PCM cold storage under various ventilation conditions

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Abstract

Cold storage is a way to deal with peak cooling loads. Cold storage integrated with building structures is independent of the approach used for building cooling – it can be used with passive cooling as well as mechanical cooling. High thermal storage capacity in a narrow temperature interval makes phase change materials (PCMs) a suitable medium for cold storage in built environments. A set of experiments was performed with the aim to investigate performance of PCM cold storage in building structures under various ventilation strategies. The experiments were carried out in two identical test rooms located in an attic of a building. The main problem of PCM cold storage in building structures is the discharge (rejection) of heat. Three ventilation strategies were used to reject heat from cold storage. These strategies were: natural ventilation, mechanical supply of unconditioned outdoor air and mechanical supply of air-conditioned air.

Keywords: ventilation, phase change materials, cold storage

Introduction

The increasing use of air-conditioning in Europe and throughout the world leads to higher consumption of electricity in the buildings. Buildings already account for most of the electricity consumption in the developed countries. Modern architecture favors light-weight building structures and transparent building envelopes. Such buildings have a very low thermal mass and the external and internal heat gains immediately translate into the increase of indoor temperature (causing discomfort of the occupants). That makes air-conditioning unavoidable in many cases.

Another trend that can be seen today is the increasing use of air-to-air air-conditioning systems (e.g. variable refrigerant flow systems). The air-to-air systems are being installed in the types of buildings where only chilled-water systems were used in the past. Modern air-to-air air-conditioning systems are easy to install, boast with high COP, and most of them can operate in the space heating mode. Those features make them a really good option in the climates where space cooling dominates but space heating is also needed during a certain part of the year. Unlike the chilled-water systems, where ice thermal storage can be employed to deal with the peak cooling loads, the thermal storage capacity has to be provided by the building itself in case of the air-to-air air-conditioning systems. That is where cold thermal storage in building structures can be employed.

PCM thermal storage

Matter can exist in three phases – solid, liquid and gas – and the transition from one phase to another is associated with transfer of latent heat. Phase change is more or less an isothermal process (more for pure chemical elements less for mixtures of substances). The liquid-gas phase change has been successfully used in many technical applications (steam turbine cycles, vapor compression cycle, etc.). The utilization of solid-liquid phase change is much less common in technical applications and its most promising potential can be seen in the area of thermal storage. Unlike sensible heat storage, where the amount of stored heat is proportional to the change in temperature of the heat storage medium, latent heat storage allows to store huge amount of heat at almost constant temperature.

The expression phase change material (PCM) generally refers to a material with high heat of fusion that is used for thermal storage purposes. The phase change materials have become a well established category in the material science and they are finding their way to application in many new areas. A number of phase change materials suitable for heat storage applications have been identified and many more materials are being developed. Sharma et al. (2009) presents a review on thermal energy storage with phase change materials. The obvious advantage of PCMs in thermal storage is their high thermal storage capacity in a very narrow temperature interval. This advantage can be utilized in cold thermal storage in building structures. Unlike ice thermal storage that operates at rather low temperatures, the PCM cold storage can operate at room temperature and thus to contribute to higher energy efficiency of air-conditioning systems.

Selection of a suitable PCM for cool thermal storage in building structures is not an easy task. Organic PCMs do not suffer from phase separation during phase change and deterioration of their properties with the undergone number of melting cycles is relatively small – Shukla et al. (2009). On the other hand, organic PCMs have relatively low density and thermal conductivity. Also, their flammability can pose a fire hazard in some situations. Inorganic PCMs offer relatively high values of heat of fusion (latent heat) per unit of mass and their thermal conductivity is generally better than that of the organic PCMs. Hydrated salts, that represent the most common inorganic PCMs, contain water and they have to be kept in airtight containers as not to change the water content. One of the main problems with the hydrated salt PCMs is their tendency for supercooling – cooling below the melting temperature without changing the phase. Supercooling of hydrated salts can be considerably reduced when a small amount of nucleating agent is added to the PCM. The nucleating agent initializes crystallization and thus suppresses the supercooling effect.

