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Energy Audits and Energy Modeling as a Tool towards Reducing Energy Consumption in Buildings: The Cases of Two Multi-Unit Residential Buildings (MURBs) in Toronto

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Abstract: This research is based on an energy audit of two multi-unit residential buildings (MURBs) located in Toronto, Canada. Energy consumption (gas and electricity) data were extracted from the energy bills of the two buildings for a consecutive period of three years. The data were then normalized to account for variations in weather conditions. Conclusions were drawn from correlation analyses between kWh, cooling degree days (CDDs), and heating degree days (HDDs), which were then compared to the energy consumption benchmarks of MURBs within the GTA. An energy simulation using e-Quest v.3.64 was performed, utilizing the advantages of the e-Quest building modeling tool to create a virtual 3D model of the audited buildings. A baseline model was constructed to reflect the actual buildings and was used to simulate the outcomes and calculate the projected energy savings from window replacements with a higher energy efficiency than the existing ones. The simulation results revealed that triple low-E glazing outperformed single- and double-glass windows, achieving reductions of 38% and 34% in gas consumption, respectively. The building envelope simulations showed that enhancing insulation reduced gas consumption by 4%, while an insulation upgrade demonstrated no discernible savings. Reducing the window area by 20% (north/south sides) led to a 6% decrease in gas consumption, while a 30% reduction resulted in approximately 9% of energy savings.

Keywords: energy audit; building performance; energy modelling; e-Quest

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1. Introduction

Buildings account for over 30% of the world's total final energy consumption and about 19% of its total greenhouse gas (GHG) emissions, making them one of the primary contributors to global warming. Consequently, numerous countries and local authorities are implementing or have already established regulations to encourage the development of ultra-low energy and low-emission buildings, aiming to mitigate the impact of global warming [1]. The city of Toronto has pledged to reduce its greenhouse gas (GHG) emissions by 30% by 2020 and aims for an 80% reduction by 2050, aligning with Canada's broader target of cutting greenhouse gas emissions by at least 80% by 2050. The Canadian federal government had invested in cleaner energy and in energy efficiency, through making buildings more energy-efficient and purchasing sustainable products and greener power. Greenhouse gas (GHG) emissions from federal operations have already been lowered by 28% compared to 2005 levels, and the government has a steadfast commitment to achieving an additional 40% reduction by the year 2030 [2]. The findings derived from the examination of electrical energy usage and indoor environmental conditions aid in the quest for sustainable measures to decrease energy consumption and enhance thermal comfort within buildings [3]. Energy efficiency could be achieved after applying a process called energy audit and planning. Energy audit is used as an efficient method tool to assess and study the energy profile of a large office building. The analysis encompasses a thorough examination of the building's diverse components, including wall specifications, roof structures, windows, lighting fixtures, office equipment, chillers, HVAC systems, supplementary air-conditioning units like split types, and other equipment present in the building [4]. Assessing the thermal conditions and conducting an energy analysis within indoor spaces holds significant importance when it comes to minimizing energy consumption and managing the indoor climate [5]. Standardized the auditing scheme for assessing energy efficiency in water supply systems; specific energy consumption and pump efficiency are not sufficient for evaluating the energy efficiency of a given system [6]. The application of a novel energy-auditing scheme in a real water supply system and its sub-systems to determine major sources of energy inefficiency is presented [7]. A dataset containing 29 audits of multifamily buildings was used to analyze buildings before and after refurbishment. The analysis showed a strong correlation between the thermal demand for space heating or domestic hot water and ventilation airflow and the thermal transmittance of windows. Ref. [8] was simulated with ArchiCAD to assess how window glazing, opaque materials, and shading elements impact the overall energy efficiency of the building. The research findings indicated that, by optimizing the window parameters, the infiltration rate and heat transfer coefficient were improved, resulting in a 3% to 6% reduction in the cooling load [9]. The evaluation of energy retrofits in Toronto's MURB (multi-unit residential building) stock is carried out; among the building characteristics analyzed, the fenestration ratio showed the highest correlation (R^2 = 0.69 for double-glazed windows) with building energy intensity [10]. The study entails performing energy (weather-normalized using the Princeton Scorekeeping Method (PRISM)), water, and solid waste benchmarking for the 120 MURBs, developing meaningful performance indicators; determining the performance ranking; and estimating different levels of savings (energy, water, solid waste, cost, and GHG emissions) [11]. This study also addresses the data limitations of the meta-analysis by examining a refined dataset composed of 40 MURB buildings in Toronto [12]; investigated the influence of different drone settings on the quality of thermographic images for building audits in comparison to ground-based acquisition [13]; presents an open-access tool that offers an automated process that can be used to audit an urban area [14]; and addresses this gap by discussing the effectiveness of retrofit energy and water efficiency measures implemented in a commercial building [15].

2. Objective of the Work and Methodology

The objectives of this research are to provide an energy audit for two multi-unit residential buildings (MURBs) located in Toronto, Ontario. Energy audits are crucial from an environmental perspective as they directly contribute to reducing energy consumption, greenhouse gas emissions, and resource depletion. The research can serve as a catalyst for sustainable practices and foster a more environmentally conscious community. The aim of this research is to assess the energy consumption patterns of two buildings and identify areas where energy efficiency can be improved. By analyzing energy use and pinpointing inefficiencies, the research aims to help reduce the overall energy consumption of these buildings. Decreasing energy consumption leads to a lower demand for energy generation, which, in turn, can help reduce the environmental impact associated with energy production. Buildings are significant contributors to greenhouse gas emissions due to their energy consumption. By conducting an energy audit and implementing energy-saving measures based on its findings, the research can help decrease the carbon footprint of the MURBs. This contributes to the global effort to combat climate change and aligns with sustainability goals. The importance and necessity of the study can be outlined as follows:

Environmental: Energy audits play a vital role in decreasing energy usage, greenhouse gas emissions, and resource depletion. By identifying inefficiencies and implementing energy-saving measures, the study actively contributes to minimizing the environmental consequences associated with energy usage.

Sustainability: The research serves as a catalyst for promoting sustainable practices within the buildings and fostering a community that is conscious of environmental concerns. Through the reduction of energy consumption and carbon footprints, the study aligns itself with global endeavors to combat climate change and actively supports sustainability objectives.

Contribution to greenhouse gas emissions: Buildings have a significant impact on greenhouse gas emissions due to their energy consumption. The study addresses this critical issue by thoroughly analyzing energy usage and identifying ways to curtail overall consumption, directly impacting the emission of carbon dioxide.

Methology

To facilitate this study, the following were conducted: a review of all pertinent drawings and documents, a review of the original electrical drawings of the two buildings, a site visit to review the building envelope and the mechanical and electrical systems, and data collection from the two buildings—measuring the windows and buildings, calculating building areas and light densities, conducting an analysis of the utility bills (gas and electricity consumption). Using standard reference software (e-Quest) v.3.64, an energy simulation analysis was conducted for the two buildings and the potential energy savings related to window replacements were estimated.

