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Thermal storage and discharge efficiency as a function of the PCM phase change temperature: simulations and experimental analysis

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Introduction

Despite their very promising building energy storage capabilities, PCM are still in the investigating phase before a large potential deployment. This is due to several challenges [1] such as high storage capacity and efficient heat extraction [2,3,4]. If the storage capacity can be adapted by implementing an appropriate quantity of PCM, the heat extraction efficiency is more delicate and difficult to optimize. It depends on the conductivity of the PCM and on the heat flow between the PCM surface and the indoor air which can be enhanced by ventilating the PCM surface.

Concept and measurements

We chose the last mentioned solution and developed the experimental set-up shown in Figure 1 and described in the current document. A hot water circuit was used to charge the insulated PCM wall and an internal ventilation to discharge it. The air flow, illustrated below by the straight arrows, was applied over PCM plates and redirected in the test room as shown with the bottom arrows.

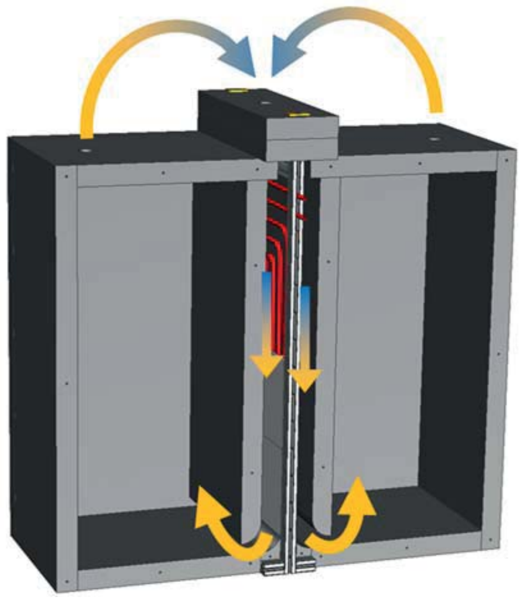

Figure 1: Measurement concept with PCM, heating circuit and air flow

Despite the low PCM phase change temperature used in the experiments: $T_{phase\ change}$ = 23°C, high discharge efficiencies were achieved with a room temperature increase of +5°C in less than 40 minutes (see Figure 2). The PCM plates: Lehmorange plaster plates [5] containing 5kg micronal per m^2, were firstly heated up to 30°C during the afternoon loading phase. The second phase corresponding to the storage lasted from the evening to the early morning. During that time the PCM lost its temperature but remained liquid. At 5:00 in the morning, the discharge was initiated by ventilating the plates with an air flow of 0.1m/s. The fast internal air temperature ($T_{air\ int}$) increase is clearly visible in Figure 2.

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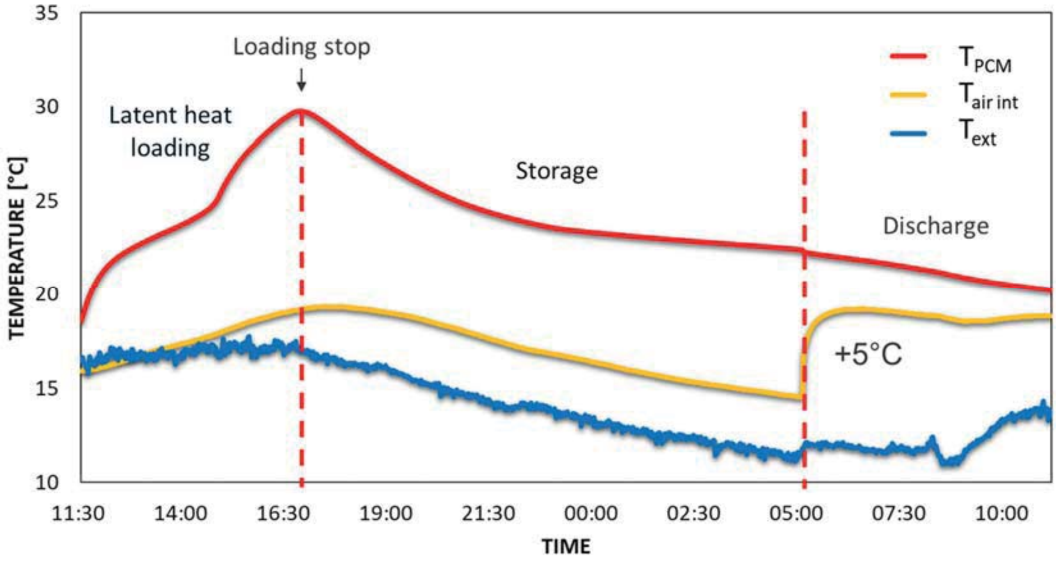

