ENG 572 – Professional Practicum / ENG 573 – Capstone Project
Plan / Proposal

STUDENT NAME: Jianru Jing **UIN:** 669741209

UIUC FACULTY ADVISOR / INSTRUCTOR: Yun Kyu Yi

COMPANY: N/A

OFF-SITE SUPERVISOR / MENTOR: N/A

COURSE (SELECT ONE): ☐ ENG 572 ☑ ENG 573

INSTRUCTIONS:

Attach a 2 – 3-page proposal that outlines scope of the practicum or the project.

Information to include:

- Professional learning objectives
- Project learning objectives
- Plan for conduct as it relates to achieving overall practicum or proposal objectives such as conceptual studies, design and build activities, feasibility studies, experimental work, and results analysis
- Anticipated deliverables
- Possible literature and state-of-the-art research to be used

APPROVALS:

Faculty Advisor / Instructor: Yi, Yun Kyu **Date:** Aug.28.2025

Site-Supervisor: __________ **Date:** __________

Program Director: __________ **Date:** __________

Notes: __________

Professional Development Requirement Objectives

Professional development requirement is aimed at developing the following skill set in the context of energy systems or plasma engineering:

- Leadership
- Teamwork
- Project development
- Project management
- Oral and written communication
- Feasibility studies
- Innovation and entrepreneurship
- Engineering economics and business aspect of technology
- Component or system-level conceptual design studies
- Design and build activities
- Experimental work
- Detailed numerical simulations
- Detailed theoretical analyses of physical systems

Use the sample cover page on the next page for proposal, interim, and final report.

Proposal

Submitted in partial fulfillment of the requirements for

ENG 573

Master of Engineering in Energy Systems

Exploiting Building Thermal Mass for Demand Response: A Double-Layer MPC Framework Based on RC Modeling

Jianru Jing

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Date: 8/24/2025

Credit Hours: 4

Term: Fall 2025

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Keywords (5):

Energy flexibility; Building thermal mass; Model Predictive Control; Demand Response; Resistance–Capacitance model

1. Introduction

With the increasing penetration of renewable energy, the mismatch between supply and demand has become more pronounced, and grid stability is becoming more challenging. These factors highlight the need for demand response (DR). In this study, we will use the metadata from ResStock to build a grey-box model that distinguish different categories of building thermal mass. The model will be used in a price-based MPC framework in which control decisions are updated dynamically to match the natural dynamic of building thermal mass in demand response. This study will also analyze the potential for MPC control strategies for demand response from the perspective of differentiating building thermal mass.

2. Background

Building thermal mass (BTM) is generally considered to be a feasible and inexpensive way to improve energy flexibility. As a storage medium, BTM has the potential to absorb heat and correspondingly release it with less additional cost, making it a valuable flexibility (Hewitt, 2012). Current studies have already explored the use of building thermal mass as an effective means for demand response (DR) optimization. The main effect of demand response (DR) in building HVAC systems is: reducing peak electricity demand and cost, enhancing energy flexibility, and mitigating the imbalance between power supply and demand in the grid (Yoon et al., 2014). Hu et al. (2019) developed an advanced MPC method to make the floor heating system grid-responsive.

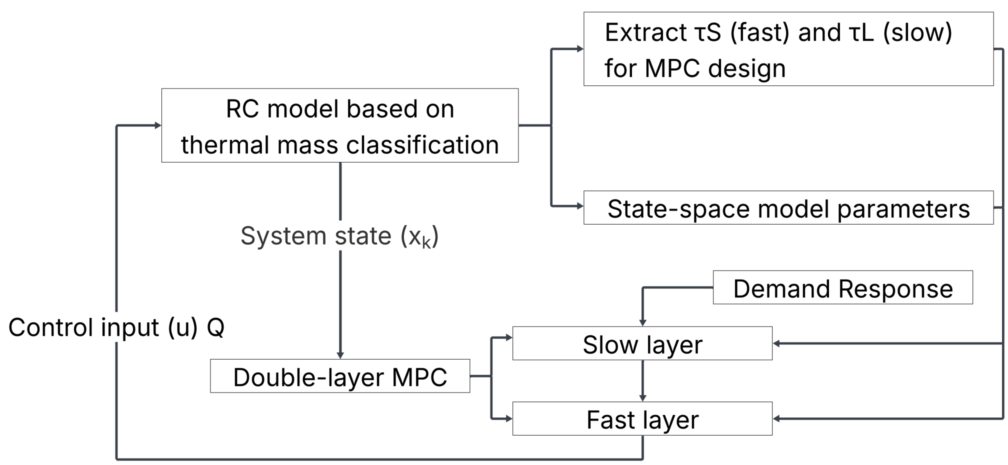
Mugnini et al. (2024) implemented a quantification methodology for clustering buildings according to their thermal mass. There were approximately 21% of buildings in their research that exhibited inconsistent classifications between short-term and long-term thermal inertia. This finding indicated that building thermal dynamics cannot be captured by a single lumped parameter and motivates the need to separate fast and slow thermal mass during modelling. These separated building models might also be combined with an MPC design. Short-term control mainly addresses fast disturbances for human comfort, while long-term control leverages structural thermal mass for slow load shifting.