To facilitate this comprehensive study, an array of essential steps and examinations were conducted. Initially, a meticulous review of all pertinent drawings and documents pertaining to the two buildings was undertaken.

Additionally, a comprehensive site visit was carried out, enabling an in-depth assessment of the building envelope, as well as the mechanical and electrical systems. Data collection was paramount, and measurements were taken for various aspects, such as window dimensions and overall building dimensions. These measurements proved vital for calculating crucial metrics such as building areas and light densities.

To better comprehend the buildings' energy consumption patterns, a detailed analysis of the utility bills was conducted. This included a thorough analysis of the electrical (Kwh) and gas consumption (m^3) during a period of three years. This encompassed a careful examination of gas and electricity consumption, identifying potential areas for optimization.

Employing state-of-the-art modelling software (e-Quest), an intricate energy simulation analysis was performed for the two buildings. This advanced simulation allowed for a precise estimation of potential energy savings directly related to the implementation of window replacements. The findings obtained from this analysis will undoubtedly serve as a valuable guide for future energy-efficient measures and enhancements in the buildings, aligning with sustainable and environmentally conscious practices.

3. Case Studies

3.1. Description of the Buildings

The two buildings analyzed are all located in Toronto, Ontario. Built in the late sixties, the buildings are of typical "flying form" construction. Building 1 is nineteen (19) storeys tall; the building has approximately 22,970 m^2 of space (Figure 1). The second building was also built in the late sixties; this building is twelve (12) storeys tall and has approximately 14,712 m^2 of space (Figure 2). The common areas of the two buildings are primarily located on the first floor and include a main entrance lobby and elevator lobby. No central cooling system is provided for the building; the corridors are vented by a rooftop air-handling unit providing ventilated air at 18°C. The rest of the heating load of the space is met by the hydronic baseboard terminals in the apartments and in the common areas.

Figure 1. Building 1 (by the author).

Figure 2. Building 2.

3.2. The Building Envelope

Building 1 has a total roof area of 1226 m^2, and Building 2 has a total roof area of 732 m^2. The existing roof systems for the two buildings have an RSI value (R-value 10). The roofs consist of 10 mm built-up roofing with build-up layers, 125 mm polystyrene insulation, 0.2 mm vapor permeable felt, and a 250 mm concrete slab. Visual observation revealed that the building's exterior walls are clad with glazed brick. It is not known if the walls have any insulation within them. The exterior wall construction is as follows: exterior face of glazed brick, 25 mm air space, 25 mm (1″) insulation board (polystyrene), 150 mm concrete masonry unit (CMU), and plaster on lath. The total RSI value is 1.51 m^2 °C/W. the walls located at the roof level showed signs of deterioration and isolated deterioration conditions (mortar joints). Windows of the two buildings consist of single-glazed, non-thermally broken aluminum frames. The glazed units are combinations of operable and fixed units. Based on site measurements, the estimated window area of Building 1 on the south elevation is 54.8%, on the north elevation 63.4%, 5.5% on the east side, and 5.5% on the west side. Site measurements of Building 2 are as follows: the estimated window area on the south elevation is 33%, on the north elevation 42.9%, 1% on the east side, and 1% on the west side (see Table 1).

Table 1. Building envelope performances, internal loads, and mechanical systems of the two buildings.

Envelope Performance		
	Building 1	**Building 2**
Model Climate Zone	Toronto, Ontario	Toronto, Ontario
Net Floor Area	22,970 m^2/247,120 ft^2	13,889 m^2/149,499 ft^2
Overall Roof R-Value	R_{SI}-4.4 (R_{IP}-25)	R_{SI}-4.4 (R_{IP}-25)
Roof Area	1226 m^2	731 m^2
Overall Wall R-value	R_{SI}-1.5, (R_{IP}-8.5)	R_{SI}-1.5, (R_{IP}-8.5)
Window Area (percentage)	North elevation: 42.9%	North elevation: 63.4%
	South elevation: 33%	South elevation: 54.8%
	East elevation: 1.1%	East elevation: 5.5%
	West elevation: 1.1%	West elevation: 5.5%
Glazing type	Single Clear, 1/8 inch, Aluminum without Breaker	Single Clear, 1/8 inch, Aluminum without Breaker
Interior Shades	None	None
Internal Loads		
Lighting Power Density (Residential units)	0.47 W/ft^2	0.47 W/ft^2
Lighting Power Density (Corridor)	0.088 W/ft^2	0.088 W/ft^2
Lighting Schedule	Standard	Standard
Lighting Controls	No Lighting Control	No Lighting Control
Occupant Density (Residential units)	ASHRAE 62.1-2007	ASHRAE 62.1-2007
Occupant Density (Common areas)	ASHRAE	ASHRAE
Occupancy Schedule	ASHRAE	ASHRAE
Mechanical Systems		
System Type	Distributed Heat Pump with Auxiliary Boiler	Distributed Heat Pump with Auxiliary Boiler
Apartments Heating Type	Hydronic basebords	Hydronic basebords
Auxiliary Heating Type	Gas Fired Modulating	Gas Fired Modulating
	Non Condensing Boiler	Non Condensing Boiler
Boiler Efficiency (Camus)	85%	85%
Domestic Hot Water (Camus) Boilers Efficiency	85%	85%

3.3. The Heating and Lighting Systems

By law, landlords must maintain a minimum temperature of 21 °C in the dwelling units during the heating season, which is designated as the 15th of September through to the 1st of June. Building 1's heat is generated by (2) Camus Boilers, 4,000,000 BTu/h Moduflame 780020, each with an energy-efficiency rating of 85%, and (2) Powermaster fire tube boilers (of 1967 vintage) with a maximum capacity of 300 hp each, operating on natural gas. The Powermasters are only used in the deep winter months, when additional heating capacity is required. The Powermaster boilers appear to be the original equipment and are in poor condition (i.e., they are considered to have reached the end of their service life). The Camus boilers were installed in the 2000s and appear to be in excellent condition. The boilers provide hot water to heat the building and to heat the domestic hot water supply. It appears that, originally, the terminals (radiant hot water baseboard heaters) were controlled by thermostat-actuated hot water control valves, with one thermostat per apartment unit or common area. In this configuration, there is no method for unit occupants to locally control the heating system.

3.4. Heating Terminals

Heating is provided by hot water radiant baseboard heaters. The baseboard heating is controlled by thermostats located in the apartments which actuated the hot water control valves. Most of the original control systems were found to be disabled and removed. Therefore, the heaters' current condition is such that there is no control to reduce or increase the amount of heating output to match the actual heating loads.

