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MELT Plates: The Abolition of Overheating in Lightweight Buildings through an Optimised form of Latent Heat Storage

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1 ABSTRACT

The predominant form of construction of residential and commercial buildings in the Federal Republic of Germany and other industrialized countries is that of solid construction. However, increased public awareness of the need to reduce CO_2 emissions is resulting in questioning this classic way of constructing buildings as the immense energy consumption in the production of cement and concrete makes the search for alternative designs indispensable. Alternative building methods with lower CO_2 impact are lightweight construction methods like prefabricated wooden buildings or even container-based buildings. One disadvantage of such buildings, even though they often are very well insulated, is their low thermal storage mass and, thus, that they overheat in summer and cool down quickly in winter, provided there are no constant sources of cooling or heat available. Technically this constant energy sources would be available in most of the cases, but as we want to use renewable energy sources, which are only available on a fluctuating basis, a thermal storage effect of the building itself is of primary interest.

This paper presents the benefits and limits of so-called MELT Plates, a newly developed method of the startup MELT to apply latent heat storage technology in buildings significantly contributing to micro climate improvement, and practical applications based on relevant experimental methodologies applied by the authors.

MELT's products will make a decisive contribution to the heat transition. The previously very cost-intensive niche product "phase change material (PCM)" will become more user-friendly and significantly cheaper thanks to technical innovations and can, therefore, open up the mass market. The initial application addressed is increasing the thermal storage capacity of lightweight buildings by installing the materials in the building envelope. This serves as overheating protection in summer and in winter, through a combination with photovoltaics and/or dynamic electricity tariffs, an even more ecological and economical heating system with heat pumps is made possible. Thanks to their adaptability, MELT products are also ideally suited for numerous other applications, such as the intermediate storage of heat in industrial processes.

Keywords: overheating, climate change, temperature conditions, heat storage, prefabricated buildings

2 BENEFITS AND OVERCOMING PREVIOUS SHORTCOMINGS

2.1 The Functioning of MELT Plates

Whilst the CO2 footprint is already reduced in wood-based pre-fabricated houses, further CO2 savings are suggested by turning to modular, scalable container construction. However, the disadvantages of all types of construction with lower mass are related to the lower thermal inertia, which means that the buildings heat up more quickly to above comfortable temperature and also cool down again quickly. This unfavorable circumstance can be counteracted by a new dosage form of so-called latent heat storage, which thermally stabilizes at exactly the melting temperature. Latent heat storage uses the solid/liquid phase transition of selected materials to deposit heat and cold. In contrast to water or ground heat storage, the temperature does not change when energy is added or released, hence, granting for a sustainable, continuous power supply (Saha et al., 2021). This method is regarded to fill the gap between demand and supply inherent in inefficient energy systems (Jouhara et al., 2020). In the past, many authors have investigated and published interesting applications for phase change materials in buildings in a scientific context (Liu et al., 2022; Reddy, Ghazali and Kumarasamy, 2024; Baylis and Cruickshank, 2023). Most investigations showed very good results from an energy point of view. The authors of this publication have published several promising studies on the use of PCMs in buildings (Sonnick et al., 2018; Sonnick et al., 2016; Sonnick et al., 2020). In Sonnick et al. (2020), for example, a reduction in day/night temperature fluctuations of 62 % was achieved in a lightweight prefabricated house using phase change materials as a natural cooling in summertime. In addition to applications in the building sector, the materials can be used, for example, in electrically powered refrigerated vehicles to increase their range (Gaedtke et al., 2020). Solar heat can be temporarily stored in heating buffer tanks (Kunkel et al., 2019; Kunkel et al., 2020) and, in the transportation sector, temperature-sensitive goods, such as food or medicines, can be safely shipped using PCMs. Even though scientists agree on the effectiveness of PCM, no product that is specifically designed for use in buildings has yet been able to establish itself, particularly from an economical point of view.

Furthermore, the previous disadvantages of this storage medium were addressing ecological concerns, fire load, poor heat transfer and a lack of quantitative scalability.

