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Reflection

This reflection of the master thesis “Changing Phase” looks back at the story that led to the exploration of phase change material and how it relates to the master track of building technology and the faculty of AUBS. The reflection also discusses the process of arriving at the final design and its relevance in societal and scientific aspects.

The Master’s track of building technology within the Faculty of Architecture, Urbanism, and Building Sciences aims to bridge the gap between architecture and engineering. A core part of the program is focused on designing building systems and products that are sustainable and innovative and can be used to improve energy performance in new and existing constructions. Phase change materials, or PCMs, are thermal energy storage materials with great potential to reduce energy use in the building industry. The material was briefly covered during the 1st semester of the research and innovation course. The introduction to the material and the potential of latent heat storage in lightweight buildings led me to further study the material in the final research paper in the same course. During the same time, the cold winter caused the indoor temperature in my apartment to drop significantly due to the poorly insulated walls and windows. My interest in improving thermal comfort without cranking up the radiator or spending thousands of euros on a building renovation led me to pursue designing a product containing phase change material.

Process

The process started with a literature study to be on par with the latest research on phase change materials, different encapsulation methods, and what products are available on the market. The decision to go with a salt hydrate came down to the significant price difference, which made the final product more cost-effective. Although, choosing a salt hydrate has a few tradeoffs, such as the risk of overheating, causing chemical degradation, and its corrosive nature. Therefore, the encapsulation design had to be very well thought out to reduce the risk of overheating and provide a durable encapsulation that can afford to fall to the ground without breaking. Different encapsulation types were considered, such as a rigid shell that is easy to manufacture and form but may crack if it falls. Another option was designing a soft shell similar to Ariel detergent pods, which can likely survive a fall to the floor and quickly be mounted to the curtain. However, soft shells are more restrictive in the design aspect and more challenging to ensure long-term UV resistance. Although, after conducting physical experimentations of the various shell designs, it was concluded that rigid encapsulation materials have a very snug fit to the curtain and are aesthetically pleasing. Therefore, the choice was to go with PET since it is less brittle than PMMA and PC. The recycling process is also more straightforward with PET since other parts of the curtain can also be made with PET-based polyester.

The next challenge was finding a way to mitigate the risk of overheating in the summer while maximizing melting efficiency in the winter, which is a contradictory demand. In addition, the risk of overheating is only there if the occupant uses the system in the wrong configuration, which is prone to happen, given the uncertainty of human nature. In addition, operating the system as intended requires an understanding of thermodynamics, but to make it easier for the occupant, a premium version with an automated motor that can close and open the curtain based on the weather is a good option. Although, the standard and basic versions do not have that feature, the risk of overheating still has to be taken into account, and since PET does not handle high-temperature coating processes very well, the most suitable option would be to implement a form of spectrally selective pigment/tint during the mixing process, which will make the encapsulation reflect a slightly blue-greenish tone at certain light conditions. This could affect the aesthetics, but it is the most practical solution based on the options available.

Another aspect that caused some concern in terms of thermal performance is the total volume that can be used per square meter of the curtain without compromising the folding profile. Several strategies and physical trial and error attempts led to a folding pattern similar to the accordion instrument. This design option prevents the encapsulation from clashing into each other by providing predetermined folds through seems. The possibility of implementing a more considerable amount of PCM, upward of 1.95 liters per m2, opened up. Although, this discovery came quite late into the project, and as it turns out, larger windows can hold several dozen kg.

The initial MATLAB performance evaluation of this curtain system with 16 liters of PCM, revealed a fundamental design flaw that should have been addressed early on in the design process. It turned out that mounting the encapsulations on the insulative curtain blocked all beneficial solar gain in the winter, causing a spike in the total heating load. The solution was straightforward: simply mounting the encapsulation on a semitranslucent curtain and having a separate curtain that can act as a thermal barrier. This configuration also solves the daylight issue that could not be resolved earlier in the design process. This design would also allow for a much thinner folding profile than before.

With that said, the semitransparent curtain might not be able to support the weight of several kilos of PCM due to its thin and loose textile. Hence, the long-term durability might be questionable for this system. However, further research and physical testing could verify that the curtain has enough tensile strength. In addition, the durability of the button and encapsulation should be tested to get insight into how much wear and tear it can resist before starting to sag. Finally, multiple factors besides the energy performance potential need to be tested in real life to determine the system's actual functionality. The advantages of using this curtain system is both the thermal performance benefits, but also the ability to control the lighting conditions similar to a regular curtain system with multiple overlapping curtains. Therefore, the strong argument can then be brough up that if a customer would need a new curtain, this options can be very attractive.

The potential of the curtain system is excellent, and if it is used as intended could lead to energy benefits. However, it requires awareness to change it twice a day into a specific position, which could make it intimidating or complex to understand at the beginning. It is reasonable to assume that after a prolonged time, the daily interaction will be reduced, and the PCM will be left in the same position for long periods until the weather or occupant behavior suddenly changes. Therefore, the premium version is an excellent option because it does all the thinking for the occupant. The other option would be to design something static that does not require daily interaction to gain positive energy benefits.

Sustainability

One aspect considered multiple times was the choice to use virgin-grade PET for the encapsulation, which goes against the goal of minimizing the use of petroleum-based materials. In addition, PET is a highly recyclable polymer but contributes significantly to ocean microplastic pollution. Its impact on the environment depends on how it is disposed of after use, as it can either be recycled into new products or end up as pollution in the ocean, potentially harming marine life. Despite this, polymer encapsulation is the most durable material containing salt hydrate. The other option would be to use a bio-based PCM instead. This would allow for a different encapsulation material that does not require resistance to salt. The product would be more environmentally friendly, but the price for the bio-based alternatives did not match the core idea of providing a cost-effective product with a short payback time. With that said, the system's design is modular, so eventually, if the price for bio-based alternatives becomes an option. The encapsulations could be swapped out without much hassle.

Societal relevance

According to Bland et al. (2017), the awareness of PCMs and their advantages is low among the general public and contractors. He claims that companies developing PCM products need to do more to highlight their unique thermal storage characteristics, especially companies focusing on building applications. The lack of awareness can be solved by introducing PCM products such as this curtain system that homeowners can purchase off-the-shelf in any home improvement store and install themselves without any contractor or power tools. After seeing the benefits of lower energy bills and increased thermal comfort, the product and PCM can potentially be recommended among friends and neighbors. In the broad picture, if enough homeowners implement PCMs, a reduction in CO2 emissions will be noticed on a large grid scale.

This sort of system is relevant in other countries and building types that are poorly insulated and need to be renovated. In addition, the system is more affordable than conducting a building renovation. Therefore, it can be used as an intermediate tool to save money on the utility bill to afford a renovation eventually.

Scientific relevance

The project is relevant from a scientific point of view because it can further the knowledge of phase change materials as a thermal energy storage system in lightweight dwellings. It explores creative ways that phase change materials can reduce energy demand during cold and warm seasons. Investigate the relevance of a modular approach to PCM encapsulations. Inform how much volume of phase change material can be applied to a curtain without compromising the core function of what a curtain is intended to fulfill. Finally, this research could bring awareness of opportunities, drawbacks, and potential risks of a modular PCM system that people with no expertise or previous knowledge can operate.

Reference

Bland, A., Khzouz, M., Statheros, T., & Gkanas, E. (2017). PCMs for Residential Building Applications: A Short Review Focused on Disadvantages and Proposals for Future Development. Buildings, 7(3), 78. https://doi.org/10.3390/buildings7030078