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Experiment and prediction of hybrid solar air heating system applied on a solar demonstration building

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ABSTRACT

As solar space heating is one of the most efficient ways to reduce fossil energy consumption, a hybrid solar air heating system for building space heating is proposed in this paper. The system includes passive and active dual function solar collectors. It was tested on a solar demonstration building, which was located on USTC (University of Science and Technology of China, Hefei China) campus. Different operation strategies of the hybrid solar air heating system were tested experimentally in order to evaluate heating effect of the system. The results showed that the strategy of passive solar heating for southern room space heating and active solar heating for northern room was a better operation strategy, by which the average indoor temperature of both southern and northern rooms reached 17.0 °C during the experiment. Based on the experimental results and software of TRNSYS simulation, the solar fractions of the system during the heating season in Hefei and Nyingchi were predicted with values of 39.5% and 69.0%, respectively. Above all, it presented an efficient design philosophy for building to utilize solar energy for space heating.

1. Introduction

Nowadays, buildings energy consumption accounts for approximately 25–30% of total energy consumption in China. Although this proportion is still lower than that in the developed countries, it is highly probable that the proportion will increase to a higher level due to people's ever-growing demand for better thermal comfort with the rapid development of China [1,2]. Applying solar thermal energy for space heating is considered as one of the most efficient and environment friendly ways to reduce fossil energy consumption.

Numerous researchers have exploited solar energy for space heating and optimized components, systems and operation strategies for better thermal performance and comfort [3–6]. These solar technologies for space heating can be classified into passive and active solar heating. For passive heating system, such as solar sunspace [4], windows [7] and Trombe wall [8], solar energy is passively utilized with no moving part in the system. On the contrary, active solar heating system adopts mechanical energy to distribute absorbed solar energy to desired rooms [9]. In the recent research of passive solar heating, Sun et al. presented a PV-Trombe wall, which can convert solar energy into heat for space heating and electricity simultaneously [10]. Kara et al. presented a Trombe wall containing phase change material and investigated the performance of coupled novel triple glass and PCM wall [11]. In the aspect of active solar heating, Zheng et al. presented an experimental test on applying multi surface solar concentrator for air heating [12]. Moreover, Yang et al. presented a solar assisted heat pump system for building space heating with a roof integrated solar collector as the evaporator [13]. However, both techniques have their own drawbacks that passive solar heating is limited to sunny slope rooms and the active solar heating is more costly [14]. It is expected that a hybrid system that has advantages of both passive and active techniques might provide an economical and feasible solution for utilizing solar energy for building space heating. In this respect, Badescu et al. simulated an active space heating system in a passive house and calculated contributions of passive and active solar systems to the thermal load of the residential building. The simulation results showed that the effect of solar heating depended on the operation strategies of the heating system [15,16]. Albeit tremendous efforts have been put on this area of research, to the best of our knowledge, few experimental investigations have ever been reported on the hybrid solar space heating system.

Therefore, a hybrid solar air heating system for space heating is proposed in this paper. The system employs two types dual function solar collectors (DFSC), one of which functions like the Trombe wall and provides passive space heating, the other operates like

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Nomenclature

A	area, m^2
COP	coefficient of performance
C_p	specific heat capacity of the air, J/(kg K)
$\dot{m}$	air mass flow rate, kg/s
$P_{electric}$	total electric power consumption, kW
Q	thermal energy gain, kW
V	volumetric flow rate of air, m^3/h
RE	relative error
RME	experimental mean error
S	solar irradiance, W/m^2
SF	solar fraction
T	temperature, °C
T	time

Greek

ρ	density, kg/m^3
η	efficiency, –

Subscripts

0	start time of the experiment
act	active
amb	ambient
ave	average
exp	finish time of the experiment
heat1	auxiliary heating consumption without hybrid solar air heating system
heat2	auxiliary heating consumption with hybrid solar air heating system
out	outlet