Figure 2: PCM loading, storage and discharge phases for a 24h cycle
and temperature behaviour of PCM, interior and exterior air

Simulations

To understand the high efficiency achieved despite the low phase change temperature, we performed daily cycle simulations with PCM charge, storage and discharge phases for two different phase change temperatures: 23°C and 26°C. The PCM was integrated in the non bearing walls of a two-floor building, illustrated in Figure 3, with an external wall heat loss of 0.15 W/(m^2·K). The bearing walls corresponds to concrete walls.

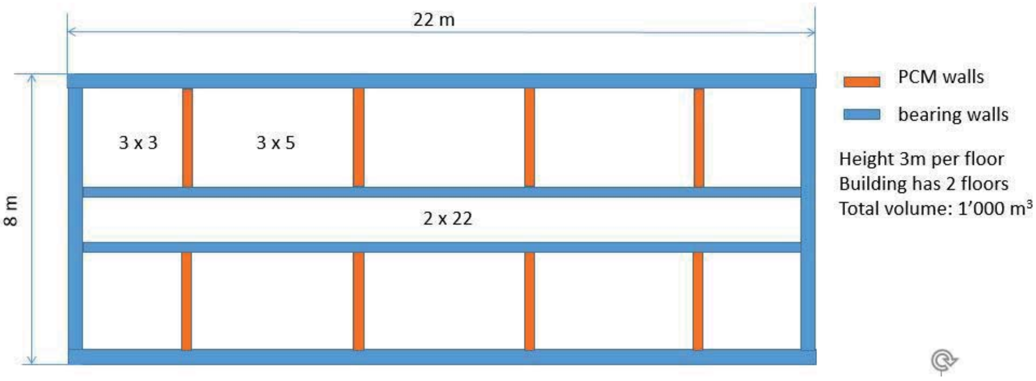

Figure 3: Reference building used for the simulations with bearing and PCM walls.

As the current analysis concerned administrative buildings, an indoor air comfort temperature of about 20.5°C was maintained between 6:00 and 17:30 with potential lower temperatures overnight. External temperatures, T_{ext}, were simulated between -15°C and +10°C and considered constant during the entire day. Two different daily cycles were used: a first one using daily solar energy for loading and a second one performing night loading (due to lack of renewable energy). In the first simulation, the PCM was loaded around midday at the solar energy peak production time with a comfort indoor temperature maintained between 6:00 and 17:30. The simulation results are shown in Figure 4 for PCMs with phase change temperatures of 23°C and 26°C. Note that a ventilation of 0.05m/s was used for the PCM of 23°C and natural convection for the PCM of 26°C.

