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Latent Heat Storage to Improve the Urban Microclimate

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1 ABSTRACT

Whilst the world is trying to find a way without fossil fuels it still needs to find a possibility to switch heat or cooling capacity from times generated to times needed. This will even be more of interest when all energy needs are switched to electric generation and thus to renewable energies. Coming to this point, energy will be generated when available and be stored in between. Nevertheless, there will be a large difference in case of costs using energy when it is generated and when in abundance. Therefore, energy storage, especially for heat, will be indispensable in the future, in particular for places where lots of people live and large amounts of heat are necessary. Such storages can be made of phase change materials that store heat in the phase change from solid to liquid and vice versa. Thus, this paper expands on the current discussion on traditional phase change material for latent heat storage by innovatively suggesting salt hydrates. Based on explaining the principles of phase change material, the authors illustrate the application of salt hydrates resulted from experiments of the authors. In doing so, they differentiate between integrating phase change materials in active (i.e. in the water heat system) and passive heat storages (i.e. in the building structure). With these applications shown, which are either already available or necessary to be provided in near the future, an ecologically efficient improvement of the microclimate can be engineered.

Keywords: examples, latent heat storage, micro climate, benefits, experiments

2 INTRODUCTION

One of the most important challenges of the near future is the energy generation based on renewable energies. However, for this storages must be built on a large scale, and not only for electric energy but also for heating purposes (Mavrigiannaki and Ampatzi, 2016). Especially heating is thereby a major challenge because it is commonly based on fossil fuels which are a major detrimental effect on climate change and microclimate. Avoiding any combustion of fossil fuels, the future climate control of buildings will mainly be based on heat pumps. However, because of fluctuations in renewable energies and thus changes in the costs of electricity, heat generation will ideally be switched to times when these costs are less intensive, such as night times (Konuklu et al., 2015). This can be provided by using phase change materials (PCM) (Tyagi and Buddhi, 2007). Pointing to existing research gaps, Mavrigiannaki and Ampatzi refer to gain further knowledge on potential contributions of this technology in reducing carbon emissions (Mavrigiannaki and Ampatzi, 2016). Furthermore, authors called for further research on technologies and applications for specific alimates and building typologies. Based on a basic explanation of the functioning of PCM, experiments and practical applications of the PCM made of salt hydrates are provided in the following sections.

3 BASIC PRINCIPLE OF PHASE CHANGE MATERIALS

To store large amounts of heat energy in small volumes, it is reasonable to use physical phase changes, because the corresponding enthalpy is much larger than just a change of temperature (Khudhair and Farid, 2004). Furthermore, the operating point is fixed through the melting temperature, and thus the application has not to be appropriate to a steady increase or decrease in temperature, for example. This is underlined by the number of papers dealing with phase change materials that were published between 2011 and 2019 (Mustapha et al., 2021). The number was steadily increasing, especially in China, the United States of

America, and Germany. This is due to legislative changes in these countries and to state fundings that were granted.

The whole physical effect of phase change materials is similar to using ice cubes to cool down drinks or to a so-called hand warmer used during the skiing season. The storage material can thereby bridge the time between energy generation and consumption and therefore reduce any energy wastes or process inefficiencies (Konuklu et al., 2015; Kabeel et al., 2017). Especially when the process implementation must have a constant temperature, this kind of material is more appropriate to be used instead of a large water storage, for example. For the future this will even be more important when the energy generation is based on renewable sources and the ongoing climate change is considered because excess energy can be stored and used when needed avoiding unnecessary efforts or useless large storage designs (Rouault et al., 2016).

A known disadvantage, so far, were the material costs, hence the small amount implemented in building structures. This can be avoided using salt hydrates with a phase change enthalpy of a minimum of 80 kWh/m³ instead of paraffines being chemically and toxically harmless and inexpensive enabling the integration of large masses into the construction (Sonnick et al., 2018). The principle of phase change materials is shown in Fig. 1. With sensible heat, a material can be heated or cooled down, but it is connected to a change of temperature. Whilst during the phase change, the temperature is kept similar and, usually, significantly more energy can be stored during this step, because no large temperature changes are typically desired.

