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Review of solar thermoelectric cooling technologies for use in zero energy buildings

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ABSTRACT

Energy crisis and global warming have become more and more serious with the social development. Since buildings account for a significant proportion of the total energy consumption and carbon emissions, it is very necessary and urgent to decrease building energy consumption. Minimizing the need for energy use in buildings through energy-efficient measures and adopting renewable energy are the basic strategies. Zero energy buildings, which only consume solar energy and other renewable energies, have been considered as one solution and have drawn more and more attention in recent years. Solar thermoelectric cooling technologies can be powered directly by a photovoltaic (PV) and cause no harm to the environment, which fully fulfill the demand of ZEBs. This paper reviews solar thermoelectric cooling technologies and proposes a technical route of solar thermoelectric cooling technologies for use in zero energy buildings. It can be seen that solar thermoelectric cooling systems can minimize the energy demands, increase energy effectiveness and reduce fossil energy consumption in buildings. With the thermoelectric and PV industry's development along with the advent of new materials, the solar thermoelectric cooling technologies for use in zero energy buildings are promising.

1. Introduction

The environment pollution and energy crisis have become the focus of attention all over the world. As the world population increasing and economic development, the world has experienced large increase in energy consumption over the past 30 years. 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 counties is consumed by buildings and predicted to increase by 34% in the next 20 years [3,4]. Meanwhile, buildings are responsible for about 30% of the global anthropogenic carbon emission in 2004 according IPCC report [5]. In China, buildings contributed up to 1/4 of the total carbon emission in 2007 [6]. Many efforts have been made to find ways to decrease the building energy consumption to help ease the energy crisis by scholars worldwide and zero energy buildings (ZEBs) have been considered and drawn many attentions in recent years.

Zero energy buildings are kind of buildings which totally depend on solar energy and other renewable energy and do not consume conventional energy. The basic principles of selecting the technologies used in these buildings are to use the energy resources more efficiently and to reduce building energy consumption and carbon emissions as much as possible. Many countries have adopted or been considering ZEBs as their future building energy targets. For example, EU regulators have published the Energy Performance of Buildings Directive (EPBD) [7]. The EPBD mainly focuses on reducing the operational energy consumption of buildings, but it will also establish that by 2020, and it demands that every new building in the EU must be a "nearly-zero" energy building, which means to reduce the building energy demand and to produce energy on building site (or nearby) to balance the building energy demand in a cost-effective way.

In general, ZEBs involve two design strategies: minimizing the need for energy use in buildings through more energy-efficient measures, and adopting renewable energy and other technologies to meet the minimal energy needs [8]. The building industry's advance toward zero energy means the probable integration of additional energy-saving and clean energy producing components and systems. Energy saving in building envelopes, internal design conditions and building service systems are three main measures to minimize the energy demand in ZEBs. As to renewable energy application in ZEBs, the most commonly applied technologies are building integrated PV technology, wind turbines technology and solar thermal technology.

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Nomenclature

TE	thermoelectric
ABE window	active building envelope window
COP	coefficient of performance
COP_{int}	the integrated coefficient of performance is defined to estimate the energy utilization of the integrated system
ZT	the figure of merit of thermoelectric materials

Thermoelectric cooling systems have no mechanical moving parts and do not employ working fluids, which transfer heat from the cold side of the modules to the hot side with consumption of electricity [9]. 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 [10–14]. Thermoelectric cooling systems can be powered directly by a photovoltaic (PV) without the help of AC/DC inverter, which greatly reduces the costs. Moreover, 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, which fully fulfill the demand of ZEBs [15].

Recently researchers have created lots of novel solar thermoelectric cooling systems and improved the systems' performances. In this paper, applications of solar thermoelectric cooling technologies are reviewed and the possibility of their application in ZEBs is discussed. In details, in Section 2, solar thermoelectric cooling system is introduced. In Section 3, technologies of thermoelectric active building envelope including active wall and window system, which both use solar energy active control the thermal flux of building envelope, are introduced. In Section 4, the researches on applications of thermoelectric technologies in waste heat and cold recovery are reviewed, including heat recovery in mechanical ventilation system, thermoelectric air conditioner condense heat recovery, waste water heat recovery, kitchen exhaust heat recovery. In Section 5, solar thermoelectric air conditioners such as thermoelectric radiant air conditioner and solar thermoelectric energy storage air conditioner are presented. In Section 6, summary of solar thermoelectric cooling theologies for use in ZEBs are conducted. Finally, conclusions are drawn in Section 7.

