Performance and opportunities of air-to-PCM heat exchangers in buildings

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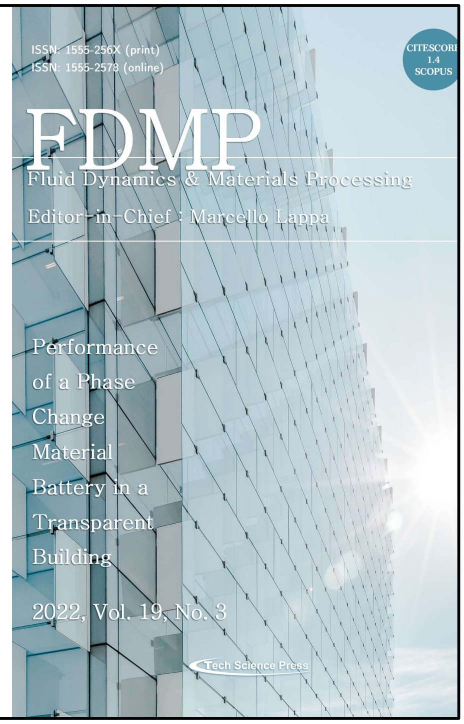


An air to PCM heat-exchanger is developed for a meeting centre at Green Village of the TU-Delft. The research was recently published in two different journals, which are referred to in this presentation. One of them became a cover story.

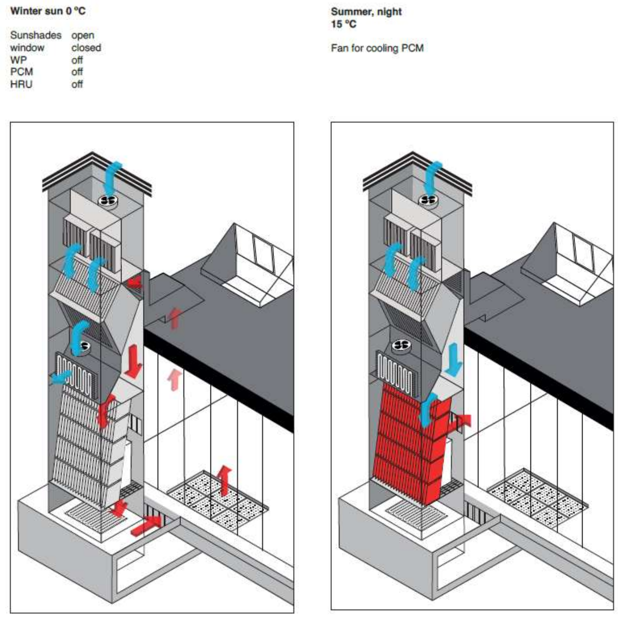
Research and design

Meeting centre TU-Delft with heat pump, heat-exchanger and PCM-battery, combination of active and passive energy

The meeting centre is fully transparent. The goal is to use a smart combination of passive and active systems. In this case it are isolation, outside sunshade, a heat pump, high efficiency heat recovery, natural ventilation, thermal mass and a PCM-battery for heating and cooling.

Heating and cooling

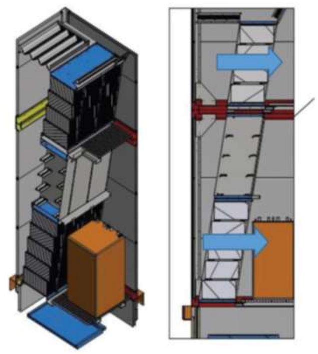
- Optimization of passive heating and cooling
- PCM uses cold outdoor air
- PCM uses internal + solar heat after the heat exchanger



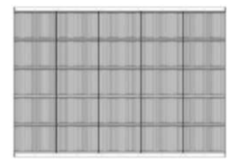
The PCM uses cold outdoor air to cool or precool the air when there is a cooling demand. When there is a heating demand internal and solar heat can be used, before the heat pump becomes active. Mostly there is only a small heating and cooling-demand so the PCM reduces the usage of the heat pump substantially.

Construction of the battery

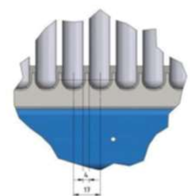
- From 1,170 to 1,482 PCM-panels
- 2,700 kg
- From 20 - 23 to 17 - 23 ^{o}C (later)
- Low pressure difference:
  8 Pa at 0.8 m/s, 16 Pa at 1.5 m/s



3D-view of the PCM battery



Front view 5 layers of PCM panels



The free space (4 mm) between two adjacent panels.

