

## Research Article

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## Air and Water to PCM Batteries in Buildings

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### ABSTRACT

PCM-batteries have the capacity reducing energy consumption for heating and cooling, the capacity of heat pumps and the risk of grid congestion. The design characteristics and behaviour of two different air handling units with air-PCM batteries are discussed. In one of the buildings also water-PCM batteries are applied. These batteries can be loaded two times a day and evade times with a high electricity demand. The design and integration characteristics of these systems are very different. The research is a part of the Acapulco-project. The aim of this project is to reduce the grid-congestion risk with 90 %. In order to make this possible three types of storage are applied: Storage in the ground, in surface water and in PCM-batteries.

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**Received:** September 10, 2026; **Accepted:** September 15, 2026; **Published:** September 25, 2026

### Introduction

Two different air-PCM applications are discussed. These are located in the Green Village, a laboratory site of the Delft University of Technology, where new sustainable techniques are tested. In the Co Creation Centre several different buffers are compared: an air-PCM buffer, a water-PCM-buffer, a buffer via poles in the ground and surface water. In another research facility, the Office Lab an air-PCM buffer is tested. The glass to floor percentage of the Co Creation Centre is 121 % and of the Office Lab 35 %. This makes the thermal behaviour of both buildings very different. In the following figures the working principles of the building and different buffers are presented. The main aim is reducing peak loads of the grid in winter (heating) and in summer (cooling).



a. Co Creation Centre in Summer at the South Side



b. In the Heating Season the Sun is Used to Heat the Building



c. The Location of the Air-PCM Buffer and Water-PCM Buffer is Presented (Left Side)



d. The Building Uses Heat and Cold Storage Via Pipes in Poles in the Ground and Via Pipes Integrated in a Shore Construction of Surface Water

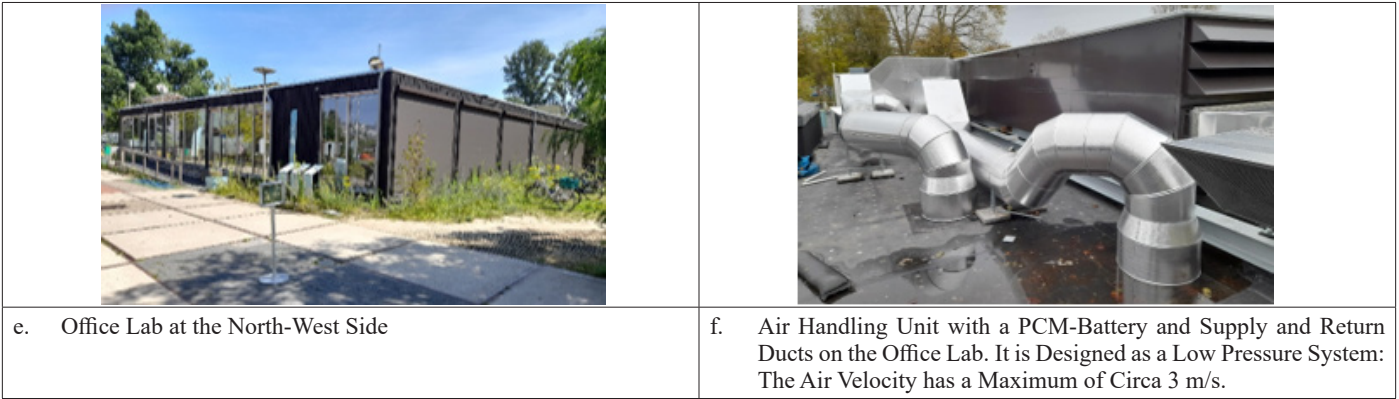


Figure 1: Overview of the Research Buildings and Applications

In the following figure with a hydraulic scheme all the thermal buffers are presented:

