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Article

Comprehensive Energy and Decarbonisation Audit of a Multi-Unit Residential Building in Toronto: Methods, Findings, and Recommendations

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Abstract: This research investigates a structured energy audit methodology to support the decarbonisation of multi-residential buildings, with a primary focus on operational energy performance. The objective is to develop and apply a systematic framework that integrates audit levels, detailed data collection, and software-based energy modelling to quantify energy use and greenhouse gas emissions. The methodology combines site inspections, thermographic analysis, benchmarking, and eQuest simulation to evaluate baseline conditions and retrofit scenarios. Results identify space heating and electricity consumption as dominant energy and emissions drivers. Targeted retrofit measures demonstrate substantial potential to reduce energy demand and carbon intensity when expressed in kg CO_2e. Importantly, the correlation analysis does not capture retrofit interactions, system efficiencies, or behavioural adaptations following upgrades, nor the compounding effects of bundled measures. Carbon-counting results show these combined effects to be significant, with the full retrofit package achieving an overall emissions reduction of approximately 25%, equivalent to more than 1,100 t CO_2e annually. Overall, separating results from interpretation strengthens decision-making and confirms the value of operationally focused audits for prioritising decarbonisation strategies in existing multi-residential building stock.

Keywords: Energy audit; Multi-unit residential building (MURB); Energy efficiency; Thermographic analysis; Energy modeling; Decarbonisation; Retrofit strategies; Toronto; Net-zero buildings.

1. Introduction

Under the Paris Agreement, Canada has committed to reducing its greenhouse gas (GHG) emissions to 40–45% below 2005 levels by 2030, and to achieve net-zero emissions by 2050 (Government of Canada, 2024). The City of Toronto has established ambitious goals to reduce greenhouse gas (GHG) emissions through its TransformTO climate action initiative. The targets, measured against 1990 levels, include a 30% reduction by 2020, a 65% reduction by 2030, and achieving net zero emissions by either 2040 or 2050. In 2021, the city introduced the TransformTO Net Zero Strategy, which accelerated the net zero target to 2040. This plan provides a roadmap for reaching community-wide net zero emissions, with a milestone of a 65% reduction by 2030, and highlights the significant lifestyle, building, and transportation changes required to meet these objectives (City of Toronto, 2020).

Research on multi-unit residential buildings (MURBs) in Toronto reveals significant opportunities for energy efficiency improvements. Energy benchmarking studies of Toronto MURBs show wide performance variations, with energy consumption ranging from 141-580 kWh/year-m² (Ghajarkhosravi et al., 2020) and 242-453 kWh/m² for high-rise buildings (Huang, 2021). Key performance indicators include energy consumption per square meter, per occupant, per unit, and per floor (Ghajarkhosravi et al., 2020). Energy audits demonstrate substantial retrofit potential through building envelope improvements. Window upgrades to triple low-E glazing can reduce gas consumption by 34-38%, while enhanced insulation achieves 4% reductions (Taileb & Sherzad, 2023). Window characteristics and heating system type most significantly influence energy intensity (Binkley, 2012). Weather normalization methods like PRISM provide reliable benchmarking, though simpler methods may over- or underestimate savings by approximately 20% (Huang, 2012). These findings support Toronto's greenhouse gas reduction targets, as buildings contribute 25% of the city's emissions (Ghajarkhosravi et al., 2020). Energy audits are foundational in identifying inefficiencies and guiding retrofits in MURBs. Recent work by Taileb and Sherzad (2023) demonstrated that detailed energy audits in Toronto-based MURBs resulted in actionable recommendations that directly reduced energy consumption and greenhouse gas emissions. Their study underscores the audit process as not just technical but also strategic for achieving sustainability targets, especially when combined with energy modeling and benchmarking techniques. Advanced this by integrating high-detail energy audits with decarbonization potential assessments, emphasizing the growing need for granular data and holistic approaches that consider operational and embodied energy (Nakayama et Al, 2024). Energy performance benchmarking helps owners and managers compare building performance, identify underperforming assets, and prioritize upgrades. Large-scale benchmarking of 45 Toronto MURBs revealed significant variance in energy use intensity, highlighting the potential for targeted interventions (Huang, Y, 2012). A systematic review by Identified financial constraints, lack of awareness, fragmented incentives, and technical knowledge gaps as persistent obstacles to adoption of energy-efficient technologies in buildings (Yeatts *et al.*, 2017). Found that in British Columbia, the split incentive problem—where building owners pay for retrofits but tenants benefit from energy savings—remains a major barrier, and suggested policy and financing innovations to resolve this (Bain, 2015). Other studies have explored architectural factors, such as the influence of balconies and envelope characteristics, on overall efficiency, recommending that retrofit strategies be tailored to specific building typologies (Rana & Mughal, 2025). Decarbonizing MURBs requires a mix of technological, behavioral, and policy interventions. Analyzed retrofit strategies for mid-rise MURBs in Toronto, showing that combinations of envelope upgrades, electrification, and renewable energy integration can deliver substantial emission reductions while improving thermal resilience (Minniti, 2025). Proposed a framework for integrating climate adaptation and mitigation in urban MURBs, advocating for solutions that address both present comfort needs and future climate risks (Judah, 2020). Used multi-criteria analysis to show that renewable energy and high-efficiency HVAC systems can be tailored for dense, multi-unit housing in different climates (Go et al., 2024). Reviewed the implementation of building energy codes and found that while codes are effective at setting minimum standards, significant gaps remain in enforcement and in addressing older building stock. They suggest that more robust policy frameworks and incentive schemes are necessary to accelerate deep retrofits in MURBs (Perera et al., 2024). Developed a detailed energy audit and financial analysis for the transformation of a building towards nZEB (nearly zero-energy building) target (Corrado, 2017). Results from the analysis of electrical energy consumption and the indoor environment help search for sustainable solutions for reducing energy consumption and improving thermal comfort inside building (Kumara, 2015). The research argues that Canada can most effectively decarbonize its residential sector by prioritizing direct electrification of all homes using heat pumps while focusing building envelope upgrades on older homes built before 1980, especially pre-1940, to maximize emission reductions, energy savings, and equity with limited resources (McDiarmid, Bonner Septien & Parker, 2024).

Research demonstrates that energy audits are essential tools for uncovering inefficiencies and guiding decarbonisation in MURBs. While technical solutions are well understood, persistent economic and behavioral barriers require targeted policy innovation. A combination of benchmarking, robust retrofit strategies, and supportive regulatory frameworks will be key to unlocking energy and carbon savings in this critical sector. In parallel, a rigorous assessment of life-cycle carbon impacts is required to ensure that retrofit strategies lead to durable and verifiable decarbonisation outcomes. This includes the life-cycle carbon impacts of the retrofit measures themselves, as well as operational changes resulting from the retrofits—such as reduced energy use for heating, cooling, and lighting. In some cases, only operational savings are counted if that is the primary focus. By defining these boundaries, the approach extends a conventional operational energy audit to capture the broader carbon implications of retrofit decisions.

2. Objective of the work and research Methodology

This research aims to assess energy consumption patterns and identify potential efficiency improvements in a multi-unit residential building (MURB) in Toronto. The study focuses on detecting areas of heat loss, evaluating electrical and mechanical system performance, and providing actionable energy management recommendations. The study emphasizes operational changes due to retrofit and quantifies their impact in terms of CO_2-equivalent (CO_2e) reductions.

To achieve these objectives, the study adopts a multi-method energy audit framework. This approach aligns with established best practices in building energy assessment and prior peer-reviewed studies of multi-unit residential buildings. It provides a holistic view of the building's energy performance by combining quantitative data with observational and modeling methods.