The original PCM phase change was between 20 and 23 oC. Finally, a phase change between 17 to 23 oC is applied to use the PCM more effective. The yearly heating demand is much higher than the cooling demand. The PCM-panels have a free distance of 4 mm. The air resistance of the system is very low making it possible to use a low-pressure ventilation system.

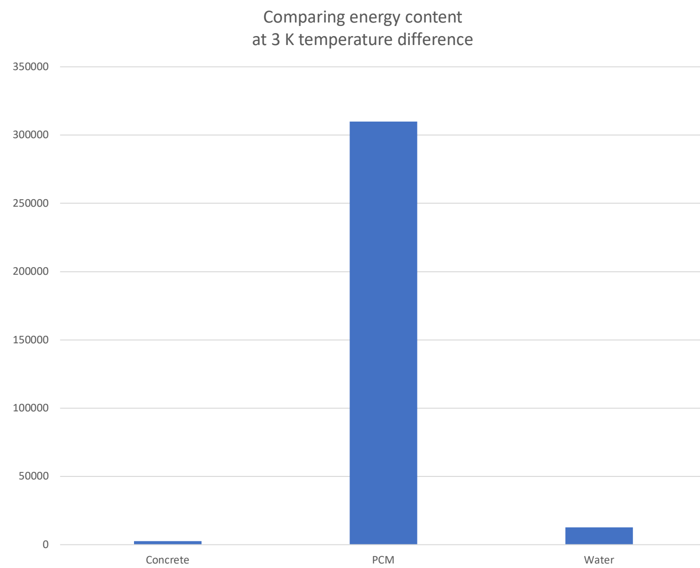
PCM Thermosol HD 23 element

- easy to integrate element
- low maintenance
- long lifetime
- fire resistant, salt mixture: calcium chloride hexahydrate
- HDPE casing, divided in 6 semi-open compartments

A salt hydrate, calcium chloride hexahydrate, is used. It is inflammable, has a long lifetime and a high energy content.

Energy content PCM type CSP 275

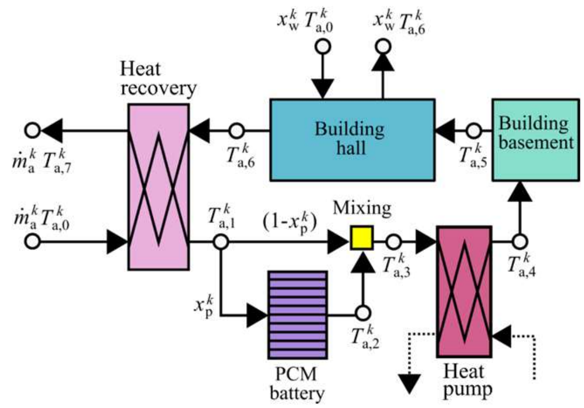
PCM has 123 times more energy content than concrete and 25 times more than water



PCM can store much more energy than concrete or water at the chosen temperature range.

Matlab model of all the relevant components

Thermal mass of the building and natural ventilation included

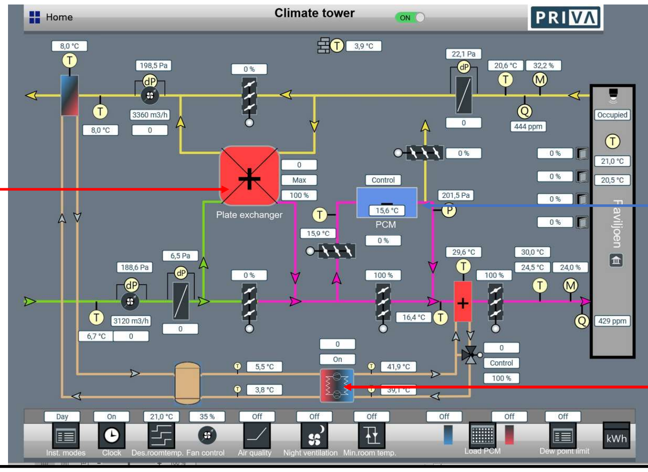


Source: Luigi Antonio de Araujo Passos, Peter van den Engel, Simone Baldi, Bart De Schutter. Dynamic optimization for minimal HVAC demand with latent heat storage, heat recovery, natural ventilation, and solar shadings. Energy Conversion and Management 276 (2023) 116573

The building and its installation components, including operable windows and thermal mass, is simulated in a Matlab-model. With model-predictive control the most optimal control strategy can be found to maximize comfort and reduce energy consumption.

