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Opportunities of Air- and Water to PCM batteries in buildings

For a transparent meeting centre at the TU Delft a large air to air PCM-battery is integrated in an air handling unit. Based on the experiences with this battery a new battery on another office building is under construction. The PCM makes use of the outdoor and indoor temperatures like a flexible thermal mass with a high thermal capacity, flattening high and low indoor temperature peaks. In case of very warm of very cold outdoor night temperatures the battery can additionally be loaded with a heat pump. In this way the thermal and electrical capacity of the heat pump can be reduced significantly. This makes the battery an economic and energetic favourable alternative. Additionally there is a water to PCM-battery in the crawl space with the same kind of panels. In the heating season heat from the heat pump with a higher temperature can be stored, making use of low, zero or negative electricity prices via solar panels or the grid. The performance of the PCM-batteries are both evaluated with a CFD-program (Phoenics), a building simulation program (DesignBuilder) and additional calculations.

1. Introduction

It is possible to make use of free available indoor and outdoor energy and store this in a PCM-battery for both heating and cooling. This is possible in summer and winter by choosing the most suitable phase change temperatures. In two buildings at the Delft University of Technology PCM is integrated in air handling units. The PCM has a phase change of 17 to 23 ºC by combining different panels. Especially for light weight buildings the diurnal swing can be reduced by PCM, making additional active heating and cooling less necessary. On top of that, because the PCM-battery can be bypassed in the air handling unit, undesirable heating up of the thermal mass in the cooling season can be prevented. More thermal mass is not always better, think of a tent in summer which is pleasant in evening and night when the outdoor air is cooler.

The PCM-battery can be loaded by indoor air at a heating mode when the air temperature is higher than the minimum required for thermal comfort. The PCM can also be loaded by outdoor air at a cooling mode when the outdoor air temperature is lower than 23 ºC. After evaluation the performance of the first building it became clear that loading the PCM with cold of hot air via the heat pump is an additional attractive option. During the night in summer the outdoor temperatures are lower than during the day. Less cooling will be necessary, the COP of the heat pump will be higher and the electricity prices are usually lower as well. In that period a buffer can be loaded with cold. During the day electricity of photovoltaic panels can be used. This will also reduce the required thermal and electrical capacity of a heat pump, making a PCM-battery more attractive by reducing the return of investment. The PCM-battery can deliver cold additionally to or instead of the heat pump.

A second option for buildings is a water to PCM-battery with a phase change temperature of, for instance, 36 - 40 ºC. In winter the PCM-battery can be loaded with heat of, for instance, 45 ºC when the heat pump is not fully in use. This type of battery can be loaded any time, separate from the air handling unit, when the electricity prices are relatively low during the day. At the moment, in spring and autumn, electricity is even costless between 12:00 and 17:00 h via some energy companies. The type of energy contract determines the best options. A water to PCM-battery is able to load a battery in a short time, because the energy content of water in J/kgK is 3,500 times higher than air. Combined with low pressure differences, water velocities can be more than 100 – 500 times lower than air.

PCM is also increasingly applied in ceilings and walls. Using a phase change between 20 and 23 ºC is generally sufficient for summer and winter in a moderate climate. In (sub)tropical regions the PCM is usually only applied for the cooling season. A recent paper evaluates the indoor climate of apartment buildings with natural or hybrid ventilation and uses PCM with phase change peaks for cooling between 25 and 31 ºC (lit. 1).

For light weight buildings combined with PCM there are two ways of CO_2-reduction:

1. Less cooling and heating energy
2. Less massive material like concrete which has a high CO_2-demand in its production time.

2. Technical outline of the systems and discussion

The following figure shows an example of a PCM-panel with 6 semi-open compartments. The casing is of HDPE-material and the PCM-material is Calcium Chloride Hexahydrate.

Figure 1: example of a PCM-panel in an air or water to PCM battery with 6 semi-open internal compartments

In the Co Creation Centre the panels are stored in a battery in a Climate Tower, a different shape of an air handling unit.

