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Evaluating the Impact of Time-of-Use Billing on Energy Costs in a University Building in Newfoundland, Canada

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ABSTRACT

Globally, buildings contribute to about 30% of total energy demand, with over half of this consumption in Canada attributed to space heating and cooling. This presents an opportunity for substantial energy and cost savings. Many buildings are transitioning to electric heating for efficiency and cost-effectiveness, but different tariff structures can result in unexpected cost increases, necessitating adjustments to the building's regular operational patterns to mitigate expenses.
This study employs a building energy model developed with the OpenStudio application to conduct a comparative analysis, focusing on the impact of various tariff structures using the MUN CSF building as the case study. It investigates the impact of transitioning from a flat-rate tariff to a time-of-use tariff on energy costs, even with the adoption of energy-efficient electric resistive heating compared to the current oil-fired hot water boiler.
The findings indicate that the retrofit, which proves cost-effective under a flat-rate tariff, might not yield financial savings and could potentially increase energy costs under a time-of-use tariff. The simulation results show an energy cost of CA$1,029,089 under the flat-rate tariff, derived from historical data, and CA$1,980,110 under the time-of-use tariff, based on current tariffs in Newfoundland and Ontario. This suggests that energy costs under the time-of-use tariff can nearly double compared to the flat-rate tariff, with the same amount of energy consumed and a similar usage pattern.

1. INTRODUCTION

1.1 Energy Consumption of Buildings

The energy consumption in constructed spaces has significantly increased in recent decades, primarily attributed to factors such as population growth, increased indoor occupancy durations, heightened expectations for indoor comfort, and shifts in climate patterns. Research suggests that buildings, on average, account for around one-third of global energy consumption [1], [2], [3]. Comparatively, in Canada, the built environment consumes approximately 30% of the national energy consumption, notably influencing the country's energy demand [4]. In the Canadian building sector, space heating and cooling emerge as the predominant energy consumer, representing about 61% and 57% of the total energy consumption in the residential, commercial, and institutional sectors, respectively [5], [6].

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The expansive and diverse landscape of Canada has resulted in varied energy production and consumption patterns across its provinces and territories. A survey encompassing 26,000 buildings nationwide, summarized in Figure 1, reveals that electricity is the primary source of energy in the building sector. However, in the case of commercial and institutional buildings, natural gas has emerged as the favored energy source. Research reveals that around 53% of the total energy demands in this sector are satisfied by natural gas [8]. Additionally, natural gas accounts for meeting over 55% and 85% of the total energy requirement and space heating requirements in educational facilities, respectively [9], [10]. The energy consumption of educational facilities in Canada as of 2020 is outlined in Table 1.

However, in Atlantic Canada, a substantial increase in the contribution by refined products in meeting the energy demands in the built environment can be observed. This is attributed to various factors, notably limited access to alternative sources, infrastructure constraints, and relatively higher costs. Within commercial and institutional buildings in Atlantic Canada, electricity satisfies around 60% of the energy demand, while a combination of light fuel, kerosene, coal, and propane collectively accounts for approximately 16.1% of the demand [11]. In comparison, educational buildings in the region predominantly rely on electricity to meet the majority of their energy demands, followed by natural gas and refined products, as outlined in Table 2. In contrast, data for residential buildings in Newfoundland reveals that electricity is the predominant source meeting energy demands, followed by refined products, with natural gas playing no part in the energy mix [14].

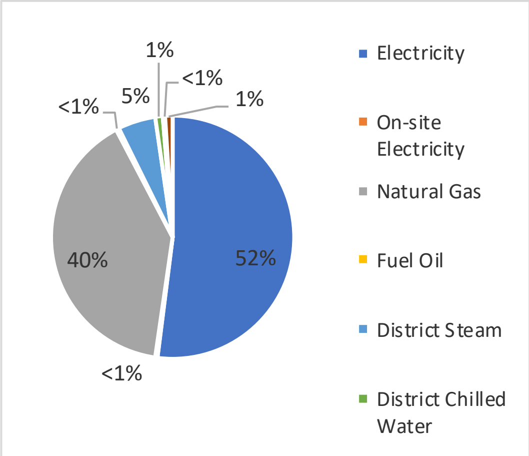

Fig. 1. Energy use in buildings by source (adapted from [7]).

Table 1. Energy consumption (in PJ) by educational buildings in Canada (adapted from [9], [10]).

	Electricity	Natural Gas	Light Fuel Oil and Kerosine	Heavy Fuel Oil	Steam	Other
Non-space conditioning						
Lighting	19.3	0	0	0	0	0
Aux. motors	5.6	0	0	0	0	0
Aux. equipment	20.8	0.9	0	0	0	0.9
Water heating	0.4	7.5	0.7	0	0	0.2
Space cooling	6.8	0.4	0	0	0	0
Space heating	9	77.3	1.3	0	0	3.1
Total	61.9	86.1	2	0	0	4.2

Table 2. Energy consumption (in PJ) by educational buildings in Atlantic Canada (adapted from [12], [13]).

	Electricity	Natural Gas	Light Fuel Oil and Kerosine	Heavy Fuel Oil	Steam	Other
Non-space conditioning						
Lighting	1.4	0	0	0	0	0
Aux. motors	0.3	0	0	0	0	0
Aux. equipment	1.2	0	0	0	0	0.1
Water heating	0.025	0.3	0	0	0	0.025
Space cooling	0.8	0	0	0	0	0
Space heating	1.1	2.2	0.2	0	0	0.2
Total	4.825	2.5	0.2	0	0	0.325

The increased electricity consumption in the built environment in Atlantic Canada can be primarily ascribed to the relatively affordable electricity tariffs. Statistics reveal that Atlantic Canada features some of the most affordable electricity tariffs in the country, with rates in 2022 averaging from 8.44 to 11.40 cents per kilowatt-hour (kWh) for large power customers throughout the region [15].

