THERMAL MODELING, ANALYSIS OF MUN CSF BUILDING, AND FEASIBILITY STUDY OF SPACE HEATING USING ELECTRICITY

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ABSTRACT

Globally, buildings represent 30% of total energy demand, and in Canada, they contribute 25% to final energy consumption, predominantly in space heating, constituting about 60% of this consumption. This underscores a substantial opportunity for significant energy and cost savings. While many buildings are transitioning to electric heating for efficiency and cost-effectiveness, a thorough analysis, considering technological and financial aspects, is essential to explore the outcomes of such transitions.

The current study focuses on the Core Science Facility at Memorial University, evaluating the feasibility of transitioning to electric resistive heating. Initial steps involve scrutinizing 2022 energy data, comparing it with similar buildings, and performing a calculation to gauge potential savings based on existing tariffs and transition costs. Subsequent phases include creating a thermal energy model using Energy3D and conducting a feasibility analysis with RETScreen Expert. OpenStudio is then utilized to develop a Building Energy Model for a comprehensive assessment of the transition's advantages. The final step extends this model to analyze the transition's impact under a potential future switch from a flat rate to a time-of-use electricity tariff in Newfoundland.

The Core Science Facility's current energy consumption exceeds the national median for university buildings. Transitioning to electric resistive heating, akin to current rates, can yield energy cost savings. A RETScreen feasibility study forecasts substantial annual cost reductions compared to 2022 data. The OpenStudio-derived Building Energy Model indicates additional energy savings. However, analysis of Time of Use and Flat Rate tariffs suggests potential benefits may not be realized. Comprehensive surveys covering occupancy, electricity usage, operational schedules, and construction details can enhance the energy model's accuracy. Further improvements can identify energy-saving measures and optimize operational strategies for the building.

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LIST OF ABBREVIATIONS AND SYMBOLS

AEDG	Advanced Energy Design Guides
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ANL	Argonne National Laboratory
BB	Black-Box
BCL	Building Component Library
BEM	Building Energy Modelling
BES	Building Energy Systems
BIM	Building Information Modelling
Btu/h.ft^2.°F	British thermal unit per hour per square foot per degree Fahrenheit
°C	Celsius
CAD	Computer-Aided Drafting
CFD	Computational Fluid Dynamics
CSF	Core Science Facility
DOE	Department of Energy
DDY	Design Days
EUI	Energy Use Intensity
FR	Fixed Rate
FTE	Full-Time Equivalent
GJ/m^2	Giga-Joules per Square Meter
GUI	Graphical User Interface
gbXML	Green Building Extensible Markup Language
GHG	Greenhouse Gas Emissions
GB	Grey-Box
HST	Harmonised Sales Tax
HVAC	Heating, Ventilation and Air-Conditioning
h.ft^2.°F/Btu	hour per square foot per degree Fahrenheit per British thermal unit
J	Joules

kVA	kilo-Volt Amperes
kWh	kilo-Watt Hours
kWh/m^2	kilo-Watt hours per square meter
LBNL	Lawrence Berkeley National Laboratory
LR	Linear Regression
LHV	Lower Heating Value
MJ/l	Mega Joules per Liter
MW	Mega-Watts
MUN	Memorial University of Newfoundland
tCO_2	Metric tons of Carbon Dioxide
MMBTU	Million British Thermal Units
NREL	National Renewable Energy Laboratory
NN	Neural Networks
ORNL	Oak Ridge National Laboratory
O&M	Operations and Maintenance
NPPL	Pacific Northwest National Laboratories
PJ	Peta Joules
RTP	Real-Time Electricity Pricing
RC	Resistance-Capacitance
RETScreen	RETScreen Clean Energy Management Software
SDK	Software Development Kit
SHGC	Solar Heat Gain Coefficient
m^2	Square meter
SVM	Support Vector Machine
TWh	Tera-Watt hours
TOU	Time-of-Use
UA	Utility Annex
UC	University Center

UI	User Interface
VLT	Visible Light Transmission
WB	White-Box

LIST OF APPENDICES

CHAPTER 1. INTRODUCTION

1.1 Introduction

Over the past decade, climate change has emerged as a serious global concern, with mounting scientific evidence underscoring its extensive consequences for ecosystems, economies, and societies. As a result, the international community has taken rigorous actions to tackle this urgent challenge. The 2015 Paris Agreement, a landmark accord, witnessed countries committing to curb global warming to below 2 degrees Celsius (°C) above pre-industrial levels, with an ambitious target of limiting it to 1.5 degrees Celsius [1]. This pivotal agreement has spurred collaborative efforts worldwide, focusing on curtailing emissions and fostering sustainable development. Among the strategies employed to combat climate change, energy efficiency has risen as one of the fundamental cornerstones [2]. By optimizing energy consumption in diverse sectors like transportation, industry, and buildings, energy efficiency not only reduces greenhouse gas emissions but also strengthens energy security and drives economic advancement. In the context of the swiftly evolving climate landscape, energy efficiency assumes a vital role in realizing emissions reduction objectives and cultivating resilience against the impacts of a warming planet.

Across the globe, the building sector has always been one of the main consumers of energy [3], [4], [5], [6]. Even in Canada, residential, commercial and other institutional buildings account for more than 20% of the total energy consumption over the past twenty-five year period [7]. In a global scale, energy consumed by buildings can become as high as 40% [5], [8]. Energy consumption in buildings has progressively increased over time, and factors such as population growth, increase in time spent indoors, technology and comfort are among the key contributing factors for this phenomena [4], [5], [8]. Research suggests that heating, ventilation and air-conditioning (HVAC) accounts for approximately 40% of the energy consumed by buildings on average, while in regions with cold climates, this can be as high as 60% [9]. As a result, improving the energy efficiency of space heating and cooling in buildings is of utmost importance, both from the perspectives of energy conservation and mitigating climate change. A review of literature indicates the potential impact of energy-efficient heating and cooling technologies on climate change mitigation. The reduction in energy demand leads to fewer emissions from fossil fuel combustion, a primary source of greenhouse gases [10], while contributing to lowering energy costs for building occupants and operators.

Figure 1.1 depicts the average energy consumption by buildings, categorized by end use, for various countries (reproduced from [9]), while Table 1.1 provides a summary of the average energy usage per square meter (m^2) of floor space for various establishments in Canada (adapted from [11]).

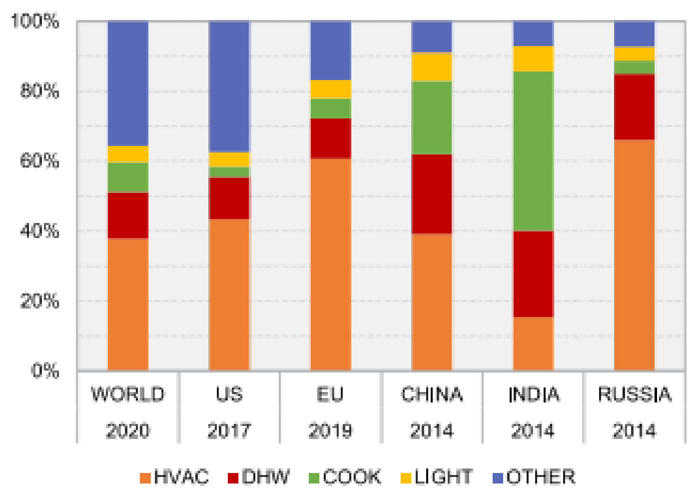

Figure 1.1. Buildings consumption by end-uses for the world, US, EU, China, India

Table 1.1. Energy use by various institutional buildings in Canada

Building Type	Energy Use (Giga-Joules per square meter- GJ/m^2)
College/ University	1.04
K-12 School	0.70
Library	1.03
Hospital (General medical and surgical)	2.20
Courthouse	0.87
Fire Station	0.66

The Core Science Facility (CSF) Building has been located on the premises of the Memorial University of Newfoundland (MUN), St. John's, Newfoundland has been considered as a case study. The building consists of approximately 40,817 square meters of gross area, across five floors and three lobbies, and was first opened in 2021. This building was selected for the case study as it is the newest building in the university complex. The building is heated through hot water coming from the central heating plant located in the Utility Annex of the university. The hot water is supplied at approximately 138°C to the building, and the building has heat exchangers which would reduce the temperature to approximately 83°C at the secondary side. The hot water returns at a temperature of approximately 55-65°C.

Figure 1.2 displays the CSF Building (adapted from [12]), while Figure 1.3 presents a simplified schematic diagram of the space heating system.

Figure 1.2. Core Science Facility

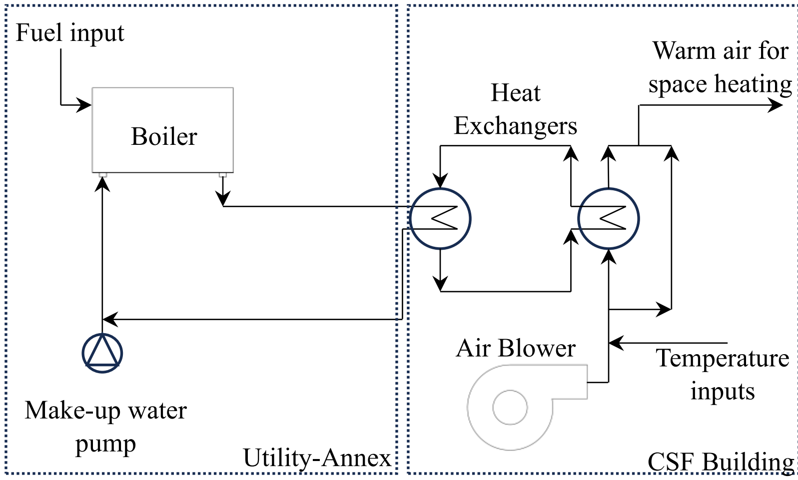

Figure 1.3. Simplified schematic of the space heating system

1.2 Literature Review

Buildings play a crucial role in providing shelter and protection to the occupants from the external environment. Research suggests that in the developed countries, buildings are responsible up to 40% of the total energy consumption, of which Heating, Ventilation and Air-Conditioning (HVAC) systems represent approximately 50% [9], [13]. Moreover, buildings contribute to 36% of energy related greenhouse gas emissions (GHG) [14]. With the efforts being made to implement climate change mitigation strategies and policies, it is evident that improving the energy efficiency in the buildings is of paramount importance. Enhancing energy efficiency in buildings, as can reduce the demand for fossil fuels, leading to decreased carbon emissions [15], which also aligns with the objectives of international agreements such as the Paris Agreement [1], which highlights the urgency of reducing GHGs and curtailing global warming. Enhancing building energy efficiency can be achieved in various methods, including, but not limited to enhancing building thermal insulation [16] and integrating solar panels for generating clean energy for self-consumption. Such methods however, though beneficial, often demand substantial investments and time commitments. On the other hand, implementing advanced techniques for managing HVAC systems can be cost effective while serving the purpose of reducing energy consumption significantly, thus reducing the energy related GHGs. As a result, this alternative can be particularly suitable for existing buildings that are already in operation [17]. Research also suggests that the utilization of recent technological advancements in energy management has the potential to result in an average reduction of energy consumption in buildings ranging from 13% to 28% [18]. However, the successful execution of these modern technological advancements is closely linked with the availability of an energy model of the building, which can be vital for making predictions, evaluating the feasibility of management policies, and other related considerations as such.

Various energy sources worldwide contribute to fueling the built environment. Similarly, the extensive and diverse landscape of Canada results in distinct energy production and consumption patterns across its provinces and territories. According to literature, in the Commercial and Institutional building sector in Canada, approximately 52% of the energy consumption is ascribed to natural gas, establishing it as the predominant energy source [19], [20]. Following closely is electricity, contributing 43% to the sector's energy demand, while the remaining portion is met by light fuel oil, kerosene, coal, propane, and other alternative fuels. Space heating constitutes the primary demand, making up approximately 57% of the total demand, with auxiliary equipment ranking second, closely followed by lighting [19]. Figure 1.4 provides a visual representation of the energy utilization categorized by end use, while Figure 1.5 depicts the energy consumption categorized by energy source in the commercial and institutional sector in Canada (reproduced from [19]).

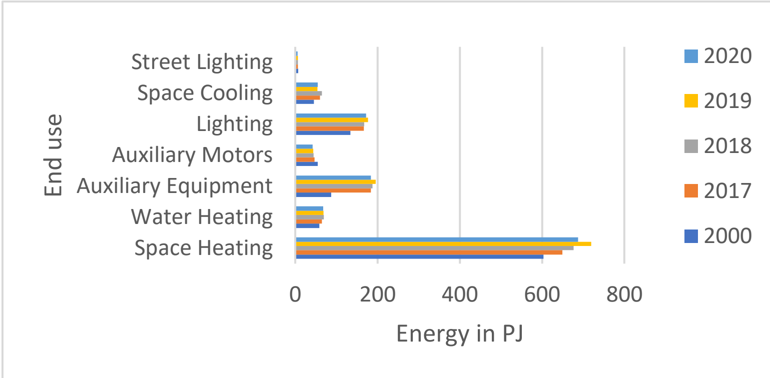

Figure 1.4. Energy use by end use in commercial and institutional buildings

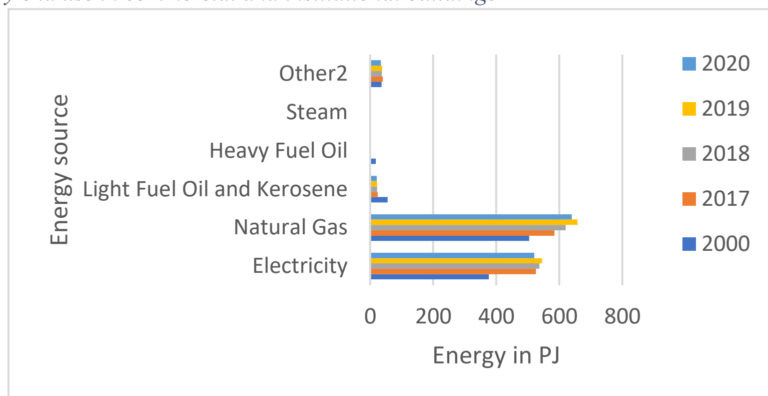

Figure 1.5. Energy use by energy source in commercial and institutional buildings

While many policies have concentrated on decarbonizing the power sector, the heat sector has seen minimal attention. Existing literature indicates that only 10% of the total heat demand is electrified [21], primarily in buildings, and about 5% is supplied by district heating, followed by renewable electricity and solar thermal, with the majority relying on the direct combustion of fossil fuels [22]. Although 10% represents the global average, electrification rates exhibit significant variations worldwide, contingent on the availability and cost of electricity or its alternatives. In regions with abundant low cost electricity, often derived from hydroelectric power, such as Quebec, residential heat electrification reaches around 66% [23]. Conversely, high penetration rates are observed only in countries with low heat demand, emphasizing the challenges of electrifying heat owing to reasons such as the variability in heat demand, posing substantial load balancing difficulties.

