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Research paper

Evaluation of a prototype active solar thermoelectric radiant wall system in winter conditions

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HIGHLIGHTS

- A novel active solar thermoelectric radiant wall was developed and reported.
- The novel wall can control the heat flux of wall by using solar energy or DC power.
- The performance of the active solar thermoelectric radiant wall operating in winter condition was investigated.
- The optimum operating current and the operation strategy for the ASTRW have been proposed.

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ABSTRACT

Active solar thermoelectric radiant wall (ASTRW) system represents a new solar wall technology that uses solar energy to compensate for passive heat losses or gains through building walls. In ASTRW system, electrical energy obtained from photovoltaic cells or DC power is used to power thermoelectric modules, which can control the heat flow through the wall. In order to assess the practical feasibility of the ASTRW system, we have developed a prototype ASTRW system and conducted experiments in different modes. Results show that the ASTRW system can not only eliminate conventional building envelop thermal loads but also provide a heating capacity for space heating. The COP can reach 2.3 and the thermal efficiency can reach 34.2% when the system is powered directly by PV system during the daytime of a sunny winter's day. During the daytime hours of a cloudy or rainy winter's day, the system is powered by a DC power and works as an air source thermoelectric heat pump, and the COP can be about 2.0 for space heating. In order to get an excellent performance of the ASTRW system, the optimal operating current for ASTRW system has been analyzed using a simplified analytical model and the optimum operation strategy for ASTRW has been determined and proposed based on the experimental results.

1. Introduction

Buildings account for a significant proportion of global energy consumption and carbon emissions worldwide. About 30% of energy consumption in china [1], 40% in USA [2], and 20–40% in developed countries is consumed by buildings and predicted to increase by 34% in the next 20 years [3,4]. One way to reduce building energy consumption is to increase the insulation requirements of building wall through different passive insulation methods. However, there are some limits of financial to this approach. One way to overcome these limitations is to transform the role of the building wall from a passive barrier to heat loss into an active building wall system. From this point of view, it is important to propose schemes to increase building solar gains and reduce heat losses while maintaining indoor room comfort in all seasons [5,6].

Passive solar systems are a well-established concept in cold climates, which use the building components to collect solar heat gains to reduce the demand for room heating in winter. Moreover, passive solar systems require no electrical or petroleum for operation, which are receiving increasing attention. The techniques used for passive heating include solar chimney [7], solar room [8], Trombe Wall [9,10], etc. However, passive solar technology usually can only be used in the daytime of a sunny winter's day for heating,

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but in a cloudy or rainy winter's day, passive solar walls cannot reduce the thermal load of building envelope. Moreover, passive solar walls cannot use solar energy for space cooling in summer. Hence, a novel solar thermoelectric radiant wall (ASTRW) system is proposed in this paper. In ASTRW system, electrical energy obtained from photovoltaic cells or DC power is used to power thermoelectric cooling modules, which can control heat flow through the wall. Therefore, the ASTRW system transforms the role of the envelope from a passive barrier to heat loss into an active system, thus reducing the need for space heating and cooling and increasing the building's solar gains in all seasons.

Thermoelectric cooling systems have no mechanical moving parts and do not employ working fluid, which transfer heat from the cold side of the modules to the hot side with consumption of electricity [11]. Due to the advantages such as high reliability, low weight, and flexibility in packaging and integration, thermoelectric cooling systems have been widely used in military, aerospace, instrument, and industrial products [12–16]. Moreover, thermoelectric cooling systems can be powered directly by a photovoltaic (PV), and these systems are Freon free, causing no harm to the environment. Therefore, the thermoelectric coolers and the solar cells combined technologies are beneficial to solar energy using and environment protection. Several studies on the solar thermoelectric cooling system have been carried out. Xu and Steven tested a solar thermoelectric window system [17]. Sabah et al. designed a solar thermoelectric system, and found that cooing performance was strongly dependent on the hot and cold side temperature of the TE modules [18]. Cheng et al. studied a solar thermoelectric system with a waste heat regeneration system for building application [19]. Liu et al. have studied a solar thermoelectric air conditioner integrated water heater technology in the application of low-carbon buildings [20]. In their studies on solar thermoelectric cooling, a number of data and analyses of great significance have been provided.

