Electricity Usage in Toronto's Public Facilities: Analyzing the Impact of Building Size on Energy Consumption*

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This study examines the relationship between building size(m²) and electricity consumption(kWh) in Toronto's public facilities. Data from over 500 buildings, including schools,libraries, and hospitals, show a consistent positive correlation between GFA and eletricity usage. Larger facilities, particularly healthcare centers, demonstrate higher energy consumption per square meter. These results help inform efforts to improve energy management in Toronto's public buildings.

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*Code and data are available at: https://github.com/zilin1017/Toronto_annual_energy_consumption.git.

1 Introduction

Public infrastructure, including schools, libraries, healthcare centers, and government offices, forms the backbone of urban services in any modern city. As Toronto continues to expand, managing electricity usage in public buildings becomes increasingly critical. Energy efficiency in public facilities not only reduces operational costs but also contributes to environmental goals, such as carbon reduction and climate change mitigation(Droege 2018).

One of the primary determinants of electricity consumption is building size, commonly measured as Gross Floor Area (GFA). Larger buildings tend to consume more energy for lighting, heating, cooling, and equipment operations, but this relationship is influenced by other factors such as building type, operational hours, and energy management systems (Hong et al. 2016). As such, it is crucial for policymakers to understand how building size and other factors influence electricity consumption in Toronto's public facilities (Li and Colombier 2009).

Several studies have shown that energy efficiency measures in public buildings can lead to significant reductions in electricity consumption. For example, retrofitting large government buildings or healthcare facilities with modern energy management systems can reduce energy use, while smaller buildings like libraries and schools often exhibit lower per-square-meter energy consumption (Scott et al. 2008).

This paper explores the relationship between Property GFA (m^2) and electricity usage (kWh) in over 500 public facilities in Toronto. The study aims to identify patterns in electricity consumption and provide insights for optimizing energy use in Toronto's public sector.

2 Data

2.1 Raw data

The data used in this paper came from the OpenData Toronto portal through the library (Gelfand 2022). Data were cleaned and analyzed using the open source statistical programming language R (R Core Team 2023). The particular data set used to analyze the Consumption of Energy is the Annual Energy Consumption Data in 2021 (Toronto Open Data Portal, n.d.). The following packages helped with the data analysis: tidyverse (Wickham et al. 2019), here (Müller 2020)), dplyr (Wickham et al. 2023) and ggplot2 (Wickham 2016) was use for making graphics. All data analysis was conducted using R (R Core Team 2023).

The data used in this analysis comes from the City of Toronto's Open Data Portal(Gelfand 2022), specifically focusing on energy consumption across various property types in Toronto for the year 2021(Toronto Open Data Portal, n.d.). The dataset consists of 1,802 unique entries, each representing a specific property in various regions of Toronto. For each property, the data captures critical metrics such as the building size, self-reported in gross floor area (GFA) in square meters (m^2), and the total electricity consumption, measured in kilowatt-hours (kWh), purchased from the grid. No personal or property-specific information is included. The data was last updated on July 4, 2023, and helps understand energy usage trends across different building types in Toronto.

2.2 Cleaned Data

The cleaning process focused on removing irrelevant or incomplete data to ensure the dataset was suitable for analyzing electricity consumption patterns in Toronto's public sector. Missing values(NA) were removed during the data cleaning process, particularly those related to electricity usage. And buildings that did not meet the size criteria (less than 30 square meters or greater than 2,500 square meters) were also filtered out.Additionally, variables irrelevant to the study's focus were also omitted. Furthermore, the cleaned data retains only the key variables required for the analysis: property type, electricity use, floor area, and log-transformed area. This ensures that the final dataset is both accurate and relevant for understanding electricity consumption trends across different public facilities in Toronto.