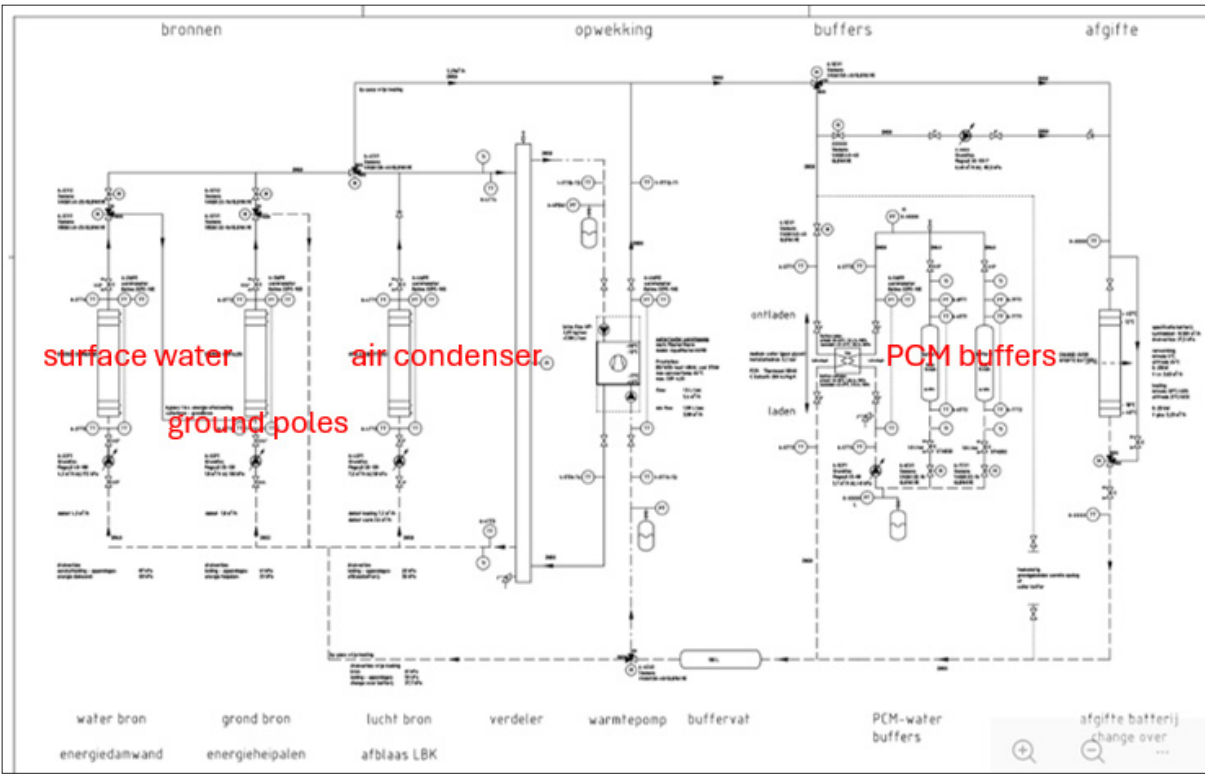


Figure 2: Hydraulic Scheme of the Buffer System with a Presentation of the Buffers or Energy Sources

When the heat pump produces heat or cold water the most favourable source option can be chosen via the BMS-system.

**Air-PCM Batteries**

The Co Creation Centre is a fully glazed conference building. The Office Lab is the central office of the Green Village. The heating and cooling capacity of the batteries are not the same. In the Co Creation Centre, the capacity is 121 kWh (9,000 m<sup>3</sup>/h) and in the Office Lab 60 kWh (5,400 m<sup>3</sup>/h). The phase change temperatures vary both between 17 and 23°C. This makes the battery appropriate for cooling as well as heating. However, in the Office Lab there is also the option to cool the PCM-battery separate from the building via the heat pump, when the nights are not cold enough. Due to climate change the nights become warmer in The Netherlands. The Air-PCM batteries integrated in air handling units are already discussed earlier [1, 2]. Only the follow-up of results is discussed here. The technical outline of the water-PCM buffers will be discussed in more detail.

**Water-PCM Batteries**

Below the floor of the Co Creation Centre water-PCM batteries are placed. There are two containers with PCM-batteries with a capacity of 10 kWh each. The phase change temperature is between 43 and 48°C. The casing of the panels is of polyethene.