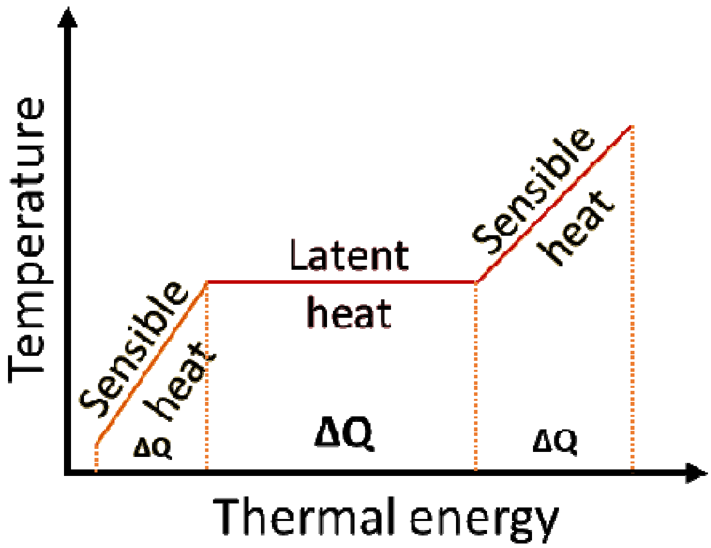

Fig. 1: Typical temperature curve of a phase change material.

Following are some applications shown, which are either already available or are interesting for the future to efficiently improve the microclimate ecologically.

4 BUILDING CLIMATE CONTROL

As already explained, in the future will be more distinguished between times when heat is generated and used. During nighttime most people do not use heating, therefore it has to be stored until times when it is needed. Thereby, it can be differentiated between active storage included in the water heating circuit and passive storage included in the building structure.

4.1 Active PCM integrations

As shown in Fig. 2 two different integrations of active storage PCM in the water heating system are possible. One is to extend the heat storage capacity of the water tank by adding PCM to the wall or by putting it directly into the water tank whereby it has to be macroencapsulated (left pictures). This system can also be used to store heat during the day from a solar thermal system for showering in the evening and simultaneously melting the PCM. During nighttime, the PCM is heating the water again providing warm water in the morning time. In Fig 2. on the right side a different system is shown. An additional heating liquid circuit is installed which is not soluble with the PCM and thus can change heat via direct contact (Kunkel et al., 2018, 2020). The thermal liquid can be heated by solar thermal energy thus melting the PCM. Switching the thermal liquid circuit to another heat exchanger which is flushed with the water heating circuit of the building, can provide warm water for several applications within the building. For these applications, PCM with a melting temperature of about 56 °C should be reasonable. (Kunkel et al., 2019)

Fig. 2: Examples for active storages in the water heating circuit.

4.2 Passive PCM storages

Another possibility to store energy is to integrate macroencapsulated PCM within the building wall or roof as a passive system. However, in this scenario, it is necessary that the PCM can remain there for the lifetime of the building and still perform. Key advantages of this system are that no additional space has to be kept clear and that no further energy is necessary. If the sun is warming the outer wall the PCM will start to melt and therefore keep its temperature not warming the living rooms up until the whole PCM is melted. During nighttime when the temperature drops to a lower point than the phase change temperature of the PCM, the PCM begins to crystallize and will again keep the room temperature stable until all the PCM is crystallized. This kind of system with wall installations is shown in Fig. 3. Thereby, the PCM is installed double-layered to realize ventilation between the packages and to improve heat transport. Measurements with PCM with a melting point of 21°C were performed against another room with no PCM showed a reduction of the day/night temperature fluctuation of 62 % and an overall reduction of the fluctuation of 57 % against the reference room. (Sonnick et al., 2020)

Fig. 3: Macroencapsulated PCM within the building wall with space for ventilation

In Fig. 4 PCM (21 °C) integration in an intermediate ceiling and in floor compartments of a tiny house is shown. The results showed a reduction of overheating during summertime and a more stable temperature during nighttime when the outside temperature dropped (Sonnick et al., 2018). This was especially significant because this tiny house is made of wood and thus has a low heat storage capacity by itself. Therefore, PCM can affect the temperature stabilization of buildings as well as increase the overall heat storage capacity especially when it is built out of wood or other light materials.

Fig. 4: Macroencapsulated PCM integrated in the floor compartments (left, middle) and in the intermediate ceiling (right).

4.3 PCM integration in concrete

Besides aforementioned examples, PCM can also be integrated within concrete walls or blocks. Thereby, the shape of the PCM together with the macroencapsulation is of main importance to achieve the best heat transfer (Erlbeck, Schreiner, Fasel, et al., 2018; Erlbeck, Schreiner, Schlachter, et al., 2018). In Fig. 5 two concrete blocks were produced whereby one was filled with a macroencapsulated PCM package (right block). Both concrete blocks were left in the sunlight to warm up. As can be seen, the concrete block with PCM takes more time to increase the temperature. It is imaginable that such tiles can be used to build a terrace at home as well as to decrease the overheating of cities by installing such tiles for sidewalks within the city center or at a place where it is expectable that the sun will warm up the floor.