A sample of the cleaned data can be seen in Table 1. The cleaned analysis dataset is loaded using the R programming language (R Core Team 2023). The folder structure for this analysis is also inherited from Professor Rohan Alexander (Alexander 2023). Figures and tables are then generated using the knitr (Xie 2023) and tidyverse (Wickham et al. 2019) packages.

Table 1: Sample of cleaned data

Property Type	Electricity Use (kWh)	Area (m^2)	Log of Area (m^2)
Police Station	610692.1	2395.0	7.781138
Other - Public Services	9469.3	40.0	3.688880
Other - Lodging/Residential	76707.2	1783.7	7.486445
Office	124585.4	934.0	6.839476
Heated Swimming Pool	344470.3	1922.0	7.561122
Pre-school/Daycare	81602.7	652.0	6.480045

2.3 Data Analysis

In Figure 1, we observe the density of electricity usage versus building size across different cities in Toronto. Denser clusters of data points in central areas such as Toronto and Scarborough suggest a higher concentration of both building sizes and electricity consumption. Specifically, Toronto shows a dense clustering of buildings in the range of 25,000 to 50,000 m², indicating that larger facilities in central locations tend to consume significantly more electricity compared to those in peripheral cities. In contrast, cities like Maple and York have relatively fewer buildings, and their electricity consumption is more evenly distributed, as indicated by the sparse density of points. This density pattern supports the paper's objective of analyzing how building size influences electricity use and points to central urban areas as having the greatest potential for energy efficiency interventions.

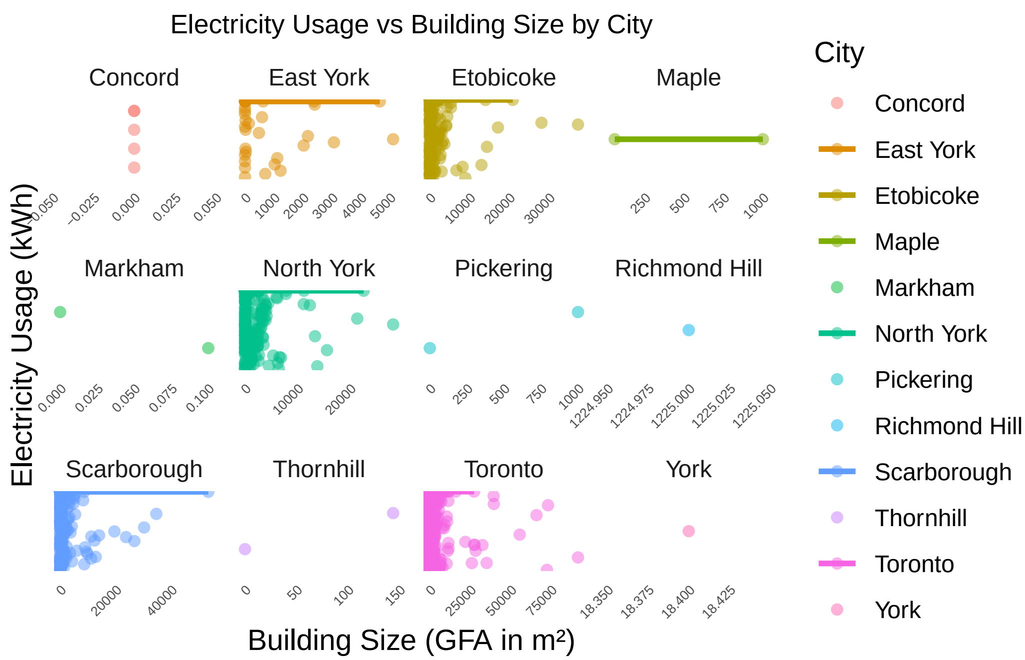

Figure 1: Density Plot for Property Area in Toronto (By City)

In Figure 2, the bar plot illustrates the total electricity usage across various property types. Notably, the Other category dominates with 38.3% of the total electricity consumption, suggesting a wide range of public facilities categorized under this label that may significantly differ in size and function. Other high-consumption categories include Fire Stations (15.8%), Libraries (13.7%), and Social/Meeting Halls (11.3%). These property types account for a substantial portion of electricity use, highlighting their operational demands. The distribution of percentages provides a clear distinction between high-demand and low-demand property types. This segmentation supports the paper's objective of identifying the specific categories where energy efficiency efforts may yield the most impact, particularly in facilities that operate intensively throughout the year.