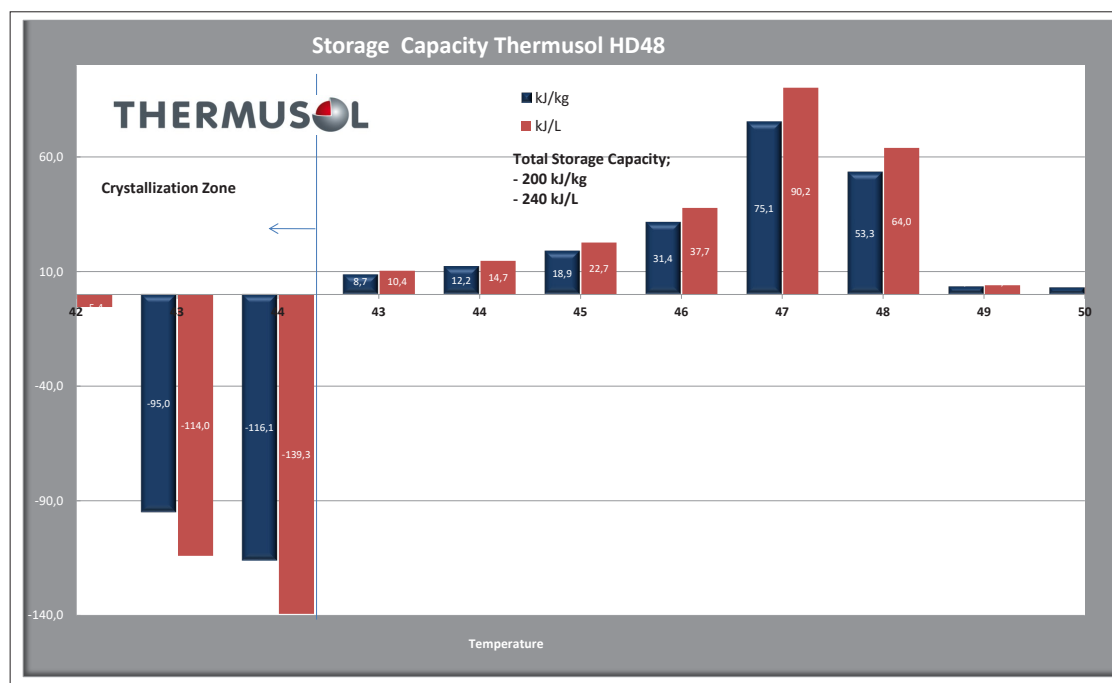


Figure 3: Phase Change Between 43 and 48°C

This temperature is sufficient to heat the building. In winter the average maximum heat loss is around 10 kW, making it possible for the batteries to heat the building during two hours. The idea is to load the buffers outside congestion period two times a day, when electricity prices in are lower. Because the building is equipped with PV it is also often possible to use free available own energy. In a technical way a water-PCM battery is more complicated than an air-PCM battery.

