EXPERIMENTAL AND NUMERICAL STUDY INTO SOLAR AIR COLLECTORS WITH INTEGRATED LATENT HEAT THERMAL STORAGE

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Summary

The main goal of the study was to assess the thermal performance of a solar air collector with latent heat storage integrated with the solar absorber plate. The investigations involved two flat plate, single-glazed, front-and-back pass experimental solar air collectors of the same dimensions. One of the collectors had a solar absorber plate made of sheet metal while the solar absorber plate of the other collector consisted of aluminum containers filled with paraffin-based phase change material (PCM). The experiments were performed under real climatic conditions. The collectors were positioned side by side with the same tilt and the same orientation. A numerical model of the collectors was created in the TRNSYS simulation tool with the use of an in-house model for latent heat thermal storage.

Keywords: solar air collector, latent heat storage, phase change materials

1 Introduction

Solar radiation is the most abundant form of renewable energy available to mankind. Though solar energy is not the general answer to mankind's energy needs it does make a lot of sense to employ all viable ways of solar energy utilization. Solar systems utilizing air as a heat carrier fluid are not as common as the systems employing water or other liquid for that purpose but they can be used in many applications including pre-heating of ventilation air or space heating of buildings. Solar pre-heating of ventilation air is probably the simplest way to employ solar air heating in buildings. A lot of attention has been paid to double-skin building envelopes in the last two decade. Some of the double-skin envelopes function as solar air heaters in certain modes of operation. Much simpler arrangements of solar air heaters can be used for warehouses, assembly hall and other types of industrial buildings with little glazing in external walls. Simple unglazed types of collectors are quite often used for this purpose. Most of these applications do not require thermal storage and that makes such systems relatively inexpensive and easy to install. Solar heating systems with heat storage are more complicated [1], [2], [3]. The packed beds (mostly containing rocks) represent a common way of heat storage for solar air heating systems [4]. The size of the packed beds depends on the required heat storage

capacity and the beds can occupy a lot of space if they are supposed to provide heating for several days (not to mention seasonal heat storage). That is why solar air heating systems with long-term heat storage are rather unique. However, in some cases thermal storage can be used only to attenuate fluctuation of the air temperature at the outlet of the air heater (e.g. on cloudy days when solar radiation intensity changes rapidly). In such a case thermal storage can be integrated directly with the solar absorber plate.

2 Case study description

The main goal of the investigations reported in this paper was to assess the thermal performance of a solar air collector with latent heat storage integrated with the solar absorber plate. The investigations involved two flat plate, single-glazed, front-and-back pass experimental solar air collectors of the same dimensions. A front-and-back pass solar air collector is a collector where air passes in the same direction on both sides of the solar absorber plate. The dimensions of the aperture of each of the two experimental collectors were 900 mm by 1500 mm. The air cavity on each side of the solar absorber plate was 25 mm wide. The ambient air entered the collectors at the bottom and the solar heated air was drawn from the collector at the top (pre-heating of ventilation air). A circular duct with the diameter of 100 mm was connected to the outlet of the collector and an axial fan was used to maintain the desired air flow rate through the collectors. The cross-section of the collector is shown in Fig. 1a.

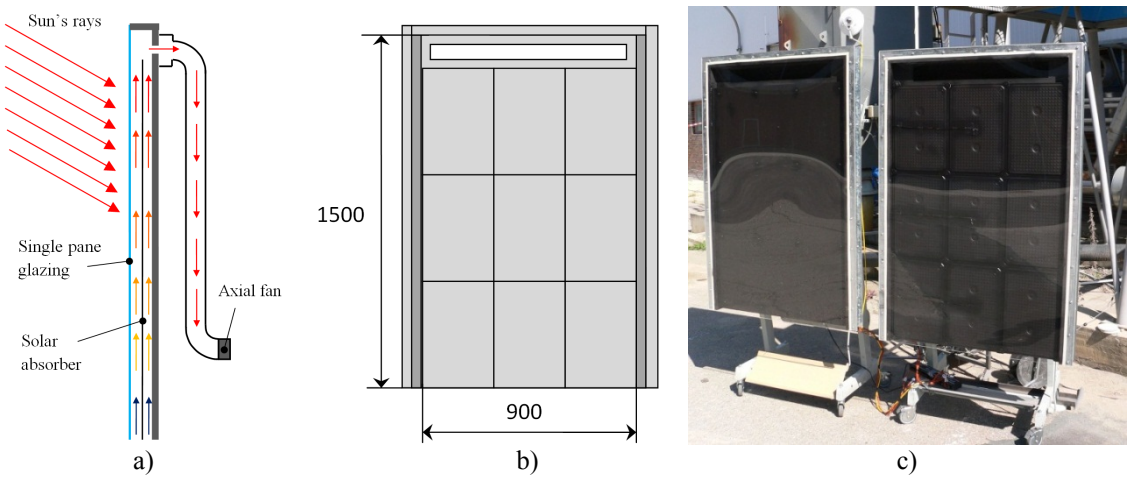

Fig. 1 *Experimental solar collectors*

One of the collectors had the solar absorber plate made of sheet metal while the solar absorber plate of the other collector consisted of 9 aluminum containers filled with paraffin-based phase change material (Fig. 1b). Similar containers were used in other studies [5] because the containers can rather easily be integrated with various structures. The dimensions of the containers were 300 mm x 450 mm x 10 mm and each container accommodated approximately 700 ml of the PCM. The phase change temperature range of the PCM was between 37 °C and 43 °C. Most PCMs have rather wide melting ranges and the melting and solidification process depends, among other things, on the speed of the temperature change [6]. The thermal capacity of the PCM was 174 kJ/kg in the temperature range between 35 °C and 50 °C. The density of the PCM was 880 kg/m^3 in the solid state

