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	**Yu Hsiu Tung**
Student number	**5577632**

Studio		
Name / Theme	**Building technology graduation studio**	
Main mentor	Laure Itard	Building Energy Epidemiology
Second mentor	Charalampos Andriotis	Artificial Intelligence
Argumentation of choice of the studio	Building technology graduation studio	

Graduation project	
Title of the graduation project	Exploring Energy Performance and Potential Improvements through Machine Learning Techniques: An Analysis of User Energy Profile Patterns, Anomaly Detection, and Clustering of Uilenstede Campus Energy Consumption Data
Goal	
Location:	Uilenstede
The posed problem,	The energy consumption of the Uilenstede campus is currently monitored by distributed monitors and sub-meters in the east part of the buildings, which provide data on cold water, heat (total demand for domestic hot water and heating), and electricity. However, there is a lack of understanding of the energy consumption patterns and opportunities for energy conservation. The goal of this thesis is to explore energy performance and identify potential improvements in the Uilenstede campus.

research questions and	Research Questions: "How can machine learning utilizing smart meter data and end-user energy profiles inform energy conservation efforts towards a CO2-free district at DUWO's Uilenstede campus?" Sub questions: 1. What data is needed to understand and improve energy efficiency in buildings? 2. How can inefficiency or waste be detected through analysis of energy consumption patterns using machine learning techniques such as clustering, regression, or decision tree analysis? 3. Could introducing extra information such as building features, weather, comfort, and schedules improve energy consumption and conservation opportunities? 4. How can opportunities for energy conservation be identified through analysis of current consumption patterns?

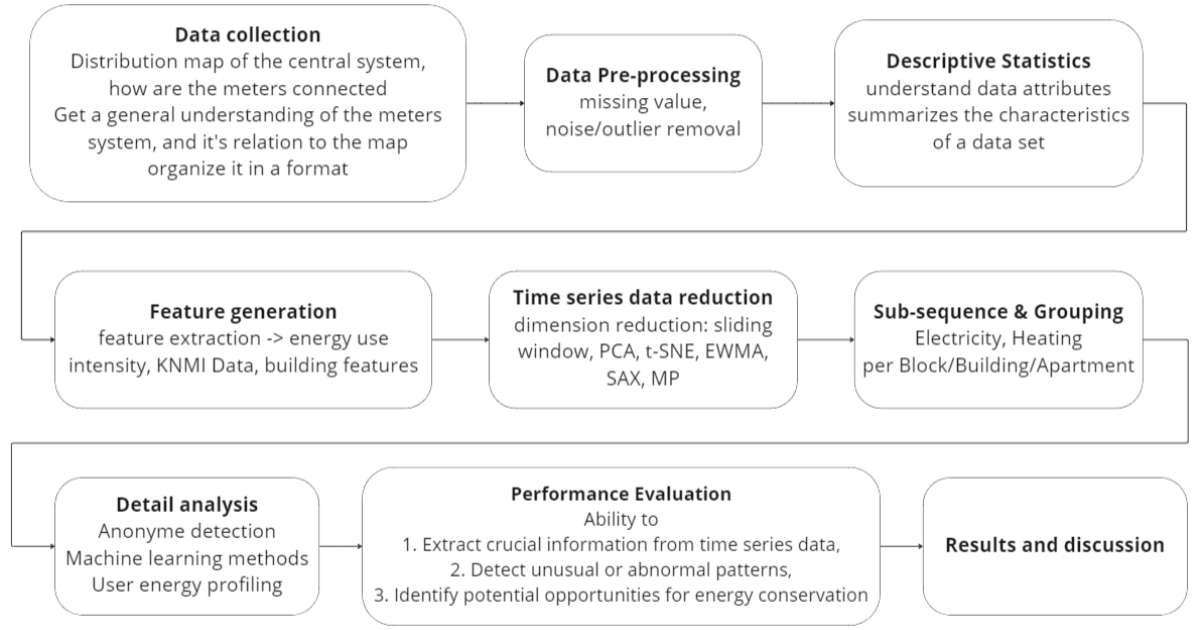
design assignment in which these result.	Research objectives: 1. Using machine learning methods, develop a comprehensive understanding of the energy consumption patterns and consumption trends at Uilenstede campus. 2. Understand building occupants' energy usage by analyzing energy consumption patterns at building blocks and individual building levels, including daily, weekly, and seasonal trends. 3. Use anomaly detection techniques to detect potential energy waste or inefficiency by identifying unusual or abnormal energy consumption patterns. 4. Identify opportunities for energy conservation by analyzing current energy consumption patterns and developing end-user energy profiles. 5. To examine the impact of building features, weather, occupant behavior, comfort, and schedules on energy consumption. Design assignment: Data Collection: 1. Gather smart meter data from buildings at Uilenstede campus. 2. Collect data on building features, weather conditions, and comfort levels. Data Preprocessing: 1. Clean the data to ensure its quality and completeness. 2. Normalize the data to ensure it is on the same scale for analysis. 3. Integrate smart meter data with other features. Exploratory Data Analysis (EDA): 1. Perform EDA on the integrated data to understand the relationships between different variables. 2. Plot visualizations to understand the distribution of data and identify any outliers. 3. Summarize the data using descriptive statistics. Anomaly Detection: 1. Use machine learning techniques such as clustering or anomaly detection to detect unusual or abnormal energy consumption patterns. 2. Evaluate the performance of different techniques and select the best-performing one.