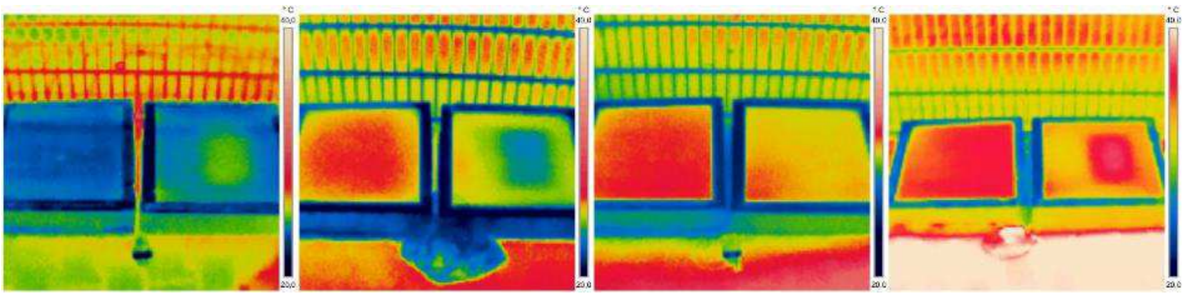

Fig. 5: Macroencapsulated PCM integrated in concrete blocks and heated by sunlight.

An exemplary temperature profile of these tiles can be seen in Fig. 6. The tile without PCM overheated quite more than the tile with PCM. The same effect did happen when the outside temperature was lower but is unfortunately not visible in the profile. Nevertheless, the tile with PCM kept the heat longer and did therefore cool down more slowly with a higher negative peak temperature than the tile without PCM.

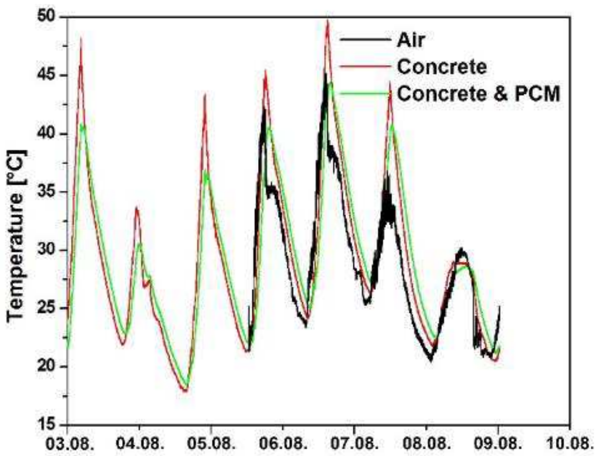

Fig. 6: Temperature profile of concrete tiles with and without PCM inside left outside in the sun.

4.4 PCM integration in furniture

Besides direct integrations into the building structure, PCM can also be integrated into design elements or furniture. In Fig. 7 some examples are shown. Two park benches were made, one of wood and one of concrete. The wooden one was filled with PCM packages and a ventilation system, whereas for the other bench, the PCM was cast in concrete improving the heat transfer via direct contact. Furthermore, several concrete columns were fabricated and integrated into the offices to improve the climate within the rooms.

Fig. 7: Several PCM integrations into furniture made of concrete or wood.

4.5 PCM for floor heating

Newly built houses tend to have floor heating, which per se does improve the energy efficiency of the building but also allows to use PCM directly within the piping system of the floor heating. However, normal PCM is not pumpable, especially in the solid phase, therefore, it is necessary to mix it with a thermal liquid. Both materials must not be soluble with each other. With the correct concentration of PCM and thermal liquid, the suspension can be pumped through the whole floor heating as well as through the heat exchanger through which the PCM can be charged by solar thermal energy, for example. Nevertheless, it is necessary to mix the solid PCM with the thermal liquid in advance, and this with the help of a disperser, so the crystals have the correct size to not only block any pipe but also to ensure a fast heat transfer. This system helps to keep the complete floor at a constant temperature level which will increase the overall efficiency of the heating system even more keeping the condensation temperature of the heat pump as low as possible. Furthermore, the same installation but in the room ceiling, combined with a PCM with a melting temperature of about 21 °C, in contrast to the heating system where the PCM should have a melting temperature of about 30 °C, could keep the room cool during summertime. Such phase change systems can be found in the scientific literature, and they are called PCD for phase change dispersions. The difference between a normal crystal growing in another fluid is shown in Fig. 8. As can be seen in the upper picture there is a large crystal pointing in the direction of pumping. Whereas the picture below shows lots of small particles evenly distributed. These small particles make sure that the pipes and if used the static mixer are not blocked, that the dispersion still has the properties of a fluid, that the heat transfer is as large as possible, and that usual installations can be used.

