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Building Energy Anomaly Detection (BEAD) Tool

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1. Introduction

The Building Energy Anomaly Detection tool project aims to support the University of Toronto's Sustainability Office and Energy Management Team in identifying energy consumption anomalies at the building level. By analyzing historical building energy consumption data (2019-2022) and future updates, the project seeks to establish a baseline profile for each building, correlated with Heating Degree Days (HDD) from the Toronto Pearson Airport station. The developed methodology will help flag monthly readings that deviate significantly from normal consumption patterns, providing actionable insights to improve data accuracy and optimize energy management across the campus. This report summarizes the methodology, key findings from exploratory data analysis, and recommendations based on identified anomalies.

2. Objectives

The following objectives were set and achieved:

1. Baseline establishment. Develop a baseline profile for each building by analyzing historical energy consumption data and correlating it with Heating Degree Days (HDD) from the Toronto Pearson Airport station.
2. Anomaly detection. Utilize the baseline to identify and flag monthly readings that significantly deviate from established tolerance levels (e.g., +/-10%, 15%, 20%, >25%).
3. Anomaly reporting. Generate a summary report that highlights flagged meter reading anomalies, enabling further investigation and data adjustments.

3. Methodology

The following section describes the data sources we used, as well as the procedure followed.

3.1. Data sources

The following data sources were used:

- The historical building energy consumption data (2018-2023) provided by the Sustainability Office and Energy Management Team (Sustainability Office and Energy Management Team at the University of Toronto, 2023) was used to establish baselines. This dataset included monthly consumption figures in kilowatt-hours (kWh) from 73 buildings on the University of Toronto campus, providing a comprehensive overview of energy usage patterns.
- Heating Degree Days (HDD) data sourced from the Toronto Pearson Airport station from Environment and Climate Change Canada (*Daily Data Report for April 2021 - Climate - Environment and Climate Change Canada*, 2024). The data was aggregated from daily to monthly in order to match it with the monthly building energy data provided.

- <u>Heating degree-days (HDD)</u> for a given day (as defined by the ECCC): number of degrees Celsius that the mean temperature is below 18°C. If the temperature is equal to or greater than 18 °C, then the number will be zero. For example, a day with a mean temperature of 15.5 °C has 2.5 heating degree-days; a day with a mean temperature of 20.5 °C has zero heating degree-days. Heating degree-days are used primarily to estimate the heating requirements of buildings (Fig. 1).