and 760 kg/m^3 in the liquid state. Figure 1c shows a photo of the collectors during the experiments. The collector with the light-weight (sheet metal) solar absorber plate is on the left and the collector with the thermal storage (PCM) absorber plate is on the right. The collector mounting frames were fitted with wheels for easier transport and positioning of the collectors. A PC-based data acquisition was used for monitoring of the collectors and the weather conditions. Solar radiation incident on the collectors was measured with a pyranometer (visible in the photo). A wind speed and direction gauge was installed on a pole above the collectors in order to account for the influence of the wind. A numerical model of the experimental collectors was created in the simulation tool TRNSYS vs. 17. An in-house model of the solar absorber plate with the PCM (implemented as a Trnsys Type) was developed for that purpose. The model uses the effective capacity approach to address phase change of the material.

3 Results

The experiments were performed under real climatic conditions with the collectors positioned side by side. The inlet (outdoor) air temperature and the air temperatures at the outlet of the collectors on September 14, 2012 are shown in Fig. 2. The solar collectors were in the vertical position oriented to due south (azimuth 180°). The air flow rate through each of the collectors was 109 m^3/hour during this experiment. The total heat storage capacity of the absorber plate containing the PCM was relatively small (0.22 kWh between 35 °C and 50 °C). Even then it can be seen that the outlet temperature of the collector with the PCM was more stable during the day. The total solar radiation incident on the aperture area of each collector between 10:20 A.M. and 4:45 P.M. was 3.78 kWh. The total heat yield of the collector with the light-weight absorber plate was 2.28 kWh. The collector with the absorber plate containing the PCM yielded 2.36 kWh during the same time period. Fig. 3 shows the simulated outlet air temperature of the collector with the absorber plate containing the PCM. The collector was in a vertical position facing due south (e.g. installation on a building facade). Pre-heating of ventilation air was considered in this simulated scenario with a constant air flow rate of 80 m^3/hour. The meteorological data (TMY) for Kucharovice, Czech Republic were used in the simulations.

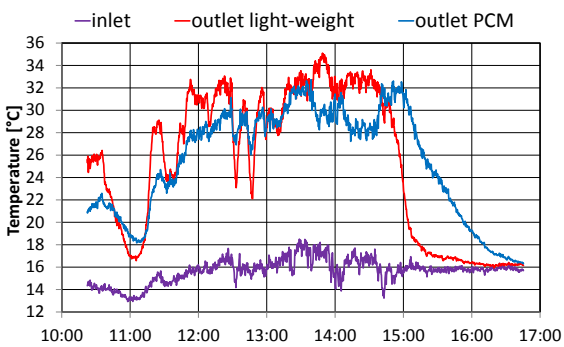

Fig. 2 *Measured temperatures (Sep. 14, 2012)*

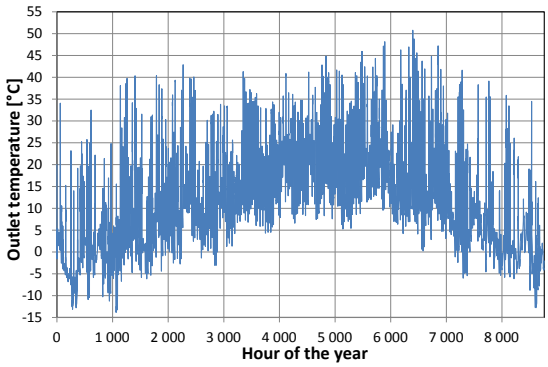

Fig. 3 *Annual performance simulation*

4 Conclusions

The thermal behavior of a solar air collector with latent heat thermal storage integrated with the solar absorber plate was investigated experimentally and numerically. Both experiments and numerical simulations showed that thermal storage integrated with the solar absorber plate contributes to higher stability of the air temperature at the outlet of the collector and also to slightly better efficiency of the collector. The higher efficiency can be explained by lower average air temperature in the collector with the PCM and therefore its lower heat loss. However, the experimentally obtained differences in the heat yield between the collectors were so small that they fell into the uncertainty range of the measurements. The annual simulations of the performance of the collectors indicate that the highest energy yields of the collectors can be expected for pre-heating of ventilation air. Solar air space heating, when indoor air is circulated through the collectors, is associated with higher thermal losses of the collectors leading to lower energy yields. The simulations showed that the air temperature at the outlet of the collectors exceeded 30 °C on sunny days in spring and autumn when operating in pre-heating of ventilation air mode.

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