1.2 Electricity Tariffs

Canada features various electricity tariff models for commercial consumers, offering flexibility and options tailored to diverse energy needs. These tariff models include Time-of-Use (TOU), where prices vary based on the time of day and the season; Demand Charges, incorporating fees based on peak electricity demand; and Flat-Rate Pricing, providing a consistent rate regardless of time or usage patterns, while some provinces offer tiered pricing, where consumers pay different rates depending on their consumption levels [16], [17], [18].

In Newfoundland, the electricity tariff for residential and small commercial consumers consists of two main components: a consumer charge and a flat rate per kWh. In contrast, large commercial and industrial consumers also incur a demand charge in addition to the flat rate, with the per kWh rate varying by consumer class. A flat electricity tariff (FR) provides simplicity and predictability, allowing consumers to easily understand their electricity costs without the complexities of variable rates. However, this approach does not incentivize energy conservation during peak hours, which can lead to inefficient usage patterns. Furthermore, it may not accurately represent the true costs of electricity generation and distribution, posing challenges for promoting sustainability and encouraging responsible energy consumption behaviors [19]. In comparison, a Time-of-Use (TOU) electricity tariff, which is a variation of the FR tariff that fluctuates based on time blocks, introduces a variable pricing structure depending on the time of day. This model offers several benefits, including incentivizing consumers to shift energy-intensive activities to off-peak hours, thereby promoting load balancing and enhancing overall grid efficiency. It also more accurately reflects the actual cost of electricity production at different times. However, the complexity of managing and adapting to fluctuating rates can be challenging for consumers. Additionally, certain industries or households may struggle to adjust their activities to align with TOU schedules, potentially leading to higher costs during peak periods [20].

A more recent approach to electricity tariff structures is the real-time electricity pricing (RTP) model, which aims to minimize the net difference between the actual costs of electricity generation, transmission, and distribution and its tariffed revenue [19]. This dynamic pricing structure allows consumers to adjust their usage during periods of low demand or lower prices, thereby reducing peak loads and improving grid reliability [21]. However, compared to TOU, RTP covers a wider range of market price variations, making it challenging for consumers to effectively manage and predict costs [22]. This can result in volatile bills, impacting the budget predictability for both households and businesses.

1.3 Building Energy Modeling

Building Energy Modeling (BEM), applicable to both new constructions and existing structures, provides a thorough and forward-looking assessment of a building's energy efficiency. By incorporating data on architectural design, materials, Heating, Ventilation, and Air Conditioning (HVAC) systems, lighting, and occupant behavior, energy models simulate the dynamic interactions within a building, quantifying energy consumption and ensuring thermal comfort [23], [24]. These models are crucial for evaluating the impact of various technologies, insulation methods, and the integration of renewable energy, offering valuable insights for decision-makers to achieve optimal energy performance. As powerful tools, building energy models facilitate the prediction, analysis, and implementation of strategies to reduce energy usage, lower operational costs, and meet sustainability goals.

Building energy models can be primarily categorized as either steady-state or dynamic. Steady-state models examine the temporary impact of variables, whereas dynamic models have the capability to monitor peak loads and effectively capture thermal effects, such as those caused by setback thermostat strategies [2]. The choice between these approaches depends on the specific needs of the analysis. Steady-state models, which are computationally efficient, are ideal for quick assessments where transient effects are less critical, making them suitable for short-term analyses and initial screenings. Conversely, dynamic models offer a more precise depiction of a building's behavior over time, accounting for transient effects, seasonal variations, and the interactions between various components. While dynamic simulations are more complex and computationally intensive, they are essential for offering a more precise representation of a building's behavior over time. This accuracy is instrumental in facilitating well-informed decision-making processes.

2. BUILDING FOR THE CASE STUDY

This study focuses on the Core Science Facility (CSF) building, which encompasses a total floor area of 40,817 square meters (m^2) across five floors. Located on the Memorial University of Newfoundland (MUN) campus in St. John's, Newfoundland, the CSF opened to the public in 2021. It houses teaching rooms, research laboratories, and office spaces primarily for the Department of Electrical and Computer Engineering within the Faculty of Engineering and Applied Science at Memorial University. Additionally, the building includes various plant and equipment, such as a cryogenic facility operated and maintained by the Department of Technical Services [25]. The CSF utilizes two energy sources: electricity and hot water for space heating, with the hot water supplied by the central heating plant in the university's Utility Annex (UA). The UA currently utilizes four oil-fired boilers, each with an 18 Mega-Watt (MW) capacity, to generate hot water for the university and nearby hospital complex. The UA employs No.2 diesel oil as the fuel for its hot water boilers.

Fig. 2. CSF Building at MUN.

The data shows that in the calendar year 2022, the CSF facility utilized 12,706,138 kilowatt hours (kWh) of electricity and 1,100,109 liters of No.2 diesel oil, incurring costs of 1,333,283.81 and 1,825,891.37 Canadian Dollars, respectively [26]. This implies an average electricity tariff of 0.105 ¢/kWh and $1.66/liter for No.2 diesel oil. It has been proposed to replace one of the defective oil-fired boilers with two electric resistive boilers, each having a smaller capacity of 15.5 MW. Taking into account the existing FR tariff in Newfoundland and the enhanced efficiency provided by the electric resistive boilers, this shift has the potential to result in substantial energy and financial savings. However, utilities around the world have been progressively providing customers with the choice to transition to TOU or even RTP tariffs [19], [20], [27]. In alignment with this trend, Canadian utilities have been adopting this practice, and it is anticipated that TOU tariffs will be introduced in Newfoundland in the future. The decision to switch to an electric resistive boiler system has been based on the potential savings under the current FR tariffs. This study explores the potential implications of switching from an FR tariff to TOU on more energy-efficient electric resistive heating, using the CSF building as an example.