	End-user Energy Profile Development: Use machine learning techniques such as clustering, regression, and decision tree analysis to understand energy consumption patterns and trends at Uilenstede campus comprehensively. Energy Conservation Opportunities Identification: Analyze current energy consumption patterns and develop end-user energy profiles to identify opportunities for energy conservation. Model Validation and Deployment: 1. Validate the selected machine learning models using a set of test data. 2. Deploy the best-performing model in a real-world environment to inform energy conservation efforts at Uilenstede campus. Conclusion and Recommendations: Summarize the results of the analysis and provide recommendations on how DUWO can use machine learning to inform energy conservation efforts towards a CO2-free district.

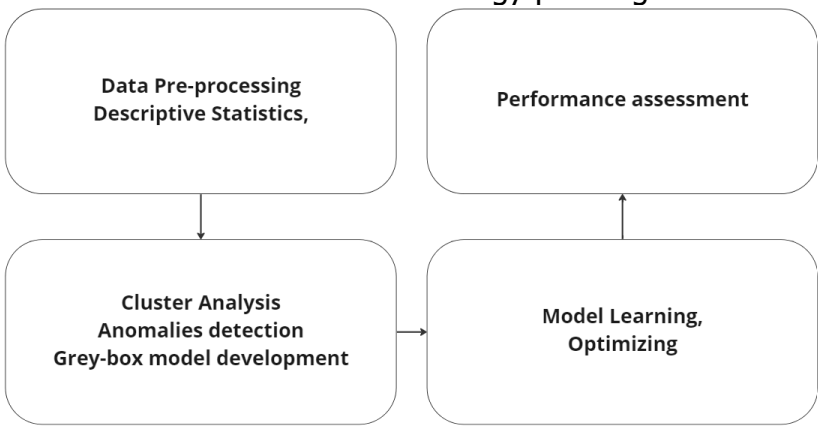
Process

Method description

Research framework



Anomalies detection and user energy profiling



Research Framework:

1) Problem definition and research question
2) Literature research:

The Literature Study is divided in three phases:

1) First phase: formulate a research question and research aims and set up a research plan with a planning of intermediate milestones with appropriate deliverables.
2) Second phase: looking at resources, find an overview of:
   - Current state of the art
   - What are the usual research approaches
   - What has been left for future work
3) Third phase: answering the main question (and it sub questions)that were formulated in the introduction.

3) Case study

This step aims to assess the robustness of the previous studies and gain insight into the method that data have been used to address the problem. And to Identify limitations or gaps in the dataset.