To overcome these shortcomings, the start-up Melt has now developed a device that is optimal for equipping buildings with low mass: the MELT-Plate.

The panels can be manufactured in big quantities by machine but can also be adapted to specific shapes. Due to the plate shape, it offers a big surface area and, therefore, good heat transfer even with small temperature differences to the surroundings. Representing a further advantage, the plate can be subsequently integrated into the building structure, even in existing or old buildings, e.g. in attic apartments. Hence, Melt-Plates, consisting of sustainable material, could be integrated into a holistic, sustainable energy concept during construction (or renovation). The combination of the MELT- Plate, which corresponds to the norms and regulations/specifications that come into force, with the well-known renewable energy sources will increase the overall efficiency of the house/building.

The MELT Plates were developed in dialog with industrial users and tailored to their needs - e.g. in terms of flexibility, mounting simplification and unit costs. The possible positioning of the MELT Plates in buildings was developed together with the prefabricated house builder “Willi Mayer Holzbau GmbH”. In the case of wall mounting, the MELT Plates are installed behind the mounting level for the classic supply lines. This greatly reduces the risk of damage. When combined with underfloor heating, the flat MELT Plates are arranged in the floor structure below the heating mats. The adjustment of the melting point to the flow temperature of the heating system leads to a considerable increase in the efficiency of the heat pump. Underfloor heating systems and MELT Plates, therefore, complement each other perfectly.

3 PHYSICAL BACKGROUND AND STATE OF THE ART

Phase change materials (PCM) are materials that melt or solidify during use and, thus, by utilizing the heat of fusion, have an enormous storage capacity at a constant temperature. Figure 1 shows the temperature curve of a PCM compared to a sensitive storage material without phase change.

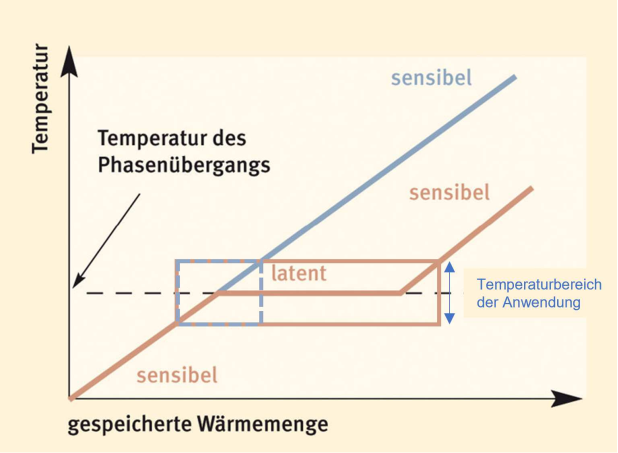

Figure 1 Temperature profile of a phase change material taking into account the melting process in comparison with a sensitive storage material such as water, wood or concrete

In technical applications, the operating temperature should often not fluctuate, or a certain temperature range must not be exceeded. With specifically used PCM, whose melting point is exactly in the temperature range of the application (e.g. 21°C for room air conditioning), considerably larger amounts of energy can be stored in the form of latent heat than in conventional storage materials (such as concrete, wood or water). In a fluctuation range of 3°C, which is common for room air conditioning, PCM can store around 35 times as much heat as concrete. However, PCM products available to date are essentially limited to use in transport boxes for temperature-sensitive medicines or food. They are offered in plastic containers in "cold pack form", which are adapted in shape and size to the shipping boxes.

MELT's product, on the other hand, is aimed at larger-scale applications. Salt hydrate-based PCMs with different melting temperatures are offered in customer-specific, modularly combinable plates - the MELT Plates. The materials are inexpensive and ecologically harmless (water hazard class 1 - like saline solution). The decisive advantage over products available on the market is the large-area and simple applicability, which is absolutely essential for the target customer group. This is achieved by a technological leap from (today’s) three-dimensional to two-dimensional, endlessly extruded encapsulation forms in cross-section at MELT. This results in enormous flexibility over several orders of magnitude.