There are a number of approaches that can be taken to develop the energy model of a building. White-box (WB) models represent a prominent choice, provided that a well-defined parametrization of the building is established [24]. WB modelling requires a comprehensive representation of the building and its construction methodologies, demanding the specification of a wide array of architectural metadata parameters such as material layers, thickness, conductivity, capacity, density, and convective coefficients for elements like walls, windows etc. [17]. Accordingly, WB offers a high level of accuracy when the provided parameter values closely resemble the actual conditions. Some of the white-box modeling and simulation tools that are considered high-fidelity and matured include both free and paid applications such as EnergyPlus [25], Modelica [26], IDA ICE [27], eQUEST [28], and TRNSYS [29], which have been extensively used for accurately capturing the thermal and energetic dynamics within buildings [30], [31], [32].

A common alternative to mitigate the complexity of WB modelling involves the utilization of black-box (BB) models. These models are constructed through pure data-driven techniques, relying on input-output data while disregarding physical relationships or architectural metadata [17]. As a result, they require only a limited number of parameters while exhibiting simplified complexity [24]. In this context, various model structures prove applicable, including linear regression (LR), neural networks (NN), support vector machine (SVM), etc. [33], [34], [35]. However, BB methodologies also indicate distinct drawbacks. One prominent example is that the parameters often lack physical significance, rendering them non-interpretable for building operators [17]. Furthermore, BB methodologies demand extended training and validation periods while being constrained to building operation conditions specified within the training period [24]. As a result, optimal accuracy is achieved only when a comprehensive array of distinct operating scenarios is imposed on the actual system for prolonged durations, which is a practice that is often impractical and undesirable.

Grey-Box (GB) modelling techniques are employed to combine the merits of both WB and BB models. In this approach, the model structure is derived from physical principles, while the model parameters are identified through input-output data [36]. Traditionally, GB methodologies are based on simple resistance-capacitance (RC) model structures, as comprehensively reviewed in [33]. Often, these methods emphasize on simplifying the modeling process [37]. In contrast to BB models, RC models possess the advantage of greater physical interpretability and do not require an extensive array of diverse operational scenarios [17]. However, GB models do not capture non-linear dynamics accurately and determining the optimal model complexity remains debatable as lower-order models might fail to capture thermal dynamics, while higher-order models risk overfitting to training data [38]. On the other hand, when compared to WB models, RC models demand less effort for development and involve fewer parameters, albeit at the cost of reduced accuracy and reduced representation of nonlinear dynamics [17]. A detailed summary of different building energy simulation programs is provided in Table 1.2.

Table 1.2. List of more commonly used building energy simulation software

	BESP	Applications	Open source	Simulation engine
1	Autodesk Green Building Studio [39]	3D CAD/BIM	Y	DOE-2.2 and EnergyPlus
2	BSim [40]	Energy, daylight, thermal and moisture analysis, indoor climate	N	Self
3	BuildingSim [41]	Thermostat, simulation, energy cost	Y	Self
4	COMSOL Multiphysics [42]	Solving 3-D heat PDE	N	Self
5	DesignBuilder [43]	Building energy simulation, visualisation, CO_2 emissions, solar shading, natural ventilation, daylighting, comfort studies, CFD, HVAC simulation, pre-design, early-stage design, building energy code compliance checking, OpenGL EnergyPlus interface, building stock modelling, hourly weather data, heating and cooling equipment sizing	Y	Self
6	DOE-2 [44]	Energy performance, design, retrofit	N	Self
7	EnerCAD [45]	Building Energy Efficiency; Early Design Optimization; Architecture Oriented; Life Cycle Analysis	N	Self
8	EnergyPlus [46]	Energy simulation, load calculation, building performance, simulation, energy performance, heat balance, mass balance	Y	Self
9	eQUEST [28]	Energy performance, simulation, energy use analysis, conceptual design performance analysis, LEED, Energy and Atmosphere Credit analysis, Title 24, compliance analysis, life cycle costing, DOE 2,	Y	DOE 2.2

		PowerDOE, building design wizard, energy efficiency measure wizard		
10	ESP-r [47]	Energy simulation, environmental performance, commercial buildings, residential buildings, visualisation, complex buildings and systems	N	Self
11	Facility energy decision system (FEDS) [48]	Single buildings, multibuilding facilities, central energy plants, thermal loops, energy simulation, retrofit opportunities, life cycle costing, emissions impacts, alternative financing	Y	None
12	TRNSYS [49]	Energy simulation, load calculation, building performance, simulation, research, energy performance, renewable energy, emerging technology	N	Self
13	IDA-ICE [50]	Building energy modeling, large scale simulations, building performance, building design and optimisation, HVAC system design and analysis, energy code compliance, Renewable energy and energy storage integration	N	Self
14	Hot2000 [51]	Residential building energy modeling, building performance, building design and optimisation, energy code compliance, benchmarking	Y	Self
15	OpenStudio [52]	Building energy modeling, large scale simulations, building performance, building design and optimisation, HVAC system design and analysis, Renewable energy integration, daylighting and natural ventilation analysis, lifecycle cost analysis, energy code compliance	Y	EnergyPlus, Radiance

Research suggests that Building Information Modelling (BIM) can provide the information required for Building Energy Modelling (BEM) [51]. This BIM-BEM process has been divided into six distinct steps: building geometry (Step 1), construction and materials (Step 2), building or space types (Step 3), thermal zones (Step 4), space loads (Step 5), and HVAC system along with its components (Step 6) [52]. Building data can be further classified into two main categories: static data and dynamic data. Static data encompasses details about the physical attributes of the building, while dynamic data pertains to time-series data that evolve over time [53]. The existing research further suggests that thermal zoning constitutes a critical step in the conversion of BIM to BEM, as different zoning strategies can impose a significant impact on simulation results [54]. While a universally accepted approach for thermal zoning is yet to be established, current methodologies exhibit variations across different standards and guidelines [55], [56]. However, some common criteria for thermal zoning has been outlined by [57]. This process suggests separating the spaces into core and perimeter thermal zones and divided by orientation first Additionally, spaces with similar attributes, such as solar gain, orientation, occupancy, schedule, and function, can be combined into single thermal zones. However, since the space attributes may change during design or operation, thermal zoning results may change, hence the process of thermal zoning can be a flexible and potentially dynamic process [51].

The BEM process involves the integration and analysis of data from four key information domains: weather, building characteristics, internal heat gain, and HVAC systems [51]. Weather domain encompasses data related to external weather conditions, such as temperature, humidity, solar radiation, wind speed, and direction. Weather data is crucial for simulating the building's response to external climatic factors, enabling accurate assessment of energy performance and thermal comfort. Building characteristics include architectural details, construction materials, envelope properties (e.g., insulation, thermal mass), and geometry. This information forms the basis for constructing a digital representation of the building, which is used to simulate its thermal behavior under varying conditions. Internal heat gains originate from occupant activities, lighting, equipment, and appliances within the building. Accurate representation of these heat gains is essential to predict internal thermal conditions, energy consumption, and load on HVAC systems. Finally, HVAC systems encompass the design, configuration, and operation details of heating, cooling, ventilation, and air distribution systems. This domain includes equipment specifications, control strategies, setpoints, and schedules. Accurate modeling of HVAC systems is crucial for evaluating energy consumption, comfort levels, and system performance.

The current research pursues WB modelling technique, using static data and EnergyPlus OpenStudio, an opensource, graphical user interface (UI) platform for BEM based on EnergyPlus. This WB model can then be used for simulation and optimization of the building.

The literature review underscores the lack of specialized building analysis software, leading researchers to employ diverse software options based on accessibility and the specific space heating technology under examination. Additionally, there is a scarcity of literature addressing and suggesting potential energy savings associated with the implementation of alternative space heating methods. This observation emphasizes the need for more comprehensive research in the field of building energy analysis, particularly concerning different space heating technologies and the potential energy and cost saving implications associated with their adoption.

1.3 Objectives of the Research

The literature review indicates that in Canada, buildings account for a significant portion of energy consumption, with educational facilities being no exception. As energy efficiency becomes increasingly important for sustainability and cost savings, there is a growing interest in exploring ways to optimize energy use in buildings. In this aspect, building energy modeling offers a valuable tool for simulating building performance and assessing the potential impact of energy-saving measures.

This thesis focuses on the energy use of educational buildings, particularly the CSF building at Memorial University of Newfoundland. The CSF building is relatively new, with no comprehensive energy audit has been done to date. The objective is to utilize building energy modeling to analyze the potential impact of changing the space heating system from an oil-fired boiler to electric resistive heating. However, it is imperative to conduct further investigation into the impacts of such a transition, considering potential future changes.

Given the considerations, the objectives of this research can be outlined as follows.

Development of Thermal Model: The first objective is to develop a comprehensive thermal model of the CSF building using EnergyPlus OpenStudio software. This model will be based on building mechanical drawings (provided in Appendix I), obtained from the Department of Facilities Management, Memorial University of Newfoundland, Canada. By creating an accurate representation of the building's thermal characteristics, this objective lays the foundation for subsequent analyses.

Analysis of Energy Consumption and Efficiency: The second objective involves using the developed thermal model to analyze the energy consumption and efficiency of the CSF building. OpenStudio software will be utilized to simulate the building's energy use, and the results will be compared with actual energy consumption data provided by the Department of Facilities Management (provided in Appendix II). This comparison will help evaluate the accuracy of the model and identify potential areas for energy optimization.

Feasibility of Electric Resistive Heating: The third objective aims to assess the feasibility of space heating using electric resistive technology as an alternative to the current heating method. This analysis will consider both the financial impact and the sustainability implications of adopting electric resistive heating, providing valuable insights for decision-making.

Influence of Programmed Heating Methods: The fourth objective seeks to investigate the influence of programmed heating methods on building energy consumption. This analysis will compare the energy performance of the current heating system with that of the proposed electric resistive heating system.

Implications of Time-of-Use Electricity Billing: The final objective anticipates the implications of time-of-use electricity billing on space heating. By considering the varying electricity rates throughout the day and the season, this analysis will assess the potential impact of the transition on energy costs and heating strategies in the event Newfoundland switches to a Time-of-Use tariff structure.

1.4 Outline of the Thesis

The contribution of the remaining chapters of this thesis is described herein. This thesis follows the manuscript format, and each chapter has been prepared as standalone documents.

Chapter 2 consists of CSF building energy consumption analysis and cost estimate of electric resistive heating system.

Chapter 3 presents the thermal modelling and simulation of CSF building, using RETScreen and Energy3D software.

Chapter 4 consists of a comparison of programmed controlled existing system vs. electric resistive heating, employing a Building Energy Model created with OpenStudio.

Chapter 5 discusses about the impact of future time of use billing on energy consumption costs, utilizing a further refined Building Energy Model derived from OpenStudio.

Chapter 6 consists of the Conclusions and further work.

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CHAPTER 2. CSF BUILDING ENERGY CONSUMPTION ANALYSIS AND COST ESTIMATE OF ELECTRIC RESISTIVE HEATING SYSTEM

Preface

A version of the manuscript has been presented at the 32nd Annual Newfoundland Electrical and Computer Engineering Conference (NECEC). The principal author of this thesis conducted the research, derived results, and prepared the first draft. The co-author, Professor M. Tariq Iqbal presented the problem, delineated the scope, and guided the principal author throughout the process of this research. Professor Iqbal also contributed by reviewing the results and revising the manuscript.

Abstract

This chapter presents findings from an energy consumption analysis of the Core Science Facility (CSF) at Memorial University of Newfoundland (MUN) and estimates the cost of implementing an electric resistive heating system. The study aims to assess current energy usage based on twelve months of actual consumption data and evaluate the feasibility of transitioning to an energy-efficient heating system. The analysis indicates the current Energy Use Intensity (EUI) is around 2.15 GJ/m^2, compared to the National median reference of 1.04 GJ/m^2 for a university.

The cost estimate includes upfront investment for procurement and installation, with consideration of operational costs. Findings will be used to develop an energy model using Energy Plus Open Studio software to explore the potential savings while reducing greenhouse gas emissions. The study highlights the importance of environmental sustainability and long-term benefits of energy-efficiency in alignment with sustainability goals.

Keywords: Energy consumption, Space heating, Building energy optimization, Electric resistive heating

2.1 Introduction

The energy demand within Canada is significantly influenced by the buildings sector, which accounts for a substantial portion of the country's total final energy consumption, approximately a quarter of it. Collectively, these demands for heating and cooling account for approximately 61% of the total energy consumption within the buildings sector [1]. In 2016, the residential and commercial buildings have consumed a total of 2,626.28 Peta Joules (PJ) (approximately 729.52 Tera-Watt hours) claiming 24.66% of total end use demand in Canada, with a projected energy consumption of 3,011.66 PJ (approximately 836.57 TWh) by buildings by 2022, which is expected to account for approximately 25.45% of the total end use demand [2]. Research also suggests that the ongoing construction of new buildings remains a potent catalyst for the demand for energy services within the building sector. Over the last decade, the expansion of floor space in Canada has outpaced population growth by approximately 5% [1].