Data governance and permissions: All utility data used in this study are aggregated at the building level and have been anonymized to prevent the identification of individual tenants. No tenant-specific or personally identifiable information was collected or analyzed. Permission to conduct the energy audit, site inspections, thermographic imaging, and use of utility data for research purposes was obtained from the property management prior to the commencement of the study.

The audit employs the following methods (Figure 1):

Comparative assessment: Utility bills for gas and electricity are analyzed and normalized against local weather records, and benchmarked against Natural Resources Canada (NRCan) MURB standards to identify deviations from expected energy performance.

On-site examination: A comprehensive site visit evaluates the building envelope, mechanical and electrical systems, lighting levels, temperature distribution, and other pertinent physical usage parameters.

Thermographic inspection: Thermal imaging identifies areas of heat loss in the building envelope and inefficiencies in mechanical systems, enabling targeted retrofit recommendations.

Software-based analysis: eQuest (v.3.65) is used to create a detailed building model, integrating data from utility analysis, on-site inspection, and thermographic imaging. The model allows evaluation of different retrofit strategies and energy-saving measures.

Return-on-investment (ROI) assessment: Simple financial calculations estimate the cost-effectiveness and payback period of potential retrofit options.

Integration of retrofit impacts: The study explicitly evaluates the contributions of retrofit strategies to decarbonisation, expressed in kg CO_2e. Operational changes due to retrofit—such as improved heating, cooling, or lighting efficiency—are quantified, and the resulting reductions in energy consumption are calculated. In cases where operational savings are the main focus, only energy reductions directly attributable to retrofit interventions are considered.

Rationale and scope: This multi-method approach ensures both an empirical assessment of current energy performance and predictive evaluation of retrofit strategies. The focus is on core building systems and the building envelope rather than individual tenant behavior, providing a representative understanding of building-level performance.

Limitations: Constraints include limited access to tenant units, absence of sub-metered data for individual apartments, and exclusion of behavioral and lifestyle variables. The study focuses on energy efficiency and life-cycle carbon impacts, without detailed analysis of water or waste systems. Operational savings are only counted where they result directly from retrofit interventions. These limitations are acknowledged to ensure transparent and appropriate interpretation of results.

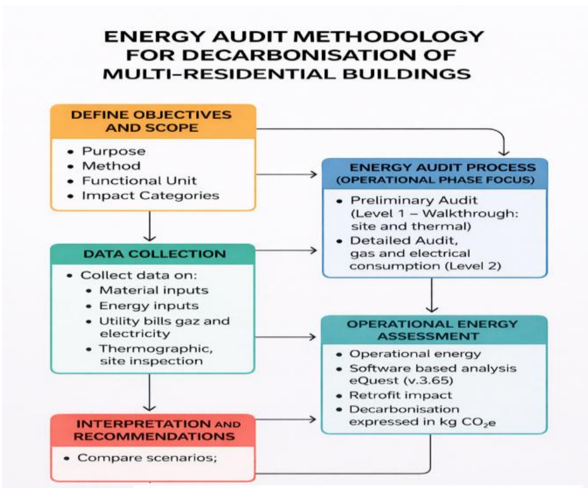


Figure 1. Methodology

3. Building description

The audited building (Figure 2) is situated in Toronto, Ontario. It exemplifies a typical multi-unit residential building (MURB) commonly found in the Greater Toronto Area, featuring a design characterized by exposed slabs and originating from the 1970s. Spanning across eighteen floors, excluding a mechanical penthouse and basement, the building encompasses a total usable floor area of 32,161m² (105,515ft²). The common areas comprise a main lobby, hallways in each of the three wings, a ground floor laundry room, a basement recreation room, and an unconditioned parking garage. Notably, the corridors maintain separate ventilation systems from the living units, and during the assessment, the hallways exhibited an average temperature of 75°F (23°C). The heating system for both the living units and common areas relies on hydronic baseboard heaters. Unfortunately, access to the tenant spaces was not possible during the visit, preventing the collection of temperature readings. Nevertheless, it is reasonable to presume that the temperatures inside the units were at least 23°C or higher.

Figure 2. The audited MURB Building (by the author)

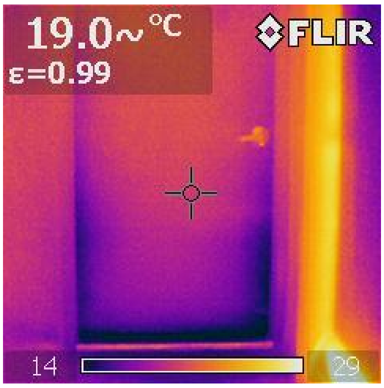
4. Thermal imaging analysis for the building envelope: doors and windows & roof

An infrared thermal camera (FLIR B60) with a 180 × 180 IR sensor (32,400 pixels) was used to detect areas of heat loss. Images were captured during winter mornings below 0°C to highlight insulation deficiencies. The camera, operating between –20 and 248°F, identified temperature differentials indicating energy losses.

Thermal bridging occurs where interior finishes meet exterior cladding, transferring heat to the outside. Thermal images (Figure 3, a-h) show temperature variations via a color scale, highlighting gaps in doors, windows, and worn weatherstripping that reduce air-tightness and increase energy inefficiency.

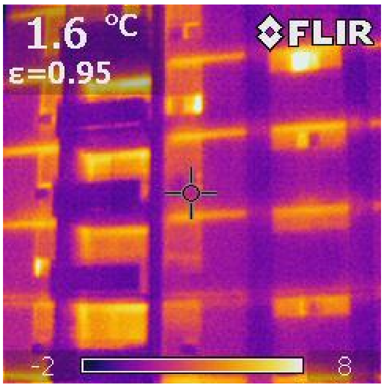
Roofing materials, degraded by age and environmental exposure, also contribute to heat loss and thermal bridging, as seen in the poorly sealed roof access hatch (Figure 3e). Stairwell exit doors with metal, low-insulated frames and worn weatherstripping further exacerbate heat loss (Figure 3d).

In summary, thermal imaging revealed significant heat loss at garage and stairwell doors, balcony doors and windows, exposed floor slabs, and the roof access hatch. Door hardware, window assemblies, and slab edges are the main contributors to envelope-related energy losses.



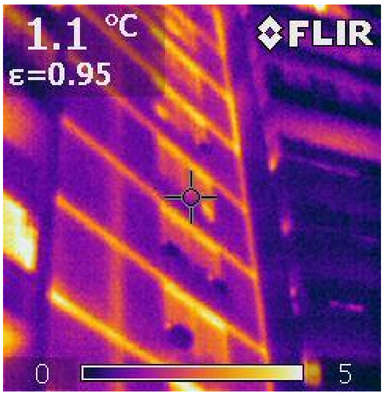
(a) Exit garage door

This thermal image shows that it is very cold around the bottom of the garage door. This is mainly due to the lack of a weather stripping and threshold at the bottom of the door. (by author)



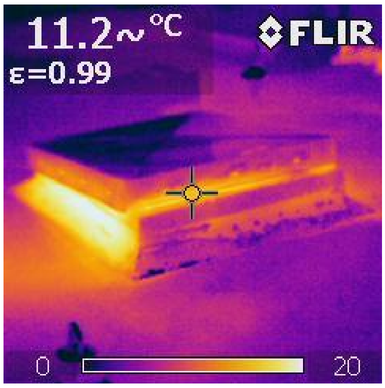
(b) windows and sliding doors

This thermal image shows the heat escaping through the windows and sliding glass doors leading to the balconies. (by the author).