The advantage of PCM thermal storage in comparison to sensible heat storage can be observed in the chart in Figure 1. The chart shows the results of an environmental chamber experiment with the aluminum containers filled with the Rubitherm® SP 25 blend. The blend has a melting temperature of 26°C and congealing temperature of 25°C. The heat storage capacity in the temperature range 15/30°C is 180 kJ/kg. One of the containers in this experiment was filled with water instead of the PCM in order to obtain comparison between latent heat and sensible heat storage. The air temperature in the chamber was increased to 29℃ at the rate of 0.1 K per minute and afterwards it was maintained at 29℃ for 10 hours. Then the air temperature in the chamber was decreased to 20℃ (at the rate of 0.1 K per minute) and kept at that level for another 10 hours. As can be seen, the temperature of water-filled container followed very quickly the air temperature in the chamber while it took almost 12 hours for the container filled with Rubitherm® SP 25 blend to reach temperature of 29℃. The phase change is not distinctly visible in the melting period. There is a distinct change in the slope of the temperature curve at about 26℃ (apparently caused by the phase change) but there is no temperature plateau so well known from the theory. The phase change is much better recognizable in the congealing period. A slight supercooling at the initialization of congealing can be seen in the chart but it is rather small.

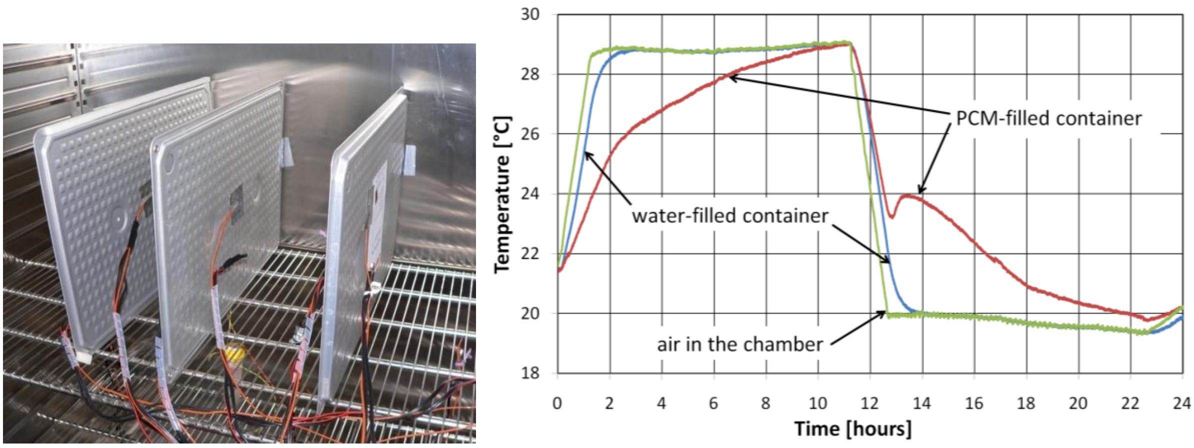

Fig. 1 Comparison of latent heat and sensible heat thermal storage

Experimental facility

Investigations of the performance of PCM cold storage integrated with building structures were carried out in two test rooms located in the attic of one of the university buildings (Figure 2). Each of the test rooms has a floor area of 14.9 m^2 and volume of 29.4 m^3. The test rooms have the same shape and dimensions. The walls of the test rooms are thermally insulated with 200 mm of mineral wool. Internal and external surfaces are covered with gypsum wall boards. A vapor barrier is installed under the internal covering.

The light-weight partition between the rooms is insulated with 400 mm of mineral wool in order to minimize heat transfer between the rooms. The clearance height of the rooms is 2300 mm. The light-weight ceiling is also covered with gypsum wall boards and insulated with 200 mm of mineral wool. There is a skylight in each of the room. The skylights are operable and are facing south west.

