dimensions with an 80cm ceiling height. Water dispensers are positioned at 20cm and 30cm heights to ensure proper hydration. A single-crystal silicon solar panel is installed diagonally on the shelter's roof, expanding solar exposure to boost energy generation and maintain system functionality. The equipment incorporates biomimetic design elements to blend with the natural environment, featuring wood-toned color schemes and a rustic cabin-style structure that seamlessly integrates shelter functions.

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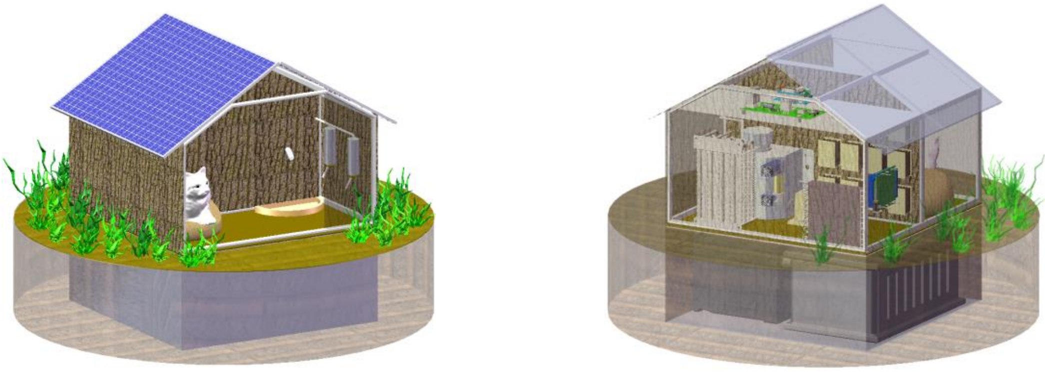

Fig. 3 Exterior Design and Internal Structure

To ensure environmental protection, our team has installed the battery, high-voltage generator, high-voltage conversion module, and circuit modules at the equipment base with waterproofing treatment. The sterilization- equipped high-voltage control module ensures safe drinking water supply for small animals. The upper section features an integrated condensation system combining drying and humidification, containing air-guiding, cooling, condensation, desiccant modules, and a water collection chamber. Through structural optimization, this design significantly increases water extraction capacity. Water pumps are used to transfer water into the collection chamber, where it slowly drips into the lower receiver, maximizing water utilization and minimizing waste.

Fig. 4 Schematic Diagram of Actual Shelter Construction

5. Operational Principle

5.1. Photovoltaic Power Generation and Maximum Power Output

Under sunlight, solar panels generate a voltage difference that converts into electricity through the photovoltaic effect. Since these devices operate outdoors where lighting conditions fluctuate, affecting panel efficiency, the system employs maximum power point tracking (MPPT) technology to maintain optimal output. The Boost DC converter adjusts circuit parameters and matching impedance to track the peak power point, thereby optimizing solar cell output power.