3.5. Lighting

Fluorescent light fixtures are common throughout the building's common areas, including hallways and exit stairwells. Most areas use 32-watt T8 lamps. The lights in the hallways and stairwells are lit at a constant level, 24 h per day in an effort to meet the City of Toronto code requirements. Light in the corridors are lit with 22 W circular fixtures. In addition, T8 fluorescent lamps are used beside the elevators. The lighting in the parking fixtures have been changed to 22 W. These fixtures are operated continuously at a constant intensity (no timers or dimmers are employed). The lighting in the apartments was found to be a mixture of inefficient incandescent lamps (bathrooms) and highly efficient compact fluorescent lamps (CFLs). All interior building lighting is manually controlled via wall switches. The building has no energy control measures such as occupancy sensors.

4. Energy Consumption

The energy consumption data for gas and electricity in two buildings (Building 1 and Building 2) were extracted from their respective energy bills over a consecutive period of nearly four years (3 years and 3 months). Table 2 displays the yearly consumptions along with an average use column. Figure 3 illustrates the electrical consumption profiles in kWh for both buildings (the top two diagrams in Figure 3 depict the electrical consumption profiles of Building 1 and Building 2, with each color representing monthly consumptions).

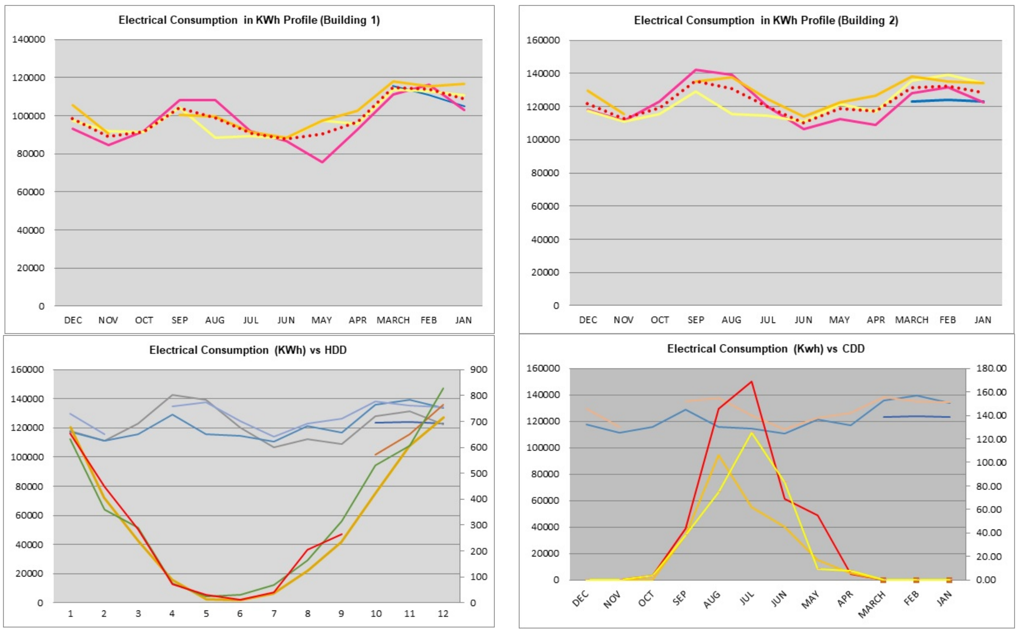


Figure 3. (**Top**) Electrical consumption in KWh for building, (**Bottom**) diagrams Kwh vs. heating degree days and cooling degree days (by the author).

Table 2. Electrical consumptions in KWh of the two buildings (building 1 and building 2) during a period of four years.

	Electrical Consumption in KWh (Building 1)				
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Average Use**
DEC		93,033.59	97,287.60	105,574.88	98,632.02
NOV		84,429.89	91,821.27	90,589.56	88,946.90
OCT		91,982.92	91,553.51	-	91,768.21
SEP		108,150.87	104,104.35	100,305.48	104,186.90
AUG		108,170.21	88,577.99	99,645.80	98,798.00
JUL		91,928.65	89,262.18	91,331.23	90,840.69
JUN		86,543.62	87,901.16	88,334.48	87,593.09
MAY		75,649.48	97,564.91	97,286.60	90,166.99
APR		92,682.08	95,494.68	102,487.12	96,887.96
MARCH	115,832.90	111,288.76	113,544.46	117,938.36	114,651.12
FEB	111,031.75	116,174.61	112,947.26	115,562.20	113,928.96
JAN	104,887.10	102,898.77	110,886.60	116,628.67	108,825.29
Total	**331,751.75**	**1,162,933.46**	**1,180,945.96**	**1,125,684.38**	1,185,226.13
	Electrical Consumption in KWh (Building 2)				
	Year 1	**Year 2**	**Year 3**	**Year 4**	**Average use**
DEC		118,087.78	117,610.72	129,773.86	121,824.12
NOV		111,408.05	111,224.60	115,692.06	112,774.90
OCT		123,093.65	115,440.47	-	119,267.06
SEP		142,441.42	128,954.01	134,987.29	135,460.90
AUG		139,204.42	115,661.21	137,809.25	130,891.63
JUL		119,890.61	114,647.71	124,678.06	119,738.79
JUN		106,505.22	110,740.24	114,069.80	110,438.42
MAY		112,496.74	121,528.71	122,724.82	118,916.76
APR		108,804.38	117,070.22	126,352.53	117,409.04
MARCH	123,305.52	128,227.45	135,665.54	138,309.51	131,377.00
FEB	123,961.72	131,601.53	139,359.06	135,401.97	132,581.07
JAN	122,971.30	122,372.97	133,900.09	134,174.00	128,354.59
Total	**370,238.54**	**1,464,134.20**	**1,461,802.57**	**1,413,973.12**	1,479,034.28

5. Normalization of Use of Energy: Heating Degree Days (HDD) and Cooling Degree Days (CDD)

Heating degree days (HDD) is a meteorological and energy management concept similar to cooling degree days (CDD), but it focuses on quantifying and estimating the amount of energy required for heating a building or a region during a specific period of time. The concept of heating degree days is based on the idea that, as the outdoor temperature drops, the demand for heating systems to maintain indoor comfort increases. It is particularly useful in regions with cold climates, where heating is a significant component of energy consumption during colder seasons. To calculate the total heating degree days for a specific period, you would sum up the individual HDD values for each day within that period. Heating degree days are used by energy analysts, utility companies, and building owners to estimate heating energy consumption and to determine the size and capacity of heating systems needed to meet heating demands during colder periods. They are also valuable in comparing heating requirements between different regions with varying climates and in assessing the impact of temperature changes on energy usage for heating purposes. The concept of cooling degree days is based on the assumption that, when the outdoor temperature rises, the need for cooling also increases.

