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A portable renewable solar energy-powered cooling system based on wireless power transfer for a vehicle cabin

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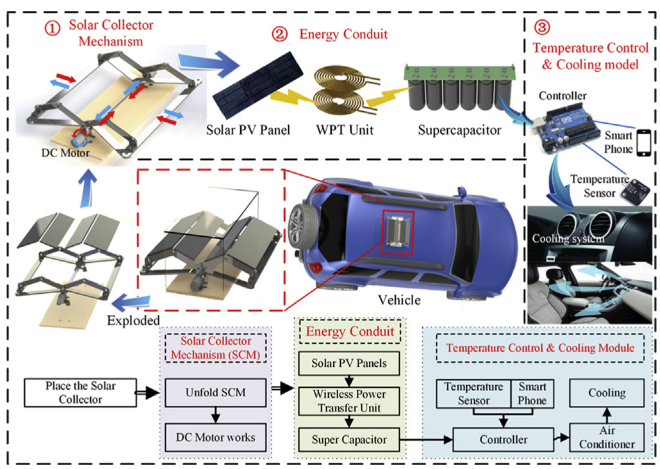
HIGHLIGHTS

- A novel portable solar collector mechanism is optimally designed.
- Wireless power transfer is first applied to cooling systems.
- A supercapacitor stores electricity and outputs a regulated supply.
- The proposed cooling system shows high efficiency in a limited space.

GRAPHICAL ABSTRACT



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ABSTRACT

As the greenhouse effect becomes increasingly serious, cooling a vehicle cabin parked under the blazing sun without running the engine or using an electric vehicle's power has received considerable attention. In this paper, we develop a novel portable, renewable, solar energy-powered cooling system with wireless power transfer (WPT) and supercapacitors to cool the vehicle cabin. The proposed system consists of a solar collector mechanism, an energy conduit, and a temperature control and cooling module. First, consisting of folding solar photovoltaic (PV) panels, the solar collector mechanism making the proposed system portable. Once collected, the solar energy is converted into electricity and stored in the supercapacitors through wireless power transfer without breaching the vehicle body. Automatic temperature regulation is achieved with the cooling device via the temperature control and cooling module. The experimental results indicate that a maximum output power of 2.181 W and a maximum WPT efficiency of 60.3% are achieved when the prototype loaded with 3 Ω and 5 Ω respectively. Meanwhile, the simulation shows the temperature inside the cabin is reduced by as much as 4.2 °C in average, demonstrating that the proposed solar energy-powered cooling system is effective and feasible in cooling a hot vehicle cabin.

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1. Introduction

Vehicles play an important role in transportation within modern society. The consumption of fossil fuels has also brought smog, hazardous emissions, and global warming, which has aroused increasing interest in new energy sources. Much research has been focused on electric vehicles (EVs) to achieve emissions reductions [1]. As another solution, many researchers have been fascinated by harvesting energy (especially vibration energy) from the environment [2–4]. Existing energy harvesting systems can be placed into different categories, including mechanical, piezoelectric, thermoelectric, wind energy, and solar [2–8].

It is vitally important to drivers that there be an air conditioner in their vehicles in the summer. One pervasive problem in the summer is that the temperature of the car cabin will rise rapidly, especially in vehicles parked outdoors. High temperatures speed the ageing of plastics, release harmful gas, consume more fuel to power the air conditioner, and compound energy problems.

Solar energy, a renewable and clean energy, has been widely used to provide heat and electricity [9]. The use of renewable solar energy to power an air conditioner while reducing greenhouse gas production and energy consumption has attracted global attention [11–24]. Numerous researchers have proposed solar energy powered air-conditioning systems, which consist of two types: (1) photovoltaic (PV) conversion, and (2) photothermal conversion [10].