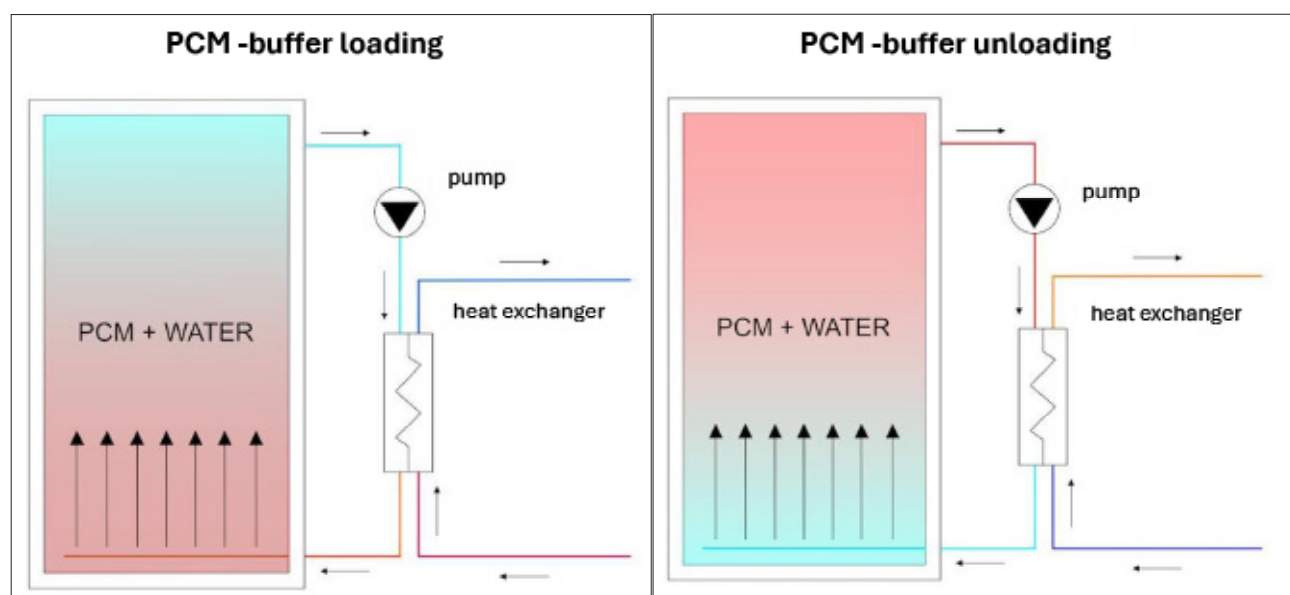


Figure 4: Loading of the Buffer with Warm Water (e.g. in 48°C, out 38/40°C) or Unloading with Water with a Lower Warm Water Temperature (e.g. in 38/40°C, out 45°C)

It is difficult to unload water with a fixed capacity, because the temperature of the buffer gradually decreases and the return temperature of heating system is difficult to control.