However, existing stock of buildings account for the majority of buildings, and for a significant portion of the energy consumption. As a result, improving the energy efficiency of buildings through better insulation, advanced HVAC systems, and sustainable design practices are crucial steps in combating climate change and achieving the sustainable goals set forth by the Government of Canada.

The residential building sector in Canada accounts for approximately 16.2% of the country's total energy consumption in 2020 [3]. Residential buildings in Canada have been primarily categorised into four segments, as single detached, single attached, apartments and mobile homes [4]. The energy consumption by residential building type, and by end-use for the year 2020 have been given in Tables 2.1 and 2.2 respectively (Reproduced from [4]). Energy usage in Canadian homes is primarily attributed to space heating, water heating, appliances, lighting, and space cooling, accounting for approximately 61%, 18.1%, 14.7%, 3.7%, and 2.5% of the residential energy consumption, respectively [4]. Furthermore, existing literature also suggests that the energy intensity of residential buildings per year in Canada varies from 75 kilo-watt hours per square meter (kWh/m^2) for newly constructed buildings up to 220 kWh/m^2 or more for buildings that were constructed before 1960 [1].

Table2.1: Energy consumption in 2020, by residential building type

	Energy use, PJ	As a %
Single Detached	980.1	68.62
Single Attached	149.8	10.49
Apartments	270.5	18.94
Mobile Homes	27.9	1.95
Total	1428.3	100

Table 2.2: Energy consumption by end-use in 2020 (residential buildings)

	Energy use, PJ	As a %
Space heating	871.3	61
Water heating	258.2	18.08
Appliances	210.5	14.74
Lighting	52.6	3.68
Space cooling	35.7	2.5
Total	1428.3	100

In comparison, commercial and institutional buildings were responsible for approximately 13.8% of Canada's energy consumption in 2020 [3]. Commercial and institutional buildings have been divided into many categories, namely wholesale trade, retail trade, transportation and warehousing, information and cultural industries, office, educational services, health care and social assistance, arts/ entertainment and recreation, accommodation and food services and other services [5]. Furthermore, the end uses of energy in the commercial and institutional building sector have been subdivided into space heating, water heating, auxiliary equipment, auxiliary motors, lighting, space cooling and street lighting, and account to approximately 56.6%, 5.6%, 15.1%, 3.5%, 14.2%, 4.5% and 0.5% of the energy consumption in the commercial and institutional building sector respectively [5]. The energy consumption by commercial and institutional sector by building type, and by end-use for the year 2020 have been given in Tables 2.3 and 2.4 respectively (Reproduced from [5]).

Table 2.3: Energy use in 2020 by building type, commercial and institutional buildings

	Energy Use, PJ	**As a %**
Wholesale Trade	62.08	5.13
Retail Trade	179.10	14.81
Transportation and Warehousing	44.61	3.69
Information and Cultural Industries	23.86	1.97
Office	402.96	33.31
Educational Services	154.21	12.75
Healthcare and Social Assistance	212.08	17.53
Arts, Entertainment and Recreation	26.69	2.21
Accommodation and Food Services	86.51	7.15
Other Services	17.46	1.44

Table 2.4: Energy consumption by end-use in 2020 (Commercial and institutional buildings)

	Energy Use, PJ	As a %
Space Heating	687.81	56.59
Water Heating	68.24	5.61
Auxiliary Equipment	183.8	15.12
Auxiliary Motors	42.56	3.50
Lighting	172.36	14.18
Space Cooling	54.77	4.51
Street Lighting	5.98	0.49

According to the information, it is evident that space heating is the predominant energy consumer in both residential and commercial buildings.

2.2 Building Space Heating Technologies

Literature suggests that within the Commercial and Institutional building sector in Canada, approximately 49.0% of the energy consumption is attributed to natural gas, making it the primary energy source [6]. This is closely followed by electricity, contributing 45.9% of the sector's energy demand, while the remaining share is fulfilled by light fuel oil, kerosene, coal, propane, and other alternative fuels. Nevertheless, in the context of space heating in the educational sector, approximately 85.2% of the total energy sources are attributed to natural gas, with electricity contributing to only around 10% [7, p. 70]. Table 2.5 summarises the contribution of each fuel type for space heating (Adapted from [7, p. 70]).

Canada's vast and varied landscape leads to diverse energy production and consumption patterns across its provinces and territories. In Atlantic Canada and the territories, a significant proportion of energy consumption comes from refined products, mainly due to the limited access to alternative sources, infrastructure constraints, and comparatively higher costs [1]. These regions primarily depend on liquid fuels for heating, driven by economic considerations and the convenience of truck transportation.

Table 2.5: Space heating by energy source in educational buildings in 2020

	Natural Gas	Electricity	Light Fuel Oil and Kerosine	Heavy Fuel Oil	Steam	Coal and Propane
Energy Use, PJ	77.3	9.0	1.3	0.0	0.0	3.1
As a %	85.2	10.0	1.5	0.0	0.0	3.4

A diverse range of options is available within the domain of electrical space heating technologies for commercial and institutional buildings, with each option presenting its distinct advantages and factors for consideration. One frequently chosen option is electric resistive heating, which usually encompasses systems like baseboard heaters and radiant heating systems [8]. These systems operate by directly converting electrical energy into heat, providing efficient and dependable heating solutions for various spaces within buildings, generally having efficiencies over 90% [9], [10]. The individual control capabilities of each unit facilitate precise temperature management in distinct areas, enhancing both comfort and energy efficiency, making them an ideal solution for zoned-spaces where only actively occupied rooms are to receive heating [8]. Electric resistive heating is simplistic and reliable, with few moving parts, reducing maintenance requirements, with lower capital investment cost compared to other technologies with the facility to control temperatures precisely [8]. However, the efficiency can be less than the more recent electrical space heating options such as heat pumps, and the operation can be expensive, especially in regions with high electricity prices [10].

When it comes to retrofitting existing commercial/ institutional buildings with energy-efficient solutions for space heating, electric boilers can be another potential option that fall under electric resistive heating. In the event the buildings already employ hot water as the space heating medium, heated through oil or gas-fired boilers, replacement of fossil fuel-fired boilers with electric boilers can be very lucrative, with almost zero to minimal modifications to the rest of the system. One of the primary benefits of electric boilers is their remarkable energy conversion efficiency, typically exceeding 95%, which outperforms many fossil fuel-fired systems [11]. Electric boilers are also known for their precision and rapid response to heating demands, resulting in enhanced temperature control and comfort for building occupants [12]. In addition to the aforementioned advantages, electric boilers offer operational simplicity, reduced maintenance requirements, and quiet operation compared to fossil fuel-fired counterparts. They also eliminate the need for on-site fuel storage and the associated safety risks.

Heat pump systems represent another favored alternative, particularly in regions characterized by moderate climates, and often are more efficient than the electric resistive heating systems, offering up to 100% efficiency [10]. Air source heat pumps extract heat from the outdoor air and use it to provide space heating. These pumps work by transferring the heat from the outside air into the indoor space, making them efficient and environmentally friendly heating solutions, and are especially effective in moderate climates. On the other hand, ground source heat pumps, also known as geothermal heat pumps, harness the stable temperature of the ground to provide efficient heating. Ground source heat pumps work by extracting heat from the earth through a series of underground pipes filled with a heat-transfer fluid, through which the extracted heat is then transferred indoors to provide space heating [13]. Ground source heat pumps are highly energy-efficient and environmentally friendly, as they take advantage of the relatively constant temperature below the Earth's surface. Heat pump technology not only offers effective heating but also addresses cooling requirements, rendering it a versatile choice for buildings [13], [14]. However, the initial capital cost of heat pumps can be significant, and contain more moving components, demanding frequent maintenance. Furthermore, research also suggests that the heat pump system performance can vary significantly in extreme cold climates [15], [16].

2.3 Building for the Case Study

This study is centered on the Core Science Facility (CSF) building, which encompasses a total floor area of 40,817 square meters. Situated on the campus of Memorial University of Newfoundland (MUN) in St. John's, Newfoundland, this facility houses various teaching rooms, research laboratories, and office spaces specifically designated for the Department of Electrical and Computer Engineering within the Faculty of Engineering and Applied Science at Memorial University. The building comprises approximately 746 thermally regulated zones distributed across three wings and spanning five floors. The CSF building is linked via Wing C's Level 2 to the University Centre of Memorial University of Newfoundland, which serves as a central hub for connecting various other buildings and departments.

Figure 2.1: Core Science Facility Building

The CSF building primarily employs two sources of energy: Electricity for lighting and appliances and hot water, for space heating. The building's heating system relies on hot water provided by the central heating plant situated in the university's Utility Annex. The hot water is delivered to the building at around 138 Celsius (°C), and within the building, there are heat exchangers that lower the temperature to about 83°C on the secondary side. The hot water returns to the central heating plant at a temperature ranging from approximately 55 °C to 65 °C. The Utility Annex uses No. 2 diesel as the fuel for hot water boilers.

2.4 Energy Consumption Analysis

The electricity, hot water and fuel consumption data for CSF building were provided by the Department of Facilities Management of MUN. Consumption data for the calendar year 2022 has been considered for this study. Tables 2.6 (adapted from [17]) summarises the electricity consumption by CSF building and the cost of electricity during this period. Likewise, Table 2.7 (adapted from [17]) indicates the oil consumption for heating water for the CSF building and the related cost of oil.

Table 2.6: Electricity consumption and cost

Month	Electricity consumption (kWh)	Cost of electricity (CA$)
January	938,238	102,320.81
February	855,079	94,450.09
March	960,000	102,766.68
April	932,419	95,471.55
May	1,001,842	102,834.86
June	1,116,581	115,952.03
July	1,239,224	128,663.04
August	1,301,140	134,127.86

September	1,151,270	119,218.06
October	1,096,985	116,203.27
November	1,047,888	107,139.62
December	1,065,471	114,135.94
TOTAL	12,706,138	1,333,283.81

Table 2.7: Oil consumption and cost

Month	Oil consumption (liters)	Cost of oil (CA$)
January	143,447	166,594.97
February	163,802	207,250.91
March	151,847	228,028.54
April	117,433	186,022.67
May	72,558	149,521.34
June	60,246	132,538.90
July	25,221	54,695.58
August	34,303	64,563.66
September	44,295	81,541.38
October	42,079	82,818.29
November	106,251	207,351.45
December	138,628	264,963.69
TOTAL	1,100,109	1,825,891.37

A typical unit considered in calculating the energy use intensity in buildings has been Gigajoules per square meter of floor space (GJ/m^2). Hence, energy consumption data for the CSF building are also converted to GJ/m^2 for this purpose and are given in Table 2.8. The energy use intensity is calculated considering a Lower Heating Value (LHV) of 38.18 Mega Joules per liter (MJ/l) of diesel and the floor area of CSF building, which is 40,817 m^2.

LHV of diesel	= 38.18 MJ/litre
Diesel consumption/ year	= 1,100,109 litres
Energy consumption for heating	= 42,002.17 GJ
Electricity consumption/ year	= 12,708,136 kWh
Electricity consumption/ year	= 45,742.09 GJ
Total energy consumption / year	= 87,744.26 GJ
Floor area	= 40,817 m^2
Energy Use Intensity	= 2.15 GJ/m^2

Table 2.8: Energy use intensity of CSF building

Description	Energy use intensity (GJ/m^2)
Electricity	1.12
Oil	1.03
Total	2.15

The energy use intensity value can be further enhanced using Energy Star portal, which considers several other factors in order to improve the calculation. These factors include weekly operating hours, total student enrollment for a year, number of full-time equivalent (FTE) workers, number of computers and annual amount of grants [18]. While it is possible to project some of the information based on existing data, it is not possible to calculate the exact values without a rigorous collection of data covering all these factors. Hence, gathering data to encompass occupancy patterns over at least a full calendar year, or a minimum of twelve months, can enhance the results of benchmarking.

The Canadian national median reference values for college/university buildings, according to Energy Star Portfolio Manager records are 1.47 and 1.04 GJ/m^2 for source EUI and site EUI, respectively [19]. It can be observed from the values given in Table 2.8 that the energy use intensity of CSF building is significantly higher than either of the median values, especially the site EUI, which is calculated based on the site energy consumption data and can be considered as a baseline for comparing the energy use intensity calculated in Table 2.8.

According to Abdo-Allah, Iqbal and Pope [20], the Engineering Building at MUN, encompassing an area of 25,412 m^2, consumes approximately 23,000 Million British Thermal Units (MMBTU) of heating and 5,500,000 kWh of electricity annually, equivalent to 24,266 GJ for heating and 19,800 GJ for electricity. This translates to an annual energy intensity of 1.73 GJ/m^2, which notably falls below that of the CSF building. As a measure of reducing the energy consumption of the CSF building, one potential solution currently being considered involves the adoption of electric resistive heating for space heating.

2.5 Cost Estimation for Electric Resistive Heating

Based on the data provided in Tables 2.6 and 2.7, it becomes clear that the predominant expense in the CSF building's energy cost, accounting for approximately 58%, is allocated to fuel used for space heating. Hence this can be considered a main area for improvements in energy efficiency.

Currently the Utility Annex uses four fuel fired boilers, each with a capacity of 18 Mega-Watts (MW) to supply hot water for space heating and processes to several buildings in the university complex, out of which, one boiler is currently non-operational. This non-operational boiler is planned to be replaced by two smaller electric boilers with a better efficiency. This initiative can enhance energy efficiency, while reducing the reliance on fossil fuel. In addition, it would also enable better forecasting of energy costs, since the future electricity costs can be reasonably predictable compared to the volatile prices of fuel oil.