Photovoltaic collectors have increasingly been used to supply solar air-conditioning cooling systems, as the cost of a solar PV system is currently economical. Anis [11] proposed a PV-powered air-conditioning system based on microprocessor control. Compared to a conventional PV powered air conditioning system, this system makes the high starting current of the motor more feasible. Daut et al. [12] presented a solar-powered air-conditioning system using PV panels consisting of a PV module, charge controller, batteries and an air conditioner. Porumb et al. [13] compared the performances of a solar-powered absorption air-conditioning cooling system and a solar-powered photovoltaic air-conditioning cooling system. They found that the photovoltaic cooling fraction was 12.1% greater than the thermal cooling fraction. Huang et al. [14] designed and built an air conditioner for a low-energy house driven by solar PV panels. The system is supported by a small buffer battery; no grid power is needed. A residential district-level cooling system combining photovoltaic and natural gas power is developed in [15]. At various times of a day, the PV generation and the gas turbine may work together or singly to provide electricity to meet the heating/cooling demand. Sanaye and Sarrafi [16] presented a combined cooling, heating and power (CCHP) solar generation system to supply cooling, heating, electricity and hot water for a building. Li et al. [17] presented a solar photovoltaic air conditioner that can meet temperature control needs in any weather with an inverter efficiency of 70–80%. The system has been deployed in a room, where the photovoltaic array is installed on the roof above the room. The solar air-conditioning system developed by [18] combines photovoltaic and thermal collectors and is able to produce both electricity and hot water.

Many researchers have used solar energy as the power supply for an air-conditioning system via photothermal conversion. In [19], the authors analyse the technology and economy of the proposed solar-powered cooling systems for industrial applications to evaluate their advantages and limitations. Rosiek et al. [20] applied occupancy sensors and chilled water storage tanks in a solar-assisted air-conditioning system. The system reduces the consumption of electrical energy by approximately 42% and the production of CO_2 by 1.3 tons during an entire summer of operation under a partial load. To select the optimal solar collectors for a solar-driven ejector air-conditioning system, Zhang et al. [21] developed a simulation program. Based on the results of computer simulation and lab tests, the selected collectors can meet the full demands of powering a 5 kW solar-driven ejector air-conditioning system for 10 h. A solar-assisted air-conditioning system combining a liquid desiccant ventilation system with an air-handling unit is proposed by Qi et al. [22]. The proposed system has been simulated in five cities representing four main climate regions, with savings of up to 45% in energy consumption. Zhai et al. [23] designed a solar-powered adsorption air-conditioning system and installed it in a green building. The solar-powered air-conditioning system outputs an average power of 15.3 kW and a maximum power of 20 kW. A review of a solar-powered ejector air conditioner is presented in [24]. The paper also analyses different cycles, one with compression enhancements and another without. In general, the main application of a solar-powered photothermal air-conditioning system is the cooling of an entire building.

Although many researchers have studied solar-powered air-conditioning systems, limited research has been conducted on applying one to a vehicle cabin. Abraham et al. [25] described a photovoltaic thermoelectric refrigerator for car heat dissipation. The group manufactured a small experimental prototype, and the results show that the temperature inside the cabin can be cooled to the ambient temperature. Another study [26] developed a solar powered cooling device for an electric car. The device in this study was installed in an electric car cabin, and the simulation results demonstrate that the proposed device can effectively displace the hot air with cooler ambient air. Zhang et al. [27] designed a solar-powered air-conditioning system for a vehicle including a foldable solar energy collector mechanism and an air-conditioning system powered by solar photovoltaic panels. Zhang et al. [28] proposed a phase-change material cooling device for vehicles. The proposed device changes phase to absorb heat from the air inside a car.

All this research makes it clear that solar-powered cooling systems are currently a hot topic. To meet the demands of thermal comfort and reduce fuel consumption and emissions, this paper presents a novel portable solar-powered cooling system for a vehicle cabin. For sake of portability and easy installation, wireless power transfer technology is applied to avoid a tangle of wires that will need to perforate the cabin. In recent decades, wireless power transfer has attracted more and more researches, such as charging electric vehicles, powering a biomedical capsule endoscope, and discussing the losses analysis [29–31].

The structure of the rest of this paper is as follows. In Section 2, a general overview of the proposed solar-powered cooling system's design is given, including a solar collector mechanism, an energy conduit, a temperature control and a cooling model. Then Section 3 models and analyses the proposed system. Section 4 provides the experimental details and results for both the field experiments and the simulation experiments. Section 5 presents a discussion of the implications of the results. Finally, the study's conclusions are presented in Section 6.

2. System design

The proposed portable solar-powered cooling system as shown in Fig. 1, consists of three parts: a solar collector mechanism, energy conduit, and a temperature control and cooling module. When parked outdoors, place the solar collector mechanism on the roof of the vehicle. The solar collector mechanism, on which the solar PV panels are installed, is designed to use folding solar PV panels to increase portability. When the system is operating, the solar collector mechanism unfolds the solar PV panels to the proper angle to collect as much solar energy as possible. The energy conduit transfers energy from the solar PV panels to