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	**Alya Farah Taufiqoh**
Student number	**5564379**

Studio		
Name / Theme	Building Technology	
Main mentor	Dr. Regina M. J. Bokel	Building Physics
Second mentor	Dr. Telesilla Bristogianni	Structural Design & Mechanics
Advisor	Chujie Lu	Building Physics
Argumentation of choice of the studio	I am interested in how building physics can be used for tackling the energy issue and improving our lives. This intersects with my interest in machine learning through the application of the building system control. My thesis topic, which focuses on the independent impacts of Model Predictive Control (MPC) and variations in facade properties in full-glass façade buildings, embodies this intersection. It presents an opportunity to explore and develop innovative solutions that optimize energy efficiency and thermal comfort. This research not only delves into the technical aspects of building design and intelligent control systems but also has the potential to make a positive societal impact by contributing to sustainable building practices and improving occupant well-being.	

Graduation project	
Title of the graduation project	Comparative Analysis of Model Predictive Control and Glazing Properties on Energy Efficiency and Thermal Comfort in Full-Glass Façade Buildings
Goal	
Location:	The case study is located in Delft, Netherlands, and focuses on TU Delft's building called Pulse which is a full-glass façade. This case study will serve as both a testing ground and a baseline for calibration testing of a model and comparisons at where various interventions will be applied.
The posed problem:	"There's a lack of understanding of how the application of Model Predictive Control (MPC), as compared to modifications in facade properties, influences the energy

	demand and thermal comfort of a glass facade building." According to the International Energy Agency's report in 2023, building activities are responsible for 30% of global final energy consumption (with 8% of emissions coming directly from buildings and 18% from generating heat and electricity used in buildings). Heat, ventilation, and air conditioning (HVAC) systems, among the other energy-demanding components within building infrastructures, contribute significantly to energy consumption at 40-60%. Inefficiencies in their operation or suboptimal thermostat settings can lead to considerable energy wastage. In addition, façade, as the interface between indoor and outdoor climate plays an important role in determining HVAC energy demand. Having a vast area of glass as a façade can be a problem as it generates a lot of heat transfer between the indoor and outdoor environment. Therefore, it is also important to consider the right façade properties and/or design as it can lead to energy waste. Apart from energy usage, thermal comfort, which usually falls out from the traditional HVAC control, is a crucial factor in building design, influencing both energy consumption and occupant comfort. The mean radiant temperature (MRT) plays a pivotal role in determining the operative temperature, a key metric for thermal comfort. When buildings use glass facades, MRT is significantly impacted due to the higher levels of thermal radiation exchanged between occupants and the building envelope and then to the outdoor environment. This phenomenon can lead to a decrease in the perceived temperature, making occupants feel colder and potentially leading to discomfort. This issue becomes particularly evident in buildings with large glass surfaces, where the control of radiant temperatures is challenging yet essential for maintaining thermal comfort.

	To that end, there are two solutions, among many others, that become the focus of this research to reduce the energy demand and improve thermal comfort of a building: improving the HVAC system and improving the façade. Breaking down the two options, the former can be in a form of changing the system/equipment or the control, while the latter can be in a form of redesigning, changing the materials, or intervening the existing materials. In this case, this thesis focusses on changing the control of the HVAC system by using Model Predictive Control (MPC) and intervening the existing materials by adding additional matters to the existing glass façade. The scope was formed this way because both solutions possess the least intervention to the existing building. This thesis introduces the use of Model Predictive Control (MPC) to optimize building systems. MPC, aligned with weather forecasting, allows for proactive adjustments in building operations, enhancing energy efficiency and occupant comfort. The core aim of this research is to develop a comprehensive model that effectively reduces energy demand in buildings with glass facades while ensuring optimal thermal comfort for the occupants. However, there's a lack of understanding of how the application of Model Predictive Control (MPC), as compared to modifications in facade properties, influences the thermal comfort and energy demand of a glass facade building. Therefore, at the end, the MPC performance will be compared with different façade properties.
research questions and design assignment in which these result:	"To what extent do the implementation of Model Predictive Control (MPC) and changes in façade properties independently influence the energy dynamics and thermal comfort in buildings with full-glass facades?" Research sub-questions (subject to change): Related to MPC:

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- How can an energy model, including HVAC control and natural climate systems, be accurately simulated and calibrated to reflect real-world conditions in building with full-glass facades?
- How can a model be developed and trained to control the building operation system in a way that minimizes energy consumption while maintaining optimal thermal comfort in buildings with full-glass facades?
- How does the implementation of MPC contribute to the optimization of energy use and improvement of thermal comfort in these buildings?