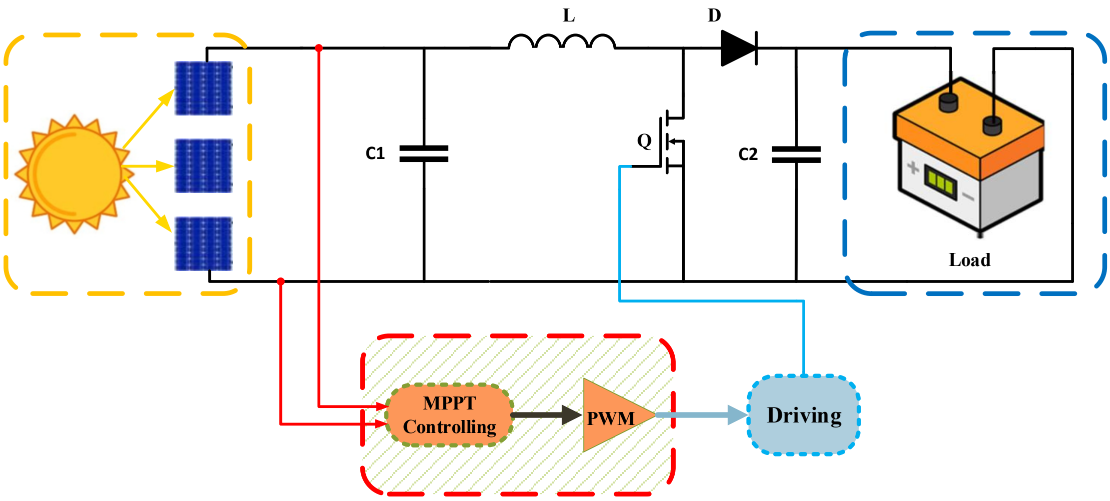

Fig. 5 Equivalent Circuit of Photovoltaic Power Generation

5.2. Dry and Wet Combined Condensation Water Production

The desiccant uses a new metal-organic framework porous adsorbent material (MOFs). Compared with traditional adsorbents, MOFs can capture more water in environments with low relative humidity and require lower temperatures for dehumidification, which means less heat consumption but faster cycle efficiency.

The integrated dry-wet condensation water production system combines air condensation with desiccant desorption technology to achieve synergistic effects beyond conventional methods. The desiccant desorption process utilizes the pressure gradient between the desiccant surface and ambient air as the driving force for moisture absorption. Photovoltaic-generated electricity heats the desiccant, causing water vapor diffusion and subsequent cooling that condenses it into liquid. In the air condensation process, humid air enters a regenerator. The condensate generated within the regenerator is collected through heat pipes, then filtered before being channeled into a high-pressure sterilization unit.

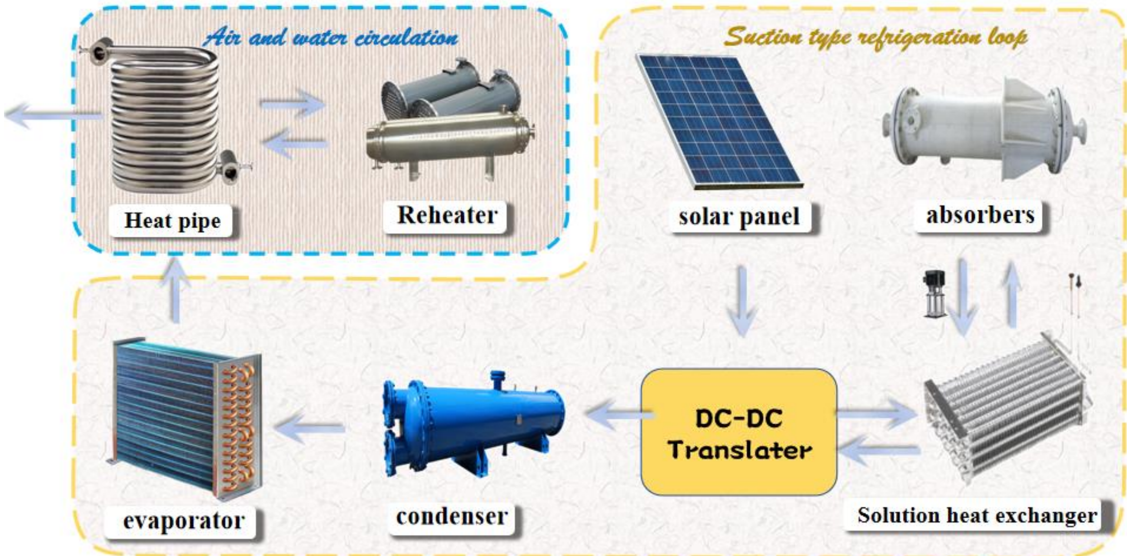

Fig. 6 Schematic Diagram of Dry and Wet Combined Condensation Water Production

5.3. PTC Calorifier

PTC refers to the phenomenon where a material's resistance increases rapidly with rising temperature. As ambient temperatures rise, its resistance rises sharply while power decreases, resulting in heat production that remains below dissipation. This cooling effect continues until thermal equilibrium is achieved, where heat generation equals heat dissipation, giving PTC heaters thermostat-like functionality. Additionally, these heaters exhibit low resistance at room temperature and high startup power, enabling rapid temperature attainment.