Overview BMS-system

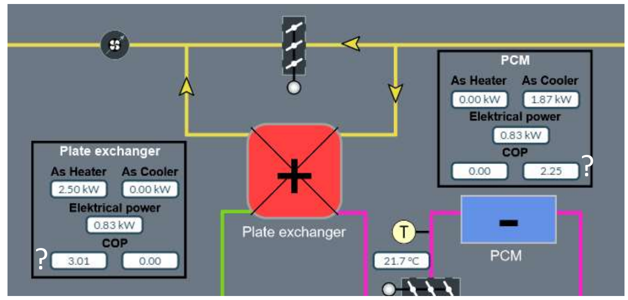
Overview of sensor data and energy consumption

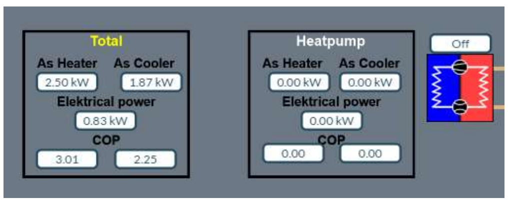


The BMS-system shows that the building is full of sensors. For instance, temperatures, CO2-levels, air flows, pressures, lighting levels and energy consumption are stored and can be presented. Extra calculation fields are added to calculate the efficiency of the heat pump, heat recovery and PCM-battery. The settings of the BMS-system can be chosen via a simulation program, a digital twin (MATLAB of Priva-Eco), for optimization.

Energy performance via BMS-system

Energy-usage, production and component efficiency. Only initial COP's are presented.

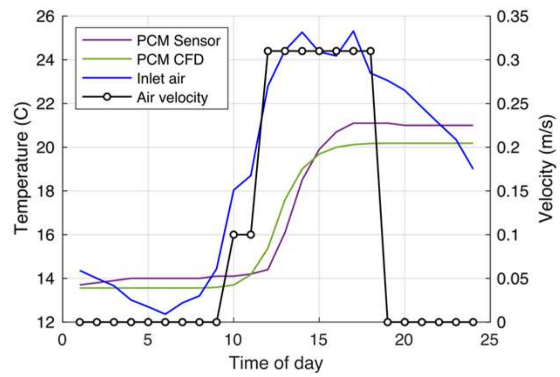




With the BMS-system the energy performance of the PCM-battery, heat-exchanger and heat pump can be evaluated as well. Energy management is essential for a low energy consumption. This calculation-system is still under development because the COP of the heat-exchanger and PCM is underestimated, due to the low resistance of these systems.

Comparing measurements with simulations

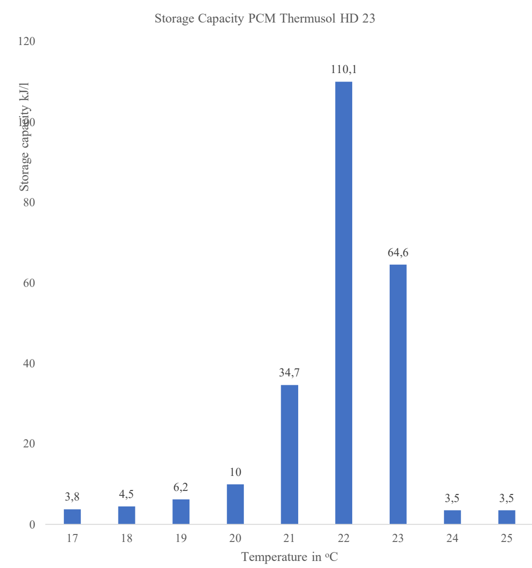
- First results, differences could be explained (hysteresis)
- Heat transport via conduction, buoyancy has only minor influence



The characteristics of the PCM-battery are measured, and first simulated in CFD. Because at each temperature between 20 and 23 oC the melting and solidification energy is different, there is a small difference between the CFD-model and the measurements. The CFD-model uses only one specific heat value in Joule per kilogram Kelvin.