3. METHODOLOGY

3.1 Development of the Building Energy Model

For this study, a BEM created using OpenStudio version 3.6.1 was utilized [28]. OpenStudio is a collaborative open-source BEM software developed by various institutions, including the National Renewable Energy Laboratory (NREL), the Department of Energy (DOE), Argonne National Laboratory (ANL), Lawrence Berkeley National Laboratory (LBNL), Oak Ridge National Laboratory (ORNL), Pacific Northwest National Laboratories (NPPL), and Pennsylvania State University in the United States. Additionally, it involves contributions from Natural Resources Canada, that facilitates comprehensive building energy modeling using EnergyPlus and advanced daylight analysis through radiance [29], [30]. Moreover, this study necessitated making assumptions and using standard parameters due to insufficient data on building operations. Key specifics such as building materials, occupancy patterns, lighting, and equipment usage were not available, largely due to the building's recent construction and the absence of a comprehensive survey to gather such details thus far. Gathering such data for an educational building, with its dynamic variations, would require a substantial investment of time, effort, and resources. Additionally, the scarcity of literature on BEM for educational or university buildings posed challenges in finding reference data. As a result, the BEM incorporated construction materials recommended by OpenStudio, aligning with ASHRAE standard 189.1-2009 for a building situated in Climate Zone 6A. Lighting loads were determined based on the prescribed lighting power densities for educational buildings according to the National Energy Code of Canada for Buildings [31]. Moreover, established schedules within OpenStudio for Large Office Buildings were applied to simulate equipment usage and occupancy densities, acknowledging that some parts of the building are designated as office spaces for faculty, staff, and students. Table 3 presents an overview of the characteristics of the construction components incorporated into the BEM, including Solar Heat Gain Coefficient (SHGC) and Visible Light Transmission (VLT) as applicable, while Figure 3 offers a depiction of the BEM when viewed from the North.

Table 3. Properties of the construction components used in BEM.

Component	R Value	U Value	Unit	SHGC	VLT
Main building					
Exterior walls	13.34		ft^2.h.R/Btu		
Roof	30.48		ft^2.h.R/Btu		
All windows and glass doors		0.45	Btu/ft^2.h.R	0.4	0.51
All solid doors		N/A		N/A	N/A
Penthouse (equipment room over the top floor)					
Exterior walls	18.07		ft^2.h.R/Btu		
Roof	30.48		ft^2.h.R/Btu		

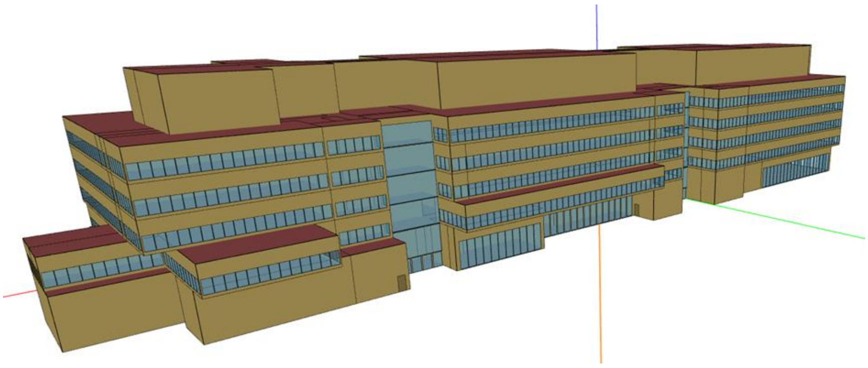

Fig. 3. OpenStudio model of the CSF building.

For the simulation of the model, various parameters, including the load profiles, intensity, and the HVAC system operation for various space types allocated within the building envelope, were considered. The HVAC system was modeled using the ASHRAE Advanced Energy Design Guides (AEDG) available in OpenStudio's Building Component Library (BCL) [32]. This resource enables users to efficiently design and simulate energy-efficient HVAC systems for buildings in a user-friendly manner. Figure 4 illustrates the floor plan of the first floor with different space types, while Table 4 provides a summary of the parameters taken into account for space heating and ventilation. In Figure 5 schedule for HVAC availability based on AEDG is illustrated in dark blue.