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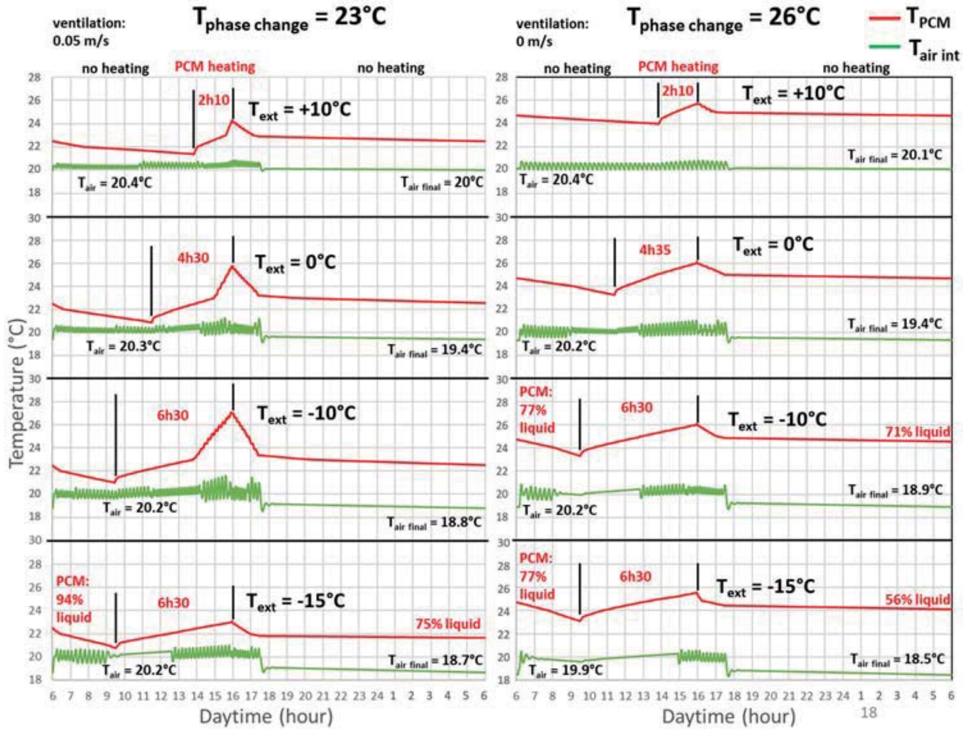

Figure 4: Indoor air and PCM temperatures with PCM loading at midday and discharge taking place between 6:00 and 17:30. The fluctuation of T_{int} is due to the controlled PCM discharge.

For the simulations as for the experiments, the indoor air temperature, T_{int}, was increased by ventilating the PCM walls. The PCM heating of 12 KW was limited to a maximal duration of 6.5 hours to simulate the peak solar power. Interestingly, T_{int} could be maintained at a comfort temperature for external temperatures down to T_{ext} = -10°C for the PCM with a phase change at 23°C. On the other side, for the PCM with $T_{phase\ change}$ = 26°C, the comfort temperature could only be maintained until T_{ext} = -5°C. Even if a larger efficiency for lower phase change temperatures could appear to be contradictory, it can be easily explained. The overnight storage phase is less efficient for PCM with higher $T_{phase\ change}$ due to their larger overnight temperature that is responsible for a larger discharge. In that respect, the bottom graphs of Figure 4 with T_{ext}= -15°C show a daily PCM liquid phase loss of only 9% for $T_{phase\ change}$ =23°C while a phase loss of up to 21% is observed for $T_{phase\ change}$ =26°C.

The second simulation was dedicated to buildings without renewable energy production. In that case, the PCM was charged overnight during periods of low energy prices. A maximal PCM temperature of 32°C was achieved at 6:00 in the morning. During the day no charge is allowed and the PCM can only discharge. As for the previous simulation, a comfort indoor temperature of 20.5°C was maintained between 6:00 and 17:30. The simulation results are shown in Figure 5.

Interestingly the PCM was totally discharged before 17:30 already at -10°C for both PCMs. Only at temperatures ≥ -5°C, the comfort temperature could be maintained until 17:30. The lower efficiency than for day loading can be explained by the large off-timing between the overnight charge and the daily discharge. The contribution of PCM remains however very valuable because it allows to be independent from external energy during the day for most of the year. Only during very cold days, night and day electricity would be used.