For the analysis of energy consumption, this study has employed a methodology which consists of the following: The analysis follows three main steps. In the first step, we need to convert the gas consumption into metrics, and we need to multiply the gas consumption by a conversion factor of 10.278 to convert m^3 into ekwh. The second step of this analysis is the normalization of heating energy by HDD (heating degree days); in this phase, we need to collect weather data, then establish correlations between heating energy and HDD and the normalization of heating energy based on climate. The third step is to compare the energy performance of a similar building with this building; this is accomplished by collecting data on the energy performance of similar buildings, then carrying out a normalization of energy use by floor area and by the number of units. An average energy consumption (E) for heating or cooling the building during a particular number of days is proportional to the sum of the differences between the daily outdoor mean temperature and some base temperature (Toutdoor–Tbase) for a given number of days E = Coef* S (Toutdoor–Tbase), where Tbase = 18 °C for Canada.

In order to compare the energy consumption, a weather normalization was carried out. Figure 4 shows the correlations between gas consumption and HDDs (heating degree days). The heating curve was above the HDD curve; this is mainly due to the overheating of the buildings. There is a strong correlation (the coefficient of correlation R^2 = 0.8215) between the exterior temperature and gas consumption (expressed here as HDD). Variances in this relationship are likely attributable to gas consumption related to domestic hot water heating. The building envelope also has an impact on the overall gas consumption; an efficient building envelope has a strong influence on energy consumption.

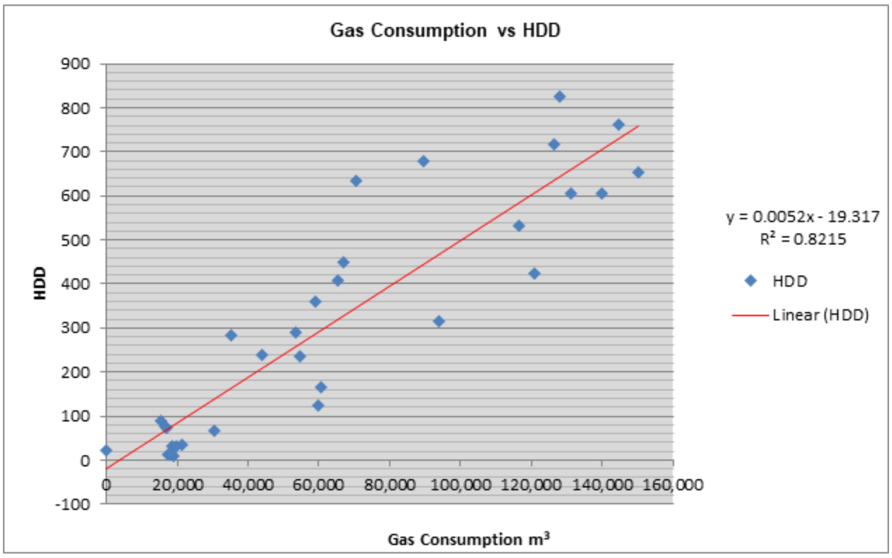


Figure 4. Correlation between gas consumption in m^3 and HDD.

Building Efficiency Index and Benchmarks

The Canadian Mortgage and Housing Corporation reported that the average annual energy consumption between 1981 and 2007 for a typical floor area (ekWh/m^2) was 212 ekWh/m^2 (Table 3). The combined energy consumption for the two buildings under study averaged 372 ekWh/m^2. Comparing this figure to the value provided by the Canada Mortgage and Housing Corporation (212 ekWh/m^2) in Figure 5, it's evident that the two buildings are using 15% more energy than comparable structures of similar size and age, and 44% more than those constructed between 1981 and 2007.

Table 3. Average energy consumption of multi-unit residential buildings (CMHC, 2001) [16].

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)	Water (m^3)	Water/Suite (m^3/Suite)	Water/Floor Area (m^3/m^2)
1981 to 2001	9	2,553,265	21,437	212	5.89	0.06	21,727	202	2.07
1961 to 1980	26	4,012,513	22,266	317	5.0	0.7	37,264	184	2.59

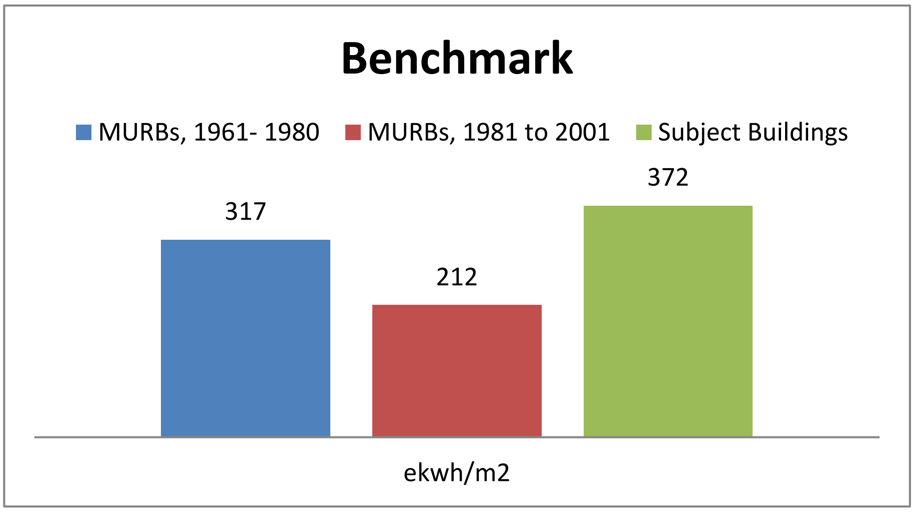


Figure 5. ekwh/m^2 benchmark of buildings across Canada compared to the subject buildings (building 1 and building 2).

6. Energy Modeling

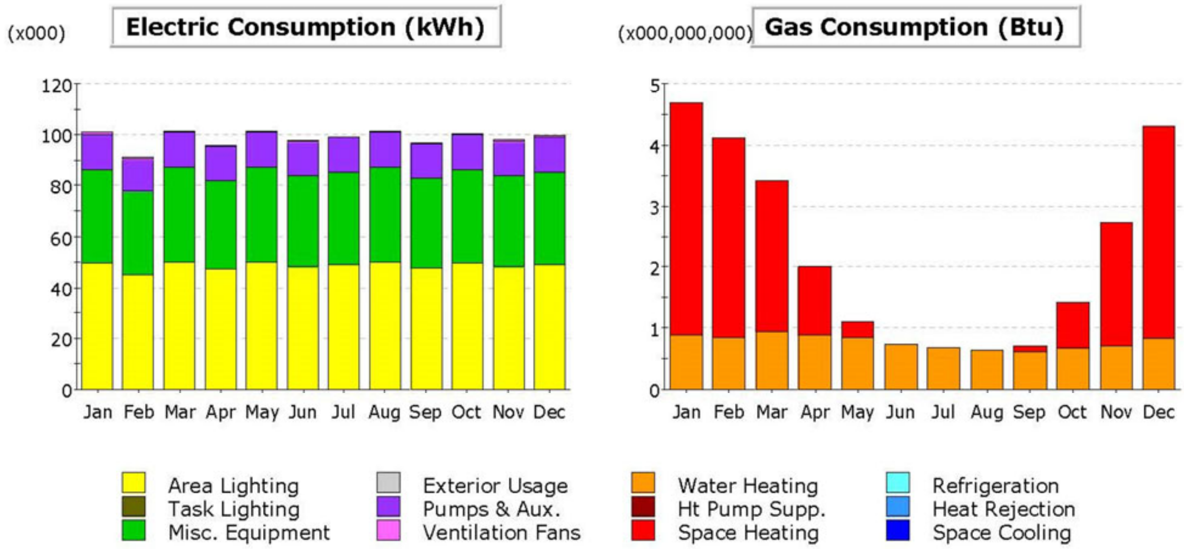
The results of the energy analysis presented in this section cannot be construed to have absolute, predictive accuracy, representing the actual energy use of the building or its individual systems. All reasonable efforts have been taken to ensure the accuracy of the energy model inputs, including verifying that the actual details correspond to the modelled building. The primary benefit of energy modeling is for a comparison of alternative options to determine their relative energy-saving potentials.