2.5.1 Cost Estimation

The estimation of costs for the electric resistive heating system can be divided into three main categories, namely the cost of all equipment and ancillaries, construction, installation and commissioning of equipment, and all support services such as engineering, project management, contract administration and operations and maintenance support during the construction period. The estimated cost for the system is given in Table 2.9.

The proposed electric resistive boilers consist of two units, each with 15.5 MW capacity, and each unit can effectively replace one 18 MW oil fired boiler. The performance data suggests that CSF building would consume the output from one oil fired boiler, hence it can be assumed that the cost of electric resistive heating system for CSF building as 50% of the cost given in Table 2.9. Furthermore, the cost indicated in Table 2.9 includes the additional cost of demolition of an existing boiler that has been non-functional.

Table 2.9: Cost estimate for electric resistive boiler system

Description	Projected cost (in CA$ millions)
Procurement of all major equipment	5.2
Construction (including the demolition of existing boiler that has been non-functional)	9.5
Engineering, Contract administration, Project management and O&M support during construction	1.6
Total	16.3

2.5.2 Boiler Performance and Potential Savings

With this conversion, it is expected that the fossil fuel consumption will be reduced by approximately 80-85%, amounting to approximately 10.5 million litres/ year [21]. The proposed electric resistive boilers are expected to have an efficiency of 95% in comparison to the current oil-fired boilers with an efficiency of approximately 85%. Table 2.8 indicates that the cost of oil for heating the CSF building per year is more than 1.8 million dollars. It also indicates the CSF building consumes approximately 1.1 million liters of oil per year. Each liter of No. 2 diesel has approximately 10 kWh of energy, which indicates the heating of CSF building requires approximately 11 million kWh per year. Assuming the same heating requirement and current electrical tariff rate of $0.11/kWh for commercial consumers in Newfoundland, the cost of electricity required for space heating can be estimated at 1.21 million dollars per year. This indicates that even without considering the boiler efficiency difference, there is a potential for saving $600,000 per year in heating MUN CSF building.

2.6 Conclusions

In this chapter, the energy consumption of building in Canada was analysed, taking the Core Science Facility (CSF) building at the Memorial University of Newfoundland as a case study. The analysis of a year's worth of actual consumption data revealed significant disparities in energy usage compared to the national median reference for a university. The current Energy Use Intensity (EUI) at CSF, standing at approximately 2.15 GJ/m^2, indicates a higher energy demand than the national average of 1.04 GJ/m^2 for a university. This finding underscores the necessity for energy efficiency improvements within the facility. The cost estimate for the conversion of heating system to electric resistive heating, encompassing upfront procurement and installation expenses along with operational costs, provides a clear picture of the financial considerations involved in such a transition. Simple calculations indicates that there is a significant potential of financial savings in switching to electric resistive heating.

Moreover, the study's results will serve as a foundation for the development of an energy model using Energy Plus Open Studio software. This modeling will allow for a more comprehensive evaluation of potential energy savings.

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CHAPTER 3. THERMAL MODELING AND SIMULATION OF CSF BUILDING

Preface

A version of this manuscript has been published in the European Journal of Engineering and Technology Research (https://doi.org/10.24018%2Fejeng.2024.9.1.3145). The principal author developed simulation models on RETScreen and Energy3D, conducted the analysis, produced the initial manuscript, and subsequently revised it based on suggestions from the co-author, Professor M. Tariq Iqbal. Professor Iqbal also played a significant role in topic selection and defining the scope, reviewed and interpreted the obtained results, and contributed to the preparation, review, and revision of the manuscript.

Abstract

Buildings play a substantial role in global energy consumption, constituting a considerable share of the overall energy use. In Canada, they contribute to around 25% of the total final energy consumption. Notably, space heating emerges as the primary energy consumer, accounting for approximately 57% of energy utilization in institutional and commercial buildings.

This chapter presents a feasibility analysis of converting the space heating system of MUN CSF building using RETScreen Clean Energy Management Software, known as RETScreen Expert, a software package developed by the Government of Canada, and the thermal modeling of the building using Energy3D, developed by the National Renewable Energy Laboratory (NREL). The feasibility study indicates that significant savings can be achieved from the transition, not only financially, but with efficient use of energy and GHG emissions. The results indicate a 24.2% savings in annual energy costs, with a simple payback period of 10.5 years. The simulation results from Energy3D are compared with the measured building energy consumption data provided by the MUN Facilities Management Department. The thermal model indicates less energy consumption than the actual measured values, that is caused by factors such as transmission losses,

interconnection between CSF building and the UC, building occupancy, the ventilation system, and degradation of equipment that are not considered in the model.

Keywords: RETScreen Expert, Energy3D, Thermal Modeling, Feasibility, Space Heating

3.1 Introduction

3.1.1 Thermal Modeling and Simulation of Buildings

Buildings are responsible for approximately 40% of the overall energy consumption worldwide [1]. In contrast, in Canada, buildings are responsible for a significant proportion of the country's energy demand, claiming approximately 25% of the total final energy consumption, which accounts for approximately 729.52 Tera-Watt hours (TWh) [2]. Due to the extended lifespan of buildings, enhancing energy efficiency within them can significantly play a crucial role in reducing operational expenses and emissions, concurrently promoting sustainability. Research suggests that new buildings employing energy efficiency measures can reduce energy consumption significantly [1]. Furthermore, it is also suggested that the use of the most efficient walls, windows, and Heating, Ventilation, and Air Conditioning (HVAC) equipment currently available can reduce heating by up to 77% and cooling by up to 78% in commercial buildings [3]. In the context of commercial buildings in Canada, space heating accounts for approximately 57% of the total energy consumed by a building [4]. This highlights a significant opportunity for energy savings in the context of building energy consumption.

Building energy modelling (BEM), that can be developed for new builds as well as for existing buildings, can provide a detailed and predictive analysis of a building's energy performance. By integrating data on architectural design, materials, HVAC systems, lighting, and occupant behavior, energy models simulate the dynamic interactions within a building to quantify energy consumption and thermal comfort [1], [5]. Building energy models can also be used in assessing the impact of different technologies, insulation methods, and renewable energy integration, guiding decision-making to achieve optimal energy performance. The models serve as powerful tools for predicting, analyzing, and implementing strategies to reduce energy consumption, lower operational costs, and meet sustainability goals, ultimately contributing to the development of more resource-efficient and environmentally friendly buildings.

The climatic condition of a building's location is a crucial factor influencing the amount of energy consumed by that specific structure, as the climatic condition of a region has a direct influence on a building's heating, cooling, and overall energy needs. For the classification of different climates, various standards such as the ASHRAE climatic data for building design standards (ANSI/ASHRAE 169), are employed to categorise climates based on a number of factors, including but not limited to temperature, degree-days, and degree-hours, wind, and precipitation [6]. These classifications help in selecting appropriate building materials, HVAC systems, and insulation, ensuring that energy models accurately reflect the real-world conditions a building will face. Based on this classification, the Government of Canada has developed the National Energy Code of Canada for Buildings 2017, a guideline for the provincial and territorial governments for formulating legislation governing the design and construction of buildings within their jurisdictions [7]. These standards and regulations can serve as a foundation for the development of BEMs, especially when building-specific data is not available.

Energy3D is a simple, versatile, and user-friendly energy modelling software tool designed for simulating and analyzing the energy performance of buildings and renewable energy systems. Energy3D stands out for its simple user interface, ability to create detailed 3D models of buildings and landscapes, allowing users to explore and visualize the impact of various design elements on energy efficiency [8]. Energy3D can facilitate an extensive scope of applications, from assessing renewable energy technologies such as wind turbines and solar photovoltaics to modeling the thermal behavior of structures [9]. With an intuitive interface, Energy3D is accessible to both students and professionals, making it a valuable tool for educators, architects, and researchers engaged in the study and optimization of energy solutions in the built environment.

3.1.2 Energy Project Planning

For any project to proceed, it must demonstrate technical feasibility and, perhaps more crucially, financial viability. In this context, the role of project planning becomes pivotal, underlining the significance of meticulous planning, especially in the context of embracing sustainable and low-carbon measures within energy projects. Proper planning lays the groundwork for efficient execution, monitoring, and reporting. In this regard, software platforms and simulation tools are regarded as reliable approaches in the planning of energy projects. Planning software plays a central role, facilitating not just in the detailed design of projects but also in the smooth incorporation of sustainable practices. These tools facilitate the identification of optimal approaches to cost reduction, enhancing quality and reliability to meet project objectives, all the while minimizing the project's carbon footprint from its initiation. Nevertheless, the effectiveness of planning software relies on its adaptability and precision, as deficiencies in these aspects could risk the overall success of planning and implementation of a project. Therefore, while planning software plays a crucial role, its choice and implementation require meticulous consideration to optimize its positive influence on the objectives of an energy project.

RETScreen Clean Energy Management Software (RETScreen) is a versatile analysis tool renowned for its effectiveness in clean energy project analysis and implementation. Having been developed by Department of Natural Resources Canada, in collaboration with a number of Canadian and International organizations, RETScreen can facilitate a comprehensive assessment of various energy sources by analyzing costs, savings, emissions reductions, and the financial viability of renewable energy and energy-efficient technologies, enabling the process of making well-informed decisions.

3.2 Building for the Case Study

This study focuses on the Core Science Facility (CSF) building, covering a total floor area of 40,817 square meters (m^2) spread across five floors. Situated on the Memorial University of Newfoundland (MUN) campus in St. John's, Newfoundland, this facility accommodates teaching rooms, research laboratories, and office spaces exclusively designated for the Department of Electrical and Computer Engineering within the Faculty of Engineering and Applied Science at Memorial University. Interconnected through Wing C's Level 2, the CSF building is linked to the University Centre (UC) of MUN, serving as a central hub for interconnecting various other buildings and departments. The CSF building is oriented in a North-West direction, positioned at an angle of approximately 40 degrees from the North. Figure 3.1 represents the CSF building as viewed from the North, whereas Figure 3.2 depicts the building's orientation.

The CSF building utilizes two energy sources, electricity, and hot water for space heating. The hot water is sourced from the central heating plant located in the university's Utility Annex. This facility generates hot water through boilers powered by No.2 diesel oil. In the calendar year 2022, CSF building consumed 12,706,138 kilo-Watt hours (kWh) of electricity and 1,100,109 liters of No.2 diesel oil [10], which have been considered as the inputs for this study.

Figure 3.1. Core Science Facility Building

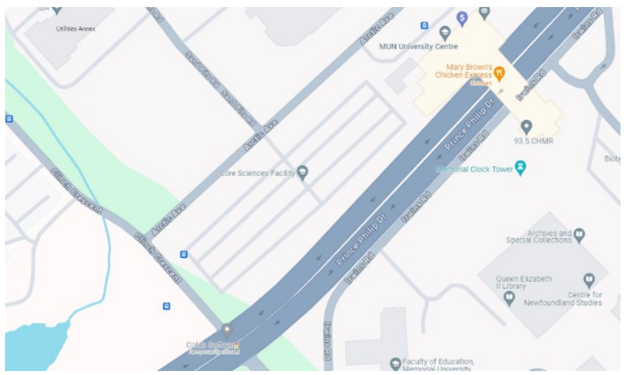

Figure 3.2. Orientation of the building[11]

The Utility Annex, under the supervision of Department of Facilities Management of MUN, intends to substitute a non-operational oil-fired hot water boiler with two electric resistive heating boilers [12]. The projected cost for this replacement, inclusive of decommissioning the non-functional oil-fired boiler, is $16.5 million. This estimate also includes expenses related to equipment, installation and commissioning, project management, contract administration, and operation and maintenance throughout the project duration.

For this study, considering the anticipated fuel savings from this project and the fuel consumption of the CSF building it is assumed that a single electric boiler with a capacity equivalent to that of those proposed for this project can fulfill the heating needs of the CSF building. The associated cost for one such boiler, encompassing installation, commissioning, and all support services, is estimated to be $8 million.

3.3 Project Feasibility Analysis Using RETScreen

The latest version of RETScreen, version 9, available as RETScreen Expert was used for the analysis.

The first screen requires the user to select an option from a list of different analysis types, including a virtual energy analyzer, Benchmark, Feasibility, Performance and an option that combine all aforementioned analyses. Scope covered under different options is graphically represented in the chart next to the list, and for this study feasibility option was considered. Figure 3.3 represents the initial screen of RETScreen.