Density Plot for Property Area in Toronto Figure 3: it illustrates the distribution of property sizes in logarithmic form, showing that most buildings fall within a moderate size range.

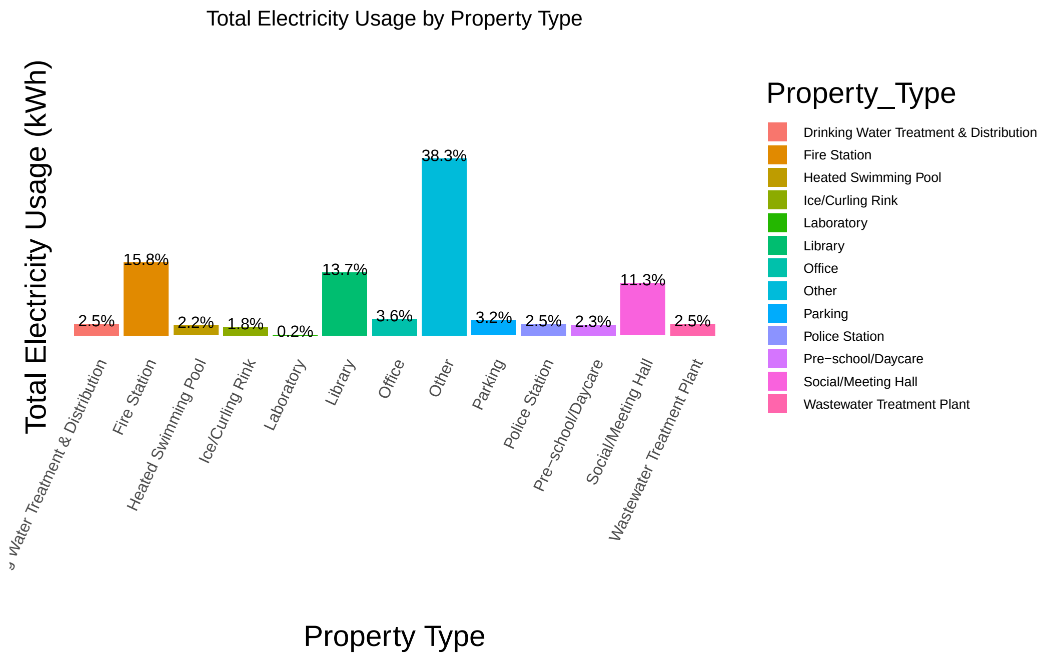

Figure 2: Percentage Electricity Usage by Properties

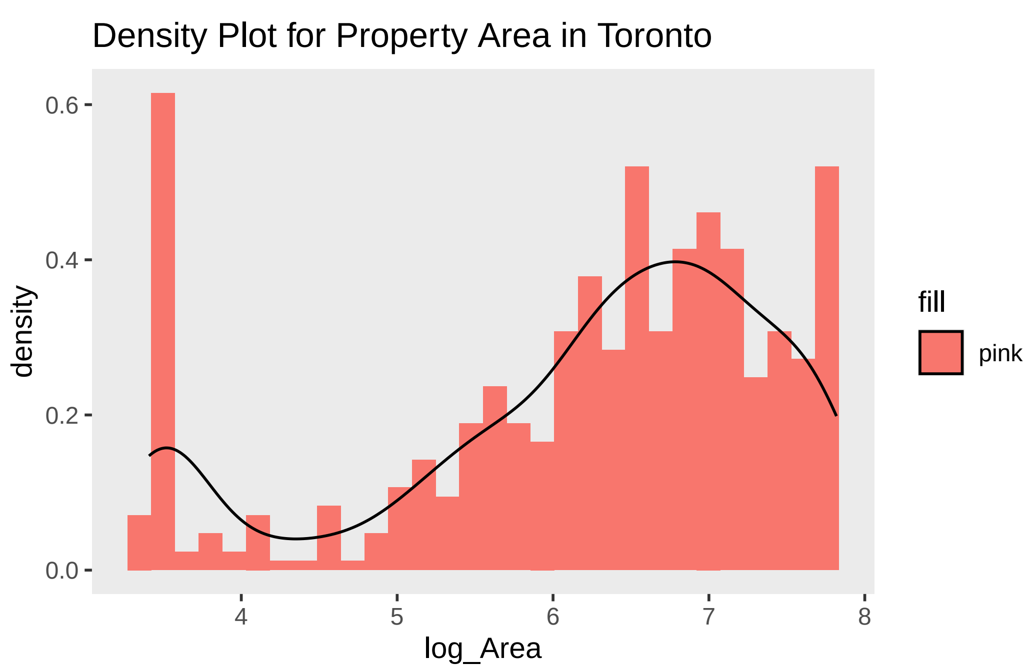

Figure 3: Density Plot of Log_Area