Hysteresis PCM Thermosol HD 23

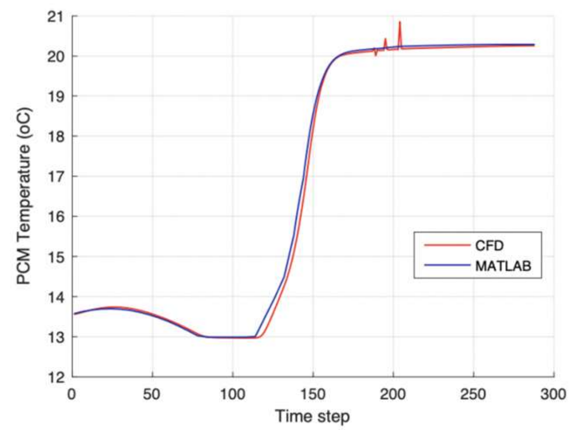
- Solidification and melting between 20 and 23 °C, peak at 22 °C
- In the future 17 – 23 °C preferred



The hysteresis of the PCM is presented on this slide. The melting peak is at 22 oC.

Comparing CFD with MATLAB

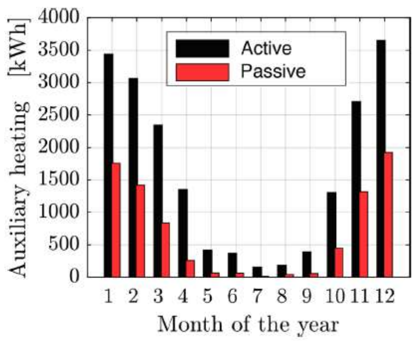
Close relation between simulations, PCM is simulated with only one high specific heat value (J/kgK) during the phase change, like a solid



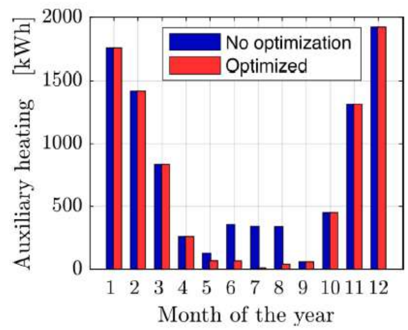
For longer periods it is possible to simulate the PCM in CFD and Matlab with only one specific heat value between 20 and 23 oC with already a high degree of accuracy.

Optimization control system

Model predictive control via MATLAB, 60 % savings



(a) Effect of passive energy on the total heat consumption

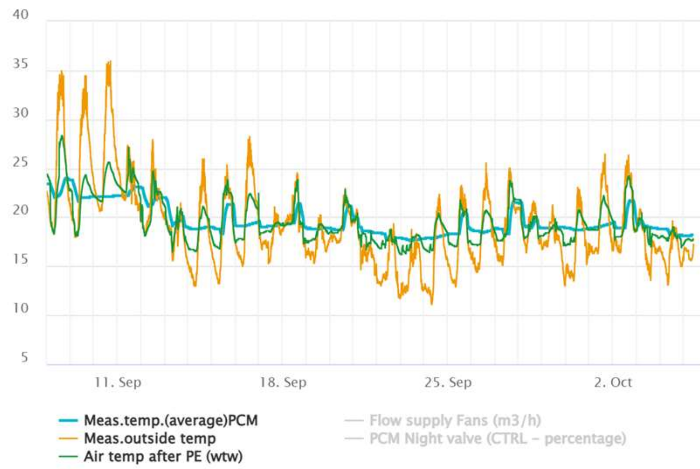


(b) Effect of optimal operation of passive energy technologies

With the Matlab-model it became clear that 60 % energy savings are possible with model predictive control of the BMS-system. Half of the savings are based on passive sources.

Measurements September 2023

PCM cools down the space during hot days and preheats the building after cold nights (phase 17 – 23 ^{o}C). Behaves like thermal mass and can act more intelligent and flexible.