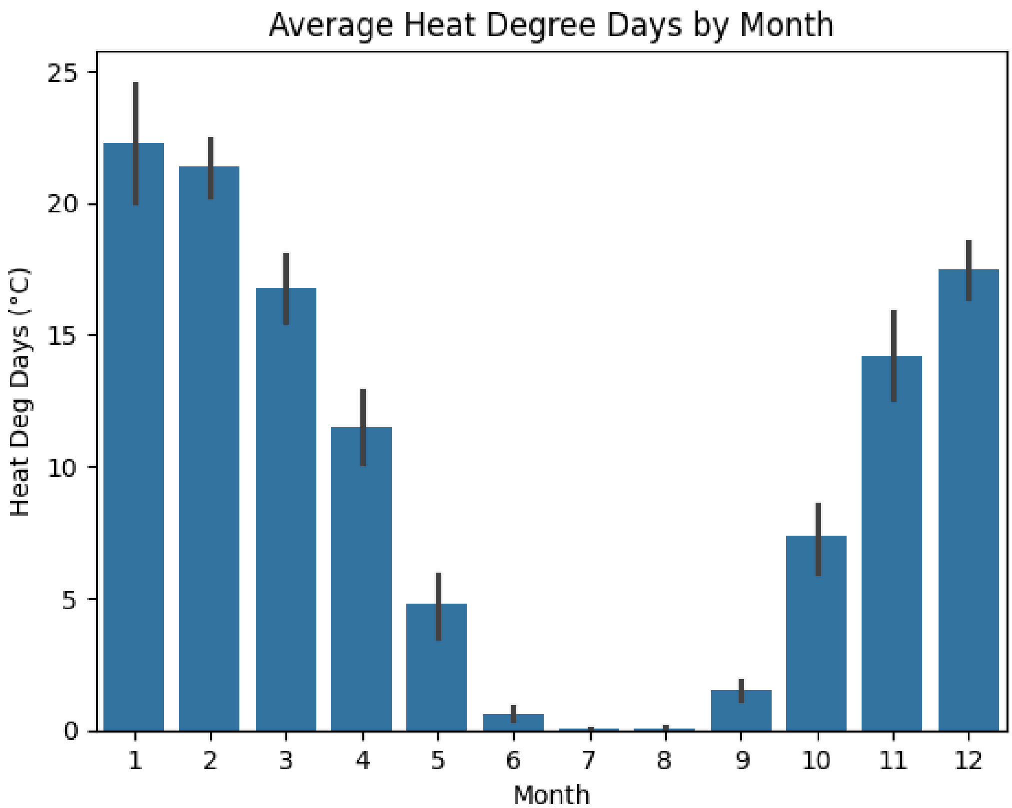

Figure 1. Average HDD by month from 2018-2022. Generated in Python using the Seaborn library.

3.2. Procedure

The steps followed to achieve the objective were:

1. Normalization

   Energy consumption data was normalized by correlating it with Heating Degree Days (HDD) data sourced from the Toronto Pearson Airport station.

2. Baseline calculation

   The baseline profile was calculated by dividing energy consumption by the corresponding HDD value for each month (Baseline = Consumption / HDD). The monthly historical median of these normalized consumption figures was used to determine the baseline for each building. The median is less affected by outliers and skewed data than the mean.

3. Establishing tolerance levels

   Anomalies were identified by comparing monthly readings against the baseline profiles. Tolerance levels were set at various thresholds (+/-10%, 15%, 20%, >25%) to capture deviations.

4. Deviation calculation

   Baseline deviations were calculated using the formula:
   (Baseline−Actual Consumption) / Baseline∗100

5. Anomaly flagging

   Monthly readings that fell outside of the established tolerance levels were flagged for further investigation.

4. Results

Dataset overview

The dataset analyzed contained 4,259 data points representing 73 buildings on the University of Toronto campus. Energy consumption data from 2018 to the present revealed substantial variation among buildings, with the Medical Sciences Building showing the highest consumption and the Innis Building showing the lowest. (Fig. 2)