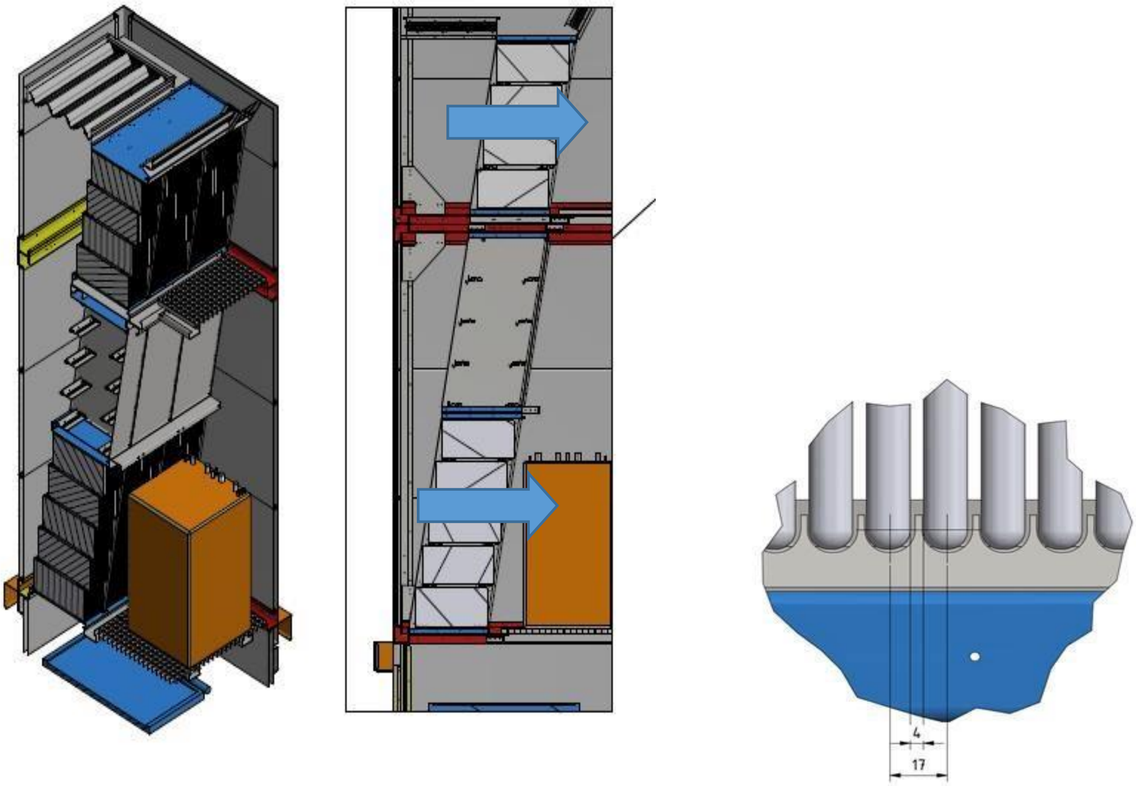


Figure 2: design of an air to PCM battery (1,170 panels, 181 kWh) in the climate tower. The distance between the panels is 4 mm. When the battery is fully loaded with 1,482 panels the capacity is 230 kWh.

In the following table the (un)loading times and other characteristics of one of the configurations of the PCM-battery (phase change 20-23 ºC) for different air flows are presented:

Table 1: Results of the CFD calculations.

The air inflow is steady-state but the thermal analysis is transient

Air flow condition	h_c (W/m^{2}K)	(un)load time (s)	ΔP (Pa)	Calculated maximum heat transfer (kW) at a ΔT of 3ºC	Calculated average heat transfer (kW)	Latent heating / cooling per panel (Wh)	Total latent heating / cooling (kWh)
10800 m^3/h, 2.3 m/s, 15 ºC	20.4	18000 s (5 h)	21	23	10.3		
7200 m^3/h, 1.5 m/s, 15 ºC	14.5	36000 s (10 h)	16	16.4	5.2	155	181
3600 m^3/h, 0.8 m/s, 15 ºC	8.8	64800 s (18 h)	8	9.9	2.8		

The h_c value is based on the calculation with equation 9, which is close to the value calculated by PHOENICS.

The next step in the development has been the option to load the battery via the heat pump. In that case the air is recirculated via the battery:

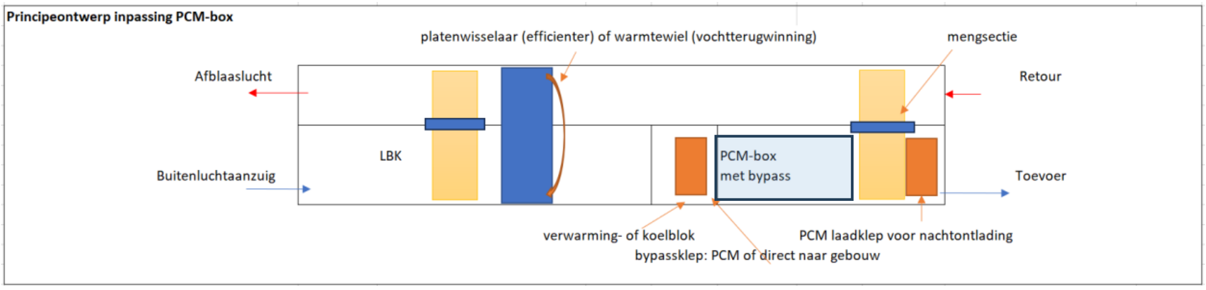


Figure 3: scheme of an AHU in which the PCM can also be loaded with a heat pump

Aan alternative additional buffer is a water-PCM battery:

Figure 4: example of a water-PCM-battery module at the top of a buffer with 80 mm isolation (lit. 2).