Extruded twin-wall sheets (multiwall sheets) made from recycled plastic serve as the basis for the MELT Plates. These are cut to size according to customer requirements, filled by robots and thermally sealed. The sealing process is difficult due to potential contamination by PCM and the low wall thickness of the sheets. New technologies, therefore, had to be developed that work reliably under these conditions.

4 MORE APPLICATIONS

In addition to the use in buildings for efficient load shifting in winter and passive overheating protection in summer, MELT Plates can be used profitably in many other applications. A small selection is explained in more detail in this chapter. Furthermore, they can be produced in any color, so there are no limits to design freedom. For the first time, PCM can, therefore, also be installed as visible elements (e.g. partition walls in open-plan offices or suspended ceilings). The load-bearing capacity of the panels is not impaired by their filling, so that they can also be used as a stabilizing component in a sandwich structure, for example.

4.1 Refrigerated vehicles

Refrigerated vehicles for transport of cooled nutrition products with electric drive can increase their range with MELT Plates and in some cases even completely dispense with a refrigeration unit.

For this purpose, the refrigerated vehicle is equipped with MELT plates containing cryohydrate. The cryohydrate (melting point minus 21 -°C) is loaded with cold at the factory at night and cools the refrigerated goods throughout the day.

4.2 Buffer tank of heat pumps

The thermal storage of heat generated by heat pumps in water storage tanks is very unfavourable because the heat pump has a poor efficiency if the sink temperature is too high. This means that all storage tanks based on the principle of sensitive heat can only store small amounts of heat per unit volume due to the small temperature difference. In the buffer tank of heat pumps, MELT Plates lead to less space requirements and larger storage capacities. In addition, lower storage temperatures reduce losses and increase the efficiency of heat pumps.

4.3 Industrial applications

Low-temperature waste heat can often not be reused well in industrial processes because the conventional, sensitive heat storage systems used to date require a temperature range that is not possible with low-temperature waste heat. This is more favourable with PCM storage systems, which can store and withdraw heat at a constant temperature. This means that industrial processes such as precipitation, humidification, drying, fermenters, food processing etc. can be supplied with heat at a constant temperature.

5 A PROTOTYPE FOR TEMPORARY BUILDINGS

As part of a research project by the Bundeswehr Research Institute for Materials, Fuels and Lubricants (WIWeB) to combat overheating problems in Bundeswehr containers, a 10ft container was to be equipped with MELT Plates in order to achieve passive temperature buffering. The aim is to prevent overheating by flattening the temperature peaks to improve the containers used for storing temperature-sensitive materials or electronic components. Figure 2 shows the container before the installation of the panels.

Figure 2: Photographs of the original container – overvie w

5.1 Design and simulations

A 10ft container with the dimensions (length x width x height) 2990mmx2438mmx2438mm forms the basis of the investigations and is, therefore, the reference object.

MELT Plates are the basis for the PCM cladding. In order to protect the MELT Plates against mechanical loads from the outside and also to achieve a certain insulating effect, the plates were laminated with polyurethane (PU) foam on the outside. These, in turn, are additionally reinforced with 2 mm white GRP for increased mechanical stability and optimized optical properties (low emissivity). This results in a composite element with good optical and mechanical properties, which enables maximum retardation of thermal environmental influences in thin visible thicknesses.

The simulations were carried out using Designbuilder software, which is suitable for special building simulation applications. The phase change material and its effect could also be simulated here. Close consideration of the container geometry is necessary here, as real effects have a considerable influence on the behaviour of this type of temperature buffer. These include, in particular, thermal bridges on uncovered sections and the property of the phase change material to undercool. This results in the requirement to consider both, the temperature profile through the wall layer and the influences along the wall: A real 3D simulation is required.

The aim of the simulations was to determine the required layer thickness of the MELT Plates and the most appropriate melting point for this application. Two salt hydrate-based phase change materials with melting points of 21 °C and 25 °C are considered.