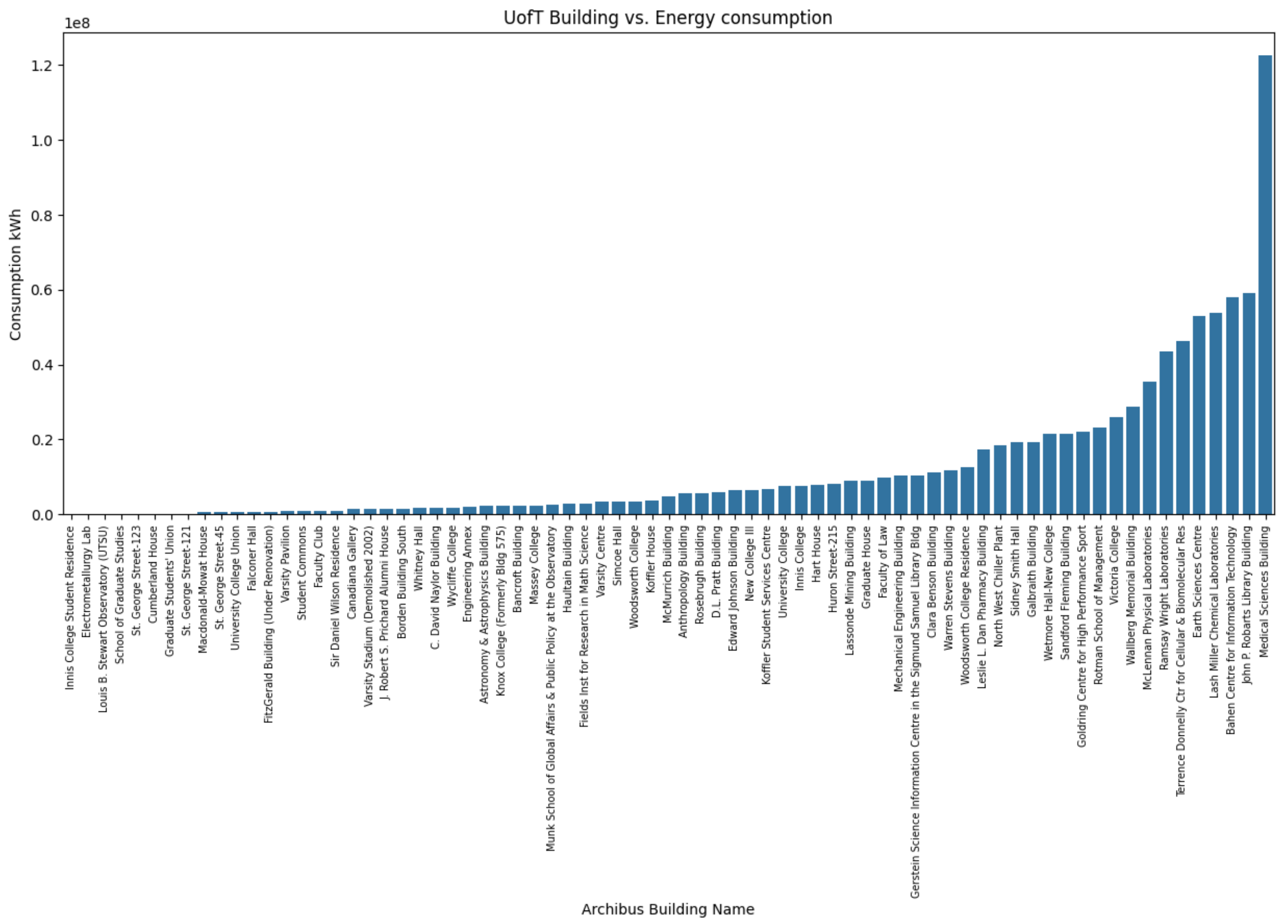

Figure 2. The total energy consumption of UofT buildings over the period of 2019-2022. Generated in Python using the Seaborn library.

The amount of HDD remained roughly similar from year to year (Fig. 3).