A water-PCM-buffer of 55 °C and 24 kWh of heating energy can be unloaded till 35 °C already within 55 minutes and 10 litres per min (= circa 0.017 m/s in the buffer). By increasing the flow this time can even be reduced proportionally.

A current option on the market for hot water is a water-buffer, for example from the Borg-firm: a 4,000 litre water buffer underneath a house of the new start-up Borg firm can store circa 200 kWh of energy Technical specifications (borg.energy), when the water cools down from 65 to 22 °C. However, the external size of 3,80 x 2,90 x 1,60 m (= 17,6 m^3) makes is difficult to install it in an existing situation. In this case 83 % of the size is isolation (for 1 % energy loss per day) and rest-space. For a diurnal storage not so much isolation will be necessary.

One of the advantages of an air to PCM storage compared to a water-PCM buffer is the relatively low weight and the high energy content at lower heating temperatures like 35 or 45 °C. The size of a battery also depends on the amount of isolation around the battery. The thickness of the isolation depends on the time that the energy should be stored: a few hours, a day, a few days, a week or longer.

For an air to PCM-battery with 1,300 panels (CSP 275, 310 kJ/kg) and circa 200 kWh storage capacity 2,340 kg will do.

In the following table the characteristics of an air or water to PCM-buffer and a water buffer are compared:

Table 2: Storage option for water or PCM-buffers. The supply water temperature is 65 ºC. The minimum water temperature is 22 ºC.

	Storage medium	Casing PCM/outside	Storage capacity	ΔT	Weight	Size internal	Size external
Borg	water	EPDM, EPS200, 300 mm around buffer	200 kWh	43 K	4000 kg water + casing	4,00 m^3	3,8 *2,9 *1,6 m =17,6 m^3, only within EPS 14 m^3?
Orange Climate	PCM52, air to PCM	HDPE, 80 mm around buffer	200 kWh	7 K	2340 kg PCM + casing	4,45 m^3	7 m^3?
Orange Climate	PCM52, air to PCM	HDPE, 80 mm around buffer	244 kWh	43 K	2340 kg PCM + casing	4,45 m^3	7 m^3?
Orange Climate	PCM52, water to PCM	HDPE, 80 mm around buffer	200 kWh	7 K	2340 kg PCM + 400 kg water + casing	4,45 m^3	7 m^3?
Orange Climate	PCM52, water to PCM	HDPE, 80 mm around buffer	260 kWh	43 K	2340 kg PCM + 400 kg water + casing	4,45 m^3	7 m^3?

The advantage of PCM52 is the high storage capacity within a 7 K phase change temperature zone between 42 and 49 ºC. Because of the relative low energy content of PCM of 2,100 J/kgK in a solid or liquid phase, water with an energy content of 4,200 J/kgK is more effective outside the phase change temperatures. However, PCM has a 35 % lower weight for the same energy content.

In the Co Creation Centre, one of the two buildings that is evaluated and subject of research, the maximum temperature via the heat pump is 45 ºC. In that case storage in water is not very efficient anymore. The ΔT between 45 and 22 ºC is only 23 ºC, reducing the storage capacity with (43-22) / 43 = 49 %. However, PCM-materials become much more effective at lower heating temperatures, because the phase change storage capacity does not change at lower temperatures. Another important parameter for the storage capacity is the energy content of the PCM material, for instance 310 kJ/kg of 195 kJ/kg.

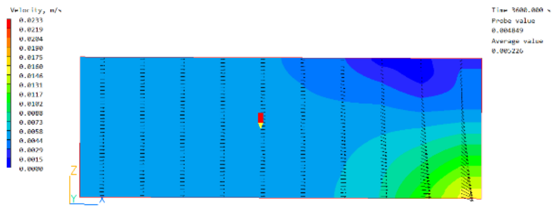
One of the research-aims is to develop modular PCM-boxes that are easy to integrate in a building.