6.1. Limitations

There are a number of factors that will cause the actual energy use of the building to diverge from the projected energy use of the model. Among these are abnormal weather conditions; variation in schedules for equipment, systems, and occupancy; and inconsistencies in the application of controls and operations strategies compared to those used in the model. In addition, there is the limitation of the software itself, such as its inability to model the infiltration rate.

6.2. Modeling Methodology

The methodology that is used for the energy simulation for the two buildings takes advantage of the e-Quest building modeling tool to create a virtual 3D building model of the audited buildings. A baseline model is created (see Figure 6) that reflects the actual buildings. The average use of the electrical energy during a period of three years was 1185.266 kWh (refer to Table 2); the model was calibrated to reflect a similar electrical consumption, 1184.600 kWh (Figure 6).



Electric Consumption (kWh x000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	-	-	-	-	-	-	-	-	-	-	-	-	-
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	-	-	-	-	-	-	-	-	-	-	-	-	-
Vent. Fans	0.8	0.7	0.7	0.5	0.4	0.3	0.3	0.3	0.3	0.5	0.6	0.7	6.0
Pumps & Aux.	13.9	12.5	13.9	13.4	13.9	13.4	13.9	13.9	13.4	13.9	13.4	13.9	163.3
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	36.7	33.2	37.3	34.7	37.3	35.9	36.1	37.3	35.3	36.7	35.9	36.1	432.5
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	49.5	44.7	49.8	47.4	49.8	48.1	49.1	49.8	47.8	49.5	48.1	49.1	582.7
Total	100.8	91.2	101.6	96.0	101.4	97.8	99.4	101.3	96.8	100.5	98.0	99.8	1,184.6

Gas Consumption (Btu x000,000,000)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	-	-	-	-	-	-	-	-	-	-	-	-	-
Heat Reject.	-	-	-	-	-	-	-	-	-	-	-	-	-
Refrigeration	-	-	-	-	-	-	-	-	-	-	-	-	-
Space Heat	3.79	3.26	2.47	1.12	0.25	0.00	-	-	0.09	0.75	2.01	3.49	17.25
HP Supp.	-	-	-	-	-	-	-	-	-	-	-	-	-
Hot Water	0.90	0.85	0.94	0.89	0.84	0.73	0.68	0.64	0.62	0.67	0.72	0.82	9.29
Vent. Fans	-	-	-	-	-	-	-	-	-	-	-	-	-
Pumps & Aux.	-	-	-	-	-	-	-	-	-	-	-	-	-
Ext. Usage	-	-	-	-	-	-	-	-	-	-	-	-	-
Misc. Equip.	-	-	-	-	-	-	-	-	-	-	-	-	-
Task Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Area Lights	-	-	-	-	-	-	-	-	-	-	-	-	-
Total	4.69	4.11	3.41	2.02	1.09	0.73	0.68	0.64	0.71	1.43	2.73	4.31	26.54

Figure 6. Electrical consumption in kWh × 000 and gas consumption—baseline model.

The baseline model is then used to incorporate the various energy-saving measures (building envelope improvement, window replacement to a higher efficiency, and boiler efficiency improvement) and calculate the projected energy savings for each. The e-Quest v.3.64 tool has the ability to combine multiple measures and consider the impact of the interaction of individual measures on the overall savings, which is shown as runs (Run 1, Run 2, Run 3, etc.).

The buildings were divided into zones (see Figure 7c,d) according to the spaces' operation and function, and heating loads. A simulation model was established with e-Quest in accordance with the data gathered in the site visits, and drawings provided (plan drawings). Simulations were performed in e-Quest v.3.64. Table 1 (above) summarizes the major design parameters used for the creation of the e-Quest building model (Figure 7).

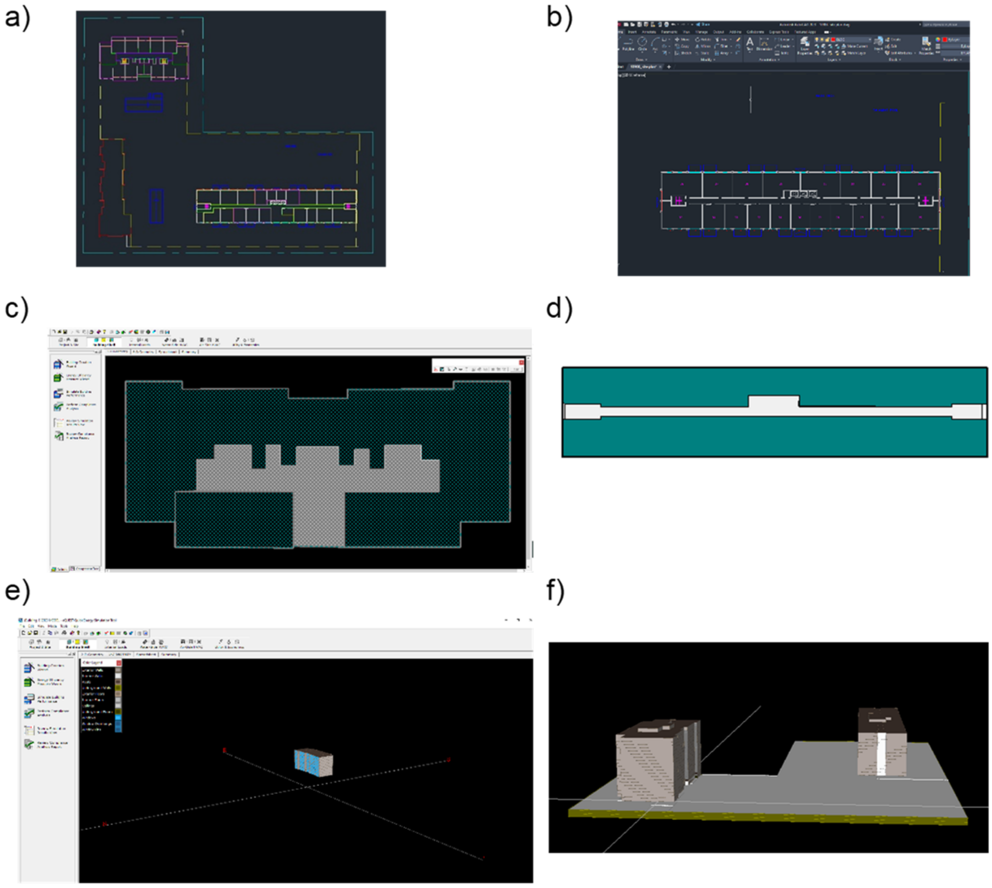


Figure 7. (**a**,**b**) CAD shows layout of the two buildings; (**c**,**d**) building zones; (**e**,**f**) e-Quest building models.