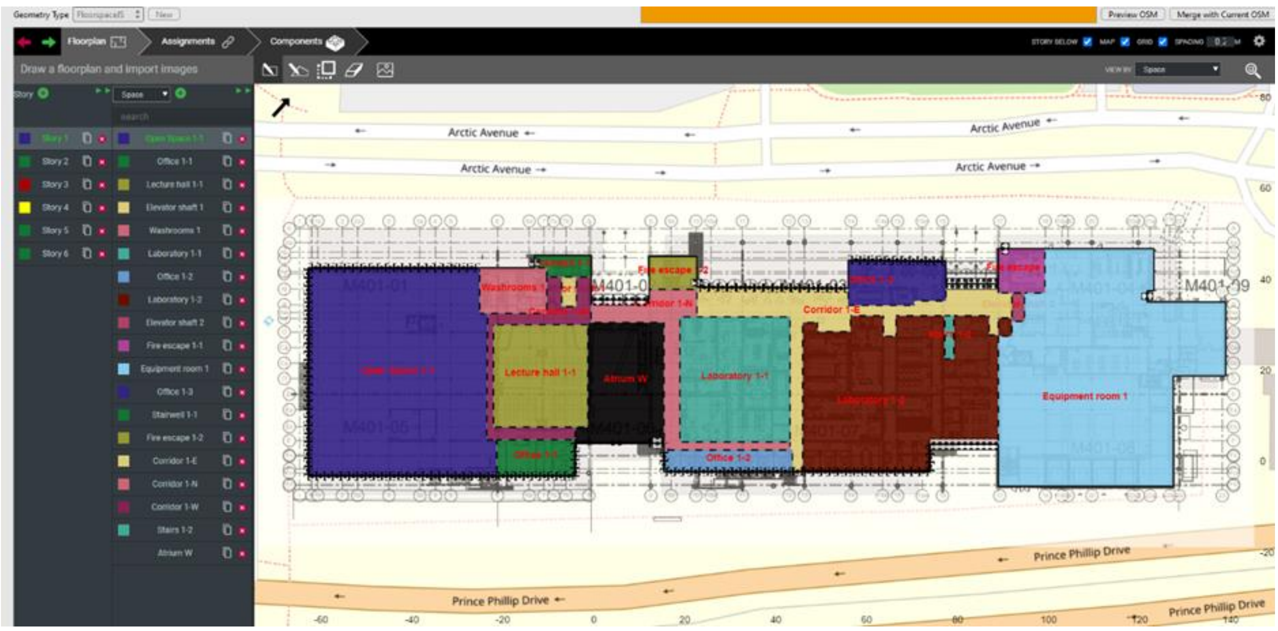

Fig. 4. Floor plan for story 1.

Table 4. System parameters for heating, cooling and ventilation.

Parameter	Unit	Value
Thermostat setting- heating	°C	22
Thermostat setting- cooling	°C	26
Relative humidity	%	45
Equipment room thermostat setting for freeze protection	°C	15
Hot water temperature at the inlet of CSF loop	°C	85

Various schedules were taken into account in the BEM for the building's operation. The CSF building operates continuously throughout the day over the year, and therefore, it was assumed that lighting loads in public spaces, including lobbies, corridors, stairs, and restrooms, consisting of all LED lamps, remain operational around the clock. The profiles for lighting and equipment loads in office and laboratory spaces are presented in Figure 5 in orange and green, respectively, with the occupancy schedule for the building shown in light blue.

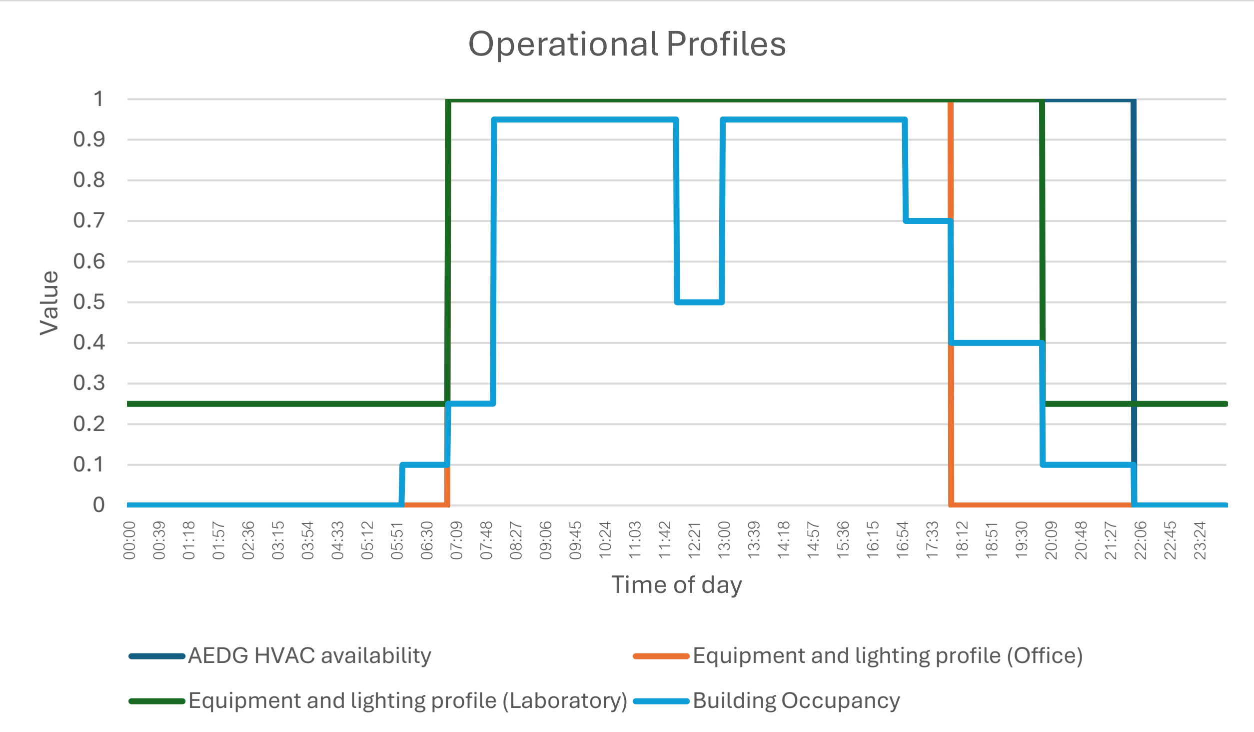

Fig. 5. Operational schedules considered for simulations.

3.2 Selection of Energy Tariff

Historical data of the CSF building indicates that in 2022, the average tariffs were 0.105 ¢/kWh for electricity and $1.66/liter for No.2 diesel oil. While Newfoundland has yet to implement TOU tariffs, several Canadian provinces, including Ontario, have adopted diverse tariff structures, including TOU [16], [33]. In Ontario, the TOU tariff is presently available for residential and small business consumers, featuring variable rates depending on distinct times of the day and seasonal fluctuations. In addition to various other tariff structures, Ontario provides residential consumers with a FR tariff of around 8.2 ¢/kWh. [34].

In contrast, Newfoundland employs a block tariff system for industrial consumers with a demand exceeding 1,000 kilo-volt amperes (kVA) [35].