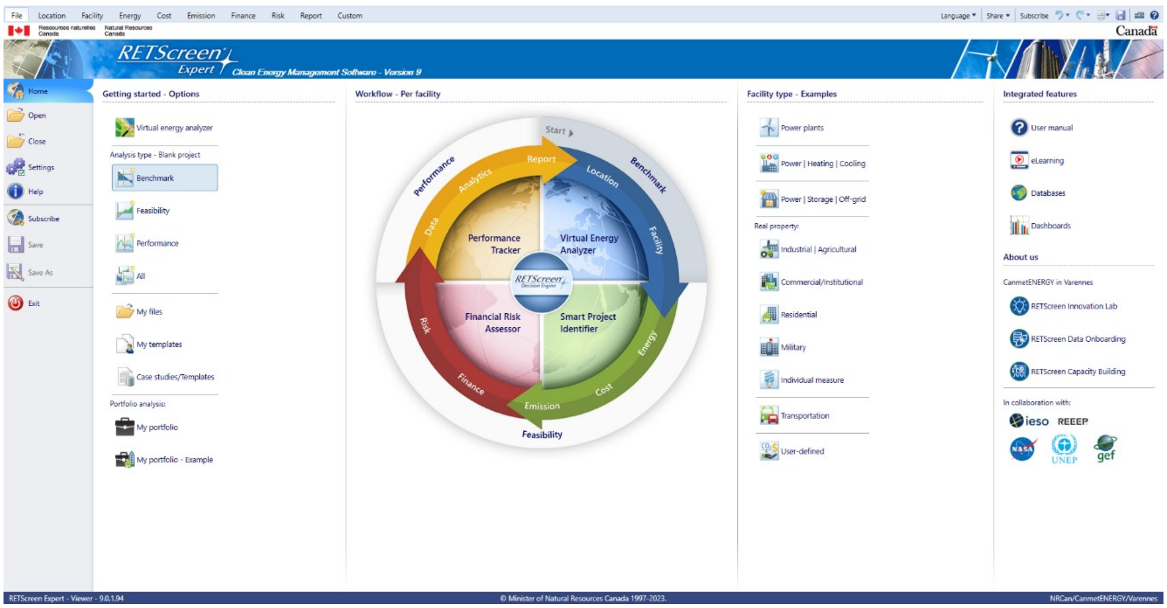

Figure 3.3. Types of studies available in RETScreen

In the next screen, location of the project was selected. Selection of location was done through an interactive map available within RETScreen, which returned a range of data applicable to the site, including but not limited to the geographical coordinates, climate zone in accordance with ASHRAE thermal climate zones [6] and weather data on a monthly basis, as depicted in Figure 3.4. These data can serve as the foundation for assessing heating, cooling, and overall energy demands accurately.

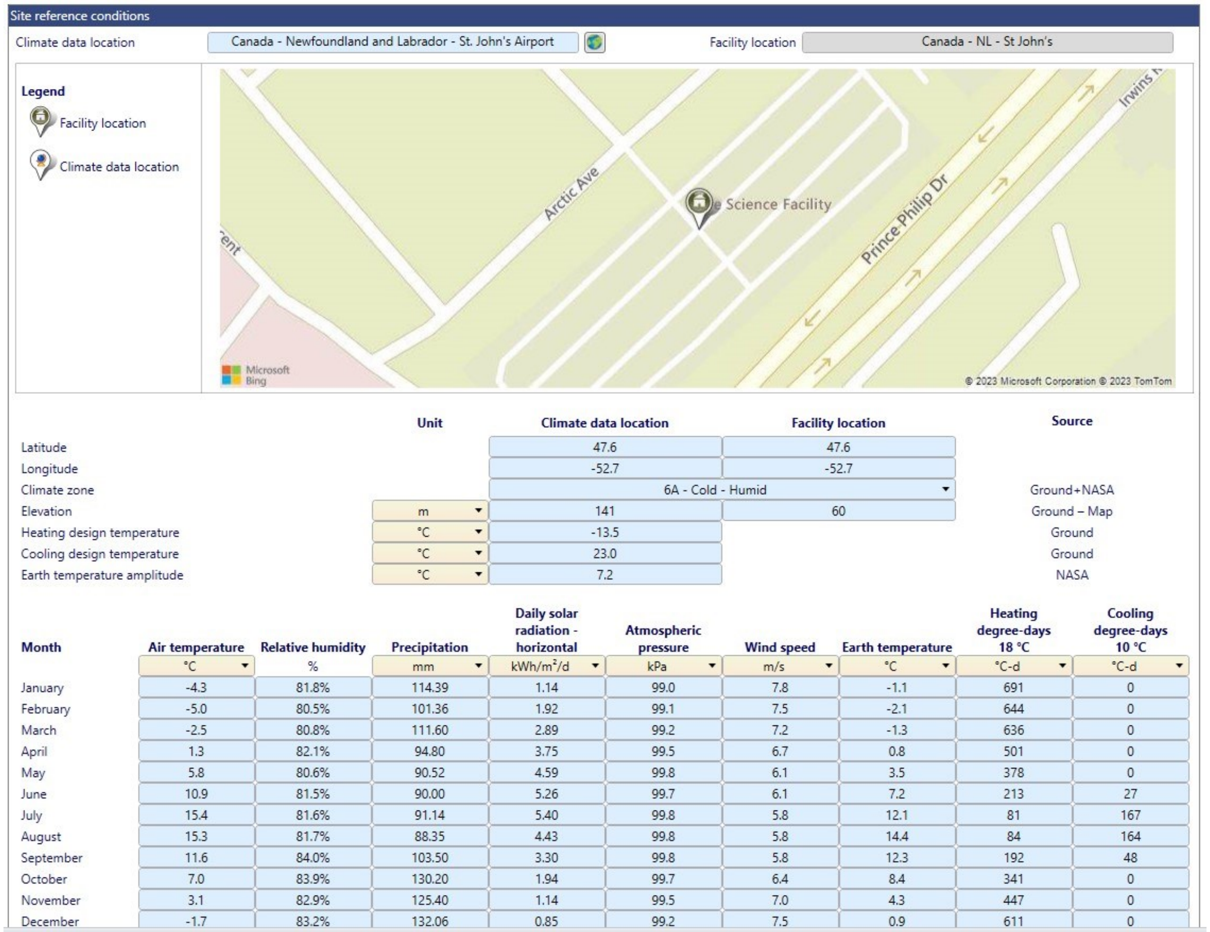

Figure 3.4. Selection of location on RETScreen

Following the entry of the exact location, the subsequent screen, found under the Facility tab, facilitated the input of building details into the software. Information such as the type of the facility, building's floor space, annual electricity, and diesel oil consumption were provided, which in turn calculated results such as total energy consumption in kilowatt-hours (kWh) and the energy use intensity (EUI) in gigajoules per square meter of floor space (GJ/m^2). Additionally, this screen can also be used for the input of any anticipated energy-saving targets and benchmark the energy consumption of the building with other similar facilities. Throughout the application, the term base case was considered as the existing scenario, and the term proposed case was considered as the replacement of oil-fired hot water boiler with an electric resistive boiler unit. Figure 3.5 depicts the information found under the Facility Tab.

Figure 3.5. Facility information on RETScreen

In the subsequent tab labeled "Energy," comprehensive details regarding energy consumption were input, including information on electricity and fuel types, rates for fuel and electricity, seasonal efficiency for equipment in both base and proposed cases, and fuel consumption for both base and proposed scenarios. Annual average rates of fuel were calculated from the energy report for CSF building [10]. It was assumed that the energy consumption of the building would remain the same for both base and proposed case, with no additional energy efficiency initiatives taken. Furthermore, it was also assumed that the operational and maintenance cost would remain the same for both cases, even though this is likely to reduce for electric resistive boiler system, when compared to oil fired hot water boilers.

This tab also facilitates the incorporation of operational parameters, such as set temperatures for heating and cooling, and occupancy rates, which were not considered under this study. The data considered under this section is tabulated in Table 3.1.

Table 3.1. Parameters considered for the feasibility study

Section	Sub section	Parameter	Base case	Proposed case
Fuels and schedules	Electricity and fuels	Fuel type and rate	No.2 diesel oil– $1.66/ liter	Not considered
			Electricity – $0.105/ kWh	Electricity – $0.105/ kWh
Equipment	Heating- Boiler	Fuel type	No.2 diesel oil	Electricity
		Seasonal efficiency	82%	95%
		Incremental initial cost	-	$8,000,000
		Incremental O&M savings	-	-
End-use	Electrical equipment	Energy consumption	12,706,138 kWh	12,706,138 kWh

	Process heat (Space heating)	Energy consumption	9,597,228 kWh	9,597,228 kWh

Upon inputting all the necessary data, RETScreen generated a summary of the proposed project. This summary, represented by Figure 3.6, provided a comparison between the base and proposed cases, highlighting the annual savings in both cost and fuel.

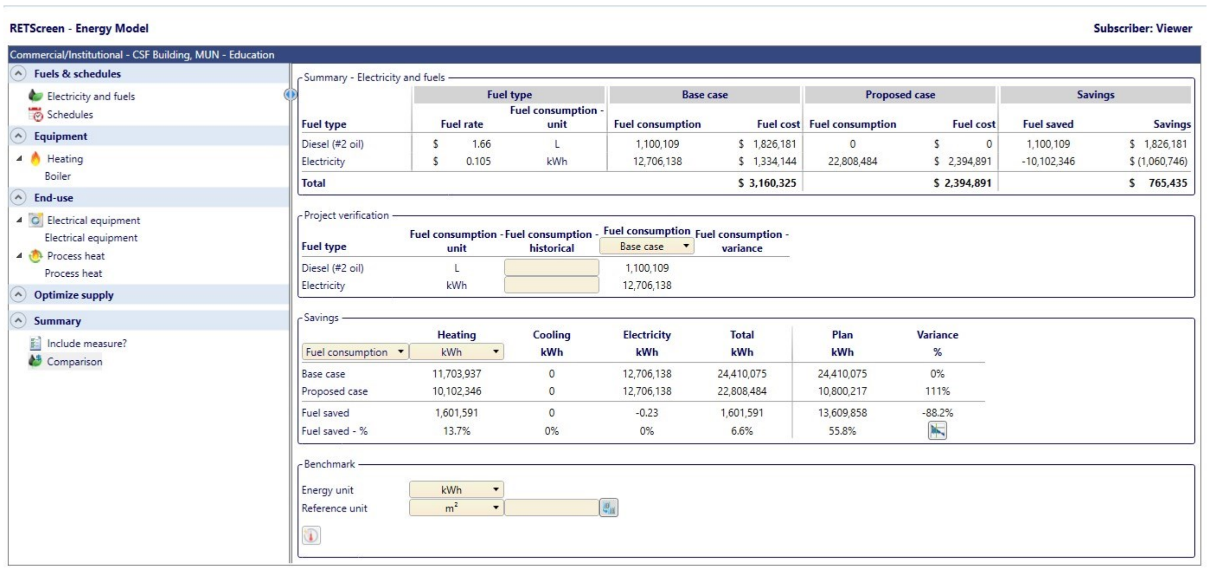

Figure.3.6. Comparison in RETScreen

RETScreen has the capability to conduct a more thorough assessment of energy projects, considering factors such as emission savings, project financing alternatives, and sensitivity and risk analysis. However, this in-depth analysis was not incorporated into the scope of this study.

3.4 Building Energy Modeling on Energy3D

Energy3D requires three primary inputs, the location of the structure, geometry and properties of construction materials, and generates time graphs and heat maps, facilitating in-depth analyses [9]. The location can be input in two ways: by choosing from the existing list of locations or by selecting a location from an interactive map. Since St. John's, NL is not currently available on Energy3D, Halifax, NS, with climate conditions resembling those of St. John's, was selected as the location.

The creation of geometry can be undertaken through various methods, such as sketching up a structure or importing a sketch from an existing CAD file and overlaying it on a map image [9]. The building geometry was created by sketching, using the engineering drawings of the CSF facility as the foundation. The directions indicated in Energy3D can serve as the reference for orienting the sketch-up. The model assumed the absence of neighboring buildings that could induce shading effects on the CSF building, even though, in real-world conditions, the University Center connected to the CSF facility and other buildings in the vicinity might have some impact in this regard. Figure 3.7 depicts the building geometry created in Energy3D.

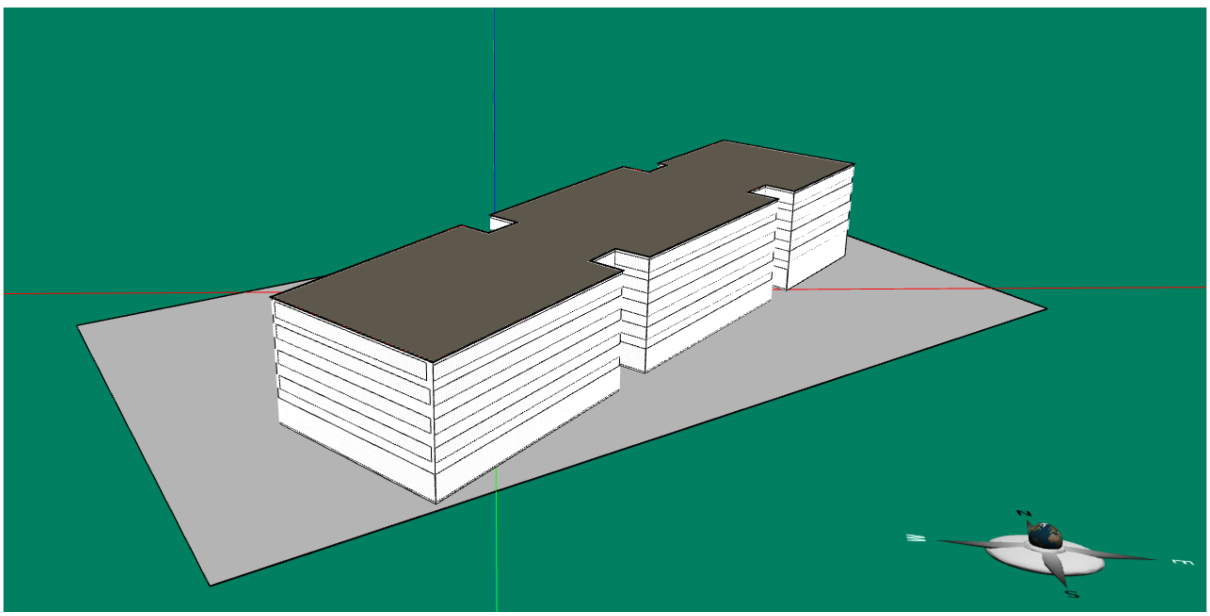

Figure 3.7. Building geometry in Energy3D

After the building geometry was completed, various surfaces of the structure were assigned physical properties to closely emulate the model in relation to the actual construction. Energy3D allows for the assignment of physical properties to external walls, windows, and the roof. Energy3D permits the design of internal floors/ceilings; however, it lacks the capability to assign any physical properties to them. The properties considered in this study are presented in Table 3.2.