5.4. Three-Port DC-DC Converter

A three-port DC-DC converter system utilizing the STM32F407 microcontroller as its driver core employs a Boost circuit.By implementing a duty cycle adjustment through perturbation observation method, maximum power point tracking is achieved to maximize the output power of the analog photovoltaic cell, thereby enhancing photovoltaic efficiency. The microcontroller automatically regulates the PWM duty cycle to control the switching of MOSFETs in the flyback circuit, generating pulsating DC output on one side. A high-voltage transformer boosts the voltage. After sampling by the circuit, the signals are fed back to the STM32F407 controller for output adjustment.

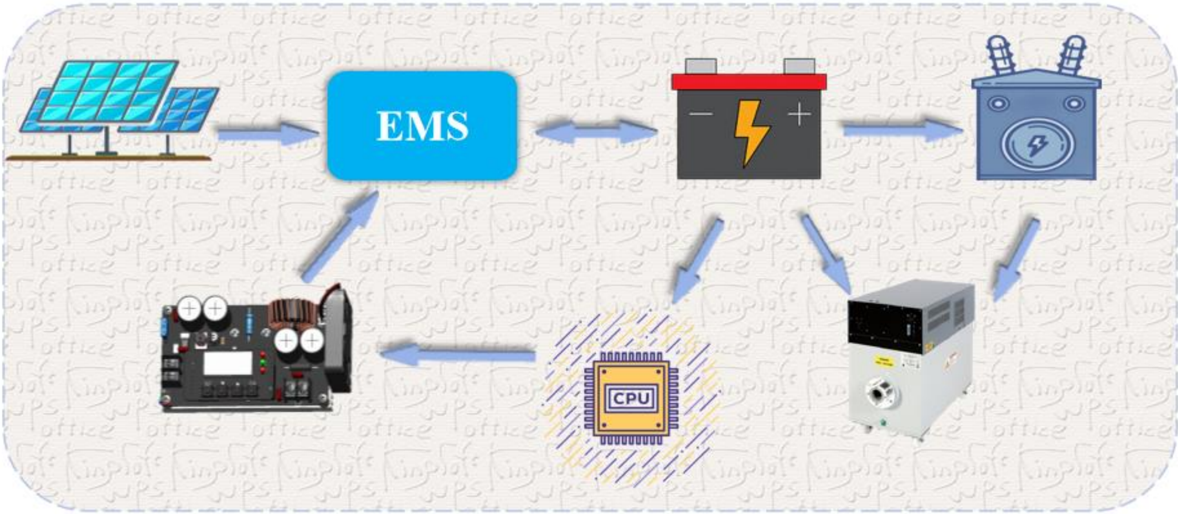

Fig. 7 Three-Port DC-DC Converter Structure and High Voltage Generator Equipmen

6. Theoretical Design Calculation

6.1. Analyze the Amount of Water Produced

When the air enters the condensation equipment through the air supply system and the temperature drops below the dew point, it condenses into water. Theoretically, the amount of water produced by the air water production equipment can be calculated by the following formula

$$W = G\rho(d1 - d2) \qquad (1-1)$$

Where: G is the air volume, unit m^3/h; p is the air density, unit kg/m^3; d1 is the moisture content of the incoming air, unit g/kg; d_2 is the moisture content of the outgoing air, unit g/kg.

The air water-making equipment was tested under different temperatures and relative humidity conditions, with water production data recorded. Based on the table in the diagram and considering the error losses caused by temperature and air humidity, the condensation water-making system actually produced enough water to meet the drinking needs of normal small animals during its 10-hour normal operation.

