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PCM thermal storage system for cooling and heating of buildings

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Abstract

In order to reduce building energy use, system with phase change material (PCM) was constructed. During summer nights, cold is stored (PCM solidifies) and is delivered during the day for pre cooling of the fresh air, whereas in winter, heat from solar air collector is stored (PCM melts) during sunny day for heating during cold evening and night hours. System consists of a stand-alone unit, composed of 30 plates filled with paraffin RT22HC, fan, hatch and solar air collector during winter time. The objective was to examine the functioning of the system in the office room on an annual basis. Measurements were conducted year round in order to determine system feasibility for both cooling and heating.

Keywords – PCM, Thermal energy storage, CSM plates, Hot air collector

1. Introduction

In developed countries buildings account for a 40 % of the total final energy consumption. More than 50 % of that energy goes to HVAC systems. Therefore one of the priorities of the EU is to minimize the energy consumed by buildings. The EPB Directive states that it is necessary to choose alternative solutions for heating and cooling [1]. One option is thermal energy storage (TES) using phase change materials (PCMs).

We built an experimental system for cooling and heating an office in our building [2, 3, 4]. The idea was to utilize natural sources within stand-alone active system. Outdoor cold during summer nights is stored and supplied to the indoor environment during the day when the cooling load increases. For the heating requirements, energy from the sun is used with help from solar hot air collector. Heat during the sunny day is stored and supplied to the office in early mornings or late evenings or in cloudy days. The main objective was to examine closely the functioning of the suggested system on an annual basis and to explore the feasibility of using it for office cooling as well as for heating.

2. Eperimental setup

An experimental rig for testing storage unit's thermal response was set up as shown in figure 1. On the basis of calculations of office cooling and heating loads, we determined type and quantity of phase change material for the thermal storage. Chosen PCM should operate in temperature range between 20 and 26 °C. We decided to use PCM RT22HC, produced by Rubitherm GmbH, with melting point around 22 °C [5].

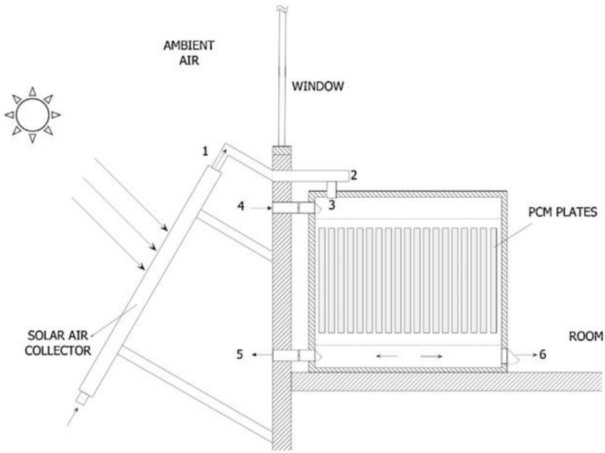

Figure 1: Conceptual design of experimental setup

Thermal storage casing was made of 5 cm thick EPS and the internal dimensions were 73 cm × 45 cm × 39 cm. Used PCM was macroencapsulated in the form of CSM plates. Outer dimensions of plates were 30 cm × 45 cm × 1.5 cm and they were horizontally positioned in the storage tank (the shorter side parallel to the flow). The unit contained 29 CSM plates (air gap between plates was 0.8 cm). Measured average mass of filled plate was 1361 g, weight of paraffin in the plate was 1003 g and volume of each plate was 1.48 liters. Approximately 12% of the plate's volume is empty in order to compensate the volume expansion of the liquid PCM and to avoid deformation of the plate due to higher pressure. Thermal storage tank is on both sides gradually moving to the tube with diameter 110 mm. Tubes are isolated with 20 mm of insulation. Fan, connected with speed regulator is installed before the thermal storage tank. It has five speed levels. At the output of the air from thermal storage we installed a hatch, which can direct airflow to the office or out. Part of the setup is also a solar hot air collector which is installed on the outer wall of the office. Experimental setup is shown on figure 2.

Working of the experimental system is different for heating and cooling.

In heating mode system operates from 8 am to 4 pm. When there is enough sun radiation, collector heats air and that heat is stored in thermal storage (PCM melts). In evening and mornings or during days with low or no sun radiation, stored heat is used to heat the office (PCM solidifies).

In cooling mode system is working in two cycles. First cycle is happening during the night, when cold air is supplied to the thermal storage and its cold is stored (PCM solidifies). Second cycle is happening during the day, when warm air is supplied to the thermal storage where it is cooled down (PCM melts) and supplied to the office.