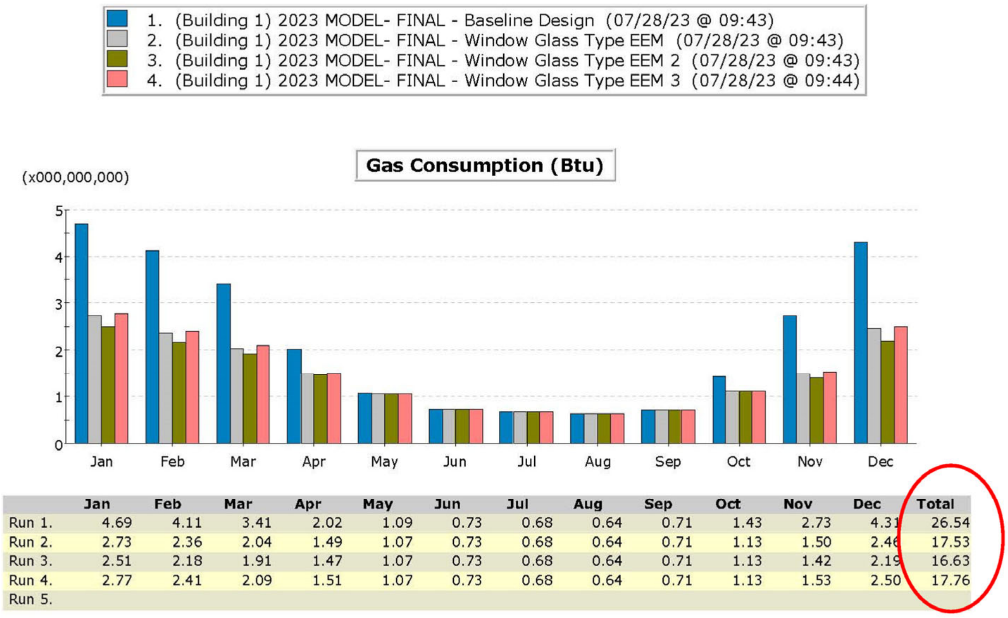
6.3. Potential Efficiency Improvements

As mentioned previously, the benefit of energy modeling is the comparison of alternative options to determine their relative energy-saving potentials. The following are the building energy-saving alternatives which were examined (runs) in the simulation using e-Quest:

(a) Improve window glazing to a double glazing;
(b) Improve window glazing to a triple glazing;
(c) Improve the exterior wall insulations;
(d) Improve the building roof insulations;
(e) Add exterior window shadings;
(f) Reducing window areas by 20% and 30%.

6.4. Total Calculated Savings

A baseline model was generated on the basis of the data gathered from the site review. Three framing options were studied: Figure 8 and Table 4 shows all three of the studied options, and the baseline is shown in blue as Run 1.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Run 1.	4.69	4.11	3.41	2.02	1.09	0.73	0.68	0.64	0.71	1.43	2.73	4.31	26.54
Run 2.	2.73	2.36	2.04	1.49	1.07	0.73	0.68	0.64	0.71	1.13	1.50	2.46	17.53
Run 3.	2.51	2.18	1.91	1.47	1.07	0.73	0.68	0.64	0.71	1.13	1.42	2.19	16.63
Run 4.	2.77	2.41	2.09	1.51	1.07	0.73	0.68	0.64	0.71	1.13	1.53	2.50	17.76
Run 5.													

Figure 8. Gas consumption in Btu (simulation), baseline model in Run 1 (single glazing) and double low-E glazing (Run 2), triple low-E glazing (Run 3), and quadruple low-E glazing (Run 4).

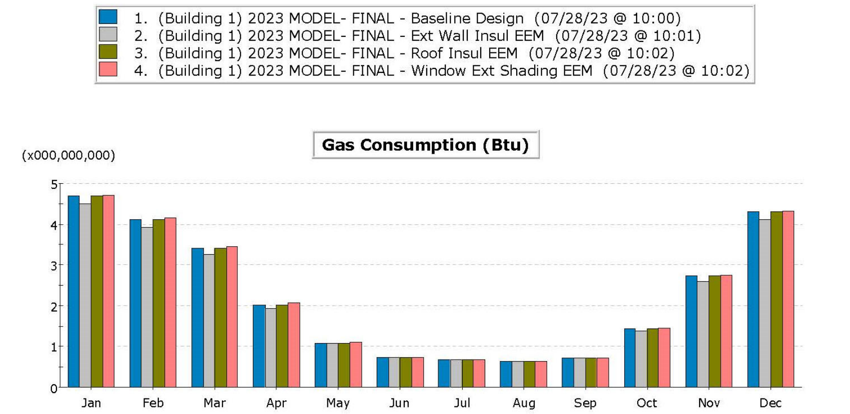
Table 4. Glazing options used in the modeling.

No.	Options	Glazing Type	Frame Type
Run 1	Base case	Single clear, U = 1.04 SHGC = 0.86	Aluminum without thermal break
Run 2	Option 1 (EEM)	Double low-E (e3 = 0.2), clear 1/4 in, 1/2 in air	Insulated fiberglass/vinyl, fixed insulated spacer
Run 3	Option 2 (EEM2)	Triple low-E (e2 = e5 = 0.1), clear 1/8 in, 1/2 in argon	Insulated fiberglass/vinyl, fixed insulated spacer
Run 4	Option 3 (EEM3)	Quadruple low-E films, clear 1/8 in, 1/3 in krypton	Insulated fiberglass/vinyl, fixed insulated spacer

The results from the simulation (see Figure 8) show that Option 3 (Run 3 in green), which corresponds to a triple low-E (e2 = e5 = 0.1) glazing, clear 1/8 in thickness, and 1/2 in argon, with an insulated fiberglass/vinyl and fixed insulated spacer, performs better than a single-glass window (Run 1: single clear, U = 1.04 SHGC = 0.86). As a result, Option 3 was able to save 38% of energy on gas consumption compared to a single-glass window and 34% of energy compared to a double-glass window (double low-E (e3 = 0.2), clear 1/4 in, 1/2 in air), and there is only 5% of savings between the double-glass window compared to a triple-glass window.