In order to be able to analyse the influence of the PCM in the wall layer, a reference simulation was created in the first step. All other simulated wall structures are measured against this. The reference container consists of a two-layer wall structure made of Corten steel and an internal wooden top layer. The floor structure is the same for all container versions tested and consists of a thicker wooden layer and also 7 mm Corten steel. The thickness of the steel sheets was calculated from the total mass of the container and its dimensions.

The encapsulation of the PCM contains supporting structures and also a certain amount of void volume. To avoid having to resolve this relatively complicated geometry numerically, mean values of the individual material values were used for the MELT Plates, which were weighted with the corresponding volume proportions. The heat of fusion (enthalpy of phase change) of the PCM used was assumed to be 101 kJ/kg (21 °C PCM) and 163 kJ/kg (25 °C PCM). Together with the high densities of 1580 kg/m³, the "MELT Plate 25" has a storage capacity of 2600 kJ/m² in the melting range (±2K around melting point) - as a practical comparison: a solid concrete wall with the same heat storage capacity in this small application temperature range would be 32 cm thick and would weigh 700 kg per square meter.

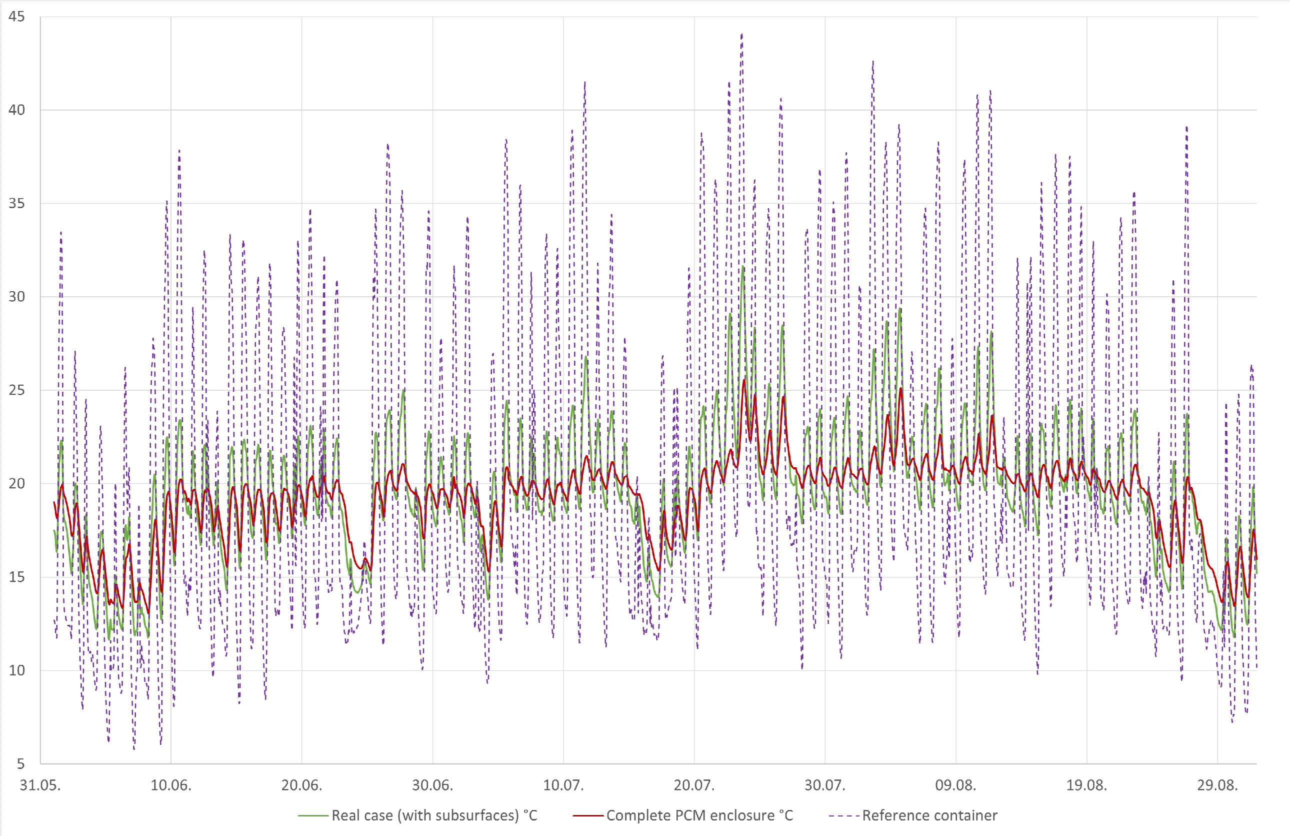

Figure 3: Simulated container temperatures for different cases (June - August in Munich, Germany) using 21 °C PCM

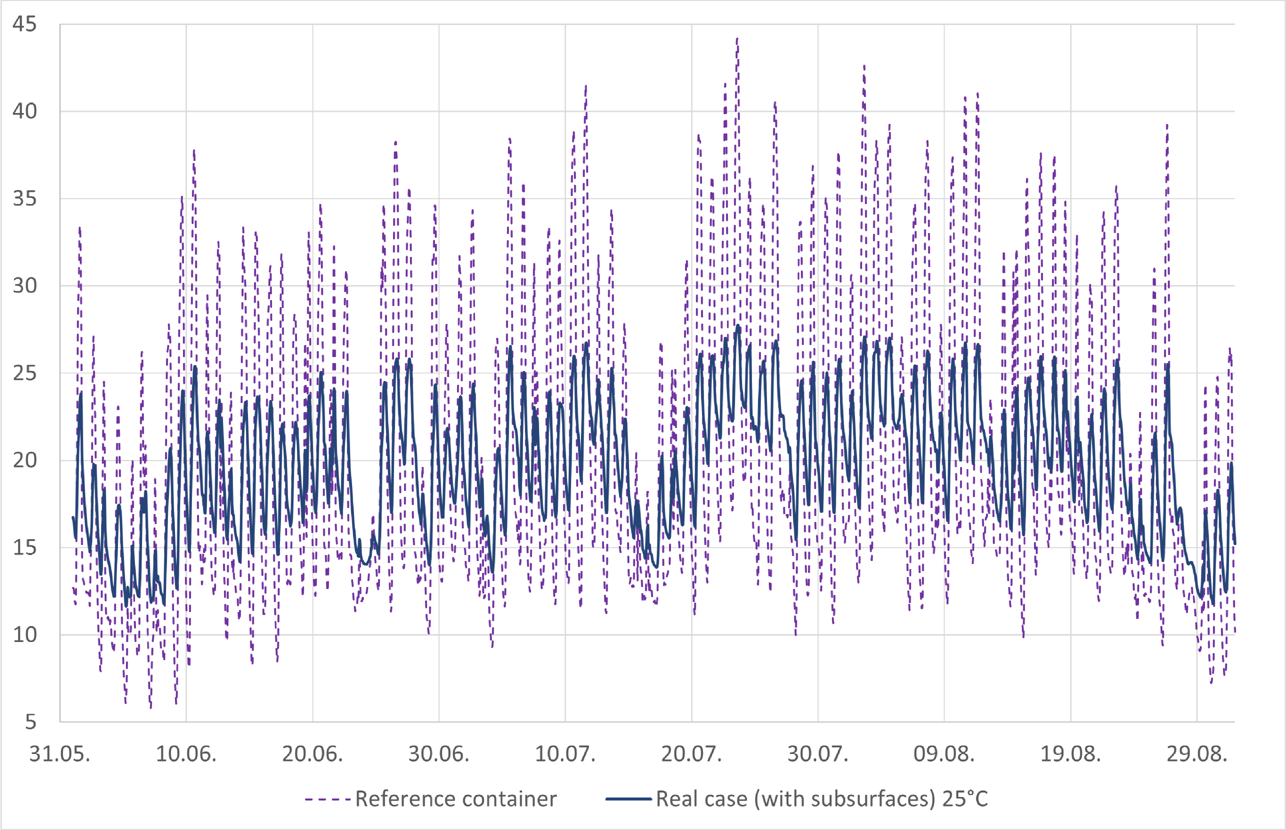

Figure 4: Simulated container temperatures for different cases (June - August in Munich, Germany) using 25 °C PCM