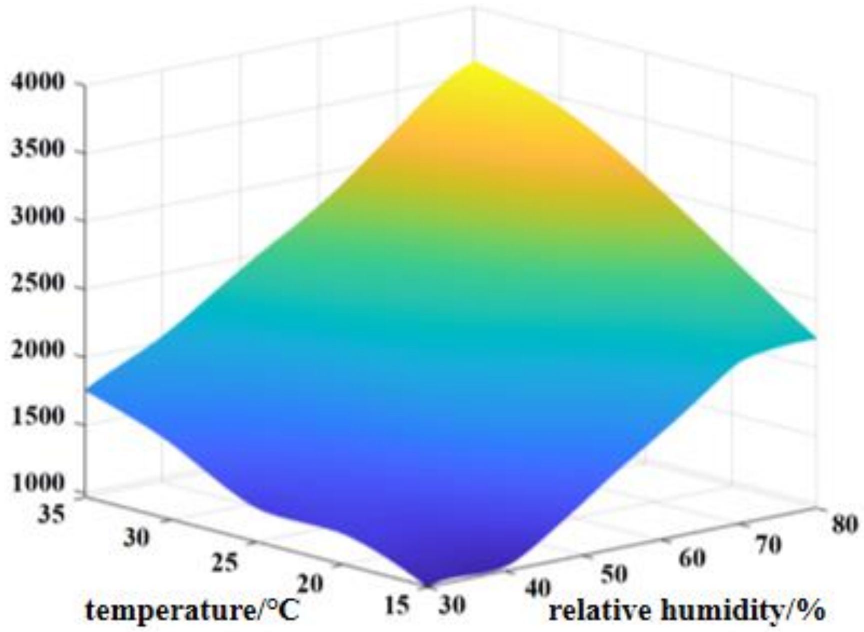

Fig. 8 Water Production Under Different Temperature and Humidity

This equipment combines a condenser with a desiccant to produce water. At an ambient temperature of 25 °C and humidity of 70%, it can generate approximately 2,436 ml of water within 5 hours. Based on the daily drinking frequency of 30 small animals (equivalent to 80ml per animal), the total water consumption reaches 2,400 ml, which meets the quantitative drinking needs of laboratory animals.

6.2. High Pressure Sterilization

This equipment adopts non-thermal treatment of bacteria ——HPEF sterilization technology for the sterilization treatment of water, and introduces Hulsheger model to analyze the relationship between microbial survival rate and field strength.

$$\boldsymbol{lgS = Kp(|P - P_c|)} \qquad (2-1)$$

N_0 and N_1represent the microbial counts in water before and after PEF treatment, measured in cfu/mL; Kp is the regression coefficient characterizing microbial sensitivity to PEF; P denotes the treatment condition (specifically electric field strength E (kV/cm) in this device); P_c represents the critical value for each treatment condition.

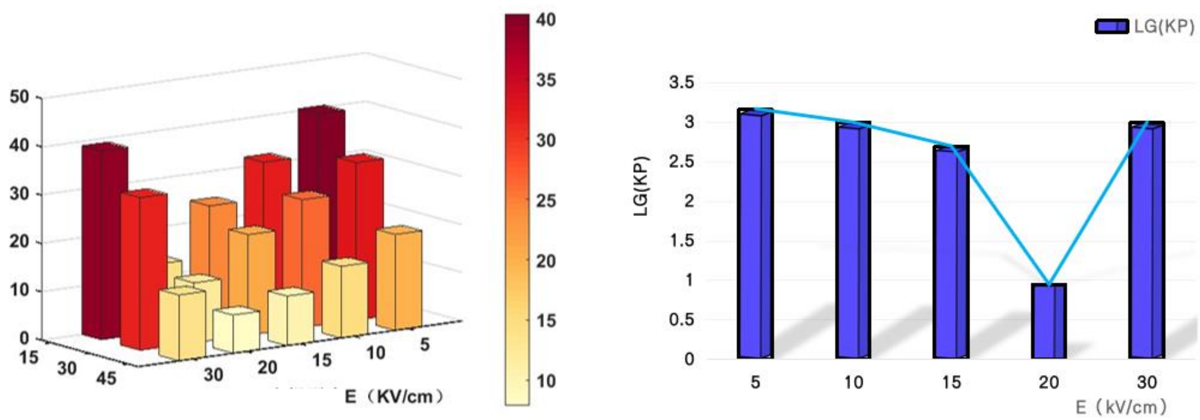

Fig. 9 Relationship Between Bacterial Survival Rate and Field Strength

Under the same sterile conditions, the condensed water was divided into equal and uniform groups, and each group was treated with different field strength. The bacterial survival rate data were recorded as shown in the figure. According to the bar chart, the sterilization rate increased significantly with the increase of voltage intensity.If Kp=100PEC=20kV/cm, the curve of microbial survival rate and electric field strength is shown above.