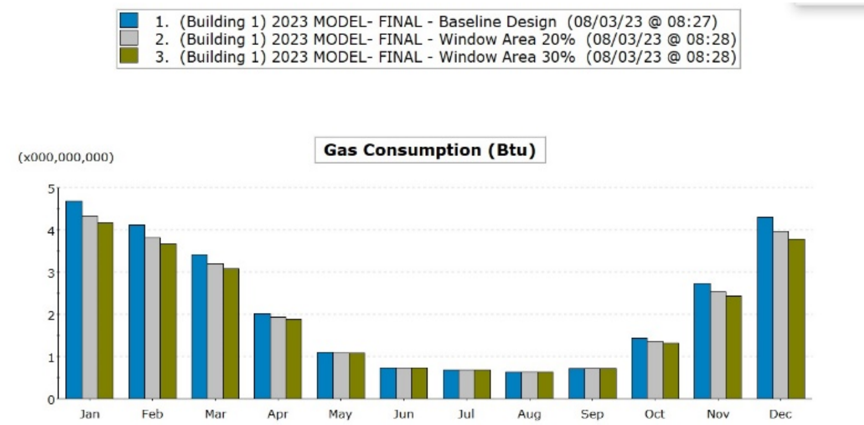
The building envelope simulations, as depicted in Figure 9, reveal the outcomes of three different options. Run 1 represents the baseline building, and Option 2 (Run 2 in grey) involved enhancing the building envelope's R-value from R-8 to R-21 by introducing metal-furred insulation, resulting in a reduction of gas consumption by approximately 4%. However, in the case of Run 3, where the roof insulation was upgraded from R-25 with a 6-inch polyiso-cyanurate to R-42, there were no discernible energy savings. Similarly, Run 4, which entailed adding 2 ft of exterior shading (overhangs and fins) to the existing windows, did not exhibit any improvements in energy efficiency.

Figure 10 shows from the simulation that a 20% reduction of the window areas (north and south sides) will lead to a 6% reduction in gas consumption, and a 30% reduction of the window area will lead to about 9% in the energy savings.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Run 1.	4.69	4.11	3.41	2.02	1.09	0.73	0.68	0.64	0.71	1.43	2.73	4.31	26.54
Run 2.	4.49	3.92	3.26	1.94	1.09	0.73	0.68	0.64	0.71	1.37	2.60	4.11	25.52
Run 3.	4.69	4.11	3.41	2.02	1.09	0.73	0.68	0.64	0.71	1.43	2.73	4.31	26.54
Run 4.	4.71	4.14	3.46	2.06	1.10	0.73	0.68	0.64	0.71	1.45	2.76	4.33	26.77
Run 5.													

Figure 9. Gas consumption (simulation) in Btu, baseline model in Run 1, modified exterior wall insulation (Run 2), modified roof insulation (Run 3), and modified exterior shading (Run 4).



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Run 1.	4.69	4.11	3.41	2.02	1.09	0.73	0.68	0.64	0.71	1.43	2.73	4.31	26.54
Run 2.	4.34	3.81	3.19	1.93	1.09	0.73	0.68	0.64	0.71	1.36	2.53	3.96	24.97
Run 3.	4.17	3.66	3.09	1.89	1.09	0.73	0.68	0.64	0.71	1.32	2.43	3.79	24.20
Run 4.													
Run 5.													

Figure 10. Gas consumption (simulation) in Btu, baseline model in Run 1, 20% reduction of window area (Run 2), and 30% reduction in window area (Run 3).

7. Discussion

The energy audit of buildings plays a crucial role in achieving energy efficiency targets and reducing greenhouse gas emissions. Buildings are significant energy consumers and contribute to a substantial portion of global primary energy consumption and emissions. The City of Toronto and the Canadian federal government have recognized the importance of addressing energy consumption in buildings and have set ambitious goals to reduce GHG emissions. This discussion will focus on the significance of energy audits, the findings from the energy audit conducted on two multi-unit residential buildings (MURBs) in Toronto, and the potential energy-saving measures identified.

Energy audits are essential tools for assessing and studying the energy profile of buildings. They provide valuable insights into the energy consumption patterns, and identify areas for improvement. In the case of the two MURBs in Toronto, the energy audit aimed to assess the energy efficiency of the buildings, particularly focusing on window replacements and mechanical systems.

The first step in the energy audit process was to review all relevant documents and conduct a site visit to evaluate the building envelope, mechanical systems, and electrical systems. Data collection from the buildings included measurements of windows, building areas, and light densities. A utility bill analysis was also performed to understand gas and electricity consumption patterns. Additionally, an energy simulation analysis using standard reference software (e-Quest) was conducted to estimate the potential energy savings related to window replacements.

The analysis of the building envelope revealed that the roofs of the buildings had insulation with an R-value of 10. However, it was uncertain whether the exterior walls had any insulation. The windows in both buildings were single-glazed, non-thermally broken aluminum frames. These findings indicate potential areas for improvement in the building envelope to enhance energy efficiency.

The mechanical systems of the buildings played a crucial role in heating. The buildings were equipped with Camus Boilers and Powermaster fire tube boilers for generating heat. However, the Powermaster boilers were in poor condition and nearing the end of their service life. The heating terminals consisted of hot water radiant baseboard heaters controlled by thermostats. Many of the control systems for the heaters were found to be disabled or removed, resulting in a lack of control over the heating system's output. These issues highlight opportunities for optimizing the heating system and improving the control mechanisms to achieve energy savings.

The lighting systems in the buildings predominantly used fluorescent light fixtures in common areas, hallways, and exit stairwells. The lights in these areas were lit continuously, without occupancy sensors or energy control measures. Upgrading lighting fixtures and implementing energy-saving measures such as occupancy sensors could lead to significant energy savings.

The normalization of energy use was employed to compare the energy performance of the buildings. The energy consumption was converted into metrics and normalized based on heating degree days (HDDs) and comparisons with similar buildings in terms of energy use per floor area and number of units. The analysis revealed that the buildings consumed more energy compared to comparable buildings and those built after 1981.

Energy modeling using the e-Quest software provided insights into the potential energy-saving measures. Different window-framing options were modeled to determine their impact on energy consumption. The results showed that windows with double low-E glazing and insulated spacers performed better than single-glazed windows, resulting in 34% of energy savings on gas consumption. The energy savings between double-glass windows and triple-glass windows showed estimated savings of 5%. The simulation showed that a 20% reduction of the window areas (north and south sides) will lead to a 6% reduction in gas consumption, and a 30% reduction of the window area will lead to about 9% in energy savings.