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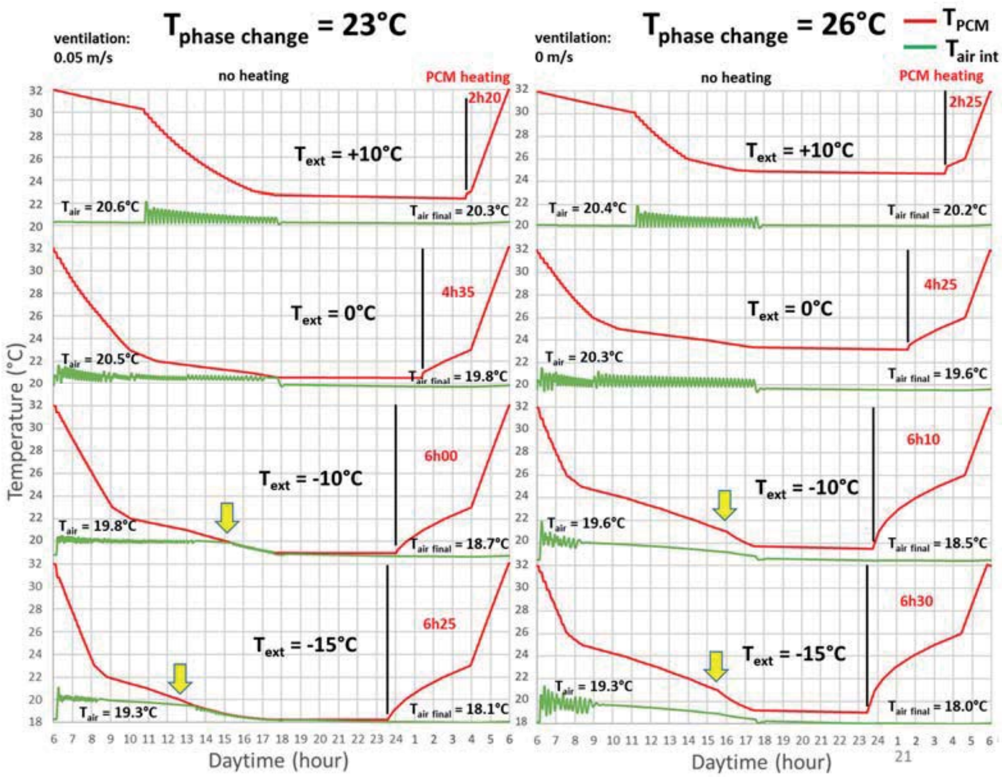

Figure 5: Indoor air and PCM temperatures with PCM overnight loading and discharge taking place between 6:00 and 17:30. The yellow arrows indicate the time of PCM total discharge.

The overall results show that PCM thermal storage drastically increases the energy autonomy of buildings equipped with solar energy, and allows to predominantly use night energy for building without renewable energy.

Note that the larger efficiency for the low phase change temperature (observed in the day loading simulation) has one advantage: the 23°C PCM could also be used to store cold in summer. This opens the door to new PCM all-seasons thermal storage perspectives especially in the context of global warming.

[1] N. Soares, J.J. Costa, A.R. Gaspar and P. Santos, *Energy and Buildings* **59**, 82 (2013).
[2] P.P. Castro, P.K. Selvam, and C. Suthan, *Imperial Journal of Interdisciplinary Research* **2**, 203 (2016).
[3] L. Socasiu, A. Plesa, P. Unguresan and O. Giurgiu, *Leonardo Electronic Journal of Practices and Technologies* **25**, 179 (2014).
[4] A. Waqas, Z .Ud Din, *Renewable and sustainable energy reviews*, , **18**, 607 (2013)
[5] Lehmorange, *Produktblatt Heizelement – Lehmwandheizung*, (07.08.2013)