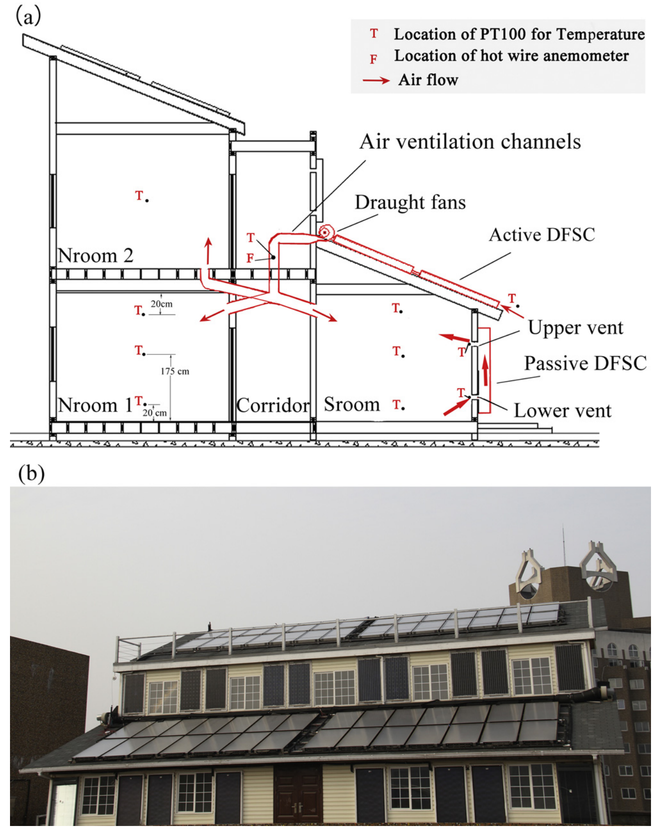

Fig. 1. Description of the solar demonstration building (a) schematic of the hybrid solar air heating system (b) south view of the solar demonstration building.

solar air collector and delivers active space heating. The system was applied on a novel solar demonstration building, which was constructed on campus of USTC. In previous research, investigation of DFSC was focused on single module [5,17,18], while in this paper experiments are carried out to investigate the performance of the whole hybrid solar air heating system and to evaluate the indoor thermal environment affected by the system. In addition, simulation by software of TRNSYS [19] was conducted to predict the solar fraction that the system contributed in total energy consumption in space heating during heating season in different districts.

2. Description of the proposed system

The hybrid solar air heating system is a combination of passive and active solar heating. It is applied on a solar demonstration building. The details of the building and the heating system are presented in the following sections.

2.1. Solar demonstration building

The two-floor building, as shown in Fig. 1, was constructed as an office building on campus of USTC. Hefei (117.23 °E, 31.87 °N) is subtropical monsoon climate with sunshine of approximately 2100 h per year and average annual temperature of 15.7 °C. The coldest month is January, with an average temperature of 2.4 °C, while the hottest is July, with an average temperature of 28.4 °C. The building was constructed with light wood frame and occupied an area of 265.6 m^2. Various solar components were integrated with the envelope of demonstration building to supply solar energy for space heating, cooling, electricity and domestic hot water. However, this paper focuses on the performance of hybrid solar air heating system for space heating during heating season.

2.2. Hybrid solar air heating system

DFSCs are the core components in the hybrid solar air heating system to convert solar energy for space heating. In winter DFSCs supply warm air for space heating and in none-heating season it provide hot domestic water to increase the annual utilization ratio of solar thermal energy [17,18]. Two types of DFSCs were used in the hybrid solar air heating system.

Six pieces of passive DFSCs with a total aperture area of 11 m^2 were embedded in the south façade, forming the passive solar air heating system. Each DFSC had an air channel connected to indoor room via upper and lower vents, as shown in Fig. 1(a). The operating principle in winter was that the incident solar energy was absorbed by air inside the DFSC and conveyed to the room by nature convection via two vents, like Trombe wall.

On the other side, twenty eight pieces of DFSCs with a total aperture area of 44 m^2 were connected as a 2 × 14 array and mounted on the pitched roof of the building. The air channels of two DFSCs in every column were linked up in series, so the air could be heated continuously for a long distance. The active DFSCs array, draught fans and the air ventilation channels composed the active solar air heating system, which delivered air from ambient to desired rooms. The route of air from ambient into rooms is shown in Fig. 1(a).

The passive and active solar heating can be operated independently or synergistically. Therefore, there are different operation strategies for the hybrid solar air heating system. The performance of different operation strategies was studied in this paper.

2.3. Test rig of the hybrid solar air heating system

To test the performance of the hybrid solar air heating system, temperatures of air at upper and lower vents of the passive DFSC,