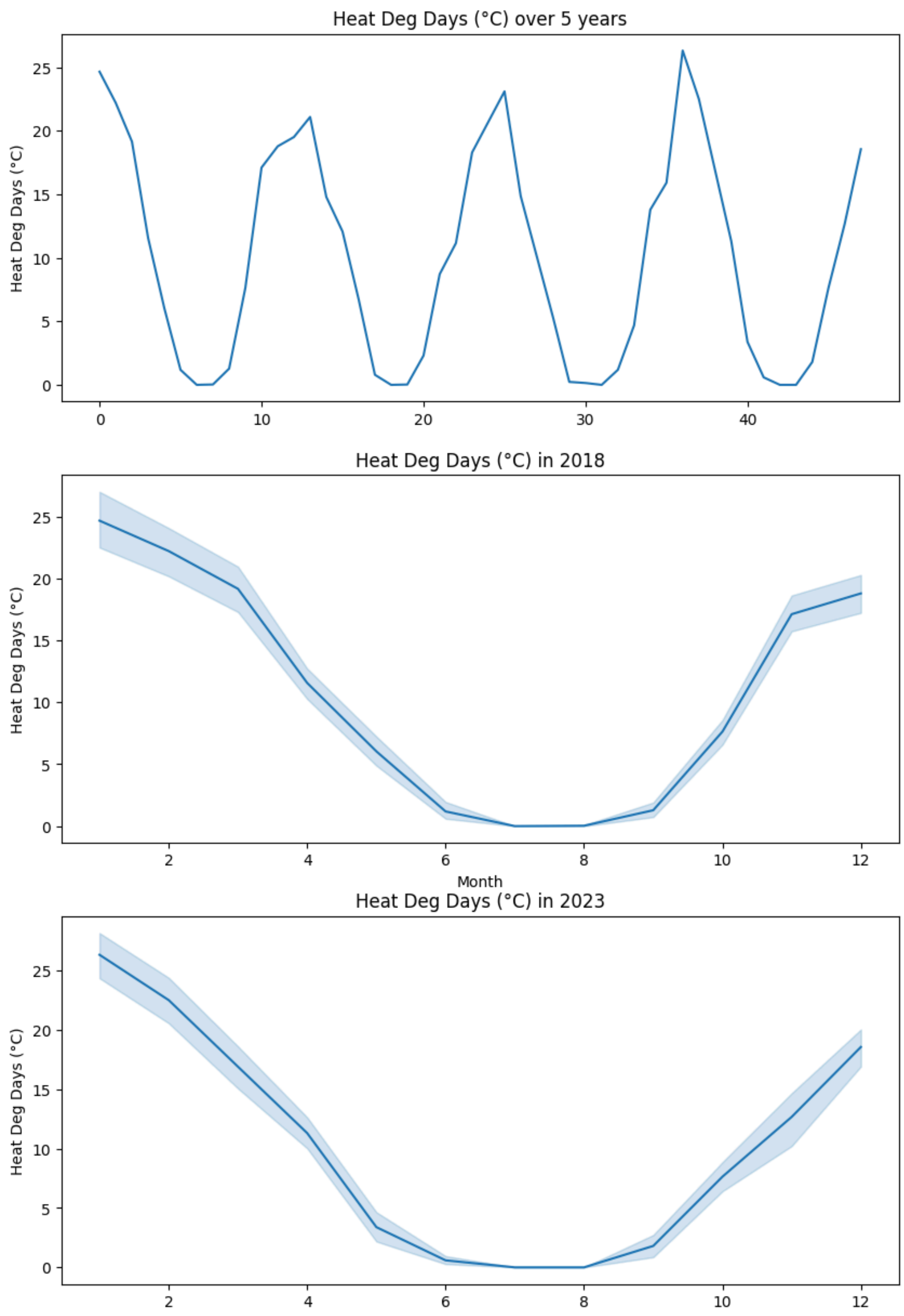

Figure 3. HDD data over the period of 2019-2022. Generated in Python using the Seaborn library.

Consumption trends

Overall consumption varied widely, with a mean of approximately 12.3 million kWh and a maximum of over 122 million kWh. Monthly consumption statistics indicated significant variability, ranging from 0 to nearly 4.4 million kWh.

Baseline deviations

The baseline for each building was determined by normalizing energy consumption based on HDD/CDD data. Most buildings exhibited deviations from their baselines, with significant deviations observed in buildings such as Innis College Student Residence. (Fig. 4)

