Graduation Plan

Master of Science Architecture, Urbanism & Building Sciences

Graduation Plan: All tracks

Submit your Graduation Plan to the Board of Examiners (Examencommissie-BK@tudelft.nl), Mentors and Delegate of the Board of Examiners one week before P2 at the latest.

The graduation plan consists of at least the following data/segments:

Personal information	
Name	**Oskar Erik Gösta Frick**
Student number	5625947

Studio		
Name / Theme	Building Technology Graduation Studio - Energy & Climate	
Main mentor	Dr.ir. Martin Tenpierik	Building physics - Energy
Second mentor	Dipl.-Ing. Marcel Bilow	Product design
Argumentation of choice of the studio	After living in a poorly insulated apartment in Delft during my first year of the master's, the interest in finding a way to passively improve thermal comfort without conducting an expensive renovation sparked. After being introduced to phase change materials during a course here at TU Delft, this type of material could be part of the solution due to its high heat storage capacity per unit weight and volume. The topic becomes even more relevant when considering how many old and poorly insulated dwellings there are in the Netherlands.	

Graduation project	
Title of the graduation project	**Phase changing curtain**
Goal	
Location:	The Netherlands
The posed problem,	In recent years, geopolitical, societal, environmental, and economic events have caused a spike in demand for sustainable stewardship from the construction industry and across all boards. The events caused gas and electricity prices to spike, significantly impacting the individual's wallet for the first time. (Ministerie van Algemene Zaken, 2022) Higher energy prices have led citizens to turn off the heating or only use it a few hours a day to save as much energy and money as possible. The situation is especially difficult for occupants living in the Dutch dwelling stock constructed

	before the 90s. Although, the Dutch government has implemented strategies to renovate all the buildings by 2050. (van den Brom et al., 2018) The goal is ambitious, and it does not get accomplished overnight. Therefore, a solution that can quickly be implemented to lower the energy bill and increase occupant comfort has excellent potential.
research questions and	**Main research question:** How can phase change material be incorporated into a cost-effective product to increase the thermal inertia of lightweight dwellings in a Cfb climate to enhance passive cooling and heating throughout the year? **Secondary research questions:** How do the summer and winter seasons affect the melting process of PCMs? What would be the ideal behavior of the product during the different seasons? How much PCM volume is required to make a sensible difference in a 15 m2 room? What would be the ideal component size to balance flexibility with thermal performance? Which is the ideal material and manufacturing method to make it a durable and cost-effective product?
design assignment in which these result.	The project consists of three design assignments: a practical experiment, a designed PCM system, and a scaled prototype of the final design. Designing and conducting a practical experiment is an integral part of the learning process, which will give an understanding of how phase change materials behave in real life. The primary assignment of this graduation project is to design a PCM product that can be implemented into old lightweight dwellings in the Netherlands to improve annual thermal performance. The product should be user-friendly and straightforward enough so homeowners can install it themselves without hiring expertise. The ability to also be able to

	replace broken components is essential to maintain good thermal performance and longevity. Furthermore, the product must be lightweight enough to move aside when not desired. Finally, it must be aesthetically pleasing, durable, cost-effective, and marketable, so homeowners want to buy and showcase it in their homes. Building a scaled prototype is the final assignment of this graduation project. The components within the model will be moveable to illustrate how the system can be adjusted depending on season.

Process

Method description

This project follows research through design structure, meaning that the knowledge gained from simulations and trial and error will lead to further understanding, which could then be applied to improve the next design iteration.

The **literature review and research** analyze the existing building stock, the envelope, and climate analysis. Then establish a base knowledge of thermal performance, heat flow, sensible and latent heat, and what phase change materials are. Desirable characteristics, PCM types, significant drawbacks, and typical building applications. After that, extensive research into encapsulation methods, benefits, and performance aspects of interior applications. Finally, product development investigates modularity, user interaction, material choices, and manufacturing methods.

The research is based on peer-reviewed literature published on ScienceDirect and technical data derived from Climate Consultant 6.0, Granta Edupack, and manufacturer's websites. In addition, professors and mentors from TU Delft provided supplemental knowledge and recommendation on scientific articles.

The **experimentation** part of the project involves filling plastic containers of different volumes and thicknesses with PCM to study the melting process and thermal performance. Understanding how PCMs operate in practice will be essential to the learning process. It will also help establish suitable encapsulation volumes for thermal performance and daily operations.

The **computational design** phase involves applying the knowledge gained from the literature study to set up a simulation in MATLAB to determine the total thermal storage capacity needed for the system. Based on the required PCM volume, a range of conceptual design ideas are generated using Rhinoceros 7 and Grasshopper. The concepts may vary in their layout pattern, component geometry, volume, and thickness. Finally, the concepts are tested in the Grasshopper plugins Ladybug and Honeybee to determine how much solar radiation each concept achieves.

The **product design** phase includes 3D printing specific components to test the modularity and connection between parts, technical detailing of critical parts of the system, developing an assembly manual, and making a prototype. The prototype will be constructed using 3D printing and conventional fabrication techniques to showcase the final product. The components within the model will be moveable to illustrate how the system can be adjusted depending on the season. The prototype is not expected to be filled with PCM due to the uncertainty of leakage due to 3D printing. Therefore, it is essential to justify the product by providing a list of manufacturing processes suitable for large-scale production.

Evaluation and discussion at the end analyze if the thermal performance and product functionality are according to the objectives and parameters set up along the process. The analysis validates if the product is feasible for mass production and market implementation. The research and design process is also evaluated to see if something could have been done differently to achieve a more intelligent or suitable result.

Literature and general practical preference

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Reflection

1. What is the relation between your graduation (project) topic, the studio topic (if applicable), your master track (A,U,BT,LA,MBE), and your master programme (MSc AUBS)?

Phase change materials can be used in many applications to store heat and control the temperature of sensitive equipment. For example, it can be used in the building environment to increase the thermal inertia, buffer heat flow and enhance the indoor comfort of buildings without using carbon-intensive thermal storage systems such as concrete. The building technology track is heavily focused on sustainability and finding intelligent ways to improve the energy performance of existing and new construction. PCMs are one such strategy, and furthering the knowledge of how PCMs can be implemented in buildings without compromising the aesthetics and structural integrity, can influence how future building renovations are conducted.

2. What is the relevance of your graduation work in the larger social, professional and scientific framework.

Societal
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 that homeowners can purchase off-the-shelf in any home improvement store and install themselves without any contractor or power tools. Then, 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 CO_2 emissions will be noticed on a large grid scale.

Scientific
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 implementation and suitable methods to connect modules for space flexibility. Inform how much volume of phase change material is needed to

make a sensible difference in a 28.8 m2 room. 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.