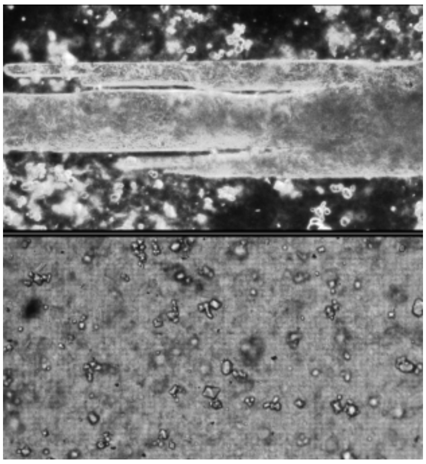

Fig. 8: Normal crystal growth in the direction of pumping direction (upper picture) and a PCD with small crystals evenly distributed (lower picture).

5 FURTHER APPLICATIONS

In a modern city, more applications of PCM are possible and will have an impact on the quality of life. If available a district cooling system can be used to cool down buildings during summertime. The water storage, which is feeding the grid can thereby be increased in case of stored energy when a large amount of PCM is included in the tank. The storage can then be charged during nighttime when the electricity costs are neglectable, and the cold can be used during daytime. As PCM, water or a salty water solution can be used to have a melting point at 0 °C or below, or a PCM with a melting point between 10 °C and 0 °C is usable. Which PCM will be used is dependent on the grid, the customers, and thus the electric effort for cooling.

Another cooling possibility is delivery trucks which drive mainly in the region of a city but no large distances. Such vehicles delivering food or medicaments for example will in future all be driven by electric motors and thus should have no climate machine onboard. Therefore, the cooling load must be sufficient enough for a whole tour through the city. This can be realized by optimizing today's cooling vans by integrating PCM within the vehicle wall to increase the overall heat capacity of the loading area. In Fig. 9 a cooling truck is shown which was simulated to show how long the cooling process would take place when the door is opened and PCM within the wall has to take up the incoming heat to keep the goods chilled (Gaedtke et al., 2020).

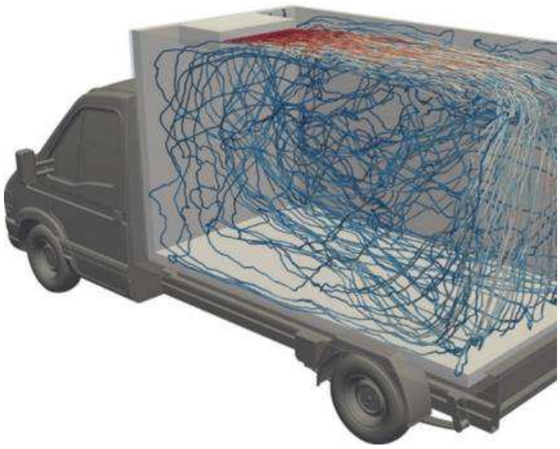

Fig. 9: Simulated flow elements within a delivery truck.

6 CONCLUSIONS

As shown in the previous text are several PCM applications already realized in use, but more is possible and will be implemented. All these options will help to control the microclimate within a city or the building itself and thus will make places more worth living at, even with ongoing climate change. Materials are developed and completely available. Furthermore, there are lot of applications where such materials can be incorporated and improve the energy management of a city or industry within a city. The potentials just have to be identified and realized.

PCM can thereby integrated within the building structure or in heating or cooling systems to increase the heat storage capacity, especially of buildings with a low thermal storage capacity as wooden houses. With cheap salt hydrate as phase change material design elements can even be produced controlling the climate within an office or keeping sidewalks cool during the day and pleasant warm during the night. Replacing combustion engines with electrical motors will lead to a reconsideration of what is really necessary and must be transported or not. This can change the designs of cooling trucks for example. PCM can be included within the vehicle keeping the goods chilled as long as the truck is on its way and can then be recharged when back at the docking station.

These examples show the whole options that are thinkable from the perspective of inhabitants, company owners, and city officials. However, it is inevitable that all these stakeholders come together to build resilient cities for the future.

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