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Performance analysis on a building-integrated solar heating and cooling panel

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ABSTRACT

The solar heating and nocturnal radiant cooling techniques are combined aiming at a novel solar heating and cooling panel (termed as SHCP) to be easily assembled as construction components for building roofing or envelope and also compatible with surroundings for its versatile coating colors, which can remove the double-skin mode from conventional solar equipment. SHCP has two functions for heating and cooling collecting. In this paper, the heating and cooling performances were analyzed in detail based on a small scale experimental system and effects of air gap and coatings were investigated. The results show that in sunny day of extreme cold January in Tianjin, China, the daily average heat-collecting efficiency is 39% with the maximum of 65%, while in sunny night during hot seasons the average cooling capacity can reach 87 W/m^2. When two different coatings were sprayed on SHCP without air gap, its heating and cooling performances were all analyzed, the daily average heat-collecting efficiency was 39% and 27% with the maximum points of 65% and 49%, respectively, and the cooling capacity was almost the same of 30 W/m^2 in January.

1. Introduction

Currently, energy consumption in buildings mainly consists of domestic hot water, heating, cooling, ventilating, lighting and electrical appliance, which accounts for approximately 27.5% of the total energy use in China, and energy consumption for heating and cooling is 63% of the whole energy consumption in buildings. It is believed that such a proportion will be greatly increased with the rapid economic development of China. Consequently, it is of great importance in the building field to exploit renewable energy, which can minimize the energy expenditure and improve thermal comfort. And it is necessary to realize the integration of solar energy equipments with the building, which can ensure the integrality and aesthetics of buildings.

Solar thermal utilization is a mature technology, but nocturnal radiation cooling is a developing technology and has the advantages of energy saving and easy integration, which transmits thermal radiation on the earth through the two atmospheric windows (8 μm ~ 13 μm and 13.5 μm ~ 16 μm) to the sky, since the sky temperature is much lower than the temperature of most of objects on the earth. Considerable researches have been carried out to study the nocturnal radiant cooling technology under different climate conditions. Evyatar Erell and Yair Etzion have set up a radiant cooling system whose cooling output was 80 W/m^2 in the arid area [1]. Maal and Kodah have built another radiant cooling system whose cooling output was 13 MJ/(m^2 night) in Jordan [2]. A model building utilizing radiant cooling technology for preserving vegetable has been built in Japan, and the cooling capacity is 40–60 W/m^2 [3]. Shuo Zhang and Jianlei Niu have studied a nocturnal radiative cooling system combined with micro-encapsulated phase change material (MPCM) slurry storage system [4]. The cooling energy consumption and the effect of energy-free nocturnal radiation application were simulated based on hour-by-hour calculations in five typical cities across China. The results showed the energy saving potential in Lanzhou and Urumqi can reach 77% and 62% for low-rise buildings. The present hybrid system was recommended to be used in northern and central China cities where the weather is dry and the ambient temperature is low at night. Giuseppe Oliveti studied the radiation exchange between the building walls and the surrounding environment (sky, ground) in the infrared band and determined the radiation heat transfer efficiency between the vertical wall and the sky, between the vertical wall and the ground, also the level roof and the sky [5]. Ursula Eicker and Antoine Dalibard developed a new type of PVT system to

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generate electricity and cooling [6]. In Madrid, the average cooling capacity measured was 60–65 W/m^2. Moien Farmahini Farahani studied a multi-step refrigeration system of the nocturnal radiative cooling technology combined with two stage evaporation refrigeration and verified the feasibility in four different climatic conditions [7]. The results showed that the multi-step refrigeration system could be the choice for refrigeration in summer. Moien Farmahini Farahani studied a set of two step cooling system including night radiative cooling unit, cooling coil unit and indirect evaporative cooling unit [8]. In summer night, the water in the cooling coil was cooled through radiative cooling way and stored in the tank. During the day, the outdoor hot air passed through the cooling coil and indirect evaporative cooling unit to be cooled.

As for the dual-functional system that solar heating is coupled with sky radiant cooling, the solar wall [9,10] and solar roofing system [11] are both the passive heating and cooling technique, using the facades and roof of buildings as solar collector or radiator and air as the working fluid, to supply the requirement energy for buildings. Evyatar. Erell and Yair. Etzion studied the heating performance of the radiative cooling system mentioned in Ref. [1], the average heat-collecting output of the system was 370 W/m^2 under the sunny but cool conditions of typical Sde-Boker winter [1,12]. M. Matsuta et al. studied a solar heating and radiative cooling system using a solar collector-sky radiator, the maximum collective and radiative capacities obtained were 610 W/m^2 and 51 W/m^2, respectively for a clear day and night [13].