For the purpose of simplifying the computational model and improving comparability, a TOU tariff was utilized, incorporating the TOU tariff currently in use in Ontario and the FR tariff in Newfoundland, without considering the Harmonized Sales Tax (HST). Table 5 provides a summary of the tariff structures adopted for the simulation.

Three iterations of simulations were completed, the first considering the existing oil-fired heating system and existing FR tariff structure, and the second and third taking into account the electric resistive heating system under the existing FR tariff structure and the TOU tariff structure developed for this study.

4. RESULTS AND DISCUSSION

The outcomes from the two simulations based on electric resistive heating provided diverse insights, offering a comprehensive understanding of energy consumption patterns, on-peak and off-peak consumption, and consumption by end-use within the CSF building based on the considered parameters. A summary of these consumption patterns is presented in Table 6.

Table 5. Tariffs considered in the study.

Simulation	Tariff tier	Rate	Winter period (Nov 1 to Apr 30)	Summer period (May 1 to Oct 31)
Considering FR	FR	10.50 ¢/kWh	Throughout the day	Throughout the day
Considering TOU	Off-peak	10.982 ¢/kWh	19.00-07.00	19.00-07.00
	On-peak	20.482 ¢/kWh	07.00-19.00	07.00-19.00
	Demand charge	5.852 $/kW	N/A	For maximum demand
		8.602 $/kW	For maximum demand	N/A

Table 6. Simulation results for energy consumption.

	Total Electricity Consumption (kWh)	For space heating (kWh)	For end uses other than space heating (kWh)	On-peak consumption (kWh)	Off-peak consumption (kWh)
January	1,219,529.79	826,727.78	392,705.81	546,467.98	673,061.81
February	1,164,738.70	810,613.89	354,031.81	531,872.55	632,866.15
March	1,027,296.60	662,308.33	392,895.61	410,789.76	643,620.16
April	823,572.86	430,405.56	381,491.53	330,293.77	482,074.44
May	704,597.88	298,375.00	404,405.78	295,978.15	406,867.56
June	498,963.53	89,363.06	410,932.19	254,727.90	245,594.40
July	489,818.52	37,016.39	451,571.11	275,168.99	213,439.27
August	479,545.01	45,072.50	433,303.89	263,829.04	214,608.69
September	483,898.05	91,071.67	396,655.31	246,901.34	240,861.69
October	659,289.49	275,535.83	397,417.72	304,058.71	367,930.56
November	1,018,515.61	607,855.56	379,327.39	418,206.38	570,546.74
December	1,231,087.18	839,569.44	391,418.19	570,104.03	660,983.12
Total	9,800,853.22	5,013,915.00	4,786,156.33	4,448,398.60	5,352,454.59

Moreover, the projected electricity costs from the two simulations, considering the FR and TOU tariff structures, are presented in Table 7.

The findings reveal a significant difference in electricity costs under the TOU tariff compared to the FR tariff, with close to 100% increase for identical consumption patterns. It is important to note that these results are specific to the FR and TOU tariffs considered in this study. The FR tariff is based on the historical data for the CSF facility, and the TOU is derived from tariff structures currently in practice in Newfoundland and Ontario. In addition to consumption, demand charges also play a key contribution to the cost of electricity. Unlike consumption charges that depend on the total energy consumed, demand charges focus on the maximum amount of power drawn during specific peak hours. According to the simulation results, the CSF building exhibits a peak demand of around 5.6 MW. A demand charge, based on the current tariff structure in Newfoundland, was incorporated in the simulation, and the results indicate that the demand charge accounts for approximately 25% of the total energy bill.

Electricity costs under TOU tariffs can be significantly higher than FR for the same consumption pattern due to the variable pricing during different times of the day. TOU tariffs typically feature peak, mid-peak, and off-peak periods, each with distinct pricing levels. When a consumer's peak electricity usage aligns with high-demand periods, they will incur higher costs as compared to a flat rate. This pricing structure incentivizes consumers to move their energy-intensive tasks to times when demand is lower, thereby fostering energy efficiency and alleviating pressure on the grid. However, failure to adjust consumption habits to align with lower-priced periods can result in elevated electricity costs under TOU tariffs. A number of inputs, such as detailed architectural plans, local climate data, occupancy patterns, energy systems specifications, and actual utility information, are required to identify an optimum operational model for the building. Simulating scenarios using the TOU tariff enables the identification of methods to reschedule energy-intensive tasks to non-peak times, thereby lowering expenses.

Table 7. Cost of electricity under FR and TOU tariffs.

	Total cost- FR ($)	Total cost- TOU ($)			
		On-Peak cost	Off-peak cost	Demand charge	Total
January	128,050.63	111,927.57	73,915.65	47,788.61	233,631.83
February	122,297.56	108,938.14	69,501.36	47,800.78	226,240.28
March	107,866.14	84,137.96	70,682.37	47,783.21	202,603.54
April	86,475.15	67,650.77	52,941.42	47,413.06	168,005.25
May	73,982.78	60,622.24	44,682.20	32,154.49	137,458.93
June	52,391.17	52,173.37	26,971.18	32,560.14	111,704.69
July	51,430.94	56,360.11	23,439.90	32,513.08	112,313.09
August	50,352.23	54,037.46	23,568.33	32,720.16	110,325.95
September	50,809.30	50,570.33	26,451.43	32,278.53	109,300.29
October	69,225.40	62,277.30	40,406.13	32,618.22	135,301.65
November	106,944.14	85,657.03	62,657.44	47,770.38	196,084.85
December	129,264.15	116,768.71	72,589.17	47,782.49	237,140.37
Total	1,029,089.59	911,120.99	587,806.58	481,183.15	1,980,110.72

Similar to numerous educational facilities, the CSF building predominantly functions during daylight hours, coinciding with tariff blocks featuring higher rates. While practices like scheduling non-critical activities during off-peak hours and adopting energy-efficient technologies can mitigate energy costs, employing strategies such as real-time predictive control mechanisms for lighting and space heating based on occupancy patterns derived either from historical data or real-time data from building automation systems and sensors can substantially reduce overall energy expenses. Electric boilers are known for their superior efficiency, precision, and quick responsiveness to heating demands, distinguishing them from oil-fired boilers. This characteristic results in improved temperature control and heightened comfort for building occupants, which can contribute to the optimization of operational strategies in heating systems.