According to the figure, the bacterial survival rate is lowest at 20kV/cm. In addition, considering the actual situation, the high voltage field strength is selected within the range of 15kV-20kV, which meets the normal drinking water of small animals.

6.3. Photovoltaic Capacity

The monocrystalline silicon photovoltaic panels used in this system have a photovoltaic panel area Ac of $1.2m^2$. The national average annual horizontal total irradiance is 1815.8kWh/m 2, η_1 is the photoelectric conversion efficiency, which is taken as 20%; η_2 is the comprehensive power generation efficiency, which is taken as 80%.
According to the photovoltaic power generation formula:

$$\boldsymbol{En = Q \cdot Ac \cdot \eta 1 \cdot \eta 2} \quad (3-1)$$

Daily power generation is:

$$\boldsymbol{En = 1815.8/365 * 1.4 * 20\% * 80\% = 1.114kwh} \quad (3-2)$$

According to the calculation, it can fully meet the power supply demand of high voltage disinfection, water system, circuit at all levels and other power consumption modules, and realize self-sufficiency.

Table 1 Power Consumption of Each Power Module

Power consumption module	power consumption (W)	Average daily hours (h)	Average daily power consumption (kWh)
High voltage plates	20	2	0.04
Condensation water treatment equipment	60	6	0.36
suction pump	15	1	0.015
PTC electric heater	80	8	0.64

Given that all components of the system are powered by low-voltage electricity, photovoltaic power generation and energy storage technology prove to be an ideal solution. The solar energy fully meets the power demands of high-voltage disinfection systems, condensation and drying units, PTC heating modules, and various circuit levels. This approach maximizes the utilization of solar energy as a renewable resource, achieving self-sufficiency and significantly reducing electricity consumption.

6.4. PTC Heater Heat Output

The heating core's overall thermal rate and temperature distribution are determined by the physical properties of both the single- layer PTC ceramic element and its layered materials. Given the inverse relationship between resistance at room temperature and heating rate, different PTC ceramic layers within the core exhibit varying thermal expansion rates when energized. This thermal behavior can be conceptualized as a flat plate with temperature gradients across multiple layers, where heat transfer follows Fourier's law:

$$\boldsymbol{\varphi = -\lambda A \frac{dT}{dx}} \quad (4-1)$$

In this formula, φ is the heat flow, which refers to the heat passing through a certain section per unit time; λ is the thermal conductivity, and the negative sign indicates that the direction of heat transfer is opposite to the direction of temperature gradient; A is the cross-sectional area perpendicular to the direction of heat transfer.

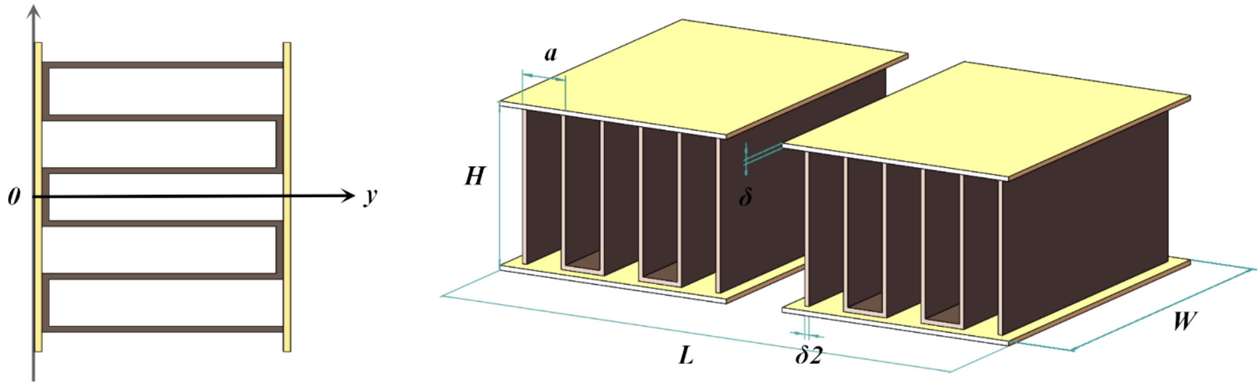

Fig. 10 PTC Radiator Structure Design

When the heat transfer in the y direction is only considered, the surface temperature of the heating core is a first function of the surface temperature of the PTC sheet, and the thermal resistance in the x direction is much larger than that in the y direction, so its influence on the temperature distribution is small.