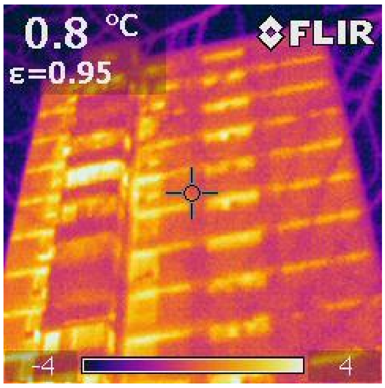
(c) Floor slabs

This thermal image shows the heat escaping between the floors (slabs) of the building. (by the author).



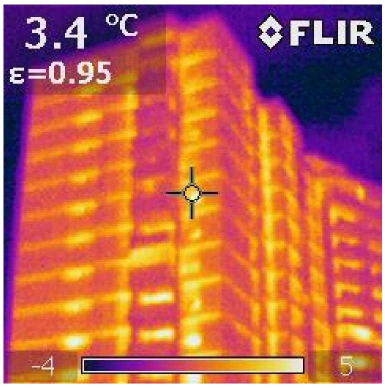
(e) Roof hatch

This thermal image shows an improperly sealed access roof hatch on that is letting cold air into the building. (by the author).



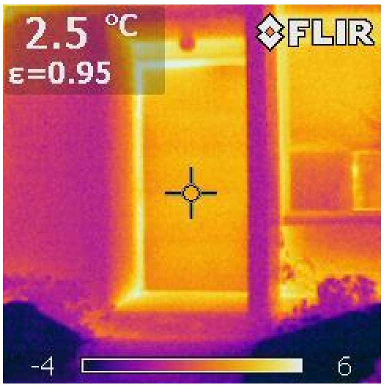
(f) Ground to top of Building

This thermal image shows the heat that the building is losing throughout the entire building. (by the author).



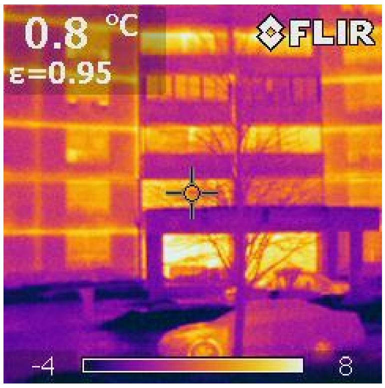
(g) Full Building

This thermal image shows all the heat that is escaping from the building.(by the author).



(d) Exit Door

This thermal image shows the heat that is escaping around the framework of the door. (by the author).



(h) Front Entrance

This thermal image shows the heat that is escaping through the glass windows and doors at the main entrance. (by the author).

Figure 3. Thermal imaging analysis for the audited MURB Building envelope (by author)

5. The electrical systems

Nomenclature:
kW — instantaneous power demand
kWh — electrical energy consumption
ekWh — total equivalent energy consumption (electricity + converted natural gas)

In this section a description will outline energy consumers and their annual usage. Lighting in the elevators are currently six 50W halogen lamps in each car. There are no timers or sensors working in conjunction with the elevator system. Annually the lighting in the elevators alone consumes 10,512kWh, shown in the calculations below.

Each floor's elevator lobby is lit by eight 32W T8 fluorescent lights, consuming 40,366 kWh annually. The two-floor indoor parking garage, with 488 32W T8 bulbs operating 24/7, uses 136,796 kWh per year, about 5.4% of the building's total electricity. The laundry room, lit by 20 continuously operating 32W T8 lamps plus natural light from exterior windows, consumes 5,606 kWh annually. No timers or motion sensors are installed in these areas.

Twelve exhaust fans provide continuous ventilation, using 86,588 kWh annually at a cost of $7,013.65. The building has no central air conditioning; fresh air is supplied via the fans. Tenants operate 193 window-mounted AC units, estimated to consume 38% of the building's total energy during May–September.

6. Building energy performing index (BEPI)

The calculation of a building's energy-performing index (BEPI) involves dividing the total equivalent kilowatt-hours consumed in a year by the total area of the building. This metric serves as a useful tool for comparing the energy performance of similar buildings or establishing a benchmark for future improvements. In 2011, the initial year of the available data, the BEPI was recorded as 277 equivalent kilowatt-hours per square meter (ekWh/m^2). However, the subsequent year demonstrated a significant improvement, with a BEPI of 227 ekWh/m^2, for reasons that are currently unknown.

$$BEPI = \frac{Total\ Energy\ Use\ (ekWh/yr)}{Gross\ Floor\ Area\ (m^2)}$$

$$BEPI_{2011} = \frac{8925828.90\ ekWh/yr}{32161m^2} = 277\ ekWh/yr$$

7. Benchmarking comparison

According to the benchmarking standards set by Natural Resources Canada (NRCan) and Canada Mortgage and Housing Corporation (CMHC) (Table 1) for buildings constructed during the same era and with similar construction, the building in question performed slightly better than the benchmark in 2011, achieving a BEPI of 277 ekWh/m^2 compared to the benchmark of 312 ekWh/m^2. In 2012, there was a notable improvement in the building's performance, with the total annual equivalent kilowatt-hours dropping from 8,925,828.90 to 7,302,859.70. This improvement resulted in a BEPI of 227 ekWh/m^2, surpassing the benchmark. In the context of NRCan's guidelines, Heating Degree Days (HDD) are used to measure the coldness of a location during a specific period relative to a base temperature. When the average temperature falls below the base temperature, the difference between the two is calculated as HDD. Similarly, Cooling Degree Days (CDD) measure the hotness of a location over a given period relative to a base temperature. In this analysis, both HDD and CDD were calculated using a base temperature of 60°F.

Table 1. Average Energy Consumption of Multi Residential Building (CMHC)

Year built	**Number of buildings**	**Energy (ekWh)**	**Energy/ Suite (ekWh/suite)**	**Energy/Floor area (ekWh/m^2)**	**Energy/Suite/ Degree-day (ekWh/suite/DD)**	**Energy/Floor/area/ Degree-day (ekWh/m^2 /DD)**
1981 to 2007	9	2,553,265	21,437	212	5.89	0.06
1961 to 1980	26	4,012,513	22,266	317	5.0	0.7

8. Correlation analysis between kWh/CDD (Cooling Degree Days)

The line graph (Figure 4) provided clearly demonstrates a relationship between the spike in Cooling Degree Days (CDD) and the corresponding increase in kilowatt-hours (kWh) consumed. This pattern occurred in two years in 2011 (277 ekWh/ m^2) and in 2012 (227 ekWH/m^2), starting in May and extending until October. This can be attributed to the operation of window-mounted air conditioning units within the building. Of particular interest are the differences observed between the two variables from July to October. The variance is more pronounced in 2011, indicating a potential change in relevant factors between the two years. Further investigation is necessary to identify the specific variables that may have contributed to this discrepancy.