Two primary metrics were considered for the insulation properties of the construction materials considered in this study. For the walls and roof, insulation value was assigned in R-value in US units, measured in hour per square foot per degree Fahrenheit per British thermal unit ($h.ft^2.°F/Btu$). R-value is a crucial metric in insulation, representing the material's thermal resistance. A higher R-value indicates better insulation performance, signifying the material's ability to reduce heat transfer. Similarly, for windows, insulation value was assigned in U-value in US units, measured in British thermal unit per hour per square foot per degree Fahrenheit ($Btu/h.ft^2.°F$). The U-value is a key indicator of the thermal conductivity of glass and represents its ability to conduct heat. A lower U-value indicates better insulating properties, as it signifies reduced heat transmission. Energy3D also includes recommendations for these parameters within each dialog box, serving as reference values in instances where specific building data is unavailable. For this study, the insulation values for external walls and the roof were taken from the Insulation building code, which forms part of the legal framework derived from the building code applicable in Ontario, Canada [13].

Table 3.2. Properties of construction materials considered

Building component	Property	Value considered (unit)	Reference for value considered
External wall	Wall thickness	0.3 (m)	Construction drawings
	Insulation	33 ($h.ft^2.°F/Btu$)	Insulation building code 2021[13]
Windows	Tint	Clear	Observation
	Insulation	0.48 ($Btu/h.ft^2.°F$)	Energy3D standard for double-glass windows
Roof	Insulation	55 ($h.ft^2.°F/Btu$)	Insulation building code 2021[13]

After confirming the accuracy of the building geometry, orientation, and material properties, the annual energy analysis for the building was calculated. Energy3D provides simulation results in a tabular format, computed for daily consumption each month. This figure was then multiplied by the respective number of days in each month to determine the monthly consumption. The results for projected energy consumption for space heating are summarized in Table 3.3 and depicted in Figure 3.8.

Table 3.3. Projected energy consumption for space heating

	Energy consumption for space heating, kWh	
Month	**Daily consumption (calculated by Energy3D)**	**Monthly consumption**
January	12395.652	384265.222
February	10632.204	308333.924
March	7962.033	246823.028
April	5569.935	167098.059
May	3576.468	110870.507
June	2486.582	74597.4520
July	1924.666	59664.6364
August	2620.119	81223.685
September	4287.353	128620.599
October	6828.859	211694.630
November	9415.052	282451.555
December	12081.783	374535.259
Total, kWh		2430178.555

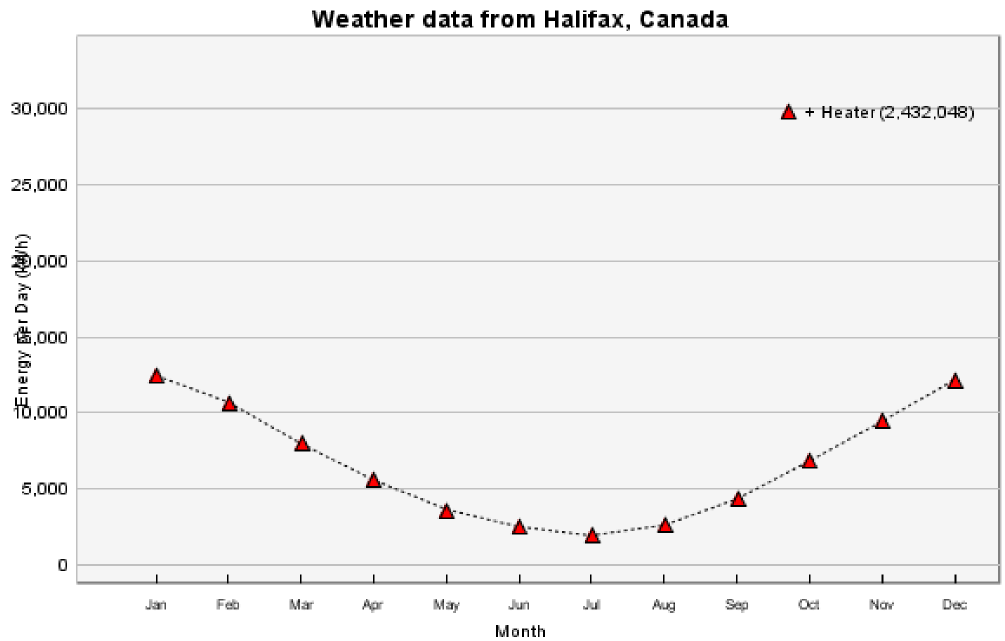

Figure 3.8. Projected monthly energy consumption for space heating

3.5 Results and Discussion

The results of the feasibility study within RETScreen demonstrated notable financial and energy savings, even without implementing additional energy efficiency measures. These results are summarised in Table 3.4.

Table 3.4. Results of the feasibility study

Description	Unit	Estimated savings
Savings in energy	kWh	1,601,591
Savings in energy	%	6.6
Savings in fuel/ year	$	765,435
Savings in fuel/ year	%	24.2%
Gross annual GHG emission reduction	tCO_2	2,665

In the feasibility study conducted in RETScreen, both electricity and fuel tariffs were assumed to remain constant over the project's lifecycle. However, in reality, the average electricity tariff for large customers in St. John’s has risen by approximately 18.8% between 2018 and 2022 [14]. Additionally, the average price of diesel fuel in Canada has experienced a substantial 71% increase from 2019 to 2022 [15]. Figure 3.9 illustrates the fluctuation in diesel prices in St. John’s compared to the national average. This disparity suggests that the variation in diesel oil prices is significantly higher than that of electricity tariffs in St. John’s, potentially resulting in greater financial savings over the project's lifetime. Furthermore, it is estimated that approximately 96% of the electricity generated in Newfoundland and Labrador has been from hydro sources [16]. This highlights the substantial reduction in gross annual greenhouse gas (GHG) emissions that can be achieved by transitioning to electric resistive heating for space heating.

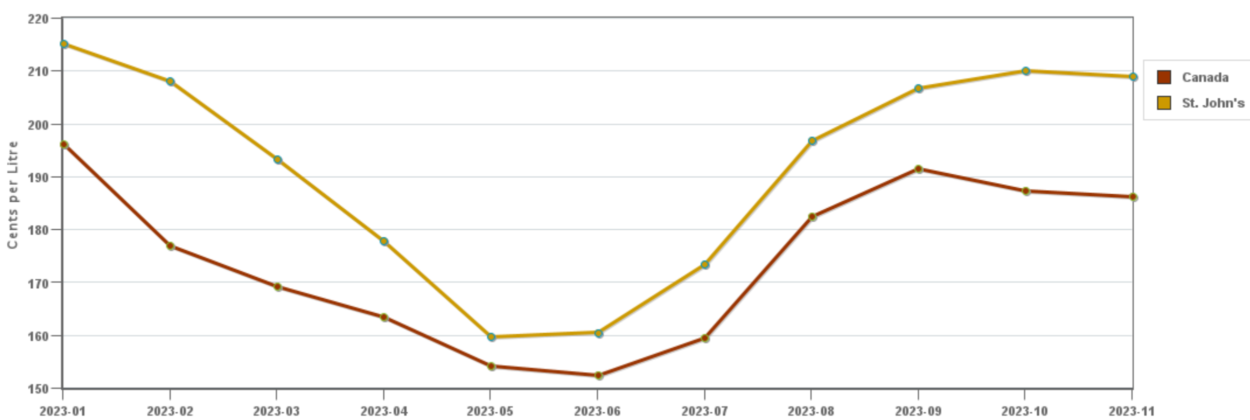

Figure 3.9. Comparison of the diesel price in St. John's with national average

The results of the feasibility study also suggested a simple payback period of 10.5 years, based on the inputs considered in the study. This calculation was entirely based on the initial capital expenditure and potential financial savings from the project, portraying it as a venture with a relatively low return on investment. Nevertheless, a comprehensive analysis, encompassing factors such as potential variations in energy tariffs, potential savings in operations and maintenance (O&M) costs, rebates based on reduced carbon footprint, and a life-cycle analysis, can reveal the complete benefits of the project.

The results from Energy3D simulation indicated the projected energy consumption for space heating in CSF building for a calendar year. Table 3.5 is a comparison between the simulation results and the actual data.

Table 3.5. Comparison of energy consumption (simulation results and actual)

Month	Consumption from simulation (kWh)	No.2 diesel oil consumption (liters)	Actual energy consumption (kWh)
January	384,265.222	143,447	1,521,335.13
February	308,333.924	163,802	1,737,211.21
March	246,823.028	151,847	1,610,421.79
April	167,098.059	117,433	1,245,442.21
May	110,870.507	72,558	769,517.90
June	74,597.4520	60,246	638,942.30
July	59,664.6364	25,221	267,482.72
August	81,223.685	34,303	363,802.37
September	128,620.599	44,295	469,773.08
October	211,694.630	42,079	446,271.17
November	28,2451.555	106,251	1,126,850.88
December	374,535.259	138,628	1,470,226.96
Total	2,430,178.555	1,100,109	11,667,277.72

The actual energy consumption for space heating was calculated using the following formulae.

LHV of diesel = 38.18 MJ/litre

Diesel consumption/ month of January = 143,447 litres

Energy consumption for heating/ January = 5,476,806.46 MJ

Energy consumption for heating/ January = 1,521,335.13 kWh

The simulation results indicated a significant deviation from the energy consumption calculated using actual data. This variance may arise from several disparities between the actual conditions and the Energy3D model.

Level 2 of the CSF building is interconnected with the University Center (UC), with a significant airflow between the two buildings. This airflow between the two interconnected buildings can lead to a heat loss from CSF building, when warm air from CSF building escapes to cooler UC. This heat loss results in increased energy consumption, as the heating system in CSF building must compensate for the dissipated heat. In addition, the UC has several openings to outdoors, which can lead to infiltration and exfiltration. These phenomena can lead to further energy losses. For the simulation in Energy3D, neither the interconnection nor the heat loss have been considered. This may lead to an estimated energy consumption that is lower than the actual values.

The CSF building as well as the UC is used by many occupants throughout the year. The behavior of occupants is acknowledged as a key factor contributing to the performance gap observed between the actual and simulated energy consumption of buildings [17], [18]. Furthermore, fluctuations in occupancy levels throughout a given day also affects the space heating requirements, leading to varying space heating needs, resulting in inefficiencies in heating. Moreover, maintaining a comfortable indoor environment includes maintaining a balance between the heating system and external environment, and varying occupancy levels can have an impact on the energy consumed for space heating. Therefore, it is crucial to account for building occupancy levels when conducting building energy modeling. However, determining occupancy levels presents significant challenges, particularly for buildings with dynamic occupancy patterns, such as the CSF building, for various reasons. Moreover, modeling dynamic occupancy levels is not feasible in Building Energy Modeling (BEM) simulations, and accordingly, occupancy levels were not considered in this study.

The CSF building houses its HVAC systems in the penthouse section of the building. This envelope has a smaller footprint than the other floors of the building and as a result, due to limitations in Energy3D, this penthouse section was omitted from the simulation. Additionally, the modeling did not include the building's ventilation system, which plays a crucial role in ensuring the proper distribution of warm air throughout the building, minimizing temperature variations, and enhancing the efficiency of the heating system. Ventilation is a significant factor in BEM, allowing for the assessment of the thermal energy needed to condition outdoor air before supplying it to the indoor space. This aspect holds particular importance in colder climates like St. John's. The exclusion of the ventilation system from the energy model may have led to an underestimation of the energy required to heat incoming outdoor air, potentially resulting in a lower-than-actual energy demand.

Moreover, the hot water supply and return lines for the CSF building are routed from the Department of Earth Science building, spanning a considerable distance of approximately 160 meters between the two structures. The simulation did not account for any energy loss within this section, despite the likelihood of significant losses occurring in actual conditions between the measuring point and the entry points of the pipes into the CSF building.

Lifespan of equipment, and operation and maintenance practices can be a deciding factor of the system efficiency. Even though the CSF building is relatively new, the oil-fired hot water boilers in the Utility Annex have been in operation for a few years. Over time, such equipment may experience wear and tear, affecting their efficiency. Such system degradation was not considered in this study, which can result in a disparity between the simulation results and the actual consumption.

3.6 Conclusions

In this chapter, the feasibility of converting the space heating system of the CSF building from existing oil-fired boiler system to electric resistive boilers was analysed, using RETScreen. Furthermore, a thermal model of the CSF building was developed using Energy3D.

The feasibility study suggested that the transition can save approximately $765,435 per annum in fuel costs, accounting to 24.2% of the total cost of energy CSF building had consumed in 2022. Furthermore, it also indicated that there can be a 6.6% savings in energy consumption, with a total gross annual GHG savings of 2,665 tCO_2.

The simulated results of the building thermal model suggested that the energy consumed by CSF building can theoretically be less than the actual figure. However, factors that were not considered in the development of the model, such as transmission losses, interconnection between CSF building and the UC, building occupancy, the ventilation system, and degradation of equipment over time can have a significant influence in the energy consumed for space heating, resulting in the higher actual energy consumption of the building.

3.7 References

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CHAPTER 4. A COMPARISON OF PROGRAMMED CONTROLLED EXISTING SYSTEM VS. ELECTRIC RESISTIVE HEATING

Preface

A version of this manuscript has been accepted for publication in the European Journal of Energy Research (https://ej-energy.org/index.php/ejenergy). The principal author developed the OpenStudio simulation models, conducted the analysis, derived the results, produced the initial manuscript, and subsequently revised it based on suggestions from the co-author, Professor M. Tariq Iqbal. Professor Tariq Iqbal assisted in the selection of the topic and defining the scope, reviewed and corrected the obtained results, and contributed to the preparation, review, and revision of the manuscript.