The energy balance equation for the PTC heater is:

$$Q_{(x)} = \int_0^x k_{(x)}(T_0 - T_{h(x)})dx = C_h(T_{h(x)} - T_{h1}) \quad (4-2)$$

Q (x) is the total heat transfer between x and the position x;k (x) is the heat transfer coefficient at x.

Since the inlet and outlet temperature, heat flow rate and total heat transfer are approximately constant, the total heat transfer is:

$$Q = C_h(T_0 - T_{h1})(e^{\frac{1}{C_h}KS} - 1) \quad (4-3)$$

The calorific value is obtained by the formula:

$$Q = T_1 - T_2/R_i \quad (4-4)$$

Here, Q is the heat release, T_1 , T_2 are the temperature difference in the thermosphere, and R i is the total thermal resistance in the heat conduction process. According to the heat calculation formula, we can get:

$$Q = cm\Delta T \quad (4-5)$$

The specific heat capacity of air is c =1.003J/(kg·°C) and the density of air is ρ = 1.29kg/m³.

According to the calculation, PTC heater can provide about 1.82 10^6 J of heat under the condition of working for 8 hours a day. Through this technology, the heat required to raise the temperature from 0°C to 25°C and maintain it for 16 hours is 1.34 10^6 J.

7. Innovation Significance and Application Prospect

7.1. Innovative Significance

"Safe drinking water" --high voltage electric field disinfection

This equipment adopts high voltage electric field disinfection technology, which has the advantages of high sterilization efficiency, low energy consumption and no pollution. Compared with the traditional high temperature disinfection, this new concept of disinfection has lower power consumption and higher sterilization efficiency.

"Harmony and symbiosis" -care for animals, practice public welfare

In today's society, the living space of animals is constantly compressed, and the survival of stray animals is facing great threats.This equipment aims to encourage more people to participate in animal protection public welfare activities, promote urban humanistic care, and let stray animals feel the warmth of the city.

"Sufficiency" -integrated light storage

This equipment adopts photovoltaic power generation technology and combined with energy storage system, which is suitable for different regional climates. Compared with traditional electrical equipment, it greatly reduces environmental pollution. Its self-sufficiency of renewable energy solves the problem of energy supply for outdoor work and ensures the stability of the system.

"Warm and comfortable" -PTC heating

This equipment adopts PTC heating technology, mainly composed of PTC heating sheet and heat dissipation structure. It heats the air and uses material resistance to achieve the effect of constant temperature, improve energy utilization efficiency, and provide a warm and comfortable environment for small animals.

"Creating something out of nothing" -taking water from the air

This equipment adopts condensation type water production and new type desiccant water production, using the difference between the evaporation pressure on the surface of the desiccant and the vapor pressure of the ambient air as the hygroscopic power, and then using photovoltaic power generation energy to heat the desiccant. This water production method is energy-saving and environmental protection, using green and clean energy, no environmental pollution.

7.2. Application Prospect

By integrating photovoltaic power generation, condensation water production, PTC heating technologies, and a public welfare-oriented small animal shelter, this system achieves cross-domain and multi-level comprehensive application. The equipment not only utilizes renewable energy but also ensures clean, low-carbon, safe, and efficient energy use, creating a win-win scenario for social, economic, and ecological benefits. Moreover, its advanced self-sufficiency and maintenance-free features transcend geographical limitations, indicating vast application potential and demonstrating tremendous future prospects. This innovation provides new momentum for building a resource-efficient and eco-friendly society while promoting sustainable economic and social development. With strong national support for public welfare initiatives, its future holds boundless promise.

Fig. 11 Design Poster of Multi-Functional Integrated Shelter for Small Animals

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