Figure 3 shows the simulation results of the temperature curves for three different container scenarios. The purple dashed line shows the internal temperature of the reference container without any use of PCM or other measures. The enormous temperature peaks caused by solar radiation clearly show the urgency of the measure. The green curve shows the expected curve for the implemented real case. Areas that could not be fitted with MELT Plates due to structural restrictions are omitted here. As the test container was not built for this purpose, different structural conditions made complete enclosure impossible within this experiment. The red line shows the ideal application of MELT Plates with complete enclosure of the object. This temperature curve would probably have occurred under ideal structural conditions. MELT Plates 21, i.e. a phase change material with a melting temperature of 21 °C, were used for the simulation of both the red and green scenarios.

In comparison to that Figure 4 shows the simulation results of the same szenario using a PCM with melting temperature 25 °C instead of 21 °C, again compared with the reference container.

The simulation results show that the material with a melting point of 25 °C is better suited to preventing heat events of > 30 °C inside the container. As this was the primary requirement in the study presented in order to create optimum conditions for a storage scenario for temperature-sensitive objects, the 25 °C material was chosen for the implementation within the present project.

5.2 Application of the MELT Plates

The panels were ultimately designed with the following thickness throughout: 12 mm MELT panel 25 °C, 22.8 mm PU foam, 2 mm GRP panel. The wall connection cannot be carried out in reality as in the simulation (100% flush), which leads to poorer coupling.

This results in a total thickness of 36.8 mm with a tolerance of =+1 mm. The equipped container is shown inFigure 5. In the figure, the sub-surfaces, i.e. the areas that could not be equipped with the MELT Plate composite system, are clearly visible due to the beige colour.

Figure 5: Container equipped with phase change composite panels at the Erding site

5.3 Results and discussion

The period from 03.07.2023 to 27.09.2023 was evaluated. Figure 6 shows the comparison of the temperature curves of the different containers. In the first four days after the start of recording, the test container was not yet fitted with MELT Plates, so it still shows very similar behaviour to the reference container. The reference container is identical in construction to the test container. It has the colour RAL 6031-F9. After equipping the test container with MELT Plates, the temperature peaks were significantly reduced. As the heat protection concept with MELT Plates is not primarily based on reducing radiant emissions, but on latent heat storage, the energy collected during the day could be used to reduce the temperature drop at night. This not only reduced the temperature peaks, but also achieved a considerable reduction in day/night fluctuations.

This meant that the test container was in the desired temperature range of 20 - 25 °C for much longer than the comparison container and the critical limit temperature of 30 °C was reached or exceeded much less frequently. Nevertheless, it was found that the + 30 °C events were not completely avoided, as predicted in the simulation. The reason for this is initially assumed to be that the actual weather conditions during the test period deviated greatly from the simulated weather data. For example, the average temperature during the test period was 19.6 °C, while the simulations were based on an average temperature of 16.6 °C.

Looking at the experimental data set in general on a daily basis one can calculate the daily temperature spread and the “critical days”. Large spreads of the daily temperature indicate a higher cooling demand or, for cases without air conditioning installed, the deviation from a fixed storage temperature. High fluctuations of temperature can lead to high humidity or water condensation on stored equipment. Figure 7 contains a box Plot of the spread as this shows the buffering effect of the MELT Plate very effectively. In the reference container only 28% of days had a spread lower than 7 K, while the container with MELT plate this increased to 90% of days. The days above the defined critical temperature range of 30°C were reduced from 45 days to 7 days, a reduction of 84%.