Abstract

Buildings consume in excess of 30% of the total energy worldwide. In the Canadian context, commercial and institutional buildings contribute to around 14% of the overall energy usage, and space heating emerges as the predominant end-use category, constituting approximately 57% of this consumption. This underscores a considerable potential for energy savings in the realm of building energy consumption.

This chapter compares the energy consumption for space heating at the Core Science Facility (CSF) of the Memorial University of Newfoundland (MUN), Canada. The analysis compares the current system, utilizing hot water from fuel oil-fired boilers, with a proposed system suggesting the replacement of the oil-fired boiler with an electric resistive boiler, by employing a building energy model (BEM) created with the OpenStudio application. The findings indicate that beyond the anticipated enhancements in energy efficiency, a supplementary energy saving of approximately 7% is attainable through the proposed transition. Comparing the simulation outcomes with actual data reveals that the projected consumption from the BEM is lower than the

actual figures. This difference is attributed to the model's development, which involved distinct considerations and assumptions compared to the actual conditions such as construction materials, building occupancy, infiltration and exfiltration, interconnected buildings, energy usage by equipment and lighting, HVAC system energy consumption, and transmission losses through piping which can significantly influence the building's energy consumption.

Keywords: Energy Plus, OpenStudio, Thermal Modeling, Space Heating, Educational Building

4.1 Introduction

4.1.1 Energy Consumption in Buildings

Studies show that globally, buildings contribute to in excess of 30% of total energy consumption [1], [2]. Correspondingly, in Canada, buildings play a substantial role in the country's energy demand, representing about 25% of the total final energy consumption, equivalent to approximately 729.52 Tera-Watt hours (TWh) [3]. Improving the energy efficiency of buildings can play a key role in reducing operational costs and emissions, especially taking into account their lifespan, which at the same time promotes sustainability as well. Although it can be simpler and straightforward to construct new buildings adhering to the latest energy-efficient standards, the existing stock of buildings constitutes the majority of stock and contributes significantly to overall energy consumption. Consequently, enhancing the energy efficiency of existing buildings can have a substantial impact. In Canada, the existing commercial and institutional buildings collectively contributed to around 14% of the total energy consumption in 2020 [4]. Notably, space heating constituted approximately 57% of the total energy consumed within the sector, accounting for approximately 191 TWh [4]. This indicates an opportunity for significant energy savings in the context of building energy consumption.

4.1.2 Building Energy Systems

Building energy systems (BES) consist of elements responsible for energy consumption within buildings, including physical equipment, machinery, processes, or a combination thereof [5]. BES typically includes heating, ventilation, and air conditioning (HVAC) systems, lighting, insulation, renewable energy sources, and control systems. The design and optimization of BES are crucial for achieving energy efficiency, reducing operational costs, and minimizing environmental impact.

Management of thermal comfort in buildings is fundamental for ensuring the well-being of the occupants while promoting energy efficiency in the building. In order to maintain thermal comfort, it is necessary to introduce or remove a specific amount of energy in the form of either heating or cooling to or from the building space [1]. This energy requirement is predominantly influenced by a number of factors, including but not limited to external weather conditions, such as outside air temperature, relative humidity, and wind characteristics; internal factors, such as occupancy levels, heat and moisture transfer through walls, and leakages to the outside. The accurate calculation of such loads for a building space is critical, as this process significantly influences not only the capital expenditure associated with the design and construction of a building but also the operational expenditure, consequently impacting the overall energy consumption. Moreover, load calculations also have a direct impact on the comfort levels of occupants of the buildings, thereby influencing their productivity.

Building energy modeling and simulation can play a crucial role in the design and optimization of energy-efficient buildings. These tools enable researchers and engineers to evaluate and forecast a building's energy performance across diverse conditions. Building energy models can be classified as either steady-state or dynamic. Steady-state models overlook the transient impact of variables, while dynamic models have the capacity to monitor peak loads and are effective in capturing thermal effects, such as those resulting from setback thermostat strategies [2]. The choice between the two approaches depends on the specific requirements of the analysis. Steady-state models are computationally efficient and suitable for quick assessments where transient effects are less critical. These work well for short-term analyses and initial screening. On the other hand, dynamic models offer a more accurate representation of a building's behavior over time, capturing transient effects, seasonal variations, and interactions among different components. While dynamic simulations are more complex and computationally intensive, they are essential for detailed analyses over a long period.

Amongst many methodologies and approaches used for building energy modeling, one frequently employed methodology is based on physical models, encompassing various approaches such as Computational Fluid Dynamics (CFD), the Zonal approach, and the Multizone or Nodal approach [6]. While regarded as the most comprehensive method, the CFD approach is complex and demands significant time and resources [6], [7]. Conversely, the multi-zone or nodal approach is seen as a relatively simpler method, operating under the assumption that each building zone represents a homogeneous volume characterized by uniform state variables [6]. Nonetheless, this approach can effectively depict the behavior of a multiple-zone building over an extended time frame with minimal computation time. It proves to be especially well-suited for estimating energy consumption and the temporal evolution of space-averaged temperatures within a space [8]. In this study, the Multizone approach is adopted, as it aligns with the methodology employed in commonly used simulation software like EnergyPlus [9], ESP-r [10], TRNSYS [11], and e-QUEST [12]. Introduced in the beginning of 1990s by Bouia and Dalicieux [13] and Wurtz [14], the zonal approach is a way to rapidly detail the indoor environment and to estimate a zone thermal comfort.

Practically, it consists of dividing each building zone into several cells, with each cell representing to a small part of a zone.

4.1.3 Building for the Case Study

This study is focused on the Core Science Facility (CSF) building, encompassing 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 accommodates teaching rooms, research laboratories, and office spaces exclusively designated for the Department of Electrical and Computer Engineering within the Faculty of Engineering and Applied Science at Memorial University. Furthermore, the building houses many plant and equipment, including the cryogenic facility operated and maintained by the Department of Technical Services [15]. The CSF building is connected to the University Center (UC) building through Wing C in Level 2. CSF building relies on two energy sources: electricity and hot water for space heating, with the hot water sourced from the central heating plant in the university's Utility Annex (UA). The UA produces hot water through boilers fueled by No.2 diesel oil.

The UA's current setup includes four oil-fired boilers, each having a capacity of 18 Mega Watts (MW). A proposal has been put forth to replace one of the oil-fired boilers with two electric resistive boilers, each having a relatively smaller capacity of 15.5 MW. This study aims to assess the impact of substituting the oil-fired boiler with an electric resistive boiler, for heating the CSF building.

Figures 4.1 and 4.2 display the CSF building and its placement on Google Maps.

Figure 4.1. Core Science Facility Building

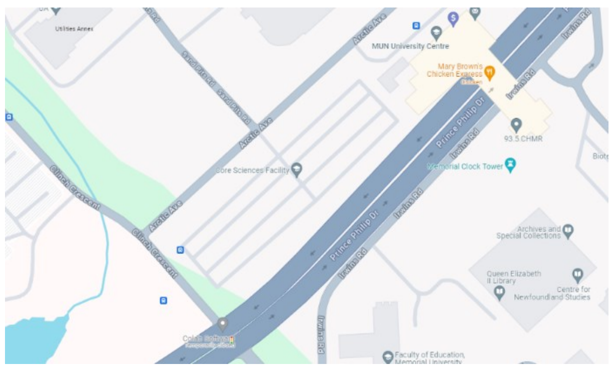

Figure 4.2. Orientation of the building [16]

4.2 Approach and the Development of Building Energy Model

4.2.1 Selection of Simulation Software

Selecting a robust software tool for Building Energy Modeling (BEM) can serve as the foundation to achieving optimal energy efficiency in construction and retrofitting projects. A good software solution enables the consideration of dynamic conditions, taking into account various factors such as climatic conditions, construction and insulation materials, HVAC systems, and renewable energy integration. This in turn can assist with accurate projection of energy consumption patterns, contributing significantly to designing sustainable structures, complying with energy standards, and minimizing environmental impact.

OpenStudio is an open-source BEM software developed in collaboration by a number of institutions, primarily the National Renewable Energy Laboratory (NREL), Department of Energy (DOE), Argonne National Laboratory (ANL), Lawrence Berkely National Laboratory (LBNL), Oak Ridge National Laboratory (ORNL), Pacific Northwest National Laboratories (NPPL), Pennsylvania State University in the United States, and Natural Resources Canada, that supports whole building energy modeling using EnergyPlus and advanced daylight analysis using Radiance [17], [18]. Apart from functioning as a Software Development Kit (SDK) and a command line interface, OpenStudio is also accessible as a graphical application, which allows users to swiftly generate the necessary building geometries, assign materials, loads, building spaces and thermal zones for EnergyPlus simulations. The OpenStudio SDK can operate across various platforms such as Windows, Mac, and Linux. It has been effectively utilized by numerous government and private laboratories to develop web and server-based applications [17], [18]. Offering the flexibility to code in multiple programming languages, the OpenStudio SDK provides a versatile platform for creating tools that can cater to a diverse range of end users. In addition to the wide array of data available on the OpenStudio application, it is also supported by a Building Component Library (BCL), which serves as a comprehensive repository of pre-defined building elements and systems, offering users a valuable resource for efficiently constructing energy models. This library encompasses a diverse range of components such as constructions, materials, HVAC systems, and schedules, which can be seamlessly integrated into the energy models, enhancing the accuracy and speed of model development.

Developed in collaboration by the DOE and NREL, EnergyPlus is considered as one of the most powerful tools for simulating building energy performance in various scenarios, including new construction, renovations, and the selection of appropriate building energy systems [9], [19].

While the OpenStudio platform has gained widespread use in BEM, existing literature indicates a limited utilization of this platform for modeling educational or university buildings.

4.2.2 Use of Standards and Guidelines

There are currently various approaches, guidelines, and standards accessible for the planning, construction, and operation of environmentally sustainable buildings [20], [21]. ASHRAE 189.1-2009, developed by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), is a standard which has been widely used, that provides total sustainability guidance for designing, building, renovating, and operating high-performance green buildings [22]. The standard encompasses various aspects, including site sustainability, water efficiency, energy efficiency, and indoor environmental quality.

OpenStudio has incorporated ASHRAE 189.1-2009 guidelines into its robust platform for building energy modeling. This alignment provides users the facility to simulate and optimize the energy performance of buildings, ensuring that OpenStudio models adhere to acknowledged sustainability principles, covering a range of aspects including energy efficiency, water conservation, and indoor environmental quality.

4.2.3 Methodology

The OpenStudio application features a Graphical User Interface (GUI) that enables users to input or select data from the built-in databases essential for simulations. The GUI has been divided into a number of tabs vertically, organized in accordance with steps commonly used in a BEM workflow. Some of these tabs are broken down into sub tabs horizontally, in the top of each window. Table 4.1 (adapted from [17]) provides a concise overview of the main tabs and Figure 4.3 illustrates the home screen of the application.

Table 4.1. Functionalities of OpenStudio tabs

Name	Purpose
Site	Specify weather conditions, life cycle costs, and utility expenses.
Schedules	Define schedules that are applied to loads within a building.
Constructions	Specify materials, construction assemblies, and sets.
Loads	Define individual building loads.
Space Types	Create space profiles for the building envelop.
Geometry	Define the building exterior and interior geometries.
Building	Assign building level defaults and exterior components.
Spaces	Assign profiles to individual spaces.
Thermal Zones	Group spaces into Thermal Zones and assign Zone Equipment.
HVAC	Define the heating, cooling, and water systems for the building.
Variables	Specify additional simulation reporting variables as applicable.
Simulation Settings	Customize simulation settings.
Measures	Assign OpenStudio and Energy Plus Measure scripts to a workflow
Run Simulations	Perform energy simulation
Reports	Review simulation results for the energy simulation

In the initial tab, "Site," data for weather information and design days (DDY), including the analyzed year, is entered under the sub tab “Weather File and Design Days”. Design day information contains extreme climate conditions anticipated for a specific location [17], and these conditions are often employed in sizing HVAC systems, as these systems need to ensure the comfort of the building's occupants under extreme circumstances, including heating, cooling, humidification, and dehumidification conditions. EnergyPlus provides comprehensive weather and design days information for St. John's, Newfoundland, which was utilized for this study [23]. ASHRAE climate zone details can also be entered in the site tab, an option providing an opportunity to enhance the simulation results. Under the Site tab, historical data for utility bills can be inserted under the sub tab, "Utility Bills". Figure 4.4 provides the key information added in Site tab.