To assess the cost of electric heating against the current system employing an oil-fired boiler, the first simulation was developed, incorporating a No.2 diesel oil-fired boiler with a thermal efficiency of 82%. The results are presented in Table 8. The energy consumption results in OpenStudio are presented in Joules (J) and were subsequently converted to liters of fuel oil and kWh of electricity using the following parameters.

Heating value of No.2 diesel (per liter) = 38.18 MJ
1kWh of electricity = 3,600,000 J

Table 8. Simulation results for the existing system.

Month	Electricity (kWh)	No.2 Diesel Oil (liters)
January	391,858.86	81,941.33
February	353,396.00	77,406.23
March	392,674.78	65,218.70
April	381,104.53	45,872.97
May	404,125.50	30,951.81
June	410,843.42	12,216.89
July	451,588.78	3,503.12
August	433,313.36	4,087.82
September	396,585.89	14,483.32
October	396,962.19	33,406.76
November	379,076.06	59,228.13
December	390,965.25	85,882.40
TOTAL	4,782,494.61	514,199.48

A summary of annual energy costs, encompassing the simulation results for the current system, the proposed system with the FR tariff, and the TOU tariff, is presented in Table 9.

The results depicted in Table 9 indicate that while the use of electric resistive heating under a FR tariff can be extremely cost-effective, this may not hold true under a TOU tariff. Under TOU, the necessity to pay elevated prices during peak operational hours of the building might diminish the financial benefits despite the inherent qualities of an electric resistive boiler, such as enhanced efficiency, precision, and rapid responsiveness, which can lead to reduced energy consumption and create a more efficient and responsive heating system. Therefore, the anticipated financial advantages from the transition from oil fired boiler to an electric resistive heating system may not be realized under a TOU tariff, should it be implemented in the future. Additionally, this study did not consider the fluctuations of diesel oil prices in Newfoundland. The market for diesel oil has exhibited notable volatility, with data indicating substantial fluctuations in consumer prices in 2023 alone [36]. The unpredictability of oil prices can lead to volatile operational costs, making it challenging to budget and plan for energy expenses. In contrast, Newfoundland has a stable and reliable electricity tariff, which provides better predictability and allows for better financial planning, making it a more dependable choice for a consistent and cost-effective energy supply. Conducting a sensitivity analysis that considers these fluctuations can contribute to gaining a more comprehensive understanding of the transition. Another aspect not considered in this study is the HST applicable in Newfoundland. Although the tax is uniform across all tariff structures, currently standing at 15%, a greater utility cost may lead to a higher tax amount, ultimately elevating the overall energy cost.

Table 9. Comparison of energy costs.

			Subsystem Energy Cost ($)	Total Energy Cost ($)
Existing System		Electricity (at $0.105/kWh)	502,161.93	1,355,733.06
		Space Heating (with FO#2, at $1.66/liter	853,571.13	
Proposed System	Under FR	Electricity, at $0.105/kWh		1,029,089.59
	Under TOU	Electricity, at $0.1098 for off-peak and $0.2048 for on-peak, including demand charge		1,980,110.72

The simulation results show a consumption pattern resembling actual usage; nevertheless, significant differences in energy consumption values compared to the actual data are apparent. Various factors may contribute to this discrepancy. The OpenStudio model of the CSF building utilized generic materials tailored for Climate Zone 6, reflecting the absence of specific construction details. These materials are engineered to maximize efficiency under the specified climate conditions. However, it's important to recognize that the actual building may have employed different materials, especially regarding insulation properties, which could influence its energy usage patterns. The model's use of climate-specific materials serves as an estimate, and actual energy performance may differ based on specific construction details. Additionally, the model simplified assumptions by neglecting internal windows and doors, assuming complete sealing, whereas in reality, air leakage through these elements can contribute to increased energy consumption.

Furthermore, the connection between the second level of the CSF building and the UC facilitates significant airflow between them, resulting in heat loss during winter as warm air escapes into the cooler UC and potential heat gain in summer as warm outdoor air enters the CSF building. This unaccounted-for heat exchange necessitates additional energy usage for heating or cooling to maintain indoor temperatures. The UC, with its openings to the outdoors, introduces the possibility of infiltration and exfiltration, leading to further energy losses. These interconnections and heat losses were not accounted for in the OpenStudio simulation, potentially leading to an underestimation of actual energy consumption.

Both the CSF building and the UC experience fluctuations in occupancy levels throughout the year. Occupant behavior plays a crucial role in influencing the discrepancy between actual and simulated energy consumption. Daily changes in occupancy affect the heating demands, introducing inefficiencies in space heating requirements. It becomes essential to adjust the heating system according to external conditions to maintain indoor comfort, and varying occupancy levels can impact energy usage for heating. While specific occupancy data for the CSF building is unavailable at present, modeling dynamic occupancy levels poses challenges in Building Energy Modeling (BEM) simulations. This study did not incorporate occupancy levels, potentially resulting in discrepancies in the simulated energy needs.