- First, look into Uilenstede Campus Energy Consumption Dataset and understand the distribution system.
- Second, elect a relevant and recent research paper that addresses a similar problem or question.
- Attempt to reproduce the results of the selected paper using the same or similar methods with current dataset.
- Compare the reproduction results to the original paper.
- List down the potential and limitation. If the reproduction is successful, use the paper as a case study to further explore the research question.

4) Research Methodology

1) Design of the study

- The study will use a mixed-methods approach, including qualitative and quantitative data collection and analysis techniques, to answer the research questions. The study will use a case study design to explore energy consumption patterns and opportunities for conservation.

2) Data collection and analysis techniques

- The sample for the study will consist of data from the DUWO data portal and any additional variables collected such as building features, weather conditions, occupant behavior, comfort level, and operating schedules.
- Quantitative data will be analyzed using descriptive statistics and inferential statistics such as correlation analysis, regression analysis, and time-series analysis.
- Descriptive statistics such as mean, median, mode will be used to summarize the data.
- Analyze the data using the methods described in the methodology section, and interpret the results in the context of the existing literature

5) Performance evaluation

- The results will be validated by comparing the results with the benchmark studies in the literature.
- The benchmark studies should be those that have addressed similar research questions and used identical data collection and analysis techniques.
- The study's results will be evaluated against the benchmark studies in terms of their ability to extract crucial information from time series data, identify potential opportunities for energy conservation, and detect unusual or abnormal energy consumption patterns.

- Additional performance evaluation for the study can be done by comparing the results with the actual energy consumption data and energy efficiency metrics of the building before and after implementing any recommendations for conservation.

6) Results and discussion
    - Present the study results clearly and concisely, using tables, figures, and graphics as appropriate.
    - Discuss the implications of the results for understanding energy consumption and improving energy efficiency in buildings.
    - Highlight any new insights or contributions that the study makes to the field.
    - Provide recommendations for future research based on the results of the study.
7) References and bibliography

Literature and general practical preference

References

Araya, D. B., Grolinger, K., ElYamany, H. F., Capretz, M. A. M., & Bitsuamlak, G. (2016). Collective contextual anomaly detection framework for smart buildings. 2016 International Joint Conference on Neural Networks (IJCNN).

Araya, D. B., Grolinger, K., ElYamany, H. F., Capretz, M. A. M., & Bitsuamlak, G. (2017). An ensemble learning framework for anomaly detection in building energy consumption. Energy and Buildings, 144, 191–206. https://doi.org/10.1016/j.enbuild.2017.02.058

Capozzoli, A., Piscitelli, M. S., Brandi, S., Grassi, D., & Chicco, G. (2018). Automated load pattern learning and anomaly detection for enhancing energy management in smart buildings. Energy (Oxford, England), 157, 336–352. https://doi.org/10.1016/j.energy.2018.05.127

Chiosa, R., Piscitelli, M. S., Fan, C., & Capozzoli, A. (2022). Towards a self-tuned data analytics-based process for an automatic context-aware detection and diagnosis of anomalies in building energy consumption timeseries. Energy and Buildings, 270(112302), 112302. https://doi.org/10.1016/j.enbuild.2022.112302

Chou, J.-S., & Telaga, A. S. (2014). Real-time detection of anomalous power consumption. Renewable and Sustainable Energy Reviews, 33, 400–411. https://doi.org/10.1016/j.rser.2014.01.088

Fan, C., Xiao, F., Li, Z., & Wang, J. (2018). Unsupervised data analytics in mining big building operational data for energy efficiency enhancement: A review. Energy and Buildings, 159, 296–308. https://doi.org/10.1016/j.enbuild.2017.11.008

Fan, C., Xiao, F., Zhao, Y., & Wang, J. (2018). Analytical investigation of autoencoder-based methods for unsupervised anomaly detection in building energy data. Applied Energy, 211, 1123–1135. https://doi.org/10.1016/j.apenergy.2017.12.005