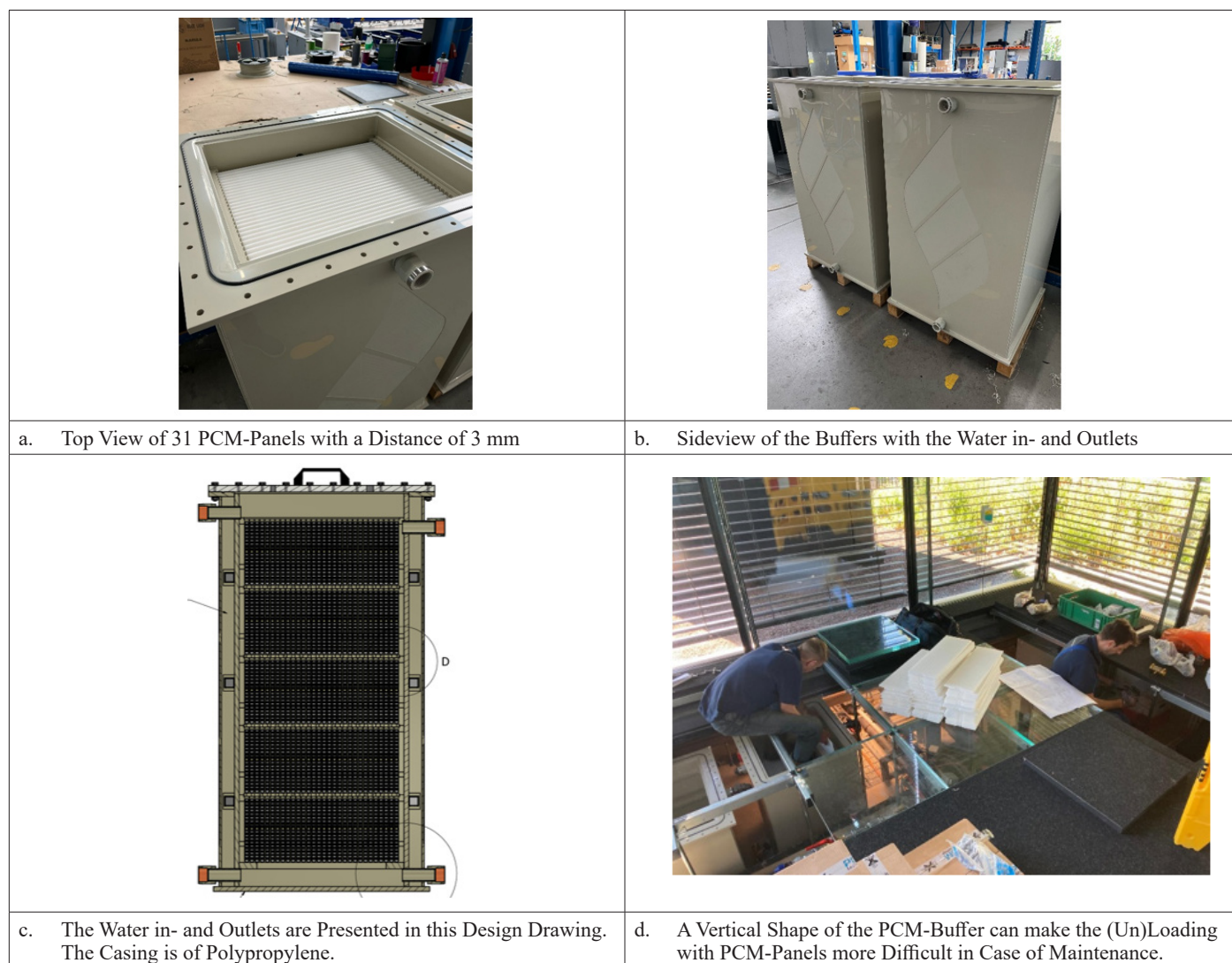


**Figure 5: Water PCM Buffers**

## Results

### Air-PCM Batteries

Measurements of the cooling and heating stored energy during a whole year show an energy storage-level in 2025 of 7,830 kWh in the Co Creation Centre (121 kWh buffer) and 15,125 kWh in the Office Lab (60 kWh buffer). This means that the battery in the Office Lab is around 4 times more effective. Simulations in Design Builder show that there is much more passive energy (80 – 90 %) available in the Office Lab, than in the Co Creation Centre which has obviously a relationship with the much lower glass to floor percentage. The in the Office Lab simulated yearly heating and cooling demand in Design Builder, without a PCM battery, is only around 7,000 kWh. The measured heating and cooling energy in the buffers is heating and cooling over a whole year. However, only 50 % of the measured heating and cooling energy in the buffers is used in a period when heating and cooling is necessary, being an addition to the available thermal mass. The PCM can be considered as a thermal buffer that uses environmental heat or cold, or heat or cold indirect from the heat pump. This makes it also possible to evade energy usage from the grid outside grid congestion times.

Earlier research with a MATLAB-model showed that passive systems could reduce 58 % of the energy of the Co Creation Centre (19,500 kWh/yr) reducing it to 8,200 kWh or 27 kWh/m<sup>2</sup>, which comes close to the current measured data [3]. However, the contribution of the PCM battery is not fully clear up to now. By comparing Design Builder calculations with PCM-buffer measurements can be concluded that around 25 % of the energy consumption for heating and cooling is used by PCM in in the Co Creation Centre and 50 to 80 % in the Office Lab, but the control strategies can influence the contribution of the PCM-buffers. However, in the Office Lab there also the option to load the buffer in an active way with the heat pump to increase the cooling capacity from 30 to 45 kW at rare very hot days with a high humidity. In that case especially fan energy instead of environmental energy is relevant. The COP of the PCM battery of the Co Creation Centre has earlier been measured and calculated as 39, but when the separate cold loading during the night is also taken into account as well it will become much lower [2]. Cold load of the PCM is favourable when the pressure difference of the fans are low, for instance below 200 - 500 Pascal.

| Co Creation Centre               |            |              | Office Lab                      |            |              |
|----------------------------------|------------|--------------|---------------------------------|------------|--------------|
| 2025                             |            |              | 2025                            |            |              |
| December                         | 148        | kWh          | December                        | 1113       | kWh          |
| November                         | 628        | kWh          | November                        | 741        | kWh          |
| October                          | 494        | kWh          | October                         | 1023       | kWh          |
| September                        | 582        | kWh          | September                       | 1487       | kWh          |
| August                           | 325        | kWh          | August                          | 1825       | kWh          |
| July                             | 660        | kWh          | July                            | 1686       | kWh          |
| June                             | 751        | kWh          | June                            | 1819       | kWh          |
| May                              | 578        | kWh          | May                             | 1066       | kWh          |
| April                            | 1329       | kWh          | April                           | 1314       | kWh          |
| March                            | 1573       | kWh          | March                           | 1321       | kWh          |
| February                         | 500        | kWh          | February                        | 973        | kWh          |
| January                          | <u>262</u> | <u>kWh +</u> | January                         | <u>756</u> | <u>kWh +</u> |
|                                  | 7830       | kWh          |                                 | 15124      | kWh          |
| 50 % = 3915 kWh                  |            |              | 50 % = 7562 kWh                 |            |              |
| 8,000 m <sup>3</sup> /h, 121 kWh |            |              | 5,400 m <sup>3</sup> /h, 60 kWh |            |              |