The HVAC system modeled in OpenStudio followed ASHRAE's AEDG for energy-efficient design. However, the actual HVAC system in the CSF building may differ, potentially being less efficient and leading to higher energy use compared to the simulation results. Additionally, obtaining energy demand data for various building equipment was challenging, prompting the use of OpenStudio guidelines for electrical equipment in office buildings (climate zones 4-8) during simulation. Variations in occupancy levels, which affect loads and operational times, also influence the accuracy of the simulation results. Moreover, energy-intensive facilities and equipment in the CSF building, such as the ground floor and penthouse used for utilities but modeled as office spaces, were not accounted for in the simulation, potentially contributing to discrepancies in estimated energy consumption.

The simulation assumed adiabatic piping for the hot water supply and return lines extending approximately 160 meters from the Department of Earth Science building to the CSF building, neglecting potential heat losses during actual transmission between the two structures. This could significantly diverge from real-world energy losses**.**

5. CONCLUSIONS

This study involved a comparative analysis using a building energy model developed with the OpenStudio application to assess the impact of various tariff structures, utilizing a university building as the case study. The results suggest that the shift from the current oil-fired hot water boiler used for space heating to electric resistive heating, which is cost-effective under an FR tariff, may not result in any financial savings and could potentially lead to additional energy costs under a TOU tariff. The simulation results, with an energy cost of CA$1,029,089 considering the FR tariff extracted from historical data and the TOU tariff, reasonably derived from the current tariffs in effect in Newfoundland and Ontario, resulting in an energy cost of CA$1,980,110, suggest that the energy cost under TOU can nearly double when compared to an FR tariff, given the same amount of energy consumed with a similar usage pattern. Although the inherent features of electric resistive boilers, such as increased efficiency and rapid responsiveness, coupled with operational practices such as improving the thermal insulation of the building, shifting non-critical loads to off-peak hours, and employing energy-efficient equipment, contribute to energy savings and cost reduction, it is doubtful that these measures alone can fully offset the potentially high energy costs associated with a TOU tariff.

The simulation results show a similar energy consumption pattern to actual usage, albeit with calculated values lower than observed. It's crucial to acknowledge that model assumptions regarding construction materials, occupancy, infiltration, interconnected buildings, equipment, and lighting energy usage, HVAC system performance, and piping transmission losses may differ from real-world conditions, thereby influencing energy consumption significantly. These unaccounted variables contribute to the higher actual energy consumption of the building.

Information obtained from an extensive survey encompassing building occupancy, electricity usage, operational schedules, infiltration/exfiltration rates, and construction details can improve the BEM developed in this study while providing a clear picture of the actual energy consumption patterns of the building. An improved BEM can play a vital role in assessing energy needs and formulating an optimized operational strategy for the building, particularly under a TOU tariff where energy costs carry substantial significance. This will help pinpoint the best strategies for moving energy-intensive activities to off-peak times. Additionally, this study could benefit from exploring the feasibility of integrating onsite renewable energy generation to lessen reliance on the grid.

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REFERENCES

[1] International Energy Agency. 2023. Buildings - Energy System. *IEA*. Retrieved January 08, 2024 from the World Wide Web: https://www.iea.org/energy-system/buildings

[2] Fumo N. 2014. A review on the basics of building energy estimation. *Renewable and Sustainable Energy Reviews* (31): 53–60.

[3] Foucquier A., Robert S., Suard F., Stéphan L., and Jay A., 2013. State of the art in building modelling and energy performances prediction: A review. *Renewable and Sustainable Energy Reviews* (23): 272–288.

[4] NRC Government of Canada. 2022. Total End-Use Sector - Energy Use Analysis. Retrieved September 01, 2023 from the World Wide Web: https://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/showTable.cfm?type=AN&sector=aaa&juris=ca&year=2020&rn=1&page=0

[5] NRC Government of Canada. 2022. Residential Sector - Energy Use Analysis. Retrieved September 01, 2023 from the World Wide Web: https://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/showTable.cfm?type=AN&sector=res&juris=00&year=2020&rn=11&page=0

[6] NRC Government of Canada. 2022. Commercial/Institutional Sector - Energy Use Analysis. Retrieved September 01, 2023 from the World Wide Web: https://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/showTable.cfm?type=AN&sector=com&juris=00&year=2020&rn=11&page=0

[7] NRC Government of Canada. 2022. Energy Benchmarking Data Snapshots For All Building Types. Retrieved September 06, 2023 from the World Wide Web: https://natural-resources.canada.ca/energy-efficiency/energy-star-canada/energy-star-for-buildings/energy-benchmarking-data-snapshots/energy-benchmarking-data-snapshots-for-all-building-types/24263

[8] NRC Government of Canada. 2022. Commercial/Institutional Sector Canada Table 1: Secondary Energy Use and GHG Emissions by Energy Source. Retrieved January 08, 2024 from the World Wide Web:

https://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/showTable.cfm?type=CP&sector=com&juris=ca&year=2020&rn=1&page=0

[9] NRC Government of Canada. 2022. Commercial/Institutional Sector Canada Table 69: Educational Services Non-Space Conditioning Secondary Energy Use by End Use and by Energy Source. Retrieved January 08, 2024 from the World Wide Web: https://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/showTable.cfm?type=CP&sector=com&juris=ca&year=2020&rn=69&page=0

[10] NRC Government of Canada. 2022. Commercial/Institutional Sector Canada Table 70: Educational Services Space Conditioning Secondary Energy Use by End Use and by Energy Source. Retrieved January 08, 2024 from the World Wide Web: https://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/showTable.cfm?type=CP&sector=com&juris=ca&year=2020&rn=70&page=0

[11] NRC Government of Canada. 2022. Commercial/Institutional Sector Atlantic1 Table 1: Secondary Energy Use and GHG Emissions by Energy Source. Retrieved January 09, 2024 from the World Wide Web: https://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/showTable.cfm?type=CP&sector=com&juris=atl&year=2020&rn=1&page=0