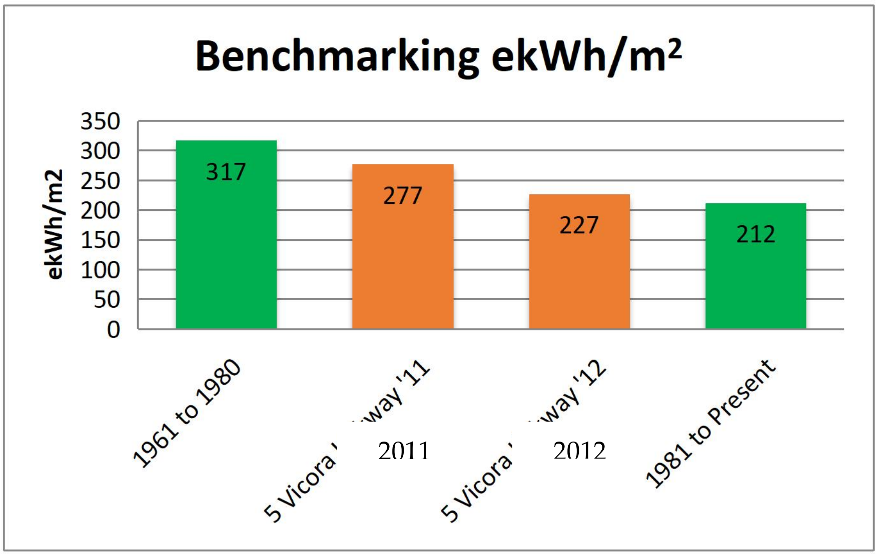


Figure 4. Ekwh/m2 benchmark of buildings across Canada compared to the subject buildings (2011 and 2012).

The regression analysis reveals a correlation coefficient of 59%, indicating a direct correlation between CDD and kWh usage (Figure 5 & 6). However, there is still ample room for improvement in terms of the strength of this relationship. Additional factors not accounted for in the analysis may influence energy consumption during the cooling period.

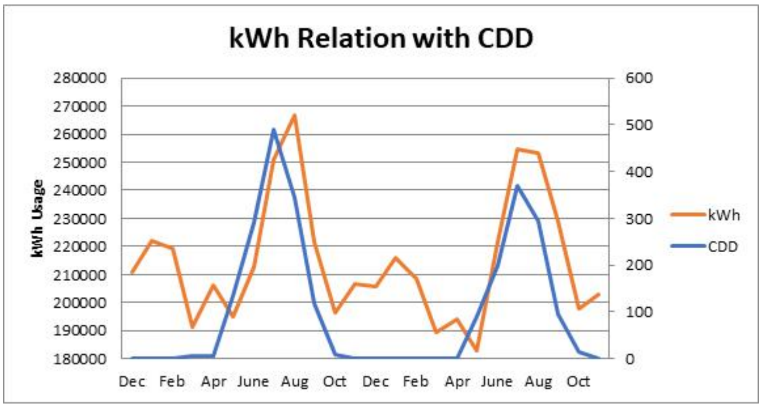


Figure 5. Correlation between KWh usage and CDD (cooling Degree Days)

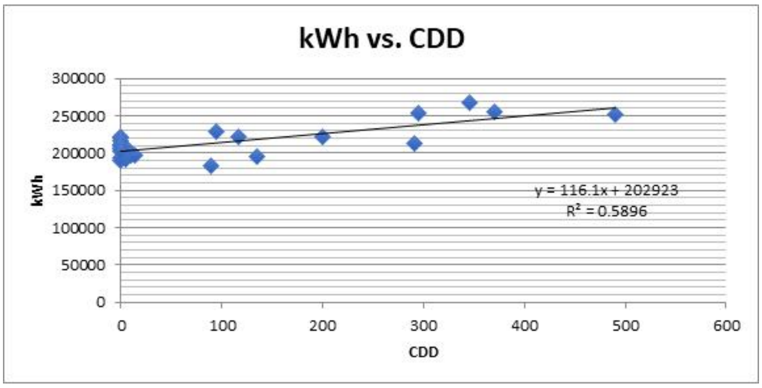


Figure 6. Correlation between KWh usage and CDD (cooling Degree Days)

8.1. Correlation Analysis between Energy Use and Degree Days

The correlation analysis examines the relationship between Cooling Degree Days (CDD) and electrical energy consumption. Figures 5 and 6 show a positive relationship between monthly CDD and kWh usage for both years analyzed. The calculated correlation coefficient of 0.59 indicates a moderate positive correlation, suggesting that cooling demand contributes to increased electricity consumption during warmer months.

Similarly, analysis of total equivalent energy use (ekWh), which combines electricity and natural gas consumption, shows a strong association with Heating Degree Days (HDD), as illustrated in Figure 7. This confirms that space heating demand is a dominant driver of annual energy consumption in the building.

8.2. Gas Consumption and Heating Degree Days

Monthly gas consumption exhibits a consistent seasonal pattern across both years, with higher usage during colder months. Regression analysis between gas consumption and HDD yields correlation coefficients of 0.91 and 0.90 for and 2012, respectively, indicating a strong linear relationship. These results demonstrate that heating requirements are closely linked to outdoor temperature conditions.

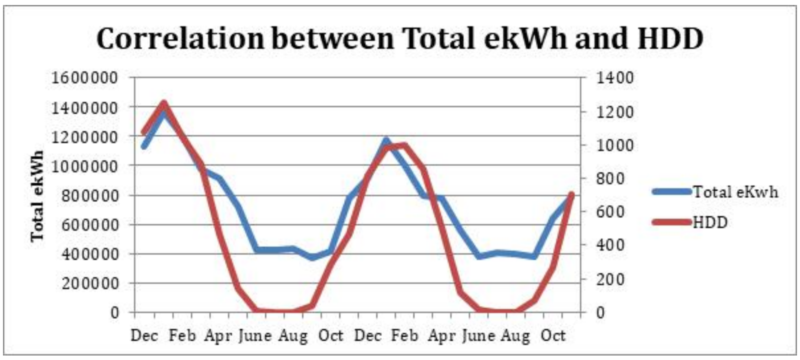


Figure 7. Correlation between eKWh and HDD (Heating Degree Days)

9. Load factor analysis

The analysis of the building's load factor Figure 8 provides insights into its energy usage. The load factor represents the ratio of peak demand to average demand. A higher load factor, closer to 1.0, indicates better efficiency and implies that the building is utilizing most of the electricity during peak demand periods. Conversely, a lower load factor suggests that the building is operating less efficiently and not fully utilizing the electricity available during peak demand**.**

During the summer months, the load factor tends to be lower, which can be attributed to the increased usage of air conditioning units. These units contribute to higher peak demands but may not be continuously operating at full capacity throughout the day, resulting in a lower load factor percentage.

Over the two-year period under consideration, the average load factor was calculated to be 70%. This relatively moderate load factor could be attributed to continuous operation of equipment and lights without downtime or the absence of variable frequency drives (VFDs). In the absence of sequencing or scheduling during startup, the constant operation of equipment and lights may contribute to a sustained load level throughout the day, resulting in a consistent load factor.

It is worth noting that a load factor of 70% suggests room for improvement in terms of optimizing energy usage and achieving higher efficiency. Implementation of strategies such as VFDs or improved scheduling and sequencing of equipment and lighting could potentially increase the load factor and enhance overall energy efficiency.

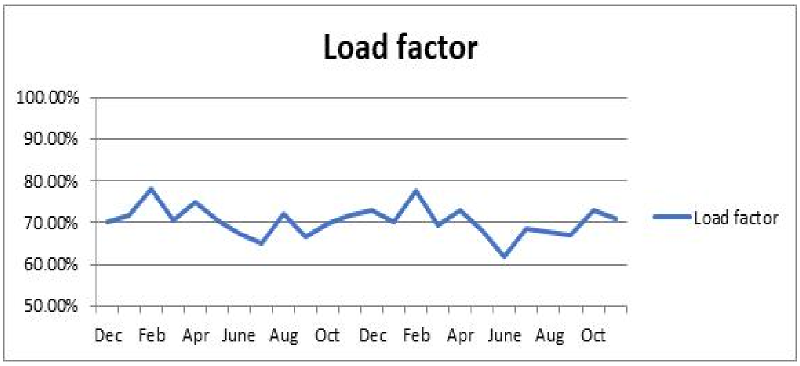


Figure 8. Load factor

10. Energy management opportunities

10.1. Lighting – Elevator lighting

The building currently has four elevators, each equipped with six GU10 bulbs that consume 50W and operate 24 hours a day. The annual consumption for interior elevator lighting is estimated at 10,512kW, with associated costs amounting to $851.47. By replacing these bulbs with Philips 6W LED MR16 bulbs, the annual consumption would decrease to 1,261.44kW, resulting in cost savings of $749.29. The total investment cost for replacing the bulbs at a rate of $16 per bulb would be $384. Considering the savings on consumption costs alone, the payback period for this investment would be less than one year.