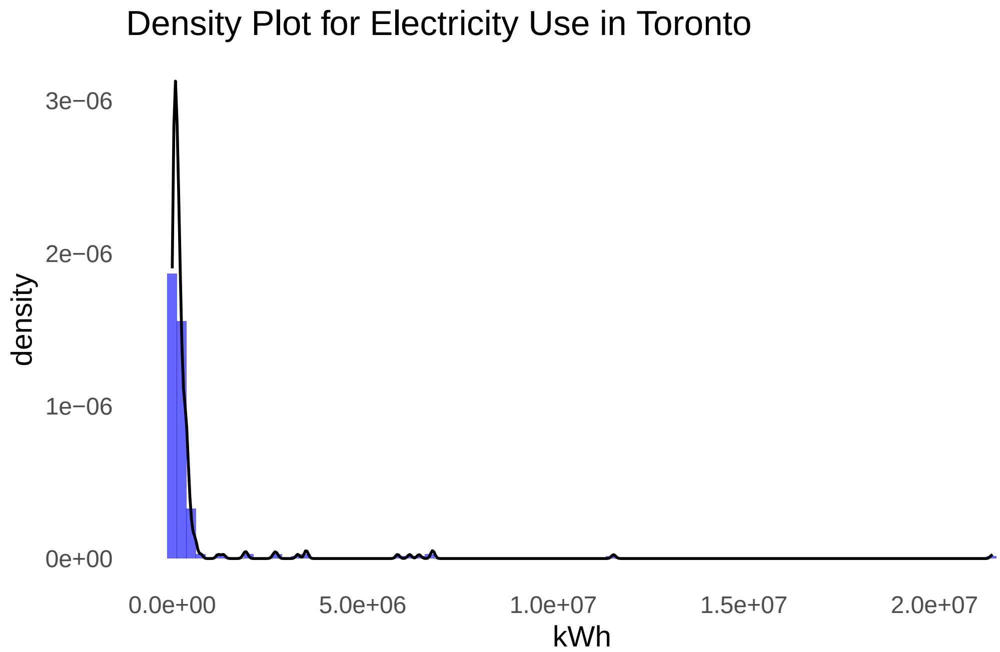

Figure 4: Density Plot of kWh

However, a smaller number of properties have much larger areas, indicated by the tail on the right side of the plot. This observation illustrates that the larger buildings tend to consume more electricity, but the relationship is not strictly proportional across the full range of building sizes.

