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	**Aneesha Madabhushi**
Student number	5214262

Studio		
Name / Theme	Building Technology/Sustainable Design Graduation	
Main mentor	Dr. Alessandra Luna Navarro	Design of Construction
Second mentor	Dr.ir. Martin Tenpierik	Building Physics and Climate design
Argumentation of choice of the studio	I chose to work with the chairs of Building physics and Design of construction as I believe that they are very much interdependent and a crucial part of the built environment. My interests lie in designing buildings for comfort and energy efficiency. To achieve this, façade design plays an important role. Thus, the two main components of my thesis are the Building envelope and comfort.	

Graduation project	
Title of the graduation project	The influence of occupant behavior on façade design during a heatwave.
Goal	
Location:	Netherlands
The posed problem,	It is a well-known fact that the main driver behind the aggravating climate change is the increasing greenhouse gas concentration in our atmosphere. With the increase in global urbanization, cities' contribution to carbon emissions and greenhouse gases is shooting up drastically (Puppim, 2017). As a result, the rate of energy use is steadily rising, but fossil energy supplies are finite. As a result of global warming and climate change, there is a continued increase in surface and air temperatures, causing heatwaves to become more common around the world each year. Heatwaves pose a risk of indoor overheating which can cause extreme discomfort and can also lead to severe health issues and even death. Unfortunately, most modern buildings in the Netherlands

	and India are not designed for extreme heat resilience, as a result, the indoor thermal comfort is affected. A study stated that over the past 40 years, the frequency of simultaneous heat waves has increased by a factor of six due to global warming (*This Is How Concurrent Heat Waves Are Impacting the World*, 2022). If this continues, heatwaves are predicted to become more frequent and could become the new norm. The building envelope plays a crucial role in determining the indoor comfort in a building as it acts as a buffer between the outdoor and indoor environments. The design of a building façade can have a great influence on the indoor climate conditions, for example adequate natural ventilation, overheating during hot days or temperature drop during cold days. Thus, proper designing of the building envelope can be greatly advantageous for thermal comfort and building energy conservation. This study will investigate the efficiency of passive design strategies incorporated in the building envelope in maintaining indoor thermal comfort during a heat wave. The study focusses on existing non-residential buildings for possible retrofitting façade solutions. There is a good amount of research conducted on the effects of various façade design strategies on thermal comfort of occupants and to reduce indoor overheating. But, to the author's knowledge, there are not many papers which study the involvement of occupant behavior. Thermal comfort is subjective and differs based on various aspects like age, gender, origin etc. Allowing users to take decisions based on their thermal comfort sensation might help in improving comfort standards. This thesis also addresses how occupant behavior can improve thermal comfort in buildings without the use of energy consuming systems.
research questions and	Following the posed problem, the main research question can be framed as : **"What is the impact of occupant-façade interaction on thermal comfort during the cooling season in non-residential buildings?"**

	The main question can be further divided in the following sub-questions for analysis: 1. What is the influence of facades on indoor thermal comfort? 2. How do heatwaves affect the building envelope and indoor comfort? 3. What are the existing possible retrofit façade solutions and which ones will be used for analysis? 4. What is the influence of occupant behavior on façade performance for thermal comfort. 5. What are the occupant behavior models that can be considered for analysis? 6. What are the main limitations of considering occupant behavior? 7. What are the performance indicators to be considered during simulation?
design assignment in which these result.	This research will culminate in a façade solution / solutions which enhances the thermal comfort of the indoor environment during a heat wave. The result will also look at the effect of occupant behavior on the façade solutions to maintain indoor thermal comfort. A simulation software will be used to test the solutions and obtain the results. Based on the results, further improvements can be suggested.

Process

Method description

The process consists of 6 main phases, ranging from research to analysis to the results. These phases may overlap at certain points for re-evaluation

Phase 1: Research framework

In this phase, the research topic is thoroughly examined and evaluated to determine its relevance and significance in the field of Building Technology and to society as a whole. The scope of the topic is assessed, and the research problem is framed based on existing knowledge. This involves critically analyzing the topic and narrowing it down to specific aspects that require attention. Supporting questions are formulated to guide the next phase, which involves gathering relevant literature to inform the final research question.