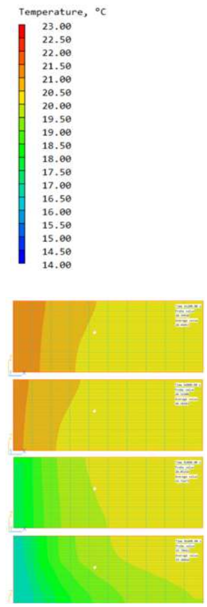
These measurements of the BMS-system show that the PCM reduces the lower and higher temperature peaks. Finally, a combination of PCM-panels with a phase change between 17 to 23 oC is applied.

Design information

CFD-results

- Air flow, heat transfer, pressure, capacity and (un)loading time
- PCM phase 20 - 23 °C, supply air 15 °C, 181 kWh storage capacity

- 10,800 m^3/h, 2.3 m/s, h_c = 20.4 W/m^2K, ΔP = 21 Pa, 29 kW, 6 hours (un)loading time
- 7,200 m^3/h, 1.5 m/s, h_c = 14.5 W/m^2K, ΔP = 16 Pa, 18 kW, 10 hours (un)loading time
- 3,600 m^3/h, 0.8 m/s, h_c = 8.8 W/m^2K, ΔP = 8 Pa, 10 kW, 18 hours (un)loading time



Loading and unloading times are calculated with a CFD-model (Phoenics). Of course, this time depends on the size of the air flow and supply temperature to the PCM.

Current new designs (offices)

Combination of heat-pump, HVAC-unit and PCM-battery

10 kW heat pump, 10 kW PCM, 1,200 kg, 100 kWh, 3,600 m^3/h air, DT = 8.0 K

30 kW heat pump (15 kW latent, 15 kW sensible cooling), 15 kW PCM, 1,800 kg, 150 kWh, 5,400 m^3/h air, DT = 8.0 K

PCM temperatures between 17 and 23 ^oC. This reduces the usage of the heat pump and maximises the usage of passive outdoor and indoor energy.

Several PCM-applications for offices are currently considered. Around half of the capacity of a heat pump can be replaced by a PCM-battery. Making use of passive thermal energy in summer and winter makes it an attractive option. Around 70 % of the thermal energy demand can be delivered by the PCM.

Future options/research

- Combination PCM-battery with other heat-exchangers like a twin-coil or a heat-recovery wheel
- Combination PCM-battery with an integrated solar tower
- Changing the position of heat recovery unit after the PCM-battery
- Design a low-pressure ventilation system
- Combination with electrical storage in batteries

A PCM-battery can also be combined with a twin-coil system or solar tower to store more passive heat. It is easy to integrate in a low-pressure ventilation system.

Performances

- Example 15 kW
  - DX-unit connected to AHU COP = 3 € 17.000,-
  - Heat pump and ground storage COP = 5 € 50.000,-
  - Only ground storage (cooling) COP = 12 € 20.000,-
  - PCM-battery (cooling, heating) COP = 40 € 15.000,-

- Light weight well isolated building and much glass, with extension
  - Heating demand 10 kW, 7,000 kWh (thermal)
  - Cooling demand 45 kW, 2,000 kWh (thermal)
  - 60 - 80 % energy reduction by PCM

For the office at the Green Village a PCM-battery is considered. Most of the heating and cooling energy can be delivered by PCM, making use of indoor or outdoor thermal energy. A PCM-battery is more flexible than thermal mass, because it can be used or not. During some periods thermal mass can be unfavourable. The investment is lower than for a heat pump with ground storage. In this project a combination is proposed.

Sustainability and economics

- Evading extra heat pump of 15 kW + storage in the ground
- Passiveness
  - Reduction of cooling, cooling with only outdoor air is often possible
  - More flexible than thermal mass (light weight becomes an advantage)
  - Reduction of heating by usage of indoor and solar heat
- Energy management
  - Cold-storage in PCM: during the night the COP of the heat-pump is much higher due to colder outdoor air
  - Usage of low energy prices during the day
  - Easier usage of low, zero or even negative electricity prices with PV and batteries
  - Using an updated digital twin for control

It has sustainable and economic advantages to reduce the heat-pump capacity with PCM. A combination of PCM, a heat pump and PV-cells is most favourable. Using passive thermal energy and the heat pump during the night with a higher COP will improve the total efficiency. With lower prices of the grid during the day and using free energy when there is a combination with PV and electrical batteries, the pay-back time could be minimized. This requires a new simulation model working as digital twin.

The Future is ours..

Thank you for your attention

Questions?