Góis, J., & Pereira, L. (2022). A novel methodology for identifying appliance usage patterns in buildings based on auto-correlation and probability distribution analysis. Energy and Buildings, 256(111618), 111618. https://doi.org/10.1016/j.enbuild.2021.111618

Li, G., Yao, Q., Fan, C., Zhou, C., Wu, G., Zhou, Z., & Fang, X. (2021). An explainable one-dimensional convolutional neural networks based fault diagnosis method for building heating, ventilation and air conditioning systems. Building and Environment, 203(108057), 108057. https://doi.org/10.1016/j.buildenv.2021.108057

Liu, X., Ding, Y., Tang, H., & Xiao, F. (2021). A data mining-based framework for the identification of daily electricity usage patterns and anomaly detection in building

electricity consumption data. Energy and Buildings, 231(110601), 110601. https://doi.org/10.1016/j.enbuild.2020.110601

Park, J. Y., Wilson, E., Parker, A., & Nagy, Z. (2020). The good, the bad, and the ugly: Data-driven load profile discord identification in a large building portfolio. Energy and Buildings, 215(109892), 109892. https://doi.org/10.1016/j.enbuild.2020.109892

Park, J. Y., Yang, X., Miller, C., Arjunan, P., & Nagy, Z. (2019). Apples or oranges? Identification of fundamental load shape profiles for benchmarking buildings using a large and diverse dataset. Applied Energy, 236, 1280–1295. https://doi.org/10.1016/j.apenergy.2018.12.025

Piscitelli, M. S., Brandi, S., Capozzoli, A., & Xiao, F. (2021). A data analytics-based tool for the detection and diagnosis of anomalous daily energy patterns in buildings. Building Simulation, 14(1), 131–147. https://doi.org/10.1007/s12273-020-0650-1

Ramaswamy, S., Rastogi, R., & Shim, K. (2000). Efficient algorithms for mining outliers from large data sets. SIGMOD Record, 29(2), 427–438. https://doi.org/10.1145/335191.335437

Talei, H., Benhaddou, D., Gamarra, C., Benbrahim, H., & Essaaidi, M. (2021). Smart building energy inefficiencies detection through time series analysis and unsupervised machine learning. Energies, 14(19), 6042. https://doi.org/10.3390/en14196042

Verleysen, M., Université catholique de Louvain, & Katholieke Universiteit Leuven. (2015). Proceedings: ESANN 2015. Ciaco.

Zhan, S., Liu, Z., Chong, A., & Yan, D. (2020). Building categorization revisited: A clustering-based approach to using smart meter data for building energy benchmarking. Applied Energy, 269(114920), 114920. https://doi.org/10.1016/j.apenergy.2020.114920

Zhao, Y., Li, T., Zhang, X., & Zhang, C. (2019). Artificial intelligence-based fault detection and diagnosis methods for building energy systems: Advantages, challenges and the future. Renewable and Sustainable Energy Reviews, 109, 85–101. https://doi.org/10.1016/j.rser.2019.04.021

Zhao, Y., Zhang, C., Zhang, Y., Wang, Z., & Li, J. (2020). A review of data mining technologies in building energy systems: Load prediction, pattern identification, fault detection and diagnosis. Energy and Built Environment, 1(2), 149–164. https://doi.org/10.1016/j.enbenv.2019.11.003

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 project topic, the studio topic, the master track, and the master program is 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 potential improvements through unsupervised learning techniques on the Uilenstede campus. 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 the graduation work addresses the critical issue of energy consumption and its impact on the environment. By exploring energy performance and identifying potential improvements through unsupervised learning techniques, this research will contribute to the larger goal of reducing energy consumption and greenhouse gas emissions in buildings. The study can provide valuable insights for building operators, managers, architects, and engineers to improve energy efficiency and reduce energy consumption in buildings. Additionally, the research could contribute to developing new methods and technologies for analyzing energy consumption patterns and identifying opportunities for energy conservation, which could be applied in other buildings and campuses.