**Figure 6:** Air Flows, PCM-Capacities and (Un)Loaded Heating and Cooling Energy

The loading and unloading time of an air-PCM battery, for instance 10 hours, is around 10 times longer than of a water-PCM battery.

### Water-PCM Batteries

- The BMS system is developed for optimal heating related to the outdoor circumstances with changing heating temperatures. For loading the buffer, a fixed temperature of 50°C is preferred. Adaptations of the control system had been necessary to make this possible.
- At the bottom of the buffer there are two round water inlets with a cross-section of 32 mm. 52 l/min is supplied. In theory the buffer could be loaded or unloaded in around one hour. However, it is difficult to realize an equal water supply between a row of 31 PCM-elements with only 3 mm of free distance. CFD calculations made clear that via a porous plate with a porosity of only 0.32 % (1000 mm<sup>2</sup>, 0.86 m/s) an equal supply is possible. This is with an unequal supply by two 32 mm water inlets at the bottom of the buffer. In that case the pressure difference will be quite high: 1600 Pascal, but the required energy consumption will remain relatively low, which can be presented with the following equation where the pump has an overall efficiency of 0.7:

$$P = \frac{0.00086 \frac{m^3}{s} * 1600 Pa}{0.7} = 2 W \quad (1)$$

Another option with probably lower pressure and a good distribution is a plate with small holes right beneath the cavities between the PCM-panels.