The mutual position of the PCM-panels is also an important parameter to consider. Are they positioned parallel to each other or in series? The first example is presented in the Climate Tower of the Co Creation Centre (figure 2). When there is a parallel position and there is a high air flow over the panels a high thermal capacity is possible which also can be seen in table 1. With a (partly) position in series the capacity seems to be more limited, but this can be compensated by the volume of the flow. For water this is easier to solve because of the very low velocities. Nevertheless in case of separated water-buffers a parallel position is preferred. In that case it is easer to reach the maximum capacity during a limited time.

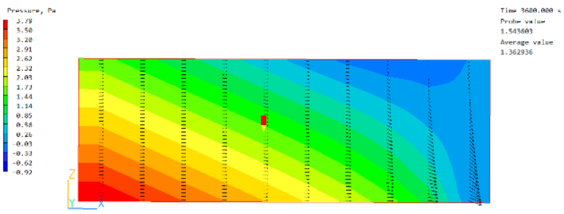
Because the temperature of a PCM-battery drops in relation to the phase change temperature, the capacity (delta T) will also become lower.

Average temperature after 6 minutes: 40 ºC

Average temperature after 24 minutes: 36 ºC



Water velocity in the water-PCM buffer: 5 mm/s



Pressure differences in the buffer: 1.4 Pascal

Figure 5: CFD-results: temperatures velocities and pressure in a water-PCM buffer

For heating or cooling purposes a high storage capacity in kW has only sense when this can also be transported to the occupancy zone via an air or waterflow and a heat exchanger with the same capacity. Usually the heating and cooling capacity of the heat-pump is the value that could be reached. A storage should be able to take over the heat pump for some time.

In all the considerations the return of investment is an important issue. This is influenced by the following parameters:

Price per kWh

- The advantage of a buffer is that there is much freedom in the choice of time when loading is favourable. So the most favourable moment of the grid can be used.
- On top of that the energy of photovoltaic cells can always be used in a period when there is a heating demand combined with sufficient solar energy.

Reduction of investment and pay-back time

When the costs per kW of a PCM-buffer are comparable with a heat pump the return of investment is short.

- In case of a buffer with sufficient capacity the capacity of a heat pump and the size of the connection to the grid can be reduced. This will reduce the investment of a buffer significantly.
- It is important to know what the maximum heating and cooling demand is, which determines the capacity of a heat pump. A limited cooling capacity of circa 80 % of the heating capacity of the heat pump is recommended for warm water-PCM buffers in order to be able to reduce the capacity of a heat pump.
- The investment costs for a small size heat pump with integration and ground-buffer are around € 2500,- per kW and of a water-PCM buffer around € 250,- per kWh and € 2500,- per kW.

- For air-PCM buffers connected to an air handling unit the investment costs are around € 100,- per kWh and € 1000,- per kW, this is comparable with the costs of an air-PCM heat-pump of limited size.
- The water-buffer of Borg of 200 kWh requiers an investment of € 14.000,- (information June 2023), including control-systems. This is € 70 per kWh.

The current electricity usage of the heat pump for heating and cooling of the Co Creation Centre is 11,500 kWh. If 5,000 kWh could be delivered by the water-PCM buffer, taking into account € 0.20 per kWh saved electricity, the total savings per year would be € 1,000. With a return of investment of 10 years the maximum investment of the PCM-buffer could be € 10,000, which is very low. Currently the average electricity price in The Netherlands is € 0.35 per kWh, including taxes, so when the electricity is generated by PV a higher maximum investment should be possible.

3. Conclusions and recommendations

When the size of a heat pump can be reduced proportionally to the size of a PCM-buffer the following conclusions can be drawn:

1. If the costs of air to PCM-buffers are comparable with air to water heat pumps, it is economic feasible to apply this.
2. If the costs of water to PCM-buffers are comparable with water to water heat-pumps, it is economic feasible to apply this.
3. When the electricity is delivered by PV the return of investment is more favourable.
4. Hot water buffers (65 ºC) are generally an attractive alternative for PCM-buffers, so a cost-benefit analysis is always necessary.
5. A water-PCM-buffer can also deliver 200 kWh energy but with a much lower supply-temperature of 45 ºC and a lower ΔT of circa 4 K. This will lead to a much higher COP for the heat pump and has a favourable effect on the return of investment. The low difference between the supply and return temperature will make it also easier to integrate in the heat supply part of the installation.
6. A water-PCM-buffer of 45 ºC can deliver 70 % more thermal energy than a water-buffer of 65 ºC at the same weight.

4. Literature

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