2. Solar thermoelectric cooling system

In commercial types, the thermoelectric modules consist of P-type and N-type blocks of semiconductor materials. Fig. 1 shows the schematic design of commercial TE modules [16]. When direct current is passed through one or more pairs of P-type and N-type semiconductors, thermoelectric cooling effect occurs. When the thermoelectric cooling system works for space cooling, the cold side temperature decreases and heat is absorbed from indoor environment. At the same time, the temperature at the hot side increases and heat is dissipated to outdoor environment. By controlling the direction of the current, the functions of cooling and heating can be easily achieved.

In solar thermoelectric cooling system, solar radiation energy is converted into electrical energy by means of a photovoltaic unit. Subsequently, the electrical energy is supplied to the thermoelectric cooling system. Solar thermoelectric cooling system uses electron gas to serve as the working fluid and thus causes no harm to the environment. Due to this characteristic, there is an increasing interest in using solar thermoelectric cooling system for domestic refrigeration systems. Moreover, recent progresses in PV and thermoelectric technologies have led to significant reductions in manufacture costs of solar thermoelectric cooling system together with moderate improvements in the system performance. Although the coefficient of performance of solar thermoelectric air conditioner is lower than that of conventional compressor air conditioner, efforts are being made to develop domestic thermoelectric cooling systems which associate the advantages with this solid-state energy conversion technology.

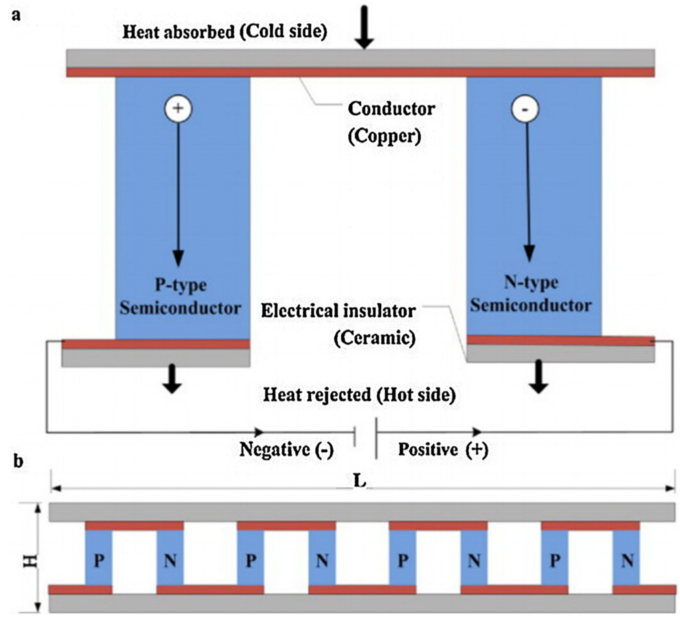

Fig. 1. Schematic design of commercial TE modules.

3. Application of solar thermoelectric technologies in active building envelopes

Building envelope separates the indoor and outdoor environment of a building, which is the key factor that determines the indoor quality. Building envelope plays an important role in building energy consumption. A large amount of energy is needed to compensate for thermal energy losses or gains that occur in building envelope systems for climate control. Conventional strategies to compensate for thermal energy losses or gains in enclosures rely on passive insulation materials and centralized heating and cooling systems. This space cooling or heating usually consumes electrical energy or non-renewable fossil fuels. In order to reduce building energy consumption, different passive methods such as insulation walls and passive solar building envelopes are used to reduce thermal energy losses or gains in enclosures.

Recently, passive solar building envelopes can be achieved by using solar system which can maximize solar heating gains in heating seasons and minimize heating gains in cooling seasons. Passive solar heating is a well-established concept in cold climates, which mainly includes solar chimney [17], solar room [18], Trombe wall [19], etc. However, both passive insulated walls and solar walls have disadvantages: (1) passive insulation cannot effectively control the heat flux and may have a negative influence on building energy consumption in summer [20]. (2) Passive solar technology usually can only be used in winter for heating. But in summer, passive solar envelopes cannot reduce the thermal load of envelope by controlling heat flux. Building envelopes integrated with thermoelectricity offer a new way for heating and cooling which can actively regulates the heat flow and provide both heating and cooling to offset the thermal losses or gains of envelopes. Compared with insulated