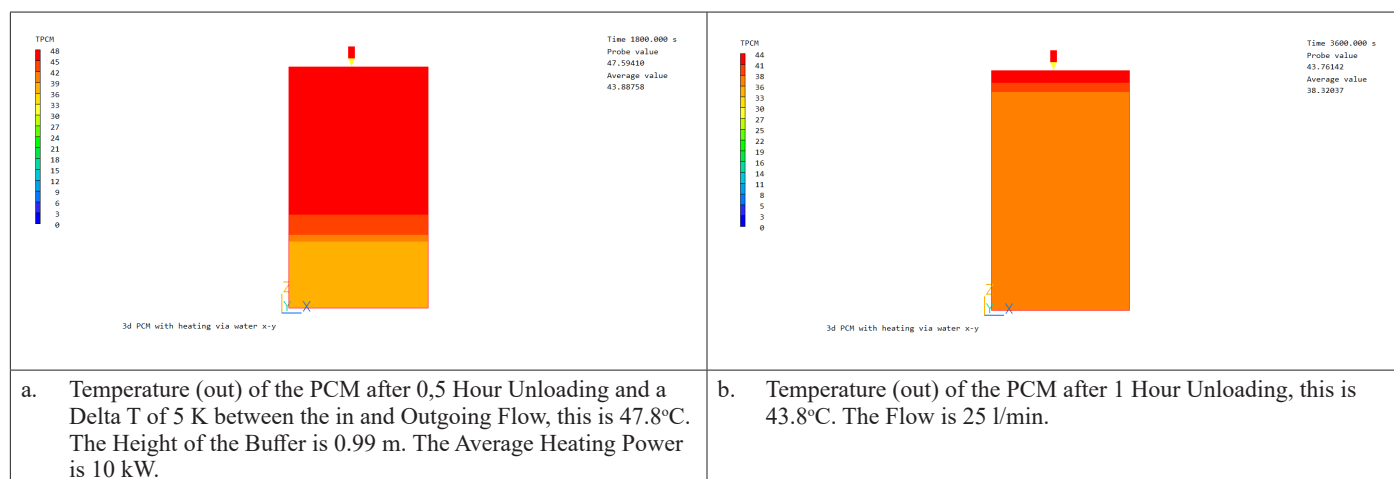


**Figure 7:** Temperature Stratification in the Buffer During an Unloading Time of 1 Hour

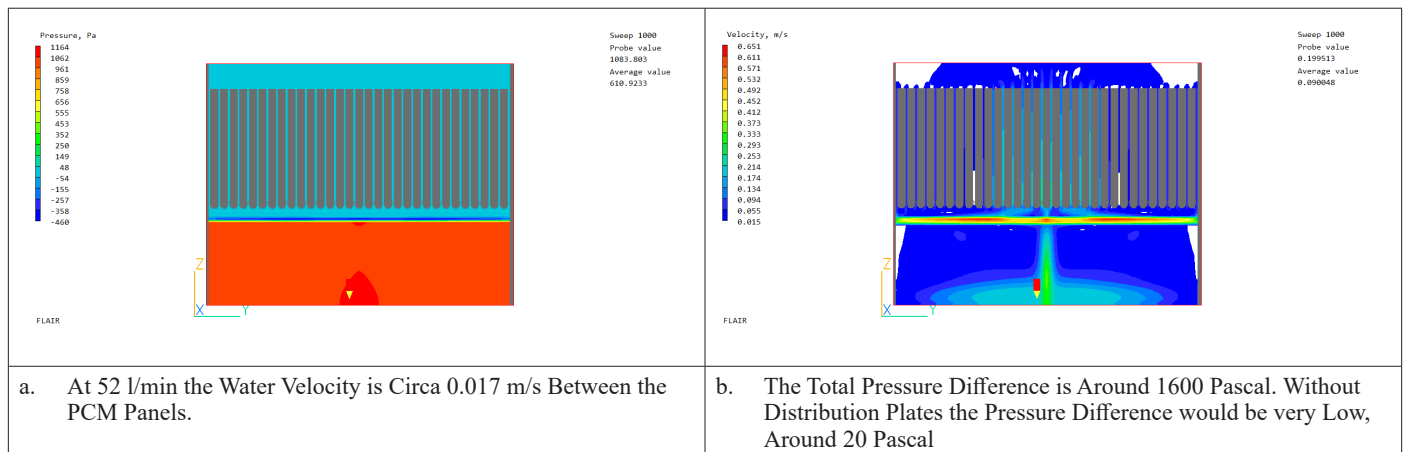


**Figure 8:** Flow Pattern Via an Ideal Perforate Plate Width 0.32% Opening (1000 mm<sup>2</sup>)

However, it is also possible just accept the differences in water supply between the PCM-elements, while improving the supply-system via the inlet ducts at first and load and unload the buffer during a longer period. For different applications and buffer-sizes no final decision has been made.

## Discussion

Most of the discussions in practise are focussed on economic issues and environmental boundary conditions.

- In a renovated health care centre, the calculated savings are 48 - 52% for a combination of PCM combined with indirect adiabatic cooling in a HVAC unit [4]. In this case no substantial cooling via the ground (aquifer) was possible, a lower CO<sub>2</sub>-footprint was leading.
- In more and more projects evading grid congestion becomes important. In that case the water as well as the air-PCM buffers will become more interesting to apply. The control strategies should take this into account.
- The cost of PCM-buffers is also determined by the size. That should be carefully chosen. A limited size is also interesting, although the costs per kWh will be higher.
- For water-PCM buffers the costs of a heat-exchanger and isolated casing are important to take into account.
- A stainless-steel casing is cheaper than a polypropylene casing but has a higher environmental impact (CO<sub>2</sub>). Polypropylene can also be recycled which makes the environmental impact lower.
- A fixed capacity is difficult to realize when unloading a PCM-buffer because the buffer-temperature gradually decreases. An option is to increase the flow via the BMS, but in practise some variation in capacity can also be accepted.
- Comparing simulations with measurements remains difficult, because during the occupation time of the buildings the setpoints for heating and cooling have often been adapted by a local climate operator: a lower cooling setpoint e.g. from 25 to 23°C and a higher heating setpoint e.g. from 20 to 21°C.
- It is very important to reduce the fan pressure difference as much as possible in order to save energy. Nowadays in Europe the total pressure-difference of large new buildings tends not to exceed 1500 Pascal instead of 2500 Pascal (supply + exhaust fan). In order to reach a high efficiency of PCM-buffers even a lower total pressure difference is recommended, especially during night cooling of the PCM. The pressure difference is also influenced by the air flow which should be carefully chosen. The maximum is generally not necessary; it also depends on the difference between the indoor and outdoor temperature. Our current estimation is that a maximum pressure difference of 500 instead of 2500 Pascal per fan would have been sufficient.