In the elevator lobbies, there are four 4' fixtures on each floor, with two 32W T8 fluorescent bulbs in each fixture. Additionally, the first floor is illuminated by seven 4' fixtures, totaling 150 bulbs. The annual electrical consumption for this lighting setup is 42,048kW, costing $3,405 per year. Replacing these bulbs with 18W LED T8 bulbs would result in annual savings of 18,423kW and $1,490. The estimated investment cost for the LED bulbs is $30 per bulb, totaling $4,500. The payback period for this investment, based on consumption cost savings, is expected to be three years.

10.2. Lighting – The garage

In the garage, the continuous operation of lighting fixtures incurs an annual cost of $11,080.48. By replacing the existing bulbs with LED bulbs, reducing the wattage from 32W to 18W and increasing the lifespan, annual savings of $6,251.92 can be achieved. Similarly, in the shared laundry facility, the replacement of ten fixtures, each housing two 32W T8 fluorescent tubes, with 18W LED bulbs would result in annual savings of 2,452.80kW and $198.68. The estimated investment cost for LED bulbs in the laundry facility is $600, with a payback period of three years.

10.3. Lighting – The laundry facility

The laundry facility currently operates 24 hours a day without motion sensors or other light controlling devices. However, by implementing motion sensors, the estimated usage time can be reduced by approximately 66% (8 hours per day). This would result in a decrease in electrical usage of 3,737.6kW and cost savings of $302.74 annually. The installation of two occupancy sensors, specifically the Leviton ODC0S-I1W ceiling mounted sensors, priced at $108.95 each, would yield a payback period of less than one year, considering the operational cost savings alone.

Figure 9 summarises the annual savings for lighting retrofits; considerable savings are achieved across all areas, particularly in the garage and elevator lighting, where energy-efficient LED replacements significantly reduce both consumption and operational costs.

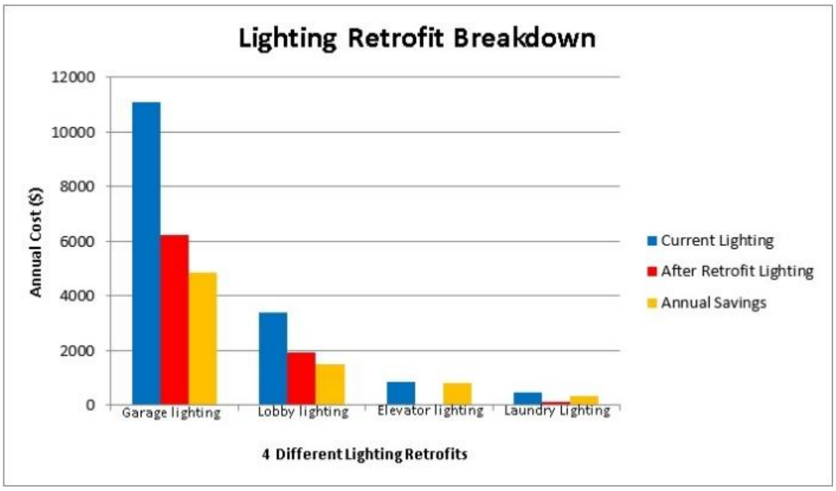


Figure 9. Lighting retrofits saving

11. Boiler replacement

Heating is supplied by three models of Futura boilers being: three Futura 1500MBH boilers rated at 85% efficiency; one 1950MBH boiler at 85% efficiency; and one 2000MBH boiler rated at 82% efficiency. If replaced with each similar MBH output all at 95% an estimated 10% reduction in annual gas consumption would return almost $9,700.00 (Calculations shown below).

$$Annual\ gas\ consumption_{2011} = 614653m^3$$

$$Estimated\ annual\ DHW\ usage = 20{,}000m^3/month = 240{,}000m^3$$

$$Annual\ gas\ consumption_{heating} = 614653m^3 - 240{,}000m^3 = 374{,}653m^3$$

$$Conversion\ to\ ft^3 = 374{,}653m^3 * 35.315 = 13.23MMft^3$$

$$Conversion\ to\ btu = 13.21MMft^3 * 1026 = 13{,}574MMbtu$$

Estimated savings of 10% = 1,357MMbtu

$$\Delta F_{Btu} = (F_{Btu} - \Delta E_{HL}) * (\eta_{new} - \eta_{orignal})$$

Where

ΔF_{Btu} = Reduction in annual fuel consumption (in Btu/yr)
F_{Btu} = Annual fuel consumption (in Btu/yr)
ΔE_{HL} = Reduction of annual heating load due to retrofits (in Btu/yr)
η_{new} = Post-retrofit equipment efficiency
$\eta_{orignal}$ = Original equipment efficiency

$$\Delta F_{Btu} = (13{,}574MMBtu - 1{,}357MMBtu) * (0.95 - 0.85)$$

$$\Delta F_{Btu} = 1{,}222MMBtu = 1{,}190{,}778ft^3 = 33{,}718.77m^3$$

@ \$0.0596 transmission charge and \$0.226 supply charge; the total annual savings for a 10% reduction would be \$9,697.55.

12. Air Conditioning units

The building does not provide air conditioning or a cooling system to the common areas. This is accomplished by supplying fresh air to the corridors through supply and exhaust fans only. Tenants control and operate individual window mounted air conditioners. A total of 193 were accounted for on the day of the initial walk through inspection. Keeping a modest estimation on the energy consumption of each unit, the total energy consumed by the conditioners total 38% of the total energy usage throughout the cooling months, May to September. Introducing a few monitoring controls or policies could possibly reduce the amount of air infiltration and electrical costs.

Policy Suggestions:

A \$40 monthly operating cost for tenants using an AC unit.

Installation review by inspector, to ensure proper and safe installation.

Calculations to show monthly charge estimation on only the 193 units counted on day of inspection, with a cooling period cost from May to September of \$35,048.64.

$$\$35{,}048.64/193units = \$181.60/unit$$

$$\$181.60/5mo. = \$36.32/mo.$$

With the expectation that some people remove their AC unit in colder months an estimated \$40/mo. would recoup the costs of the higher electrical costs during the months of May to September.

13. Exhaust fans – Time clocks

12 exhaust fans are used to control all exhaustion throughout building. A summary of fans based on type are referenced below Table 2. With fans running consistently a total annual consumption is 86,588.22kW costing \$7,013.65.

Table 2. Exhaust fan types and energy usage

Type	Amount	CFM	hp	kWh
A	3	950	1/2	1.119
B	2	2100	3/4	1.119
C	3	3850	1 1/2	3.357
D	1	3700	1	0.746
E	1	1900	3/4	0.5595
F	2	4778	2	2.984

The use of time clocks could reduce fan operation by an estimate of 8 hours per day. With this measured initiated and controlled by the DDC system on site the annual savings would be 28,862.22kW and \$2,337.88. Investment costs would be \$200 per time clock; totaling \$2,400 for all 12 exhausts fans. Payback on installing of time clocks would be 1.03 years

Baseline usage: 86,588.22kW cost \$7,013.65 per year.