The density plot for electricity Figure 4 use shows a sharp peak in the lower range of electricity consumption, with most facilities consuming less than 5,000,000 kWh annually. This suggests that the majority of public facilities operate with relatively low energy demands. However, the right tail extends toward much higher consumption values, with a few facilities reaching close to 20,000,000 kWh. The skewness of this distribution indicates the presence of outliers—facilities that consume significantly more energy than others. These outliers may represent large, energy-intensive buildings or those with specific operational requirements.

3 Results

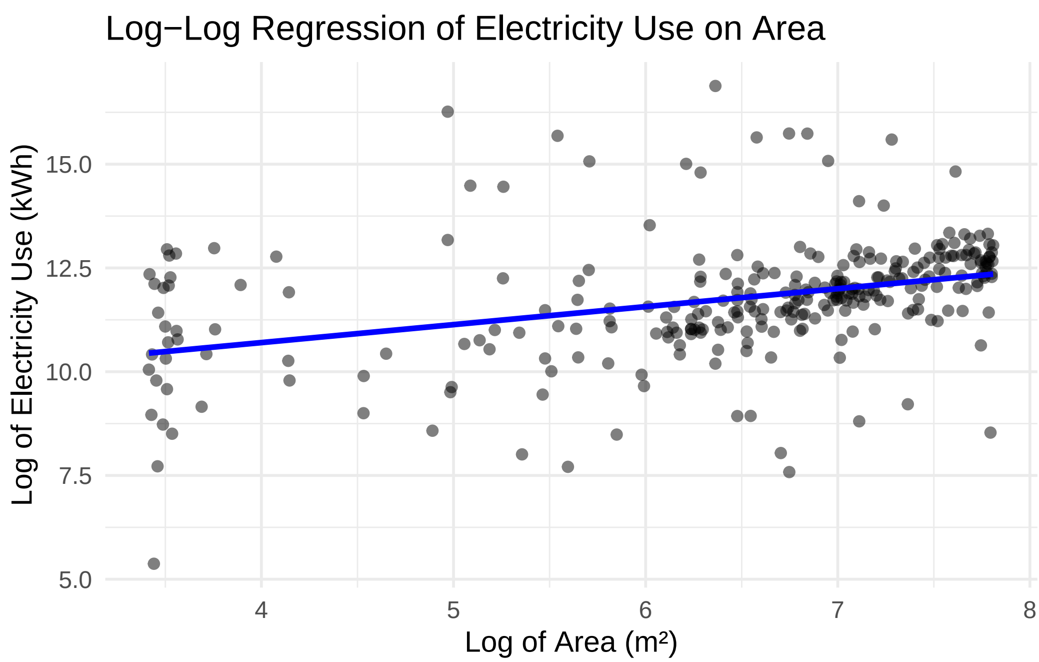

Figure 5: Regression of Electricity Use on Area

Our results, summarized in Figure Figure 5, indicate a positive relationship between electricity use (kWh) and building area (m²) in Toronto's public facilities through log-log regression analysis. This finding aligns with previous research that suggests building size is a key determinant of energy consumption in institutional settings. Larger buildings generally consume more electricity, which is consistent with the basic principle of scaling energy demand with floor area.

However, our analysis suggests that building size alone does not fully explain electricity consumption, indicating that factors such as building age, equipment efficiency, and usage patterns likely play significant roles (Yohanis et al. 2008). For instance, lighting and heating systems have been shown to contribute disproportionately to energy consumption in larger buildings (Perez-Lombard, Ortiz, and Pout 2008). Consequently, strategies to optimize energy usage should focus not just on large facilities but also on mid-sized properties, which may provide better opportunities for improving efficiency without encountering the high consumption rates associated with the largest properties (Ouf and Issa 2017).

By targeting mid-sized buildings for energy efficiency improvements, policy-makers can maximize the return on investment in energy-saving measures, as these properties may experience greater relative reductions in consumption (Santamouris, Synnefa, and Karlessi 2017). Future research should explore the role of operational practices and energy management technologies in reducing consumption across different property sizes.