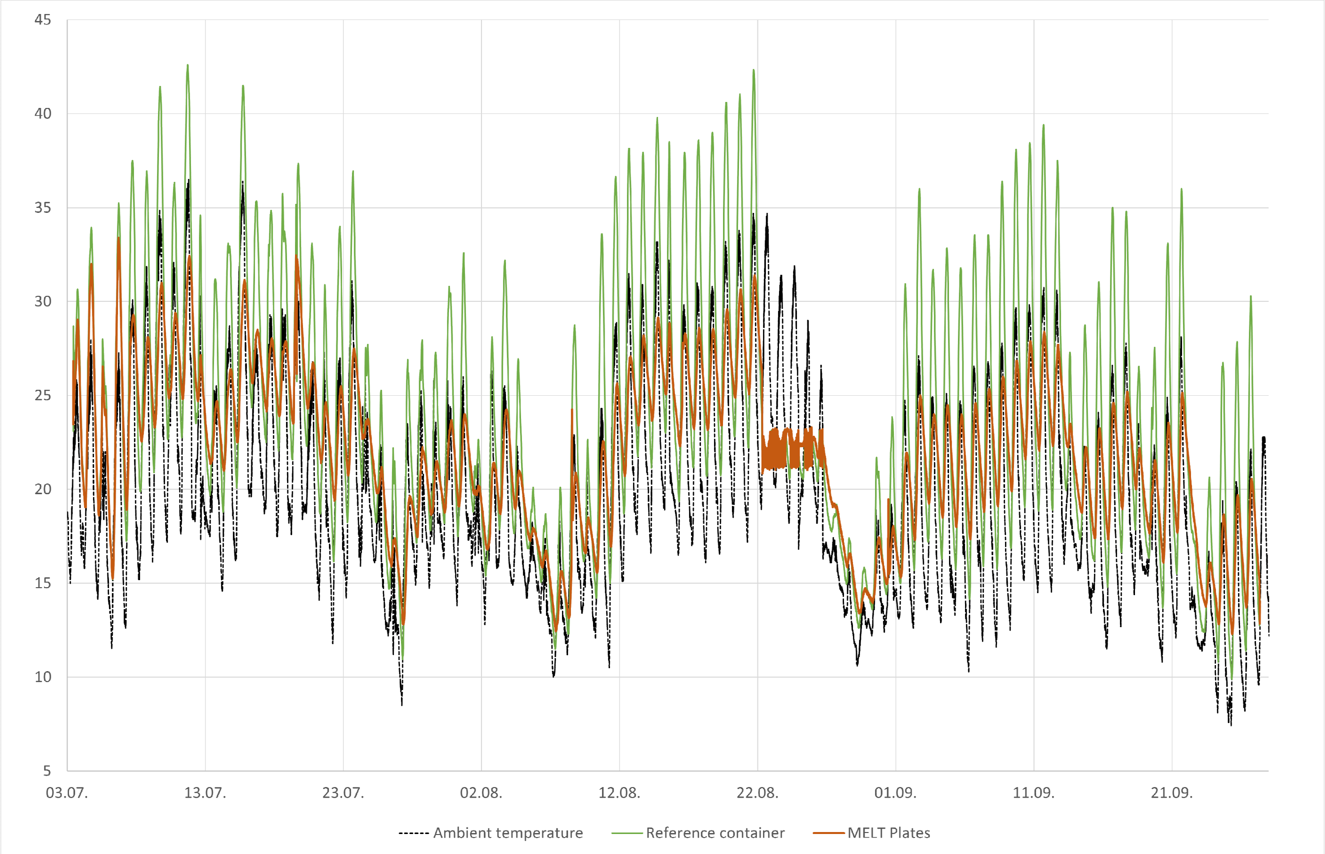

Figure 6: Temperature curves of the reference container compared to the container equipped with MELT Plates and the ambient temperature in the period 03.07.2023 - 27.09.2023. The special behavior from 22.08. to 30.08.2023 is due to the test operation of air conditioning systems, which will not be discussed in detail here.