Reduction from use of time clocks:

$$9.8845kW * 8\,hr/day * 365day = 28{,}862.22kW$$

$$28{,}862kW * \$0.081 = \$2{,}337.88$$

Figure 10 provides a summary of the energy and cost savings resulting from the LED lighting retrofits.

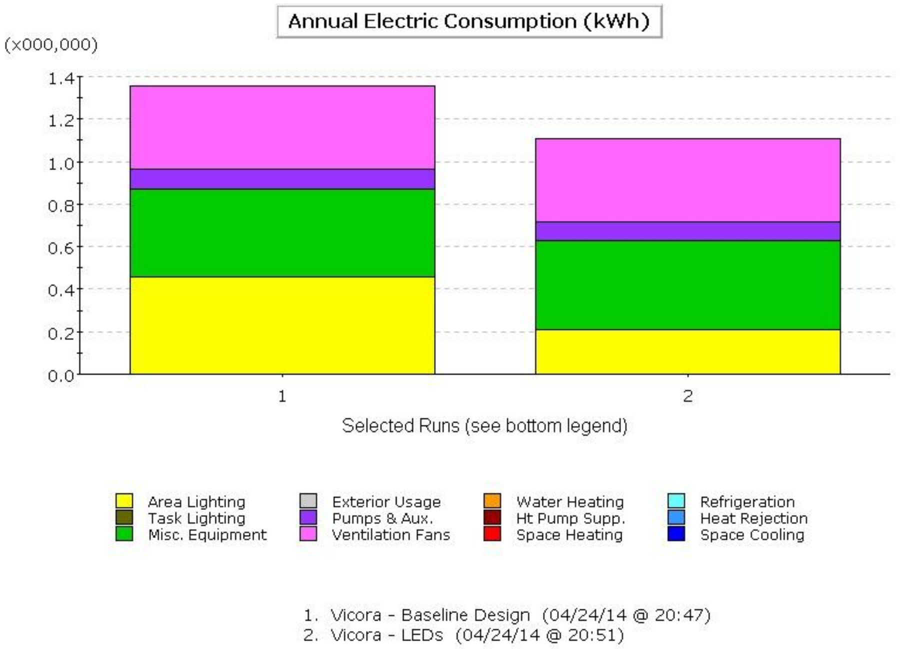


Figure 10. eQuest LED comparison

14. Energy modelling analysis

This section of the audit will employ the energy simulation tool, eQuest, which has been developed by the United States Department of Energy. eQuest allows for the creation of a 3D model of the building, incorporating the actual parameters obtained during the site visit. This 3D model can then be used to conduct energy-use simulations for various retrofit scenarios, providing a reliable estimation of the potential impact on the building's overall energy performance. Figure 11 illustrates the 3D model generated for the audited building, utilizing an AutoCAD floor plan file.

Model calibration was conducted in accordance with ASHRAE Guideline 14, using measured monthly utility data. The accuracy of the simulation was evaluated using the Normalized Mean Bias Error (NMBE) and the Coefficient of Variation of the Root Mean Square Error (CVRMSE), which are recommended statistical indicators for assessing the agreement between simulated and measured energy use. For monthly calibration, ASHRAE Guideline 14 specifies acceptable limits of ±5% for NMBE and 15% for CVRMSE. The calibrated model satisfies these criteria, indicating that the simulation provides an acceptable representation of the building's actual energy performance and is suitable for evaluating proposed energy efficiency and decarbonization measures.

14.1. Zoning

eQuest enables the modeling of the building based on user-defined conditioning zones. These zones take into account factors such as orientation, function, exposure, and heating requirements. Figure 12 displays the zoning configuration for the living areas of the building have been subdivided into three main wings to ensure that the exterior exposures are accurately represented in the model. This zoning approach allows for a more precise evaluation of the building's energy performance and aids in identifying potential areas for improvement