Patent ZL03154771.1 presents a sort of solar collector wall that can be used as construction component of building envelope, which realizes the perfect combination of solar energy equipments with the building [14]. In this paper, the nocturnal radiant cooling technology was coupled with the solar collector wall mentioned above to produce a building-integrated solar heating and cooling panel, termed as SHCP hereinafter. Experimental apparatus were set up for detailed study on its performance.

2. System descriptions

2.1. Structure of SHCP

The cross-section profiles of different SHCP is shown in Fig. 1. Fig 1a gives the sectional profile of the SHCP without air gap, which mainly concerns about heating function. The structure of SHCP is from outside functional and protective coating, metal plate, heat-conductive filling adhesive, metal tubes, tube-fixing metal fittings with grooves and finally to the inside insulation layer which also functions as the building envelope insulation layer. When local night ambient temperature is low enough to be used for cooling, an air gap was added between the plate and insulation layer but with adjustable inlet and outlet, which is demonstrated in Fig. 1b.

The panel investigated here has specified structure size and materials. Acrylic resin coating of about ten years' life length was sprayed manually on an aluminum plate with length of 2000 mm and width of 1000 mm and thickness of 1 mm; copper tubes of 8 mm diameter were mechanically fixed at a space 150 mm to the plate by 10 mm wide aluminum stripes with grooves and conductively fixed using self-made conductive glue with the conductivity of 3.12 W/(m K); high heat-proof performance polystyrene insulation board with 90 mm thickness was used and if needed a 50 mm air gap was added.

2.2. Experimental system

An experimental system was set up to test the performance of the SHCP designed above with necessary auxiliary parts shown in Fig. 2, where two 30 L tanks were used for heating and cooling storage. All the exposed surfaces of the system besides SHCP were insulated by rubber-plastic with 30 mm thickness. The SHCP was set vertically facing south aimed to act as building envelope. The red line represents the heating cycle while the blue line (in web version) gives the cooling cycle, and the arrows show the working fluid flow path and orientation. Working fluid is water in this work, while 29% ethanol solution as working fluid in winter to prevent freezing.

SHCP was used as solar heat collector at daytime while acts as radiator at night. When it is the heating cycle, the pump1, rotameter1 and valve1 are turned on with pump2, rotameter2 and valve2 closed. The working fluid in the bottom of heat-storage tank is pumped out to be heated by incident solar irradiation on SHCP, and then flows back to the top of heat-storage tank. When outlet temperature of working fluid in SHCP is lower than inlet temperature, it comes to the cooling cycle, valves and pumps are set in reverse manually. Working fluid in the top of cool-storage tank is pumped into the tubes of the panels and cooled by means of radiation and sometimes coupled by natural convection when the

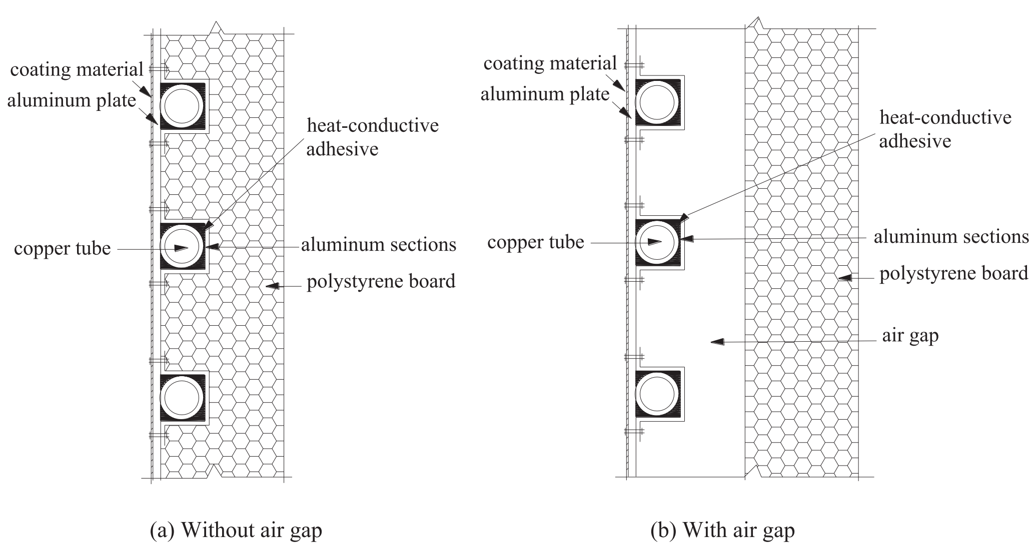

Fig. 1. Cross-section profiles of different SHCP.