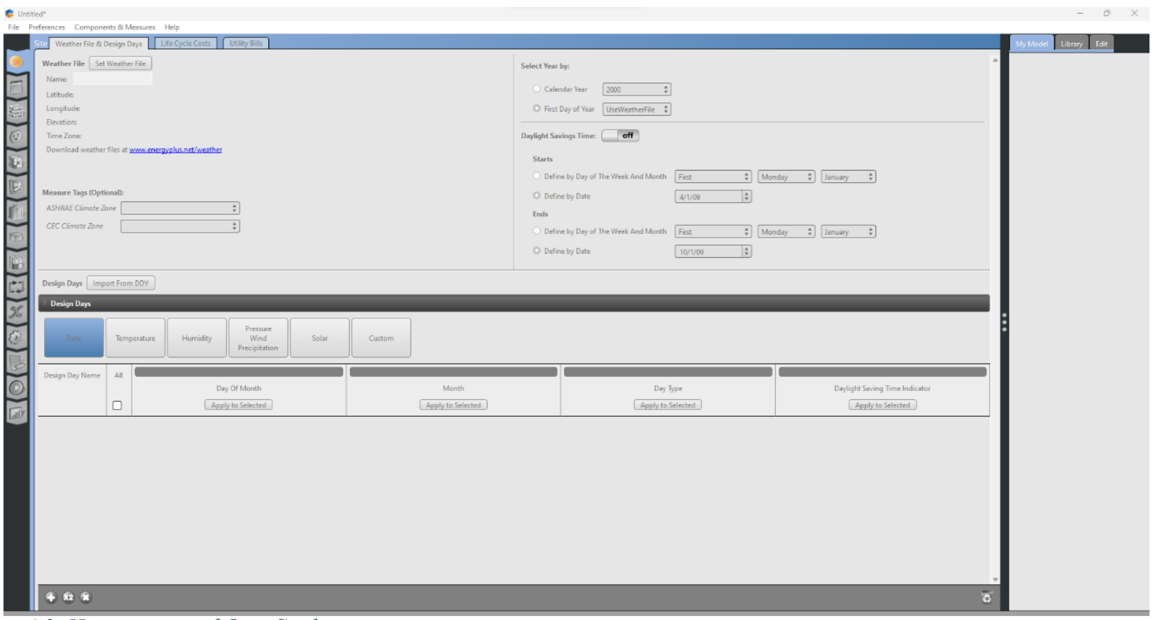

Figure 4.3. Home screen of OpenStudio

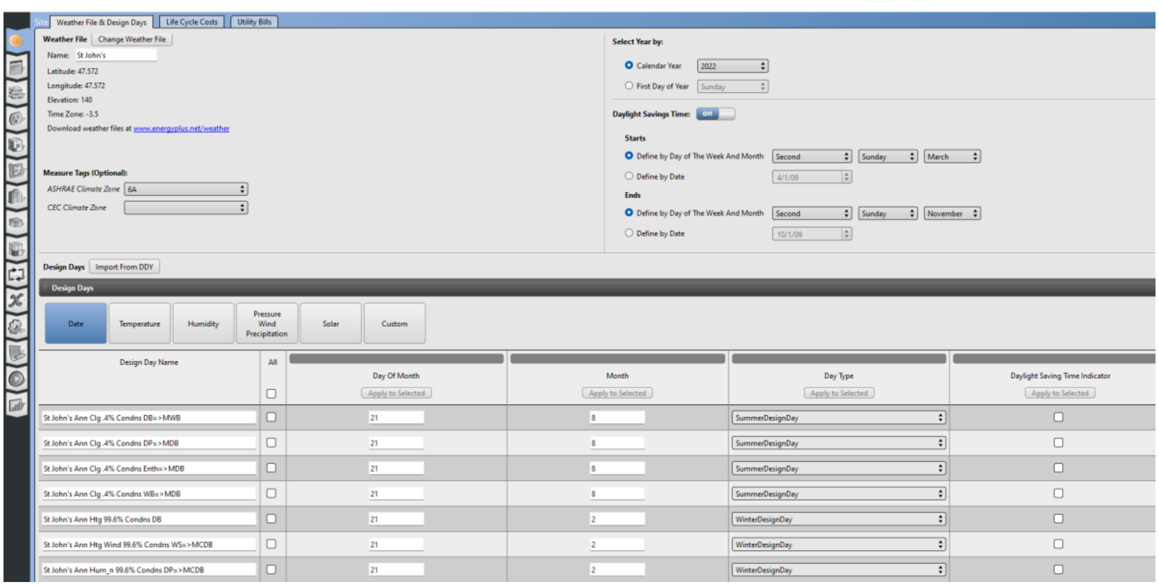

Figure 4.4. Information under Site

The "Schedules" tab is utilized for incorporating diverse schedules and schedule sets that are relevant to the loads within the building. Schedule Sets, which are combinations of schedules, encompass various parameters such as hours of operation, number of people, people activity, lighting, electric equipment, gas equipment, hot water equipment, steam equipment, and infiltration. It is possible to define multiple schedule sets for different spaces within the building. Schedules are used for defining the timing and intensity of various operations like occupancy, lighting, HVAC systems, and thermostat settings. These schedules outline patterns for the variation of such activities over time. Users have the flexibility to create and customize schedules to precisely simulate real-world scenarios, ensuring that energy models align accurately with the specific requirements and behaviors of the building.

This study required making several assumptions owing to the absence of data on building operations. Essential details such as occupancy patterns, lighting, and equipment loads were not available, primarily because the building is relatively new, and no comprehensive survey has been conducted to date. The dynamics of an educational building can vary significantly throughout the year, and the collection of such data could entail a considerable investment of time, effort, and resources. Conversely, there is also limited literature available on BEM specifically for educational or university buildings, making it challenging to locate reference data. Therefore, occupancy patterns were extrapolated by utilizing predefined schedules in OpenStudio for Office Buildings. This was done, taking into account that a portion of the building functions as office space for faculty staff and students. Given that the lighting in the CSF building operates predominantly throughout the day, common areas were assumed to have continuous lighting, while lighting for laboratories, classrooms, and offices was set to operate during daytime hours. Electrical equipment usage was primarily considered within laboratories and office spaces, following the lighting schedule for the respective space type. Notably, no considerations were made for gas, hot water, or steam equipment in this study. Figure 4.5 illustrates the schedule sets utilized and the individual schedules employed within one of the schedule sets. Meanwhile, Table 4.2 provides a summary of the system parameters considered in the study.

In the absence of specific information regarding the construction details of the CSF building, including materials, composition, insulation thicknesses, etc., pre-defined construction sets in OpenStudio were utilized. These construction sets comprise materials recommended for a building situated in a climate zone 6A, following the ASHRAE standard 189.1-2009. Figure 4.6 illustrates the construction sets implemented and the materials selected for the primary building, and Table 4.3 summarises the properties of these materials. SHGC and VLT in the table refer to Solar Heat Gain Coefficient and Visible Light Transmission respectively.

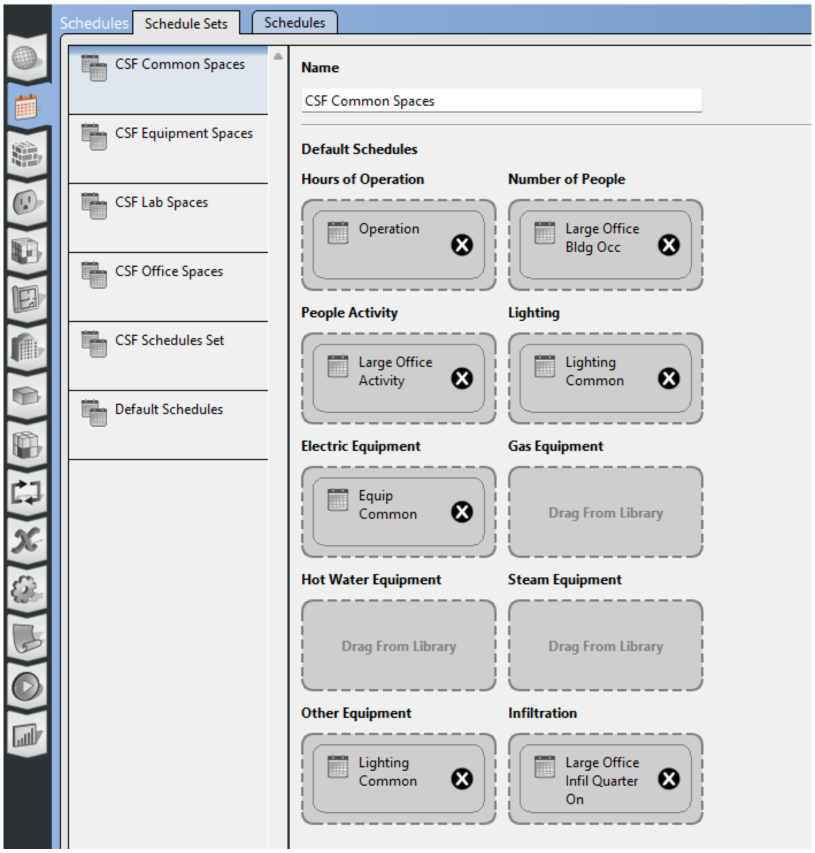

Figure 4.5. List of schedule sets

Table 4.2. System parameters considered

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

Figure 4.6. Construction materials considered for the main building

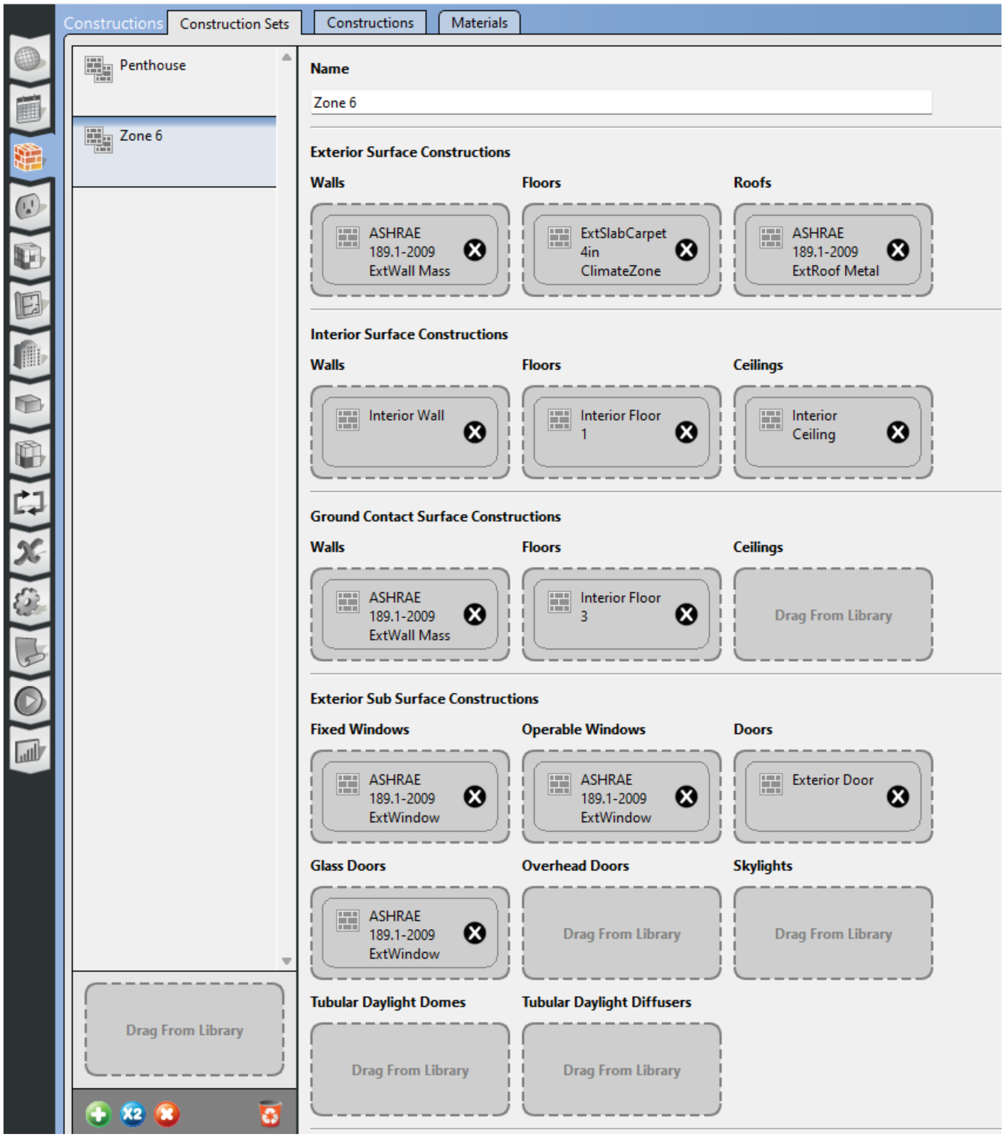

Table 4.3. Properties of construction components

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 in top floor)					
Exterior Walls	18.07		ft^2.h.R/Btu		
Roof	30.48		ft^2.h.R/Btu		

Within the loads category, three load categories; occupancy, lighting, and electrical equipment were considered. Given the absence of actual data, ASHRAE-recommended values for occupancy and electrical equipment for an Office building located in climate zone 4-8, available on OpenStudio, were used for various space types. As for lighting loads, recommended lighting power densities for educational buildings as per the National Energy Code of Canada for Buildings were applied [24].

For this study, the CSF building was categorized into various space types, named as Atrium, Office, Classroom, Corridor, Elevator, Stairs, Laboratory, Equipment Room, and Restroom. The allocation of these space types was completed upon the completion of the building geometry.

Various methods can be employed to create the building geometry in OpenStudio. The OpenStudio Application includes a floor plan editor that facilitates the development of a two-dimensional floor plan for each building story, as shown in Figure 7 (below). Additionally, OpenStudio offers a plug-in for Trimble SketchUp, enabling the creation of detailed three-dimensional building geometry. It also supports the import of geometry in Green Building Extensible Markup Language (gbXML) format, which can be generated using other third-party Computer-Aided Drafting (CAD) tools that supports the format.

The building geometry for this study was created using the integrated floor plan editor, with the building footprint located using Google Maps. Each floor plan, extracted from the mechanical drawings was imported as an image and correctly scaled, forming the foundation for the 2D geometry creation. Subsequently, height was added to each floor plan. While OpenStudio allows for the creation of plenum spaces within individual building spaces, they were omitted in this model to simplify the complexity. Following the completion of building geometry, space types and thermal zones were assigned to the building envelope. While thermal zoning can be derived based on factors like the location of thermostats, spatial positioning relative to the building facade, and variations in heating and cooling setpoints within spaces, thermal zoning in this study was conducted based on space type, given that heating and cooling setpoint temperatures were considered as constant across the entire building. Figure 4.7 illustrates the building geometry when viewed from the North, and provides a summary of the thermal zone, space type, construction set, and height of building spaces on floor 1.

Within the Facility tab, general details about the building such as the building's orientation, the count of floors, and the nominal height of each floor were added. Some of these details can be modified by the parameters defined in the "Geometry" tab. Figure 4.8 illustrates the general parameters taken into account in the study.