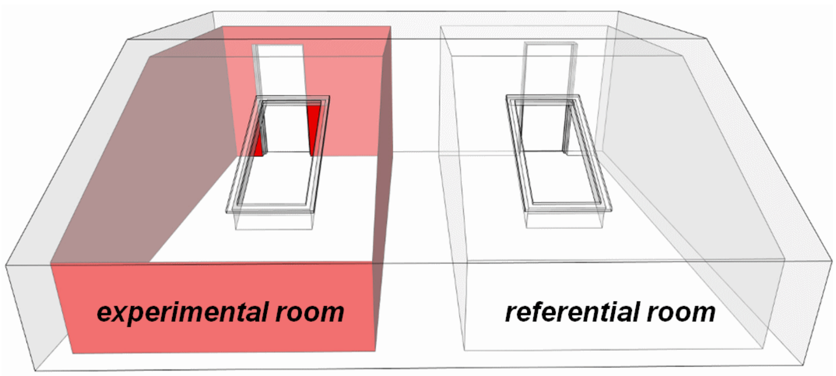

Fig. 2 Test rooms

In total 240 containers filled with the PCM were installed in one of the test rooms (the room will be referred to as the experimental room). The containers were installed on walls and the ceiling (Figure 3). The total latent heat storage capacity is approximately 36 MJ. An air handling unit is installed at the test rooms. The unit is fitted with a direct evaporator for mechanical cooling of supply air. The air supply (by means of a textile air diffuser) is situated under the ceiling and the exhaust air is extracted through the grills at the bottom of the wall. Air supply through the wall mounted grills located at the ceiling is also possible.

Fig. 3 Experimental room with PCM filled panels

Three ventilation scenarios were investigated: natural ventilation, mechanical supply of unconditioned outdoor air and mechanical supply of air-conditioned air.

Scenario 1 (natural ventilation): No energy is needed to provide ventilation in natural ventilation case but the air change rate cannot be controlled. The configuration of the test rooms does not allow cross ventilation and single-sided ventilation through the skylights is not very efficient.

Scenario 2 (mechanical ventilation with unconditioned air): The use of mechanical ventilation allows control of the ventilation rates. A minimum ventilation rate was maintained during daytime and a high air change rate was used overnight. Unconditioned outdoor air was used all the time.

Scenario 3 (mechanical ventilation with air-conditioned air at night): The minimum ventilation rate was provided during daytime (with unconditioned outdoor air) and air-conditioned air was supplied to the rooms at night.

Results and Discussion

As expected, the scenario 1 (natural ventilation) was not very effective in combination with cold storage in the tested configuration (Figure 4). The daily temperature swing in both rooms was rather small, though some stabilizing effect of additional thermal on the indoor temperature in the experimental room can observed. The experiments were carried out in early June when the highest outdoor air temperatures were relatively low (rarely exceeding 30℃). The air change rates could not be measured in this scenario, but considering the moderate decrease of temperature in the rooms overnight the air change rates had to be quite small.