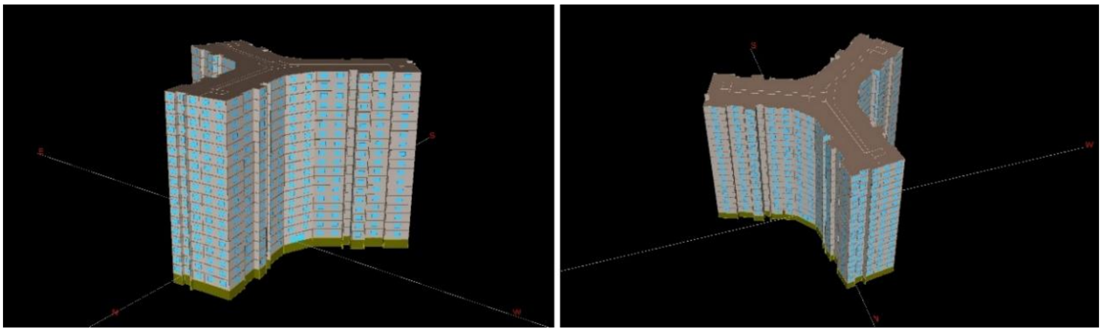


Figure 11. eQuest 3D model of the building

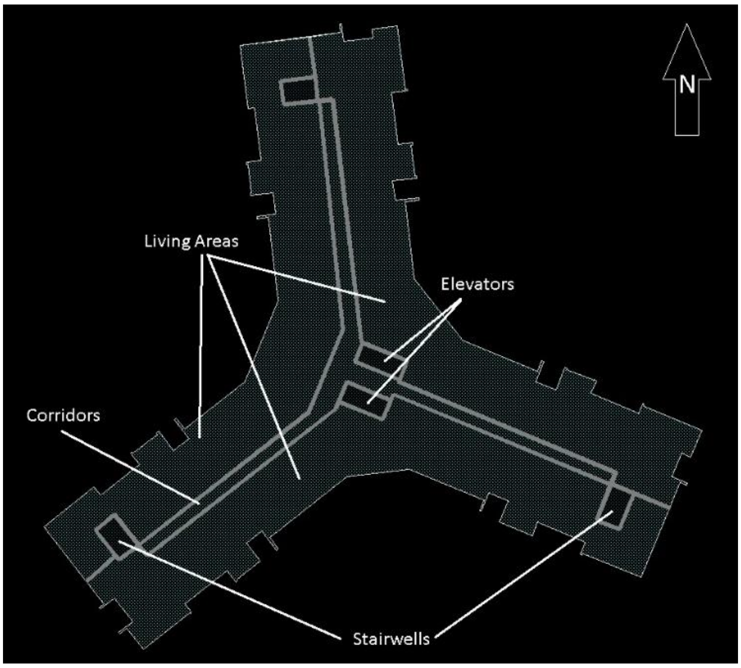


Figure 12. eQuest zoning pattern

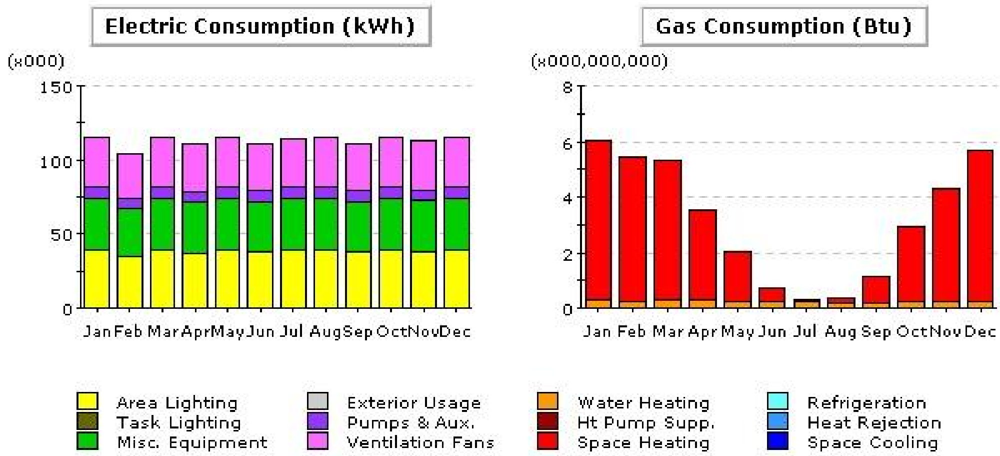


Figure 13. Baseline eQuest run

14.2. Simulation design parameters

The information gathered from the site visit and architectural drawings provided enough information to set the major design parameters for the simulation (Table 3). With these variables a baseline simulation run was established Figure 13: this base line is used as a benchmark for energy saving options. For this energy simulation two energy saving measures were examined: slab edge insulation and retrofitting the existing boilers to a higher efficient condensing boilers.

Table 3. Energy simulation parameters

Envelope Performance		**Mechanical systems**	
Parameter	Setting	Parameter	Setting
Building Type	Multifamily, hi-rise	Occupation schedule	Default MURB
Climate Zone	Toronto, Ontario	Laundry	Common area
Building Area	346,178ft²	Loads per week	~1.5
Floors (above /below)	18 above grade 1 below grade	Heating setpoint	68°F

Cooling Equipment	No cooling	Cooling setpoint	78°F
Heating Equipment	Hot water coils	Boiler Efficiency	2@83%, 1@85%
Roof R-value	R26	Boiler type	Natural Draft
Wall R-value	R11	Boiler Fuel	Natural Gas
Window type	Double pane, ¼” air gap, aluminum frame with no thermal break	# of system pumps	3
Window U-value	0.55	Pump efficiency	Standard
Apartment curtains	Yes	DHW boiler efficiency	85%

14.3. Slab edge insulation

The exposed slab edges transfer heat directly to the exterior environment. This not only causes energy loss, increasing utility bills, but also creates occupant discomfort and cold floors. An eQuest simulation was conducted to evaluate the impact of renovation on gas consumption. For the energy modeling, 2 inches of polystyrene foam board were added to the slab edges. Figure 14 shows the baseline of 37,790,000 Btu of gas and the energy efficiency benefits of adding slab insulation, reducing gas consumption to 34,230,000 Btu—a savings of 3,560,000 Btu, equivalent to approximately 101 m^3 of natural gas.

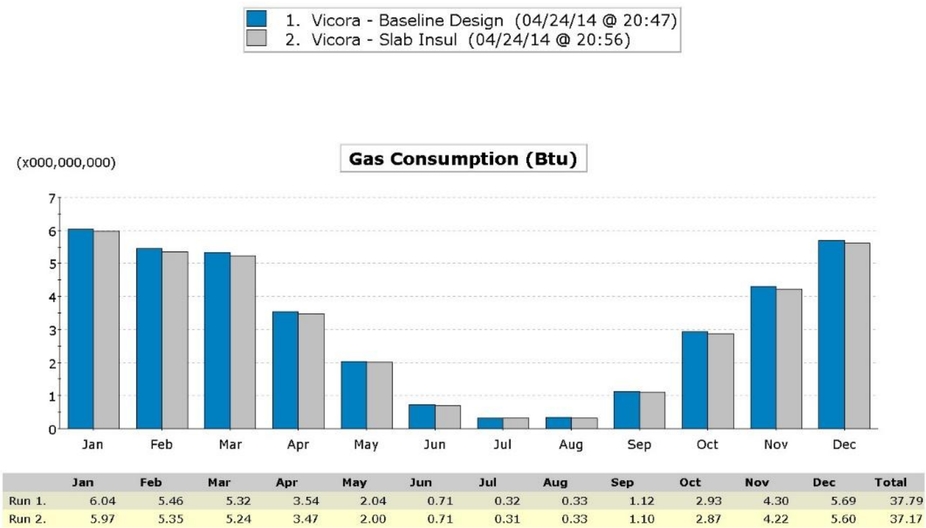


Figure 14. eQuest- slab edge insulation

14.4. High efficiency condensing boilers

The building has three boilers: two with an efficiency of 83% and one with 85%. An eQuest simulation figure 15 was conducted to evaluate the impact of replacing all three mid-range boilers with new boilers rated at 93% energy efficiency. As shown in Figure 15, there is a clear improvement, with gas consumption reduced from the baseline of 37,790,000 Btu to 37,728,000 Btu—a savings of approximately 62,000 Btu.

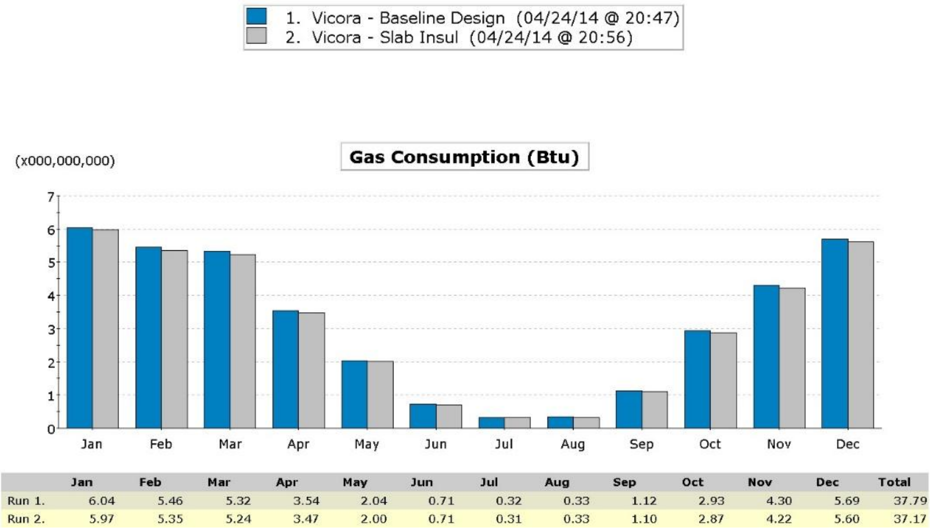


Figure 15. eQuest- High efficiency boilers

15. Greenhouse gas emissions

This building produced a total of 4,461 t CO_2e/year metric tons of Carbon Dioxide (based on electrical consumption of 5,348.508 KW/h year and gas consumptions of 1,418.791 m3/ year), contributing to the total amount of greenhouse gases emitted into the atmosphere annually. The planned building retrofits yield an annual reduction of ~1,106 t CO_2e, cutting total emissions by roughly 25% from the baseline of 4,461 t CO_2e/year (Figure 16). Key contributors (Table 4) include boiler replacements and garage lighting upgrades.