Related to façade intervention:

- What are the possible techniques on intervening an existing glass façade?
- How does intervention of glass façade affect the glass properties?
- How do different facade properties alone (for example for glazing, such as thermal transmittance, solar heat gain coefficient, and light transmittance) influence the energy efficiency and thermal comfort in buildings with full-glass facades?

Related to the comparison:
Which has a more significant impact on energy dynamics and thermal comfort in full-glass façade buildings: the implementation of MPC or variations in glazing properties?
</td></tr>
<tr><td></td><td>[Design Assignment]</td></tr>
<tr><td colspan="2">[This should be formulated in such a way that the graduation project can answer these questions.
The definition of the problem has to be significant to a clearly defined area of research and design.]</td></tr>
<tr><td colspan="2">The purpose of this thesis is to develop an MPC model that can operate a building in a way that minimizes energy consumption while maintaining optimal thermal comfort in buildings with full-glass facades. The case study will be used to develop the model as well as to test, calibrate, and evaluate its performance.</td></tr>
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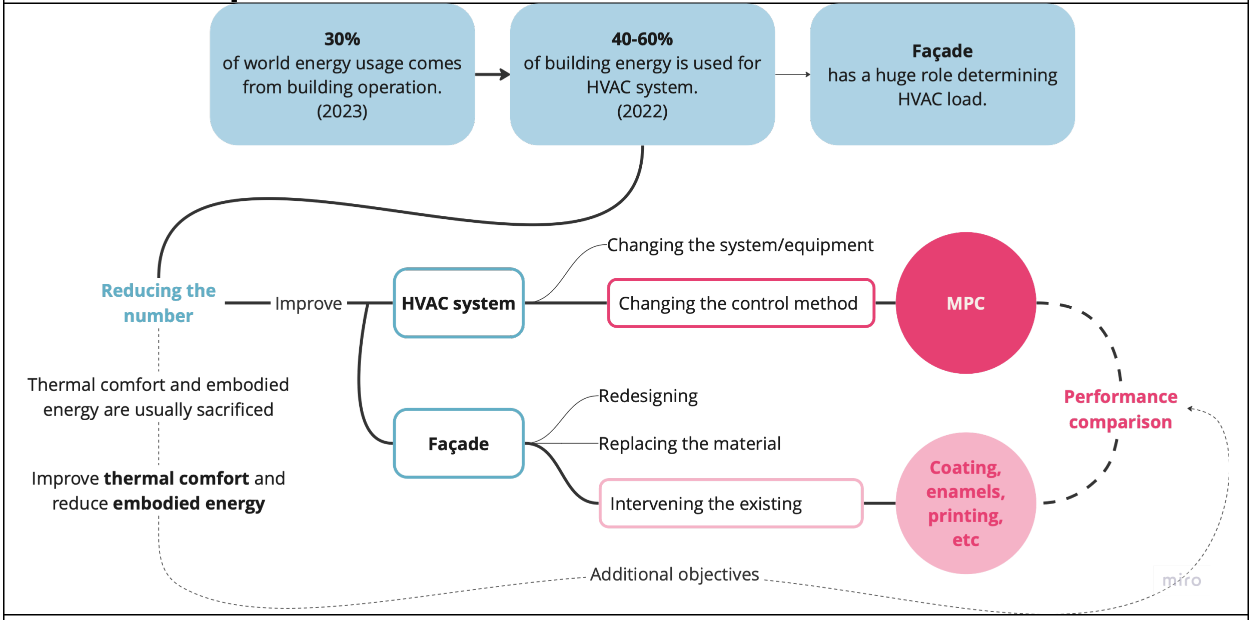
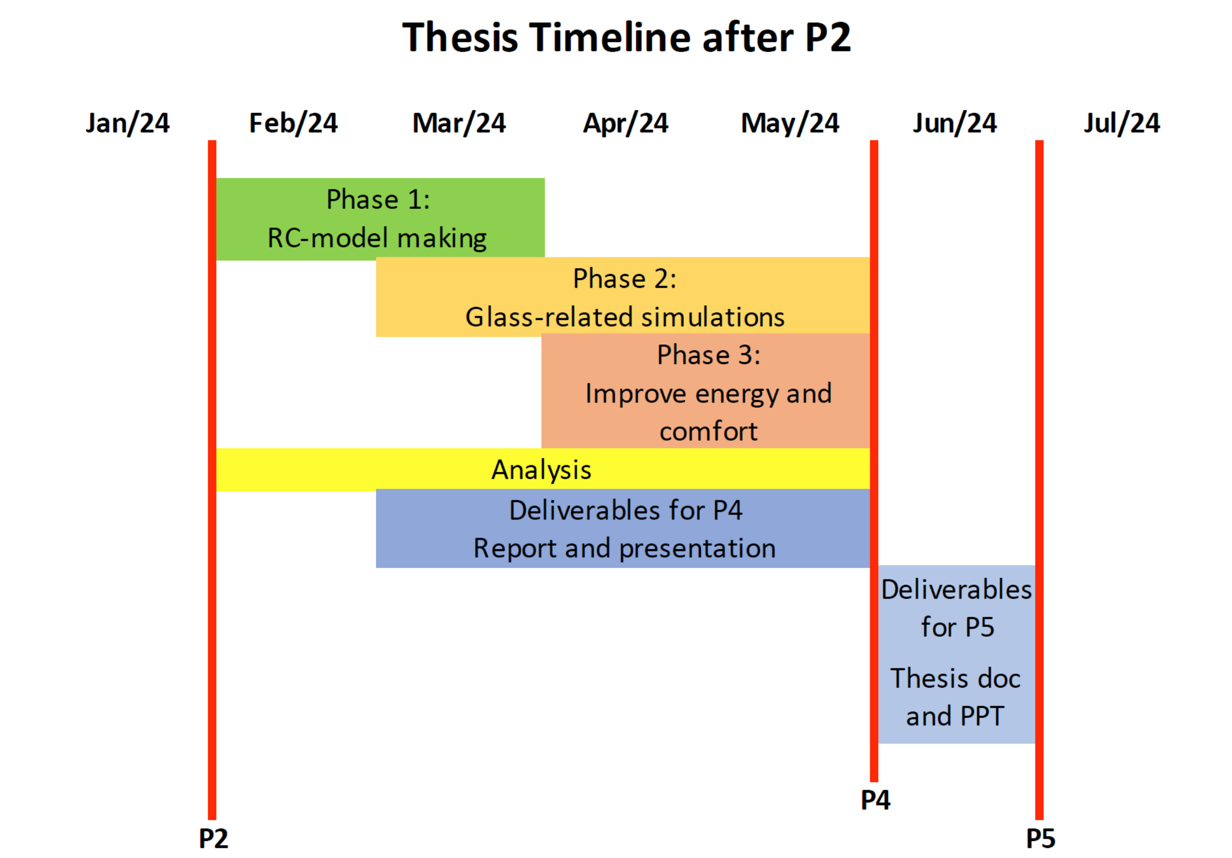
Research scope