Figure 2: Experimental system: in room (left), solar air collector outside (right)

3. Measurements

Measurements of air temperature, air flow and energy consumption were conducted. Figure 3 show us positions of measuring sensors.

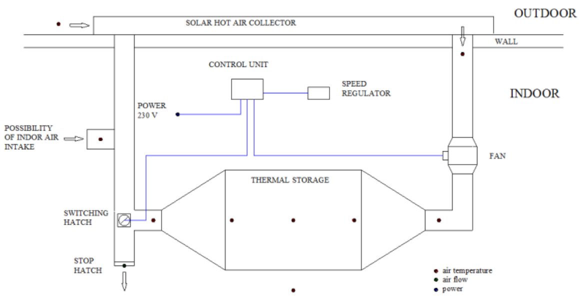

Figure 3: Testing line of PCM storage with measurement points

Electrical power of the system was measured at the connection of system to the electricity grid. Air speed was measured at the outlet of air from the system. Temperature sensors were put to nine important places. In this way we get precise data of temperature throughout the system.

Measurements in cooling mode were carried out in October 2014; in heating mode in January 2016.

4. Results

A. Cooling mode

Figure 4 depict air temperature of inlet and outlet air in thermal storage for a period of 24 hours in a day in October. We see big difference between lowest and highest temperature of inlet air. It cools down to almost 14 °C during the night (lowest at 6 am) and warms up to almost 30 °C during the day (between 1 and 3 pm). Outlet air from the thermal storage has a lot smaller difference between lowest and highest temperature. During the night PCM solidifies and give heat to the air so the temperatures do not fall below 18 °C. During the day opposite happen. Because of high temperature of inlet air PCM melts and takes away heat from that air so the outlet temperature do not exceed 22 °C.

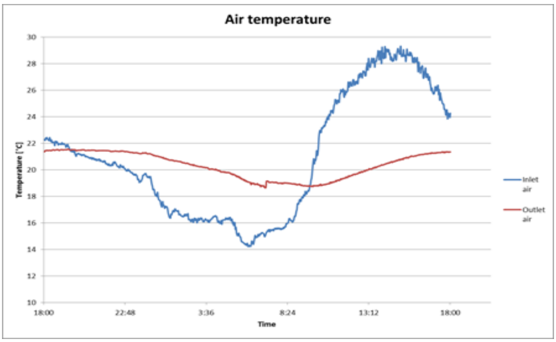

Figure 4: Air temperature cooling

We calculate stored and used cold for each day. Theoretically calculated figures were not met in any day. Energy consumption was also calculated and system efficiency was determined. Results show us efficiency between 0,6 and 2.44.

B. Heating mode

When in heating mode system operates from 8 am to 4 pm. Figure 5 shows us temperatures in inlet and outlet of thermal storage. Temperature in inlet of thermal storage is also outlet temperature of solar hot air collector. It was partly sunny day (foggy morning, some clouds in the afternoon) as we can conclude from the inlet air temperature. In the morning cold inlet air was heated (PCM solidifies), but when sun shows inlet air quickly became hot enough to reverse the process (PCM melts – heat is stored). Stored heat is then used in the afternoon and the next day.

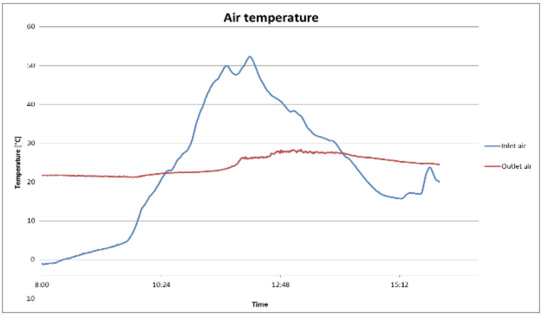

Figure 5: Air temperature heating

Efficiency of heating mode is much greater - average 12.9. Mainly because of two things: system is operating only for 8 hours (during work time) and temperature difference between inlet air temperature and melting point of PCM is much greater than in cooling mode which means that lower air flow is needed and that means low energy consumption of the system. As we can see in figure 5 we have high inlet air temperatures, but without thermal storage we cannot use all available heat because of overheating. So in reality efficiency of system with thermal storage is much greater than efficiency of system without thermal storage.

5. Conclusion

Systems with phase change technology definitely are promising alternative to conventional systems. Our results show that in cooling mode system did cool down the air, but also consume electrical energy for the fan. In heating mode results are much better and show us that in solar hot air collector systems thermal storage is mandatory. PCM thermal storage perform great with air cooling and heating systems because it deliver outlet air of almost constant temperature. Electrical energy can be decreased with using of PV modul.

Acknowledgment

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