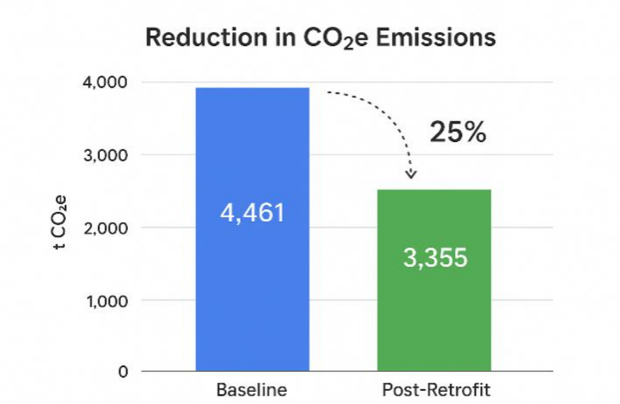


Figure 16. Reduction in Co2e emission by 25%

Table 4. Building retrofits and carbon counting kg CO_2e

Description	Units	Current Use	Energy Management	Energy Saving (kWh/year)	kg CO_2e
Lighting – Elevator Lighting	kWh/year	10,512.00	1,261.44	9,250.56	277.52
The elevator lobbies	kWh/year	42,048.00	18,423.00	23,625.00	708.75
Lighting – The garage	kWh/year	136,796.00	2,452.80	134,343.20	4,030.30
Lighting – The Laundry Facility	kWh/year	5,606.40	3,737.60	1,868.80	56.06
Boiler Replacement (m^3)	m^3	614,653.00	33,718.77	580,934.23	1,098,966.26
Exhaust Fans – Time Clocks	kWh/year	86,588.22	28,862.22	57,726.00	1,731.78
Slab Edge Insulation	BTU	37,790,000.00	34,230,000.00	3,560,000.00 BTU	192.00
High Efficiency Condensing Boilers	BTU	37,790,000.00	37,170,000.00	620,000.00	33.50
Total					**1,105,996.17**
					1,106 t CO_2e

16. Conclusion

This study demonstrates that targeted energy retrofits and electrification are effective pathways toward decarbonising Canada's multi-unit residential building (MURB) sector. The audit of the Toronto building revealed that lighting upgrades, insulation improvements, boiler replacements, and smart control systems can collectively reduce annual energy consumption by approximately 25% and lower emissions by more than 1,100 t CO_2e per year. The findings reinforce the importance of prioritizing both technical interventions and occupant engagement to achieve lasting emission reductions. As older residential buildings continue to account for a significant share of urban energy use, strategic electrification supported by renewable electricity and enhanced building envelopes offers a cost-effective and equitable route to meeting municipal and national net-zero goals by 2050.

17. Discussion: Retrofit Contributions to Decarbonisation (kg CO_2e)

The results highlight the dominant role of climatic factors particularly outdoor temperature in shaping energy consumption patterns in the audited multi-unit residential building. The moderate correlation observed between cooling degree days (CDD) and electricity use ($R = 0.59$) suggests that cooling demand is an important, but not exclusive, driver of summer electricity consumption. While increased use of window-mounted air conditioning units clearly contributes to higher electricity demand, the strength of the correlation indicates that additional factors are also influencing consumption patterns.

Unmodeled variables such as occupant behaviour, variability in air conditioner efficiency, differences in usage schedules, appliance loads, and levels of air infiltration likely affect electricity use during the cooling season. The absence of sub-metering and unit-level operational data limits the ability to isolate these effects quantitatively, and as a result, the observed correlation should be interpreted as indicative rather than causal. These findings point to the importance of combining cooling demand management strategies with behavioural and operational interventions to achieve meaningful electricity reductions.

In contrast, the strong correlations between heating degree days (HDD) and both natural gas consumption and total equivalent energy use reinforce the conclusion that space heating is the primary determinant of annual energy demand in this building. This finding is consistent with previous benchmarking and audit studies of Toronto MURBs, which identify heating loads as the largest contributor to energy intensity in older high-rise residential buildings. The carbon-counting results further substantiate this conclusion by demonstrating that heating-related retrofits deliver the largest emissions reductions among all evaluated measures.

Specifically, boiler replacement yields an estimated reduction of approximately 1,098,966 kg CO_2e per year, far exceeding the emissions savings achieved by other individual interventions. This result underscores the critical role of heating system upgrades in decarbonisation strategies for cold-climate MURBs. Additional heating-related measures, including slab edge insulation and high-efficiency condensing boilers, contribute further emissions reductions of approximately 192 kg CO_2e and 34 kg CO_2e, respectively, by reducing heat loss and improving system efficiency.

Electricity-focused retrofits, while contributing smaller absolute carbon reductions, provide important complementary benefits. Lighting upgrades in the garage, elevator lobbies, elevators, and laundry facilities collectively reduce emissions by several thousand kilograms of CO_2e annually, with garage lighting alone accounting for approximately 4,030 kg CO_2e in savings. Similarly, the installation of time clocks for exhaust fans results in an estimated 1,732 kg CO_2e reduction per year, illustrating how operational controls can yield measurable emissions benefits with relatively low capital investment.

Importantly, the correlation analysis does not capture retrofit interactions, system efficiencies, or behavioural adaptations that may occur following energy upgrades. Nor does it account for the compounding effects of bundled retrofit measures, which the carbon-counting results show to be significant. When implemented collectively, the retrofit package achieves an overall emissions reduction of approximately 25%, equivalent to more than 1,100 t CO_2e annually, consistent with the reductions illustrated in Figure 16.

Overall, separating results from interpretation clarifies the analysis and highlights the need for caution when linking energy trends to single factors. Together, the correlation analysis and carbon accounting show that prioritising heating upgrades, envelope improvements, operational controls, and cooling demand management is key for reducing emissions in similar multi-unit residential buildings. These findings support carbon-informed retrofit planning as a practical pathway to decarbonising Canada's aging MURB stock.

18. Limitations of the Study

This study is subject to several limitations that should be acknowledged. First, access to individual dwelling units was not available during the site visit; therefore, assumptions were made regarding indoor temperatures, occupant behavior, thermostat setpoints, and window-mounted air conditioner usage. While these assumptions were based on conservative estimates and field observations, actual tenant behavior may vary and influence energy consumption patterns.

Second, calibration of the energy model was conducted using aggregated monthly utility data rather than sub-metered end-use measurements. Although this approach is common in large multi-unit residential buildings, it limits the ability to capture variability at the suite level and may introduce uncertainty in modeled savings.

Finally, the life-cycle carbon assessment focuses primarily on operational emissions associated with energy use. Embodied carbon related to retrofit materials, construction activities, and equipment replacement was not fully quantified and should be explored in future research to provide a more comprehensive life-cycle evaluation.

Despite these limitations, the combined use of on-site audits, thermographic analysis, benchmarking, and calibrated energy modeling provides a robust basis for evaluating decarbonization strategies in aging multi-unit residential buildings.

19. Future research

Future research should broaden the scope of life-cycle carbon assessment to include both operational and embodied emissions associated with retrofit projects.

Other future research topic would to conduct comparative studies across diverse climate regions and building ages would help tailor decarbonization strategies to local conditions. Incorporating socio-behavioural insights such as resident comfort preferences and how buildings are actually used after retrofits could also narrow the gap between projected and real energy savings.

Moreover, future work should examine how electrified systems perform over the long term, particularly during peak winter demand, and how they interact with on-site renewable energy generation and storage. Adopting this integrated framework would enhance overall building carbon efficiency while guiding scalable policy solutions for Canada's existing residential stock.

Occupant Engagement and Awareness

Actively involving residents is essential for achieving lasting decarbonization outcomes. Creating a joint tenant–management sustainability team can encourage participation in energy-saving practices, monitor performance, and share actionable advice on everyday sustainable habits. Digital communication tools, real-time energy dashboards, and brief educational sessions on efficient appliance use and heating management can empower residents to become proactive contributors to emission reduction. These initiatives not only enhance comfort and building performance but also reinforce community engagement as a key driver in Canada's shift toward low-carbon housing.

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Competing Interests

The authors have no competing interests to declare

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