Phase 2: Background research, literature review and theoretical framework

Literature review is conducted on the relevant topics which support the main research problem. In this phase, existing literature is reviewed and analyzed to create a foundation for further phases. A theoretical framework is formed by exploring various reports, books, articles, papers, and websites. The information gathered is critically analyzed to identify the missing links or research which then forms the basis for the thesis. This phase is sub-divided into various sections, each addressing a specific topic which helps in answering the main research question

and sub-questions. The first topic for the background research is thermal comfort and its models, this section defines thermal comfort and the important parameters that affect thermal comfort. It also talks about the thermal comfort models used for analysis. The next topic is about the cooling season and rising temperatures. The main literature review consists of two main sections, the first looks at façade strategies and how they affect the indoor thermal comfort. The second is about occupant behaviour. On the whole, this section forms the groundwork required for the main research of the thesis.

Phase 3: Identifying facade archetypes and occupant behaviour models for window operation.

In this phase, specific facade archetypes are identified for comparison in terms of their performance. These archetypes are developed based on key factors that have a significant impact on the research, such as window-to-wall ratios and construction typology. Additionally, from the studied occupant behaviour models, two models are selected that have different influencing factors and levels of complexity. For comparison purposes, two additional cases are created without occupant behaviour, one with windows always closed and one with windows always open. This phase focuses on establishing a range of scenarios that will be used in the simulations to generate comparative results.

Phase 4: Case build-up

The identified facade archetypes and occupant behaviour models are combined to create 36 different scenarios. These scenarios encompass various combinations of archetypes, occupant behaviour models, base cases, and cases with night ventilation. These scenarios are used in the simulations to generate comparative results. Models are created for these scenarios in design builder simulation software.

Phase 5 : Simulation in design builder

In this phase, the simulation models created in the previous phase are used to conduct thermal performance tests. The models incorporate the selected occupant behaviour models to simulate realistic occupant interactions with the building facade. The study adopts a scenario-based approach, categorizing occupant behaviour and facade solutions into predefined scenarios. Simulations are run using weather data specific to Netherlands locations, and the thermal performance of each scenario is assessed.

Phase 6 : Results, analysis and conclusions

The final phase involves analyzing and discussing the results obtained from the simulations. Statistical analysis is conducted to compare the thermal comfort and occupant behaviour across different scenarios. The findings are critically examined, and conclusions are drawn based on the analysis. The limitations of the research are discussed, and recommendations are provided for further development in the field. Opportunities for future research in the topic are identified and highlighted. This phase brings together all the findings and insights from the study to provide a comprehensive understanding of the impact of occupant behaviour on facade performance and thermal comfort.

Literature and general practical preference

Carlucci, S. (2013). Thermal Comfort Assessment of Buildings. *SpringerBriefs in Applied Sciences and Technology*. https://doi.org/10.1007/978-88-470-5238-3

Nicol, F., Rijal, H. B., & Roaf, S. (2022). Routledge Handbook of Resilient Thermal Comfort. *Routledge Handbook of Resilient Thermal Comfort*. https://doi.org/10.4324/9781003244929

Taleghani, M., Tenpierik, M., Kurvers, S., & van den Dobbelsteen, A. (2013). A review into thermal comfort in buildings. *Renewable and Sustainable Energy Reviews*, *26*, 201–215. https://doi.org/10.1016/j.rser.2013.05.050

Zhao, Q., Lian, Z., & Lai, D. (2021). Thermal comfort models and their developments: A review. *Energy and Built Environment*, *2*(1), 21–33. https://doi.org/10.1016/j.enbenv.2020.05.007

Nasrollahi, N., & Ghobadi, P. (2022b). Field measurement and numerical investigation of natural cross-ventilation in high-rise buildings; Thermal comfort analysis. *Applied Thermal Engineering*, *211*, 118500. https://doi.org/10.1016/j.applthermaleng.2022.118500

Zahiri, S., & Altan, H. (2016b). The Effect of Passive Design Strategies on Thermal Performance of Female Secondary School Buildings during Warm Season in a Hot and Dry Climate. *Frontiers in Built Environment*, *2*. https://doi.org/10.3389/fbuil.2016.00003

Gupta, M. K., Rathore, P. K. S., & Singh, A. K. (2022). Experimental investigation of clay brick with sensible, latent, and hybrid thermal energy storage in buildings. Materials Today: Proceedings, 69, 112–118. https://doi.org/10.1016/j.matpr.2022.08.193

Mahdaoui, M., Hamdaoui, S., Ait Msaad, A., Kousksou, T., El Rhafiki, T., Jamil, A., & Ahachad, M. (2021). Building bricks with phase change material (PCM): Thermal performances. Construction and Building Materials, 269, 121315. https://doi.org/10.1016/j.conbuildmat.2020.121315

Hwang, R. L., & Shu, S. Y. (2011). Building envelope regulations on thermal comfort in glass facade buildings and energy-saving potential for PMV-based comfort control. Building and Environment, 46(4), 824–834. https://doi.org/10.1016/j.buildenv.2010.10.009