Simões et al. (2023) developed a soft sensor based on a 2R2C gray-box RC model, where the short-term effective heat capacity represented the internal thermal mass (e.g., furniture, partitions, and room air), while the long-term effective heat capacity represented the structural thermal mass (e.g., walls, ceilings, and floors). They used the RC model to assess the thermal inertia-based building energy flexibility in a typical modern office by simulating several DR events. However, while such approaches improve the estimation of thermal inertia, they mainly focus on quantifying demand response potential rather than integrating the distinction into control strategies. In this study, the potential of MPC control strategies for demand response will be explored from the perspective of distinguishing building thermal mass.

3. Objectives

- Develop a grey-box RC modeling framework that separates short-term (fast) and long-term (slow) thermal dynamics
- Integrate the fast/slow thermal dynamics into a multiple-layer Model Predictive Control (MPC) strategy
- Demonstrate the price-based demand response (DR) through HVAC control using the proposed MPC framework

4. Research Methodology



The proposed framework uses a double-layer MPC framework explicitly leveraging the building thermal mass to provide flexibility for demand response. An RC model is first established, following the approach of Mugnini et al (2024). The model will be used to classify fast and slow thermal mass components, and extract state-space parameters and dominant time constants (τ_S, τ_L). The slow layer MPC, based on the slow thermal mass model and long prediction horizons, schedules demand response actions—such as precooling or preheating—by strategically charging or discharging the building's thermal mass to minimize electricity costs during peak pricing periods. These strategic setpoints and power caps are given to the fast layer MPC, which uses the complete RC model (fast + slow mass) to maintain occupant comfort. In this way, the framework can exploit building thermal mass potential as a virtual energy storage resource by shifting loads in time while preserving comfort. Compare the electricity cost and energy consumption between the proposed double-layer MPC framework and the baseline EnergyPlus simulations from ResStock.

In the slow-layer MPC, the building HVAC system is abstracted as a controllable load or a virtual battery, which allows the controller to capture the charging/discharging behavior of the building's thermal mass. This abstraction can be implemented through existing frameworks such as DOPER, which provide load-control functionality. Direct measurement of wall or structural mass temperatures is impractical in real buildings. Instead, only indoor air temperature and external conditions are measured, while the unmeasured states (e.g., wall and structural thermal mass temperatures) are reconstructed using a state estimator, such as a Kalman filter, to provide the MPC with complete state information.

5. Timeline

Course Timeline	
2-3 pages proposal	Prior to registration
10-12 pages interim progress report	Week 10
25-30 pages comprehensive final report	Week 15
10-minute oral presentation	Week 13/14

6. References

Hewitt, N. J. (2012). Heat pumps and energy storage – The challenges of implementation. *Applied Energy*, *89*(1), 37–44. https://doi.org/10.1016/j.apenergy.2010.12.028

Hu, M., Xiao, F., Jørgensen, J. B., & Li, R. (2019). Price-responsive model predictive control of floor heating systems for demand response using building thermal mass. *Applied Thermal Engineering*, *153*, 316–329. https://doi.org/10.1016/j.applthermaleng.2019.02.107

Mugnini, A., Ramallo-González, A. P., Parreño, A., Molina-Garcia, A., Skarmeta, A. F., & Arteconi, A. (2024). Dynamic building thermal mass clustering for energy flexibility assessment: An application to demand response events. *Energy and Buildings*, *308*, 114011. https://doi.org/10.1016/j.enbuild.2024.114011

Simões, J. C., Panão, M. J. N. O., & Carrilho da Graça, G. (2023). Development of a soft sensor for thermal inertia-based building electrical demand flexibility. *Energy and Buildings*, *295*, 113341. https://doi.org/10.1016/j.enbuild.2023.113341

Yoon, J. H., Bladick, R., & Novoselac, A. (2014). Demand response for residential buildings based on dynamic price of electricity. *Energy and Buildings*, *80*, 531–541. https://doi.org/10.1016/j.enbuild.2014.05.002

By submitting this report, I give consent for my work to be shared online or in person as an example of work completed in the M.Eng. in Energy Systems.