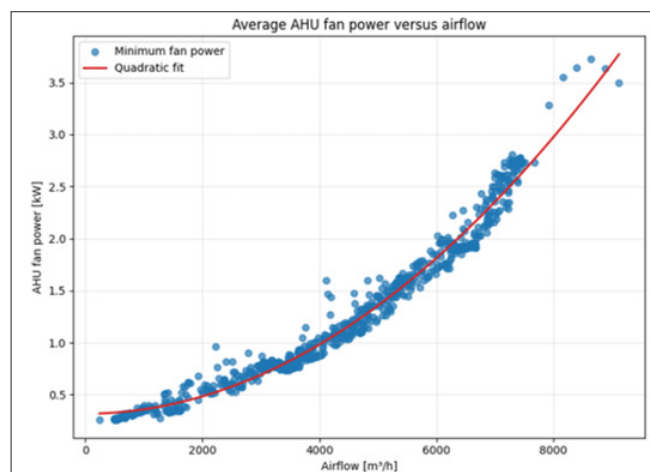


**Figure 9:** Measured Airflows Compared to the Actual Fan Power. The Relation is Semi-Quadratic. An Airflow of 2000 m<sup>3</sup>/h Requires 5 Times Less Energy than 7200 m<sup>3</sup>/h. The Total Pressure of Both Fans is around 1900 Pascal at 7200 m<sup>3</sup>/h, which could have been much Lower with a Different Kind of Fan.

The airflow of the fan is determined by the following equation:

$$P_{\text{fan}} = 4.15 \times 10^{-8} V^2 + 4.119 \times 10^{-7} V + 0.3169 \quad (2)$$

Where P is the fan power in kW and V the airflow in m<sup>3</sup>/h.

### Conclusion and Recommendations

- It is possible to design air-PCM batteries for air handling units that are sufficient robust.
- The efficiency of these batteries is difficult to assess because it overlaps the storage capacity of the building materials and the temperatures in which normally there is no active heating and cooling. However, as an addition to the thermal mass the contribution of the buffers can be measured.
- The efficiency is highly influenced by the building physical design of the building. The lower the heating and cooling load of the building the higher the efficiency.
- In order to reduce grid-congestion the buffers can be loaded outside hours with a high electricity consumption.
- Water-PCM batteries are more difficult to design because of attention that is required for an equal distribution of water between the panels.
- The fixed higher temperature of a water-PCM-buffer needs adaptation of the normally outdoor air-controlled heating system.
- A fixed capacity is difficult to realize when a PCM-buffer is unloading because the temperature gradually decreases, but could be compensated with a higher flow.
- Choose fans with low pressure differences, especially at the flows that are most common related to the occupancy.

### Data Availability Statement

The data is only restricted available via the researchers because this is stored via two BMS-systems of Priva at the Green Village of the Delft University.

### Funding Statement

This research was funded via a grant from the Acapulco project of the Rijksdienst voor Ondernemend Nederland, project number TSEGO23017.

### References

1. Engel PJW van den, Malin M, Venkatesh MK, Araujo Passos LA de (2022) Performance of a Phase Change-battery in a transparent building. Journal of Fluid Dynamics & Materials Processing 19: 783-805.
2. Peter van den Engel, Bert van Dorp, Koen Hamers (2025) Opportunities of Air- and Water-to-PCM Batteries in Buildings. J Mater Sci Manufac Res 6: 1-8.
3. Araujo Passos LA de, Engel P van den, Baldi S, De Schutter B (2023) Dynamic optimization for minimal HVAC demand with latent heat storage, heat recovery, natural ventilation and solar shadings. Energy Conversion and Management 276: 116573
4. Johan M van der Steen, VI Calixto Aguirre (2026) Passive Cooling for the Renovation of the Hoogstaete Zuyderland Healthcare Complex in Sittard. TVVL Magazine 12-18.