Regulation of Temperature by Phase Change Materials

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ABSTRACT

Important properties of the indoor air quality are temperature and humidity. Very often in new and old buildings the temperature is too high or varies too strongly. A suspended ceiling with phase change materials has a good influence to avoid too high indoor air temperatures. An additional heat exchanger at the outside of the building can increase the efficiency of the system by working in the night and cooling down the phase change material, so that after this cooling the full heat storage capacity is attainable. Further a great heat storage capacity of phase change materials decreases the heating energy demand of buildings.

KEYWORDS

Phase change materials, temperature regulation, heating energy demand.

INTRODUCTION

To avoid uncomfortable indoor air states in buildings very often air conditioning systems are necessary. The heat storage capacity of a building has an equalizing influence on the fluctuation of the temperature. Phase change materials (PCM) increase the heat storage capacity essential, Lane (1983). Additional the working range of the system can be adapted to the indoor conditions because the phase change point can be modified by the kind of PCM. An improvement of the indoor air quality by the storage effect of PCM is interesting, because this effect works in a passive way and heat pumps are avoidable.

DEVELOPMENT OF HEAT STORAGE SYSTEM

First application used phase change materials in form of an ingredient of the building materials, Kornadt (2005), Zubillaga et al (2006), Virgone et al ((2006), Stritih (2006), Kalousek et al (2006). For further improving the phase change materials are build in a board, so that more material can be used and the heat transfer is greater. A suspended ceiling with phase change materials is an excellent form of application. The heat storage in the suspended ceiling decreases the temperature and the time period with temperatures higher than the comfort level. In the Figure 1 the temperature change with and without a suspended ceiling with phase change material is represented. In a time period of the heat load the temperature rise will be limited. If the storage capacity is exhausted and all the material is melted, the temperature reducing effect stops. In a time period with cooler temperatures the storage capacity will be unloaded again. In this time the latent heat of the phase change materials heats the room and the temperature does not drop so much. The heat storage effect of the phase change material can be used as a excellent buffering effect to avoid too high and too low indoor air temperatures.

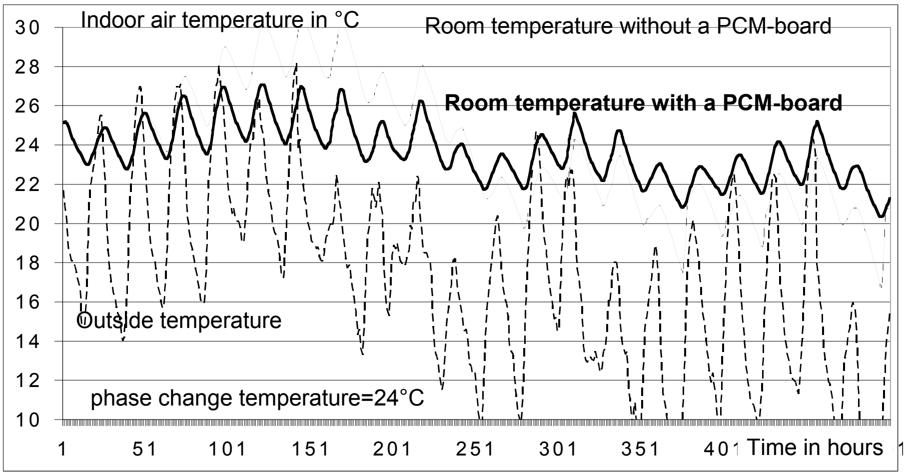

Fig. 1: Temperature versus time for one month in summer with and without a heat storage ceiling with phase change materials.

To find out the best way of using phase change materials for damping of temperature fluctuations and avoiding of uncomfortable high indoor air temperatures, the qualities of the systems and the interactions must be investigated. The efficiency of indoor temperature regulation depends of the buildings quality and the climatic conditions, of the heat transfer between indoor air and the heat storage system and of the heat capacity respectively the mass of phase change materials.

Modelling of the Processes

A model was developed for description of processes and effects and to calculate the indoor air temperature. The indoor air temperature is a result of heating, cooling, heat loss, heat storage and heat gain. The efficiency of the device can be discussed in dependence of the heat exchange, the phase change temperature and the heat storage capacity of the phase change materials.