Research timeline after P2



Process

Method description

A literature review is conducted to evaluate existing advancements and methodologies in this field. The primary sources are related to energy demand, thermal comfort, MPC, and façade improvement. Following this, the research will progress to the modelling phase of the case study, informed and guided by the insights and achievements of prior research in the field.

The case study will be executed using a grey-box model. Outputs from this simulation, which is the energy data, will serve as the foundation for developing, training, and testing the predictive model. This model will then be optimized using a control algorithm to implement Model Predictive Control (MPC), which will then be evaluated against the building's current operational status. Additionally, the baseline model will be developed for comparison, incorporating various glazing properties, to contrast their performance with that of the MPC.

The following steps can be outlined for the research process (subject to change):

1. Make model or digital twin of the building:
   White-box modelling:
   - Model the selected case study in a building simulation software/python.
   - Run the model to obtain energy and surface temperature data.

   Black-box modelling:
   - Train a model with historical data using Neural Networks.

   Grey-box modelling:
   Adding data to the historical data
   - Calculate the missing data using white-box (RC-model)
   - Combine the data with the historical data
   - Train a model using those data with NN

   Calibrate the simulation from white-box with the historical data
   - Model the selected case study in a building simulation software/python.
   - Run the model to obtain energy data.
   - Calibrate the simulation using the collected on-site data to ensure its accuracy and reliability.
2. Develop and evaluate a prediction using the model outputs. This aim to forecast energy demand.
3. Integrate the predictive model with a control algorithm to implement MPC. Optimize the control strategy for energy efficiency and thermal comfort.
4. Compare the MPC implementation against the current operational status of the building to evaluate improvements in energy efficiency and thermal comfort.
5. Modify the baseline white-box model to incorporate different facade properties.
6. Compare the energy and comfort performance of these variations with the MPC implementation.

To support the development of the models, 3ME course from TU Delft is being followed to learn essential knowledge on building energy modelling.

The following tools will be used (subject to change):
EnergyPlus and/or OpenStudio, Grasshopper with Ladybug and Honeybee, Python.

Literature and general practical references

These are some of the primary sources related to energy demand, thermal comfort, building energy modeling approach, calibration, smart building control, adaptability and transferability. There are more literatures have been examined.

[1] E. Van Bueren, H. Van Bohemen, L. Itard, and H. Visscher, Eds., *Sustainable Urban Environments: An Ecosystem Approach*. Dordrecht: Springer Netherlands, 2012. doi: 10.1007/978-94-007-1294-2.
[2] S. C. Jansen, “Overview of theory on Energy Systems for Buildings and Neighbourhoods.” Accessed: Jan. 15, 2024. [Online]. Available: https://brightspace.tudelft.nl/d2l/le/content/502866/viewContent/3097198/View
[3] N. Djongyang, R. Tchinda, and D. Njomo, “Thermal comfort: A review paper,” *Renew. Sustain. Energy Rev.*, vol. 14, no. 9, pp. 2626–2640, Dec. 2010, doi: 10.1016/j.rser.2010.07.040
[4] Z. Afroz, G. Shafiullah, T. Urmee, and G. Higgins, “Modeling techniques used in building HVAC control systems: A review,” *Renew. Sustain. Energy Rev.*, vol. 83, pp. 64–84, Mar. 2018, doi: 10.1016/j.rser.2017.10.044.
[5] D. Kim, J. Lee, S. Do, P. J. Mago, K. H. Lee, and H. Cho, “Energy Modeling and Model Predictive Control for HVAC in Buildings: A Review of Current Research Trends,” *Energies*, vol. 15, no. 19, Art. no. 19, Jan. 2022, doi: 10.3390/en15197231.
[6] Y. Balali, A. Chong, A. Busch, and S. O’Keefe, “Energy modelling and control of building heating and cooling systems with data-driven and hybrid models—A review,” *Renew. Sustain. Energy Rev.*, vol. 183, p. 113496, Sep. 2023, doi: 10.1016/j.rser.2023.113496.
[7] U. Eicker, Ed., “3 - Building energy demand modeling: from individual buildings to urban scale,” in *Urban Energy Systems for Low-Carbon Cities*, Academic Press, 2019, pp. 79–136. doi: 10.1016/B978-0-12-811553-4.00003-2.
[8] S. F. Stripp, “ClimAIte Control,” TU Delft, 2023.
[9] L. Zhang, Z. Chen, X. Zhang, A. Pertzborn, and X. Jin, “Challenges and opportunities of machine learning control in building operations,” *Build. Simul.*, vol. 16, no. 6, pp. 831–852, Jun. 2023, doi: 10.1007/s12273-023-0984-6.
[10] J. Drgoňa *et al.*, “All you need to know about model predictive control for buildings,” *Annu. Rev. Control*, vol. 50, pp. 190–232, Jan. 2020, doi: 10.1016/j.arcontrol.2020.09.001.

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 relation between the graduation topic, the studio topic, the master track, and the master program are that they are all closely related to the field of building technology and energy efficiency. The graduation project topic is focused on exploring energy performance and thermal comfort through MPC and changing on façade properties of Pulse building. The studio topic provides the opportunity for students to work on real-world projects and gain hands-on experience in the field of building technology and energy efficiency.

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

The relevance of this graduation work is that it addresses the critical issue of energy demand and thermal comfort which impact the environment. By exploring energy performance and identifying potential improvements through MPC, this research will contribute to the larger goal of reducing energy consumption and primary energy needs in buildings while keeping the occupants comfortable. The study can provide valuable insights for building operators, managers, architects, and engineers to reduce energy demand and improve thermal comfort in buildings.