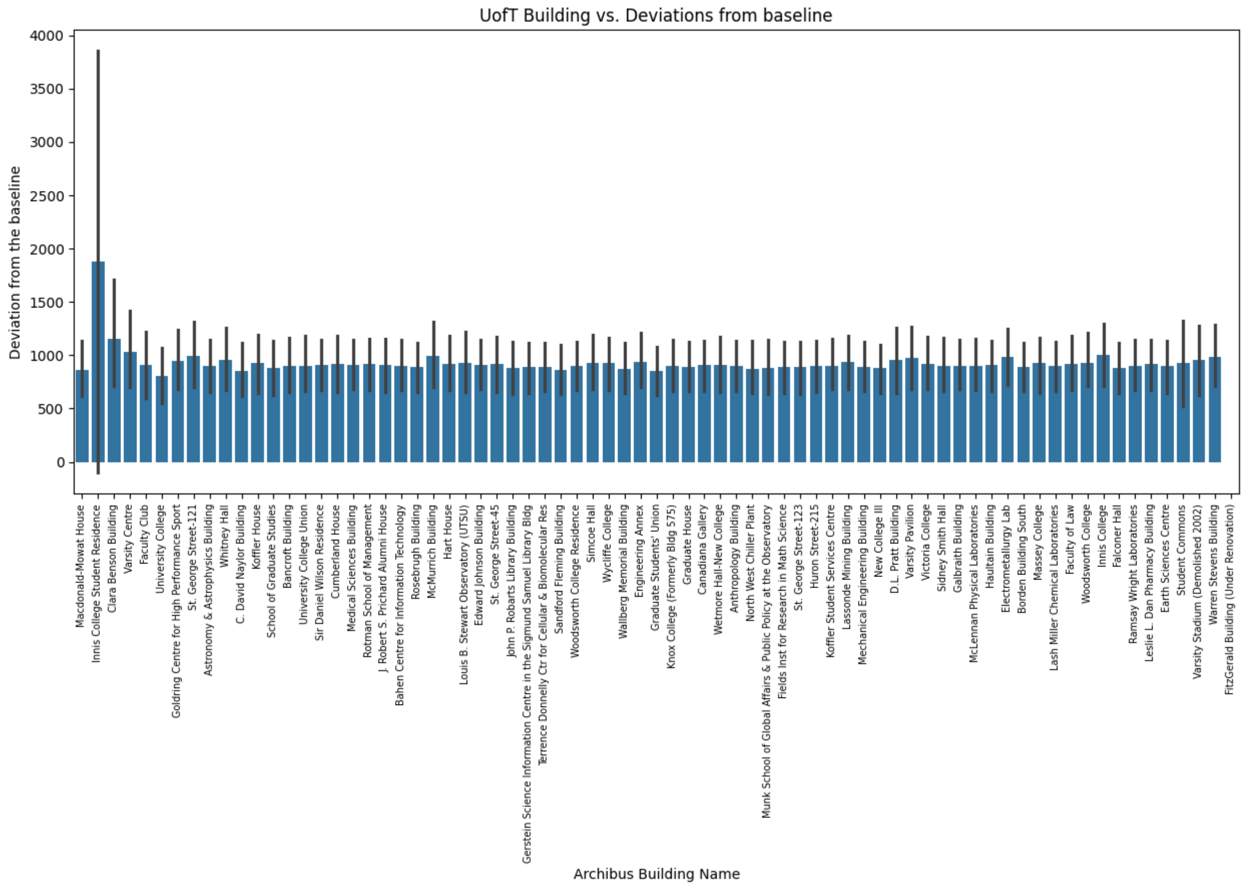

Figure 4. UofT buildings vs. Deviations from the baseline. Generated in Python using the Seaborn library.

Impact of COVID-19

More detailed results are located in the Appendix section.

5. Recommendations

Insights for energy management

The baseline deviation analysis revealed high variability across buildings on campus, highlighting the need for further investigation into the underlying causes of these anomalies. It is crucial for the Sustainability Office and Energy Management Team to prioritize further investigation into buildings with significant deviations, such as the Medical Sciences Building and Innis College Student Residence, to understand the underlying causes of the anomalies. This will help refine energy management strategies and identify potential inefficiencies in these buildings.

Data collection and analysis

Enhancing data collection processes and ensuring consistent data quality are essential. Improvements could include regular calibration of meters, updating data collection protocols, and deploying advanced metering infrastructure for real-time monitoring. Accurate and reliable data will enable better baseline calculations, anomaly detection, and trend analysis.

Actionable insights

To enhance energy management:

1. Focus on buildings showing significant baseline deviations to uncover specific issues or inefficiencies.
2. Continuously update baseline profiles with new data to reflect recent trends in energy consumption.
3. Utilize advanced data analytics tools for more comprehensive anomaly detection and predictive analysis.

By implementing these recommendations, the Sustainability Office and Energy Management Team can make informed decisions, optimize energy usage, and improve sustainability across the campus.

6. Conclusion

The Building Energy Anomaly Detection Tool project provides a robust framework for identifying anomalies in energy consumption across the University of Toronto campus. By establishing a comprehensive baseline profile for each building, the project has highlighted significant deviations that warrant further investigation. This approach aids in identifying potential inefficiencies and inaccuracies in energy usage data, enabling targeted efforts to optimize energy management.

Moving forward, it would be great to ensure that the tool can update automatically as new data becomes available, ensuring that anomaly detection remains accurate and up-to-date. This will involve integrating advanced data processing techniques and automation to continuously monitor and flag significant deviations in energy consumption.

Moreover, the analysis can be enriched by incorporating additional information such as environmental and human factors. By considering data on building occupancy, weather patterns, and usage schedules, the tool can provide a more comprehensive assessment of energy usage patterns and detect anomalies more effectively.

These advancements will empower the Sustainability Office and Energy Management Team to make data-driven decisions, continuously improve energy efficiency, and reinforce sustainability initiatives across the campus.

7. References

Daily Data Report for April 2021 - Climate - Environment and Climate Change Canada. (2024, March 27). https://climate.weather.gc.ca/climate_data/daily_data_e.html?StationID=51459&timeframe=2&StartYear=1840&EndYear=2024&Day=1&Year=2021&Month=4#

Sustainability Office and Energy Management Team at the University of Toronto. (2023). *Historical building energy consumption data (2018-2023)* [Dataset].

8. Appendices

The Colaboratory file with source code and preliminary results is available here:
https://colab.research.google.com/drive/1UcZa70QR4REL5I8KCCuhl7OEy00aQvEi?usp=sharing

- Overall consumption kWh for all buildings (from 2018 to now):
  - mean 12286760.6232
  - std 19780801.0396
  - min 2325.3000
  - 25% 1357051.4000
  - 50% 4768744.1537
  - 75% 12457620.8148
  - max 122536489.4062
- Monthly consumption kWh for all buildings (from 2018 to now):
  - mean 210702.2571
  - std 353382.5423
  - min 0.0000
  - 25% 22210.5000

- 50% 71458.0000
- 75% 257162.0830
- max 4369920.0000

- Data on baseline deviations:
  - count 3297.0000
  - mean 915.0178
  - std 911.4498
  - min -100.0000
  - 25% 10.3264
  - 50% 773.9449
  - 75% 1550.6873
  - max 6525.8123