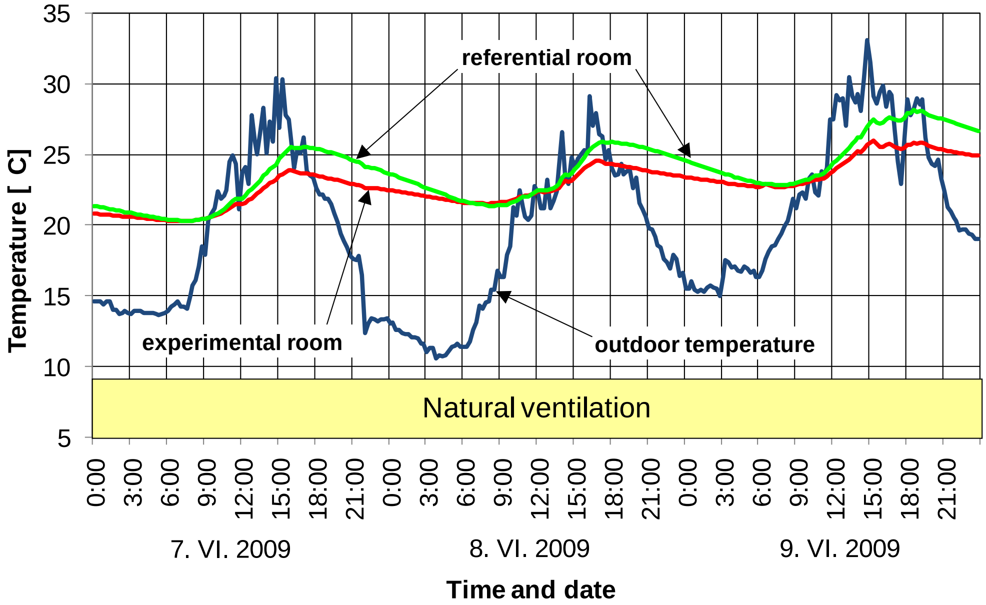

Fig. 4 Scenario 1 – all-time natural ventilation

The scenario 2, in which unconditioned outdoor air was supplied into the rooms (Figure 5), showed better results than natural ventilation. The controller of the air handling unit did not allow control of the air flow rate with regard to the outdoor temperature, therefore, a time schedule for air flow rates was used. The air handling unit operated at minimum capacity from 6 A.M. to 8 P.M. and over the night it operated at the maximum capacity. The decrease of indoor temperature in both rooms was much steeper when passive cooling by intensive mechanical ventilation was used at night than in case of natural ventilation. Even better results could be achieved with a better location of the air intake of the air handling unit. The air intake was located at the roof and the outdoor air drawn into the intake had a higher temperature than was the outdoor air temperature at a nearby (distance of 100 m) weather station. This can be one of the problems when using night ventilation passive cooling technique in urban areas (urban heat island).

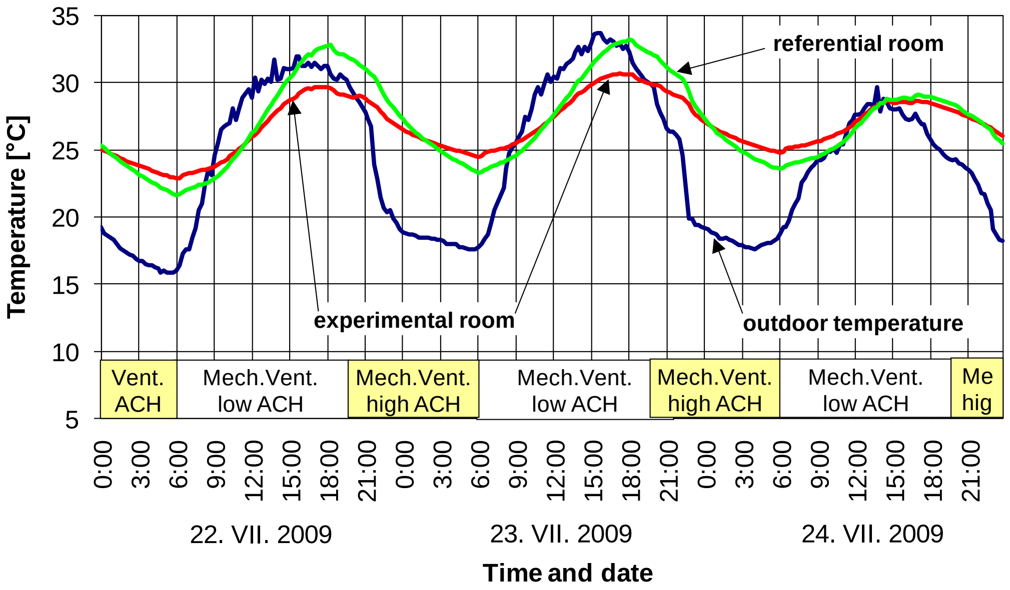

Fig. 5 Mechanical ventilation with unconditioned outdoor air

The best results were achieved in scenario 3 when air-conditioned air was supplied into the rooms at night (Figure 6). The air supply time schedule was similar to scenario 2: mechanical ventilation with the air handling unit operating at minimum capacity was used from 6 A.M. to 8 P.M. The unconditioned outdoor air was supplied to the rooms during this period. Mechanical cooling of supply air was used overnight (from 8 P.M. to 6 A.M.). There can be seen a steep decrease in indoor temperature when the air-conditioning was enabled.

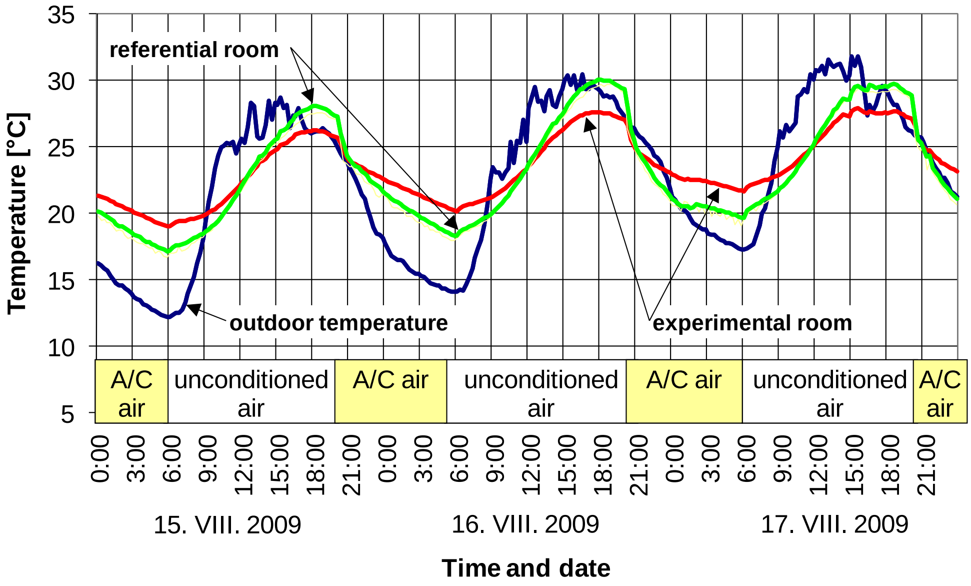

Fig. 6 Mechanical ventilation with air-conditioned air at night

Conclusions

Many office buildings with light-weight building structures suffer from overheating on hot sunny days in summer. As a consequence, mechanical cooling has to be used to maintain acceptable level of thermal comfort for the occupants. That leads to the peaks in electricity consumption on hot summer days. The consumption peaks can be reduced by application of energy saving measures. The reduction of heat gains (proper solar shading, use of low-consumption office equipment, etc.) should be the first step in the reduction of cooling load. Other measures can follow; thermal storage and passive cooling among them. This article deals with the use of latent heat cold storage integrated in building structure. As demonstrated, this approach can be used with both passive and mechanical cooling.

The experiments carried out in the test rooms showed that passive cooling by intensive night-time ventilation may not be sufficient for discharge (rejection) of latent heat from thermal storage on hot sunny days. That does not mean that passive cooling by night time ventilation is unsuitable in combination with PCM cold storage. It rather indicates that a close attention has to be paid to passive cooling and its limits (e.g. in connection to urban heat island). The experiments carried out in the test rooms showed that temperature of outdoor air supplied to the rooms was a few degrees higher than outdoor temperature measured at the nearby weather station. There is usually not a universal solution to any problem and the same applies to building cooling. Each cooling technique should be employed in the situation that suites it the best. Passive cooling can be used under favorable conditions and mechanical cooling can kick in when passive cooling becomes insufficient. Many buildings today use sophisticated building management system that make it possible to implement control strategies that would employ passive and mechanical cooling in a manner that minimizes energy consumption and operating costs.

Acknowledgments

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