In this paper we evaluate a prototype active solar thermoelectric radiant wall system in winter operation modes. Compared with conventional insulated walls and passive solar walls, the ASTRW system uses electrical energy obtained from photovoltaic cells or DC power to drive a thermoelectric (TE) cooling system and actively control of heat flux in wall. Capable of operating in both heating and cooling modes, ASTRW systems can be applied for heating as well as cooling applications simply by reversing the direction of direct current in TE component, therefore ASTRW system can be adapted to variable outdoor climate conditions and realize indoor comfort.

2. System description

To eliminate conventional building envelop thermal loads and actively control the heat flux in building envelop, a novel prototype of ASTRW system was development in this paper. This ASTRW system from the outside to the inside mainly consists of photovoltaic system, airflow channel, and thermoelectric radiant cooling system, as demonstrated in Fig. 1. The PV unit forms a building envelope surrounding the external wall with an airflow channel maintained between the thermoelectric radiant panel and the PV unit. The TE modules are connected in series and sandwiched between the aluminum radiant panel and the heat pipe sinks. The heat of the TE modules is dissipated by the heat sinks and fans. Air inlet and outlet louvers are installed below and above the PV modules. All the above elements constitute the novel ASTRW system.

By controlling the inlet and outlet louvers, the ASTRW system can achieve the functions of heating, cooling and non-ventilated. Fig. 2 presents the energy flows and the heat transfer processes in detail. When the ASTRW system works in mode 1, the solar radiation incident on the vertical PV module is partly reflected by the tempered glass layers and partly absorbed by the solar cell layers. The solar energy absorbed by the solar cells is partly converted into direct current (DC) electricity (only about 6%–15% is converted in to electricity in the PV module), and the absorbed remainder is dissipated into the airflow channel as the heat source of the TE modules. At the same time, the inlet and outlet louvers are closed and the airflow channel collects the heat from the PV. The TE modules are powered directly by the PV system. The cold side heat sinks of the TE modules in the flow channel recover the heat generated by the PV, and the aluminum radiant panel is heated by the hot side of the TE modules, thus the ASTRW system could work as a photovoltaic/thermal (PV/T) system to provide heating capacity for space heating.

When the ASTRW system works in mode 2, the inlet and outlet louvers are opened. The TE modules are powered by a DC power supply. The heat of the cold side of the thermoelectric modules is dissipated by the air in the airflow channel, at the same time the aluminum radiant panel is heated up by the hot side of the TE modules, and then the system can work as an air source thermoelectric heat pump and control the heat flux of the wall.

The ASTRW system can operate in non-ventilated mode (mode 3) to reduce building heat loss through the wall. The ASTRW system doesn't need power, thus the ASTRW system isn't connected to PV or DC power. The inlet and outlet louvers are closed and the other operations are same as for Mode 1.

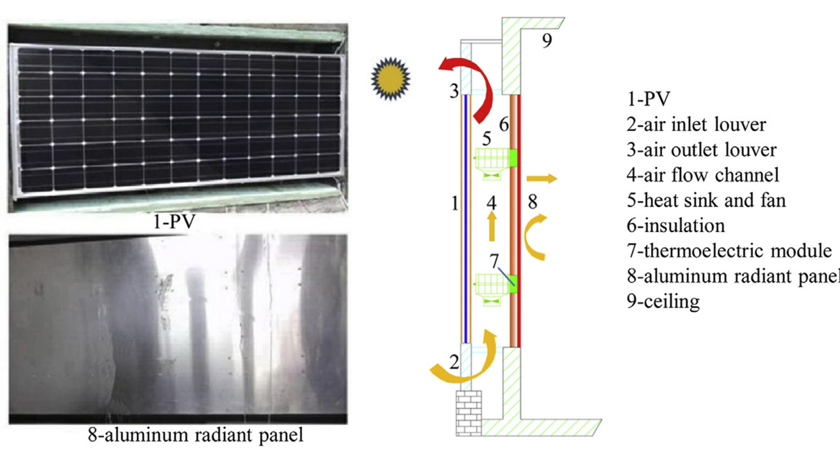

Fig. 1. The structure of the ASTRW system.