4 Discussion

4.1 First discussion point: Urban Density and Its Impact on Electricity Consumption

Figure 1 highlights how different regions of Toronto exhibit varied patterns of electricity consumption based on their urban density. Cities like Toronto, North York, and Scarborough show denser clusters of data points compared to less populated areas like Maple and Richmond Hill, where fewer observations are present. This difference in data density could suggest that larger, more densely populated urban areas have a higher concentration of public facilities that consume substantial amounts of electricity, supporting previous research (Ouf and Issa 2017). Additionally, the more scattered and sparse data points in regions such as Pickering and Etobicoke indicate that these cities have fewer facilities or public buildings consuming significant electricity, further emphasizing the urban-rural divide in energy demand.

The lack of data points in cities like Maple suggests that the relatively lower number of public buildings could lead to decreased overall electricity usage, which showing that electricity consumption is typically lower in less urbanized areas due to fewer public infrastructures. The data also raises questions about whether the facilities in these regions are less energy-efficient or simply fewer in number, as the lower density could mask potential inefficiencies.

Also, the location of a facility, including its microclimate, can have a substantial impact on energy usage, particularly in cities with diverse weather conditions like Toronto. Buildings in areas with more extreme temperatures (either cold winters or hot summers) require more heating or cooling, which drives up electricity use. This factor is especially relevant for buildings with large window-to-wall ratios or poor insulation, as they tend to lose heat more easily. In addition, the density plots from Figure 1 show that some locations, such as Etobicoke and East York, feature buildings with relatively lower consumption compared to Scarborough or Toronto, indicating that location and local climate could be influencing these trends.

4.2 Second discussion point:Factors Influencing Building Energy Consumption: Property, Functionality, Operational Intensity and Occupancy

Different types of buildings have varying operational needs, which directly impact their energy consumption. For instance, facilities like fire stations and wastewater treatment plants operate 24/7, often requiring extensive heating, ventilation, and cooling systems. In contrast, libraries or office spaces may have more intermittent usage, leading to lower electricity demand. The diversity of energy requirements across property types is a key factor influencing consumption, as demonstrated in Figure 2 where categories such as “Other” and “Fire Stations” stand out with significantly higher usage.

Buildings with higher occupancy levels or more intense operational schedules tend to consume more energy. Facilities that are open for longer hours or serve a large number of occupants, such as community centers or swimming pools, require more consistent energy to maintain lighting, cooling systems, and equipment. Studies, such as those by (Yohanis et al. 2008), show that buildings with greater occupancy or more energy-intensive activities exhibit higher energy use, even when the building size is relatively modest. In our dataset, “Heated Swimming Pools” and “Social/Meeting Halls” stand out as high-energy users due to their intensive operational demands, despite not being the largest facilities.

4.3 Limitations and Next Steps

While our analysis provides valuable insights into electricity consumption across Toronto’s public facilities, there are several limitations that must be addressed. First, the dataset lacks information on occupancy and operational schedules, both of which are key determinants of energy consumption (Yohanis et al. 2008). Without these variables, it is difficult to draw firm conclusions about why some buildings consume more energy than others, beyond their size and property type. Additionally, as shown in Figure 3 and Figure 4, the skewed distribution of electricity usage—dominated by a few large consumers—poses challenges for generalizing energy-saving strategies across all building types.

To improve the accuracy and usefulness of the analysis, future studies should incorporate temporal data on electricity use, enabling a better understanding of peak demand periods and seasonal variations in energy consumption. Further, the inclusion of occupancy data and the use of more advanced statistical techniques, such as random forest models or decision trees, could help account for the complex interactions between building size, type, and operational characteristics, leading to more actionable policy recommendations (Santamouris, Synnefa, and Karlessi 2017).

Appendix

Dataset and Graph Sketches

Drafts of the necessary dataset and the figures produced by this analysis are available in the other/sketches file of the GitHub repository.

Attribution Statement

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