It is important to note that the energy-modeling results represent the projected energy savings and may not precisely reflect the actual energy use of the buildings due to various factors such as weather conditions, occupancy patterns, and inconsistencies in controls and operations. However, the modeling simulations provide a useful tool for comparing alternative options and determining their relative energy-saving potentials.

8. Conclusions

The objective of this report was to provide an energy audit for two buildings located in Toronto, Ontario. This part summarises the findings:

The estimated window area of Building 1 is 54.8% for the south elevation, 63.4% on the north elevation, and 5.5% on the east and west elevations; these values exceed the current energy building code requirements. The estimated window area of Building 2 is 33% on the south elevation, 42.9% on the north elevation, and 1% on the east and west elevations. The windows in the two buildings consist of single-glazed, non-thermally broken aluminum frames that lose and gain large amounts of heat energy. The building's heat is generated by non-condensing boilers with an energy efficiency rating of 85%. There is a strong correlation between the exterior temperature and gas consumption (HDD). Variances in this relationship are likely attributable to gas consumption related to domestic hot water heating. The building envelope has a strong impact on the overall gas consumption; an efficient building envelope will reduce definitively the energy consumption of the two buildings. By comparing this to the value given by the Canada Mortgage and Housing Corporation (212 ekWh/m^2), the two buildings are consuming 15% more energy than those of comparable size and age, and 44% more than those built from 1981 to the present. The results from the energy simulation showed that, by replacing the single-glazed window with a double low-E (e3 = 0.2) glazing, clear 1/8 in thickness, and $\frac{1}{2}$ in argon aluminum with a thermal breaker will result in energy savings on gas consumption of 34%, and 37% of energy savings for triple low-E (e2 = e5 = 0.1), clear 1/8 in, and $\frac{1}{2}$ in argon glass.

It is important to note that the energy-modeling results represent the projected energy savings and may not precisely reflect the actual energy use of the buildings due to various factors such as occupancy patterns, and inconsistencies in controls and operations and weather conditions. In this study, several key aspects, including weather conditions, play a significant role in influencing the findings. Toronto experiences a humid continental climate, characterized by four distinct seasons. Summers are generally warm and humid, with average high temperatures around 25–30 °C (77–86 °F), while winters are cold, with average lows around −6 to −1 °C (21–30 °F), often accompanied by snowfall. These weather conditions can impact various aspects of the study, such as energy consumption patterns. For instance, during warmer months, people are more likely to engage in outdoor events. In contrast, colder months may lead to increased indoor activities and higher energy usage for heating, However, the modeling simulations provide a useful tool for comparing alternative options and determining their relative energy-saving potentials.

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References

1. Shirinbakhsh, M.; Harve, D.L.D. Feasibility of Achieving Net-Zero Energy Performance in High-Rise Buildings Using Solar Energy. Energy and Built Environment. 2023. Available online: https://www.sciencedirect.com/science/article/pii/S2666123323000673#fig0003 (accessed on 3 August 2023).
2. Government of Canada Sets Ambitious GHG Reduction Targets for Federal Operations. 19 December 2017; Ottawa, Treasury Board of Canada Secretariat. Available online: https://www.canada.ca/en/treasury-board-secretariat/news/2017/12/government_of_canadasetsambitiousghgreductiontargetsforfederalop.html (accessed on 22 May 2023).
3. Kumara, A. Electrical Energy Audit in Residential House. *Procedia Technol.* **2015**, *21*, 625–630. [CrossRef]
4. Al-Ajlan, S. Energy Audit and Potential Energy Saving in an Office Building in Riyadh, Saudi Arabia. *J. King Saud Univ. Eng. Sci.* **2009**, *21*, 65–75. [CrossRef]
5. Abdallah, A.S.H.; Makram, A.; Nayel, M.A.A. Energy Audit and Evaluation of Indoor Environment Condition inside Assiut International Airport Terminal Building, Egypt. *Ain Shams Eng. J.* **2021**, *12*, 3241–3253. [CrossRef]
6. Mamadea, A. Energy Auditing as a Tool for Improving Service Efficiency of Water Supply Systems. *Procedia Eng.* **2014**, *89*, 557–564. [CrossRef]

7. Mamade, A. Energy auditing as a tool for outlining major inefficiencies: Results from a real water supply system. *Procedia Eng.* **2015**, *119*, 1098–1108. [CrossRef]
8. Michalak, P.; Szczotka, K.; Szymiczek, J. Audit-Based Energy Performances Analysis of Multifamily Buildings in South-East Poland. *Energies* **2023**, *16*, 4828. [CrossRef]
9. Hohd Ali, S.; Mehdipoor, A.; Johari, N.S.; Hasanuzzaman, M.; Abd Rahim, N. Modeling and Performance Analysis for High-Rise Building Using ArchiCAD: Initiatives towards Energy-Efficient Building. *Sustainability* **2022**, *14*, 9780. [CrossRef]
10. Touchie, M.F. Assessing Potential Energy Retrofits of Multi-Unit Residential Buildings in the Greater Toronto Area. Available online: https://www.researchgate.net/publication/283568998_Assessing_Potential_Energy_Retrofits_of_Multi-Unit_Residential_Buildings_in_the_Greater_Toronto_Area (accessed on 8 June 2021).
11. Ghajarkhosravi, M. Utility Benchmarking and Potential Savings of Multi-Unit Residential Buildings (MURBs) In Toronto. 2013. Available online: https://digital.library.ryerson.ca/islandora/object/RULA%3A1593 (accessed on 8 June 2021).
12. Binkley, C.; Touchie, M.; Pressnail, K. Meta-Analysis of Energy Consumption in Multi-Residential Buildings in the Greater Toronto Area. 2012. Available online: https://taf.ca/wp-content/uploads/2018/02/University_of_Toronto_Report_MURB_Energy_Performance_Analysis_GTA_2012-06-20.pdf (accessed on 8 June 2021).
13. Mayer, Z.; Epperlein, A.; Vollmer, E.; Volk, R.; Schultmann, F. Investigating the Quality of UAV-Based Images for the Thermographic Analysis of Buildings. *Remote Sens.* **2023**, *15*, 301. [CrossRef]
14. Balaras, C.A.; Theodoropoulos, A.I.; Dascalaki, E.G. Geographic Information Systems for Facilitating Audits of the Urban Built Environment. *Energies* **2023**, *16*, 4309. [CrossRef]
15. Ahmed, W.; Alazazmeh, A.; Asif, M. Energy and Water Saving Potential in Commercial Buildings: A Retrofit Case Study. *Sustainability* **2023**, *15*, 518. [CrossRef]
16. CMHC. Analysis of the Annual Energy and Water Consumption of Apartment Buildings in the CMHC HiSTAR Database. 2001. Available online: https://publications.gc.ca/collections/collection_2014/schl-cmhc/NH18-22-101-142-eng.pdf (accessed on 10 May 2023).