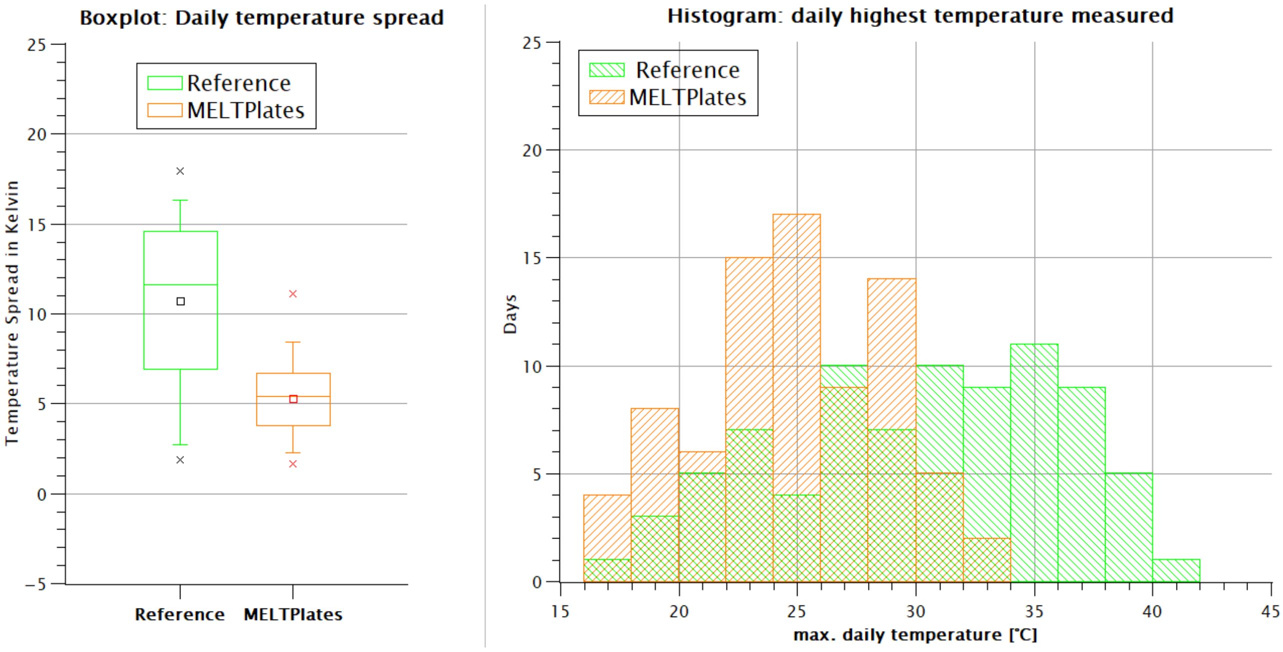

Figure 7: Experimental data on a daily basis: temperature spread and maximum values analysed

6 CONCLUSIONS

Thermal stabilization in buildings in general contributes to improving the feel-good climate that is increasingly required in buildings/homes (no more barrack climate) but also reduces the need for cooling. This leads, from a wellbeing perspective, to better recovery, better performance at work, and prevents extremely rapid temperature fluctuations if we consider specific climatic zones, or different climate conditions within buildings. However, phase change materials can also be used for passive temperature stabilization in special challenges such as the prevention of heat damage in storage scenarios, as in the study presented, provided they are available in a suitable presentation form, such as MELT Plates. From an ecological perspective, this reduces the building's CO2 footprint and the noise and waste heat pollution from air conditioning systems. Furthermore, by reducing the need for cooling, buildings equipped with the MELT Plates are more energy efficient leading to a long-term reduction in ongoing energy costs in summer and winter for residents or operators.

The potential of phase change materials for reducing the overheating of containers has been well illustrated by the previous considerations. However, there is potential for improvement above all in the installation of the elements on the container envelope. Due to the structural conditions on the container, a large part of the area could not be fitted with PCM panels (sub-surfaces, corner profiles, recess for air conditioning, power feed-through). Further investigations are planned to demonstrate the effect of a minimization of thermal bridges by either complete enclosure or combination with other technologies such as cooling coatings. Another approach would be to consider the performance of the panels in a different color, i.e. the influence of color on performance. Dark shades cannot be realized by cooling coatings, which is why PCM panels become interesting here for applications where a given cooler must be used.

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