Han, J., Lu, L., Peng, J., & Yang, H. (2013). Performance of ventilated double-sided PV façade compared with conventional clear glass façade. Energy and Buildings, 56, 204–209. https://doi.org/10.1016/j.enbuild.2012.08.017

Elsharkawy, H., & Zahiri, S. (2020). The significance of occupancy profiles in determining post retrofit indoor thermal comfort, overheating risk and building energy

performance. Building and Environment, 172, 106676. https://doi.org/10.1016/j.buildenv.2020.106676

Stazi, F., Mastrucci, A., & di Perna, C. (2012). The behaviour of solar walls in residential buildings with different insulation levels: An experimental and numerical study. Energy and Buildings, 47, 217–229. https://doi.org/10.1016/j.enbuild.2011.11.039

Zhang, T., & Yang, H. (2019). Heat transfer pattern judgment and thermal performance enhancement of insulation air layers in building envelopes. Applied Energy, 250, 834–845. https://doi.org/10.1016/j.apenergy.2019.05.070

Hengstberger, F., Zauner, C., Resch, K., Holper, S., & Grobbauer, M. (2016). High temperature phase change materials for the overheating protection of facade integrated solar thermal collectors. Energy and Buildings, 124, 1–6. https://doi.org/10.1016/j.enbuild.2016.04.020

Cakyova, K., Figueiredo, A., Oliveira, R., Rebelo, F., Vicente, R., & Fokaides, P. (2021). Simulation of passive ventilation strategies towards indoor CO2 concentration reduction for passive houses. Journal of Building Engineering, 43, 103108. https://doi.org/10.1016/j.jobe.2021.103108

Zhu, N., Hu, N., Hu, P., Lei, F., & Li, S. (2019). Experiment study on thermal performance of building integrated with double layers shape-stabilized phase change material wallboard. Energy, 167, 1164–1180. https://doi.org/10.1016/j.energy.2018.11.042

Sun, Y., Wu, Y., Wilson, R., & Sun, S. (2016). Thermal evaluation of a double glazing façade system with integrated Parallel Slat Transparent Insulation Material (PS-TIM). Building and Environment, 105, 69–81. https://doi.org/10.1016/j.buildenv.2016.05.004

Hamidi, Y., Malha, M., & Bah, A. (2021b). Analysis of the thermal behavior of hollow bricks walls filled with PCM: Effect of PCM location. Energy Reports, 7, 105–115. https://doi.org/10.1016/j.egyr.2021.08.108

Gourlis, G., & Kovacic, I. (2017). Passive measures for preventing summer overheating in industrial buildings under consideration of varying manufacturing process loads. Energy, 137, 1175–1185. https://doi.org/10.1016/j.energy.2017.05.134

Carrilho da Graça, G., Martins, N. R., & Horta, C. S. (2012). Thermal and airflow simulation of a naturally ventilated shopping mall. Energy and Buildings, 50, 177–188. https://doi.org/10.1016/j.enbuild.2012.03.037

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)?

   The sustainable design graduation studio mainly focusses on innovative technical solutions in the built environment. The master course of Building technology combines Architectural design with technical innovation which is crucial in today's

professional world. The course accentuates the importance of sustainability and healthy living in the built environment, in terms of material usage, energy conservation and circularity. In accordance with this, the thesis topic presented addresses energy conservation, and health.

This graduation topic mainly deals with 2 chairs: Design of construction and Building physics - Climate design and relates to ongoing research conducted at TU Delft. The design of construction chair is about building constructions and innovative methods to improve design. This chair ranges from structural level to building component level. In this project, the façade or building envelope is chosen for performance analysis and enhancement. Along with this the chair of building physics looks at building health and indoor comfort aspects, and for this project Thermal Comfort is taken in consideration for performance analysis. Both these topics are extremely crucial in the built environment today, thus being relevant to Building technology and the field of Architecture.

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

Façade design has a significant impact on building design, both in terms of technical and aesthetic factors. The façade holds a very important function in a building and thus has influence on other factors like Indoor comfort. As explained in the problem description, the world is facing an unavoidable climate crisis. Since the construction industry has a significant contribution to this crisis it is of at most importance that designers and engineers, consider innovating towards a better future. Energy efficient design and thermal comfort are two aspects that have been researched extensively in the professional world. In this project the occupant factor is also considered as occupants can play a crucial role in influencing indoor comfort. This topic addressed the social part by being inclusive to users and designing for users. In terms of professional and scientific framework, this topic has the potential to bring out solutions for the current global energy crisis while giving importance to healthy design.