[12] NRC Government of Canada. 2022. Commercial/Institutional Sector Atlantic Table 45: Educational Services Non-Space Conditioning Secondary Energy Use by End Use and by Energy Source. Retrieved January. 09, 2024 from the World Wide Web: https://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/showTable.cfm?type=CP&sector=com&juris=atl&year=2020&rn=45&page=0

[13] NRC Government of Canada. 2022. Commercial/Institutional Sector Atlantic Table 46: Educational Services Space Conditioning Secondary Energy Use by End Use and by Energy Source. Retrieved January 09, 2024 from the World Wide Web: https://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/showTable.cfm?type=CP&sector=com&juris=atl&year=2020&rn=46&page=0

[14] NRC Government of Canada. 2022. Residential Sector Newfoundland1 Table 1: Secondary Energy Use and GHG Emissions by Energy Source. Retrieved January 21, 2024 from the World Wide Web: https://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/showTable.cfm?type=CP&sector=res&juris=nl&year=2020&rn=1&page=0

[15] Hydro-Québec. 2022. Comparison of Electricity Prices in Major North American Cities 2022: 84.

[16] Ontario Energy Board. 2023. Electricity rates | Ontario Energy Board. *Ontario Energy Board*. Retrieved January 04, 2024 from the World Wide Web: https://www.oeb.ca/consumer-information-and-protection/electricity-rates

[17] NT Power. 2023. Commercial Electricity Rates. *NT Power*. Retrieved January 09, 2024 from the World Wide Web: https://ntpower.ca/accounts-services/electricity-rates/commercial-electricity-rates

[18] Toronto Hydro. 2023. Business electricity rates. *Toronto Hydro*. Retrieved Jan. 05, 2024 from the World Wide Web: https://www.torontohydro.com/for-business/rates

[19] Ansarin M., Ghiassi-Farrokhfal Y., Ketter W., and Collins J. 2020. The economic consequences of electricity tariff design in a renewable energy era. *Applied Energy* (275): 1-12.

[20] Wang Z. and Li F. 2011. Developing trend of domestic electricity tariffs in Great Britain. In *Proceedings of the 2nd IEEE PES International Conference and Exhibition on Innovative Smart Grid Technologies*. Manchester, United Kingdom, 05-07 December. IEEE Xplore. Retrieved January 10, 2024 from the World Wide Web: https://ieeexplore-ieee-org.qe2a-proxy.mun.ca/abstract/document/6162795

[21] Nezamoddini N. and Y. Wang. 2017. Real-time electricity pricing for industrial customers: Survey and case studies in the United States. *Applied Energy* (195): 1023–1037.

[22] Hogan W., 2014. Time-of-Use Rates and Real-Time Prices. Retrieved January 10, 2024 from the World Wide Web: https://lmpmarketdesign.com/papers/Hogan_TOU_RTP_Newark_082314.pdf

[23] Harish V.S.K.V. and A. Kumar. 2016. A review on modeling and simulation of building energy systems. *Renewable and Sustainable Energy Reviews* (56): 1272–1292.

[24] Hong T., Chen Y., Luo X., Luo N., and Lee S.H., 2020. Ten questions on urban building energy modeling. *Building and Environment* (168): 1-13.

[25] Memorial University of Newfoundland. 2023. Cryogenic Facility | Research. Retrieved December 22, 2023 from the World Wide Web: https://www.mun.ca/research/research-tools-and-resources/cryogenic-facility/

[26] Department of Facilities Management, Memorial University of Newfoundland. 2023. Facility Energy Summary for Core Science Facility Building.

[27] Foster V. and S.H. Witte. 2020. Falling Short: A Global Survey of Electricity Tariff Design. Retrieved January 10, 2024 from the World Wide Web: https://papers.ssrn.com/abstract=3549004

[28] Liyanage C.J. and M.T. Iqbal. 2024. A Comparison of Programmed Controlled Existing System vs. Electric Resistive Heating for a University Building in Newfoundland. *European Journal for Energy Research* (4): 5-19.

[29] Brackney L., Parker A., Macumber D., and Benne K., 2018. Building Energy Modeling with OpenStudio: A Practical Guide for Students and Professionals. Cham: Springer International Publishing, pp. 1-286.

[30] Alliance for Sustainable Energy LLC. 2023. OpenStudio. Retrieved December 23, 2023 from the World Wide Web: https://openstudio.net/

[31] Canadian Commission on Building and Fire Codes and National Research Council of Canada. 2020. National Energy Code of Canada for Buildings 2020. Ottawa: National Research Council of Canada, pp. 90-105.

[32] American Society of Heating, Refrigerating and Air-Conditioning Engineers. 2004. AEDG - Advanced Energy Design Guides. *ASHRAE*. Retrieved December 26, 2023 from the World Wide Web: https://www.ashrae.org/technical-resources/aedgs

[33] BC Hydro. 2024. Residential rate design. Retrieved January 14, 2024 from the World Wide Web: https://www.bchydro.com/toolbar/about/strategies-plans-regulatory/rate-design/current-activities/residential-rate-design.html

[34] Ontario Energy Board. 2024. Fixed electricity pricing effective January 18, 2022. Retrieved January 14, 2024 from the World Wide Web: https://www.oeb.ca/sites/default/files/FAQs-new-fixed-rates-january2022-20220110_0.pdf

[35] Newfoundland Power Inc. 2023. Schedule of Rates, Rules and Regulations. Retrieved January 18, 2024 from the World Wide Web: https://www.newfoundlandpower.com/-/media/PDFs/My-Account/Usage/Rates-Rules-and-Regulations.pdf

[36] NRC Government of Canada. 2023. Monthly Average Retail Prices for Diesel in 2023. Retrieved November 29, 2023 from the World Wide Web: https://www2.nrcan.gc.ca/eneene/sources/pripri/prices_bycity_e.cfm?productID=5&locationID=66&locationID=44&frequency=M&priceYear=2023&Redisplay=.