Heating and cooling systems are used for regulation of the indoor air temperature. Equation (1) described the heating and cooling power Q of the air conditioning systems.

$$Q_{Heat} = \alpha_i \cdot A_{Heat} \cdot (t_{Heat} - t_{indoor}) \text{ and } Q_{Cool} = \alpha_i \cdot A_{Cool} \cdot (t_{Cool} - t_{indoor}) \quad (1)$$

The heat exchange between room and systems is described by the heat transfer coefficient α_i, the temperatures t of room and heating and cooling system and the areas A of the heating or cooling system. The heat loss of the room is represented by the equation (2), whereby Q_{transm} is the heat flow by transmission, U the heat transmission coefficient for wall and window and t the temperatures of the indoor and outside air.

$$Q_{trasm} = U_{wall} \cdot A_{wall} \cdot (t_{indoor} - t_{outside}) + U_{window} \cdot A_{window} \cdot (t_{indoor} - t_{outside}) \quad (2)$$

With equation (3) the heat loss by ventilation Q_{Vent} is described. The heat loss depends of the air change per hour n_{Vent}, the heat capacity c and the density ρ of the air, the air volume of the interior room and the temperature difference between the indoor air t_{indoor} and the outside air $t_{outside}$.

$$Q_{Vent}=n_{Vent}\cdot c\cdot \rho\cdot V_{Room}\cdot(t_{Room}-t_{Ext.Air}) \quad (3)$$

Further must be considered the heat gain by radiation through the windows. This effect depends of the intensity of radiation q_{sunrad}, shading coefficient z, orientation coefficient of the window f_o, transmittance coefficient of the glass g and effective immission area of the window $A_{immission}$.

$$Q_{radgain}=q_{sunrad}\cdot z\cdot f_o\cdot g\cdot A_{Immission} \quad (4)$$

The indoor air temperature is a result of the heat supply and the heat loss $\{\Sigma Q_j \Delta\tau_j\}$ under the influence of the heat storage capacity $\{\Sigma c_j m_j\}$ of the room.

$$t_{Raum(n+1)} = t_{Raum(n)} + \{\Sigma Q_j \Delta\tau_j\}/\{\Sigma c_j m_j\} \quad (5)$$

In the case of a suspended ceiling with phase change materials an additional heat exchange exists between indoor air and PCM system represented by the heat transmission coefficient α_i , the area of the suspended ceiling A_{PCM} and the temperature difference between indoor air and PCM system. The heat storage effect of the PCM ceiling is limited. Therefore it is necessary to take in consideration that the energy stored in the ceiling Q_{PCM} can not be greater than the melting heat $Q_{PCM,max}$ of the whole mass of the PCM

$$Q_{PCM} = \alpha_i\cdot A_{PCM}\cdot(t_{PCM}-t_{indoor}) \text{ and } 0\leq Q_{PCM(n+1)}=Q_{PCM(n)}+Q_{PCM}\cdot\Delta\tau\leq Q_{PCM,max} \quad (6)$$

It is understandable that the storage effect must be great enough if a temperature equalizing effects should be exist. Therefore a sufficient great heat storage capacity respectively great mass is required. On the other hand it is possible to use the heat storage capacity more efficiently by additional cooling the system in the night. In this way it is possible that after a great daily heat load the heat can be lead away in the night and the whole heat storage capacity is available for the next day. To use this possibility a heat exchanger must be installed inside the PCM and at the exterior surface of the building. The heat exchange $Q_{Ext.Cooling}$ at the outside is determined by the heat transfer coefficient α_e, the area of the heat exchanger $A_{ext.cooling}$ and the temperature difference between the outside air and the PCM system.

$$Q_{Ext.Cooling} = \alpha_e\cdot A_{Ext.Cooling}\cdot(t_{PCM}-t_{Ext.Air}) \quad (7)$$

This description and the equations present a very rough reproduction of the used model to investigate the system. To use these equations it is necessary to think about the dependence of the coefficients on the temperature and air velocity. Furthermore the time and the time steps for which the system of equation is applicable must be checked. On the other hand the processes are complete enough so that it is possible to reproduce all important effects theoretically. Therefore the result represents the effects sufficiently good.

Influence of the Phase Change Temperature

The efficiency of the device depends of heat exchange, phase change temperature and heat storage capacity respectively mass of the phase change materials. Figure 2 shows the number of days with an indoor temperate higher than 26°C. If the phase change temperature is low, the heat storage capacity is exhausted to early. If the phase change temperature is too high the effect of avoiding high temperatures starts too late and the decreasing influence is too small. The damping effect for avoiding indoor temperatures higher than 26°C becomes more efficient for phase change temperatures at 23°C. For higher phase change temperatures the effectiveness of the damping effect becomes less again. The melting point must be chosen in a certain relation to the temperature level that should not be exceeded. Results of the influence of the phase change on the temperature equalizing effect and how it is possible to optimize the material properties is represented in Figure 2.

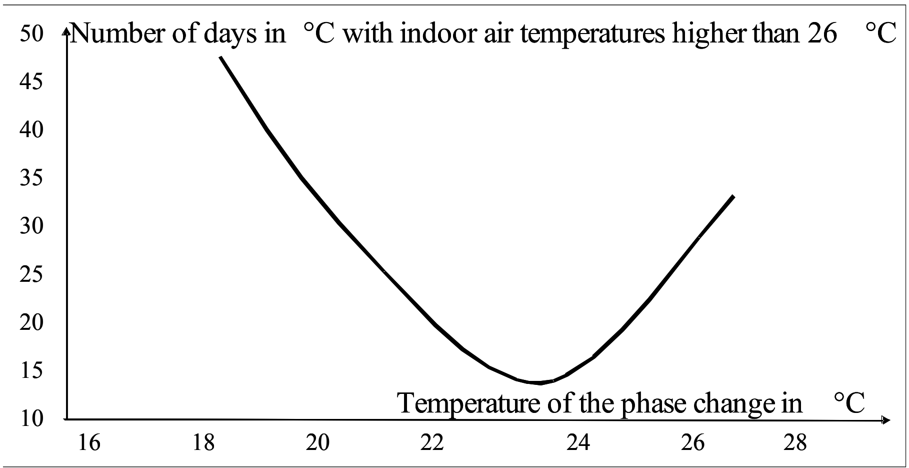

Figure 2: Influence of the melting point of the PCM to the number of days with indoor air temperatures higher than 26°C

Influence of an Additional Cooling

The effect of passive temperature regulation is better if a suspended ceiling with an additional heat exchanger at the outside of the building is used. The heat exchanger is integrated in the window. This heat exchanger works in the night and cools down the phase change material, so that after this cooling the material is solid and the full heat storage capacity is attainable. In Figure 3 the behaviour of the indoor air temperature in a summer time period of 40 days for several cases is shown. Case 1 shows the temperature without any influence of phase change materials. Case 2 shows the situation with a suspended ceiling with phase change materials. Case 3 shows the effect of a suspended ceiling with PCM and an additional heat exchange in the night by an external heat exchanger. It is clearly to see, that the temperature equalizing effect become better and better if a heat storage system with PCM is used and if additional a night cooling is also used.

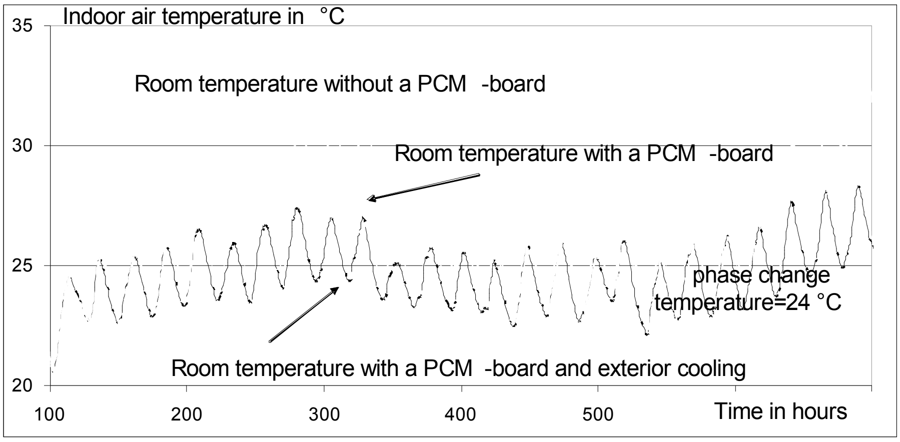

Figure 3: Influence of a PCM system and an additional night cooling.

The effectiveness of the additional heat exchange was investigated by comparison of a system with an additional heat exchange in the night with the efficiency of a system without an additional heat exchange. Figure 4 shows results of an investigation about the influence of the amount of PCM on the reduction of times with too high indoor air temperatures.

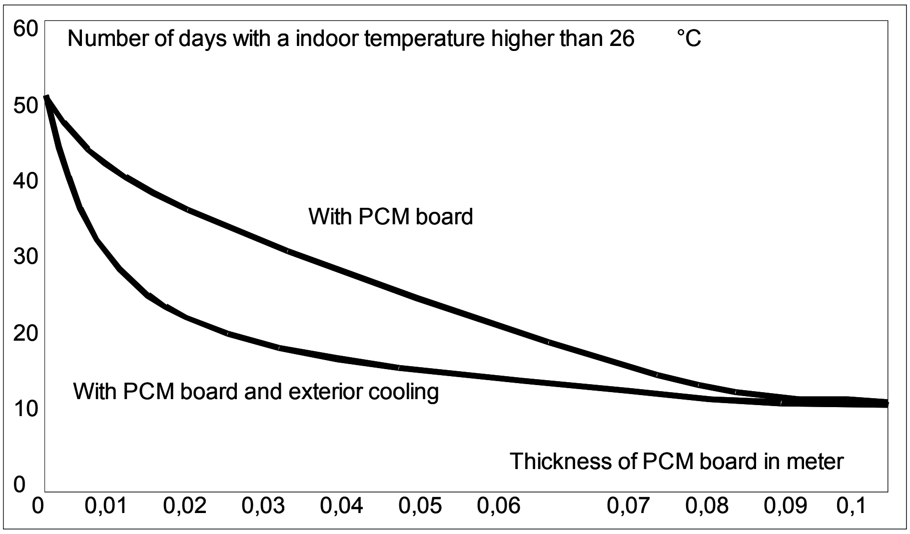

Figure 4: Influence of the thickness respectively the amount of the PCM on the reduction of times with too high temperatures

The number of days with temperatures higher than 26°C decreases more if the additional heat exchange is used. The heat transfer and the heat storage effect of the PCM system can be optimized. It is recognizable that the storage system is exploiting better and the equalizing effect is reachable with less mass through the additional heat exchange. Especially in the case of small amount of PCM the effect is greater.

POSSIBILITIES FOR REDUCING THE HEATING ENERGY DEMAND BY PCM

The storage capacity of buildings increases the efficiency of solar and internal gains. The application of PCM can improve this effect. In figure 5 the heating demand of a building in dependency of the insulation level is represented. The graphs show the reduction of the energy demand per year in the case of a greater heat storage effect by PCM. For a low insulation level the differences are relatively small. For a high insulation level and low transmission coefficients (U ≈ 0,1 W/m²·K) the effect is more interesting because the reduction is relatively greater For passive houses with an energy demand of lower 15 kWh/m² is this effect very interesting, because a higher efficiency can decrease the energy demand further. Important is the dependence of the phase change temperature. The effect is better if the phase change temperature is lower. In the case of a phase change temperature in the range of 19°C....20°C the heat storage effect can be so great that hardly any heating energy is required.

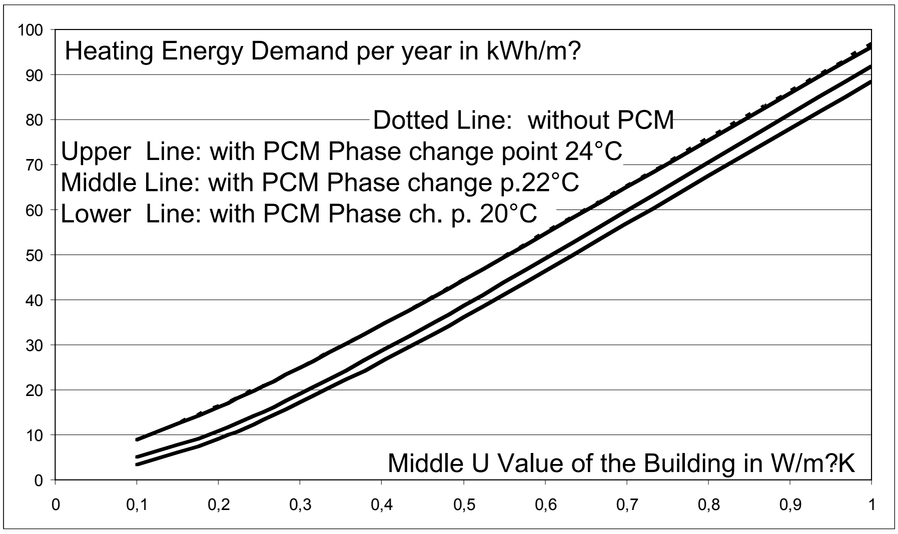

Figure 5: Decreasing of the heating energy demand by using PCM for different phase change temperatures in dependency of the middle U-Value of the building

SUMMARY

Phase change materials (PCM) increase the heat storage capacity of a building. The heat storage effect is in certain temperature ranges very high and the PCM can be used as an excellent buffering system to avoid too high and too low indoor air temperatures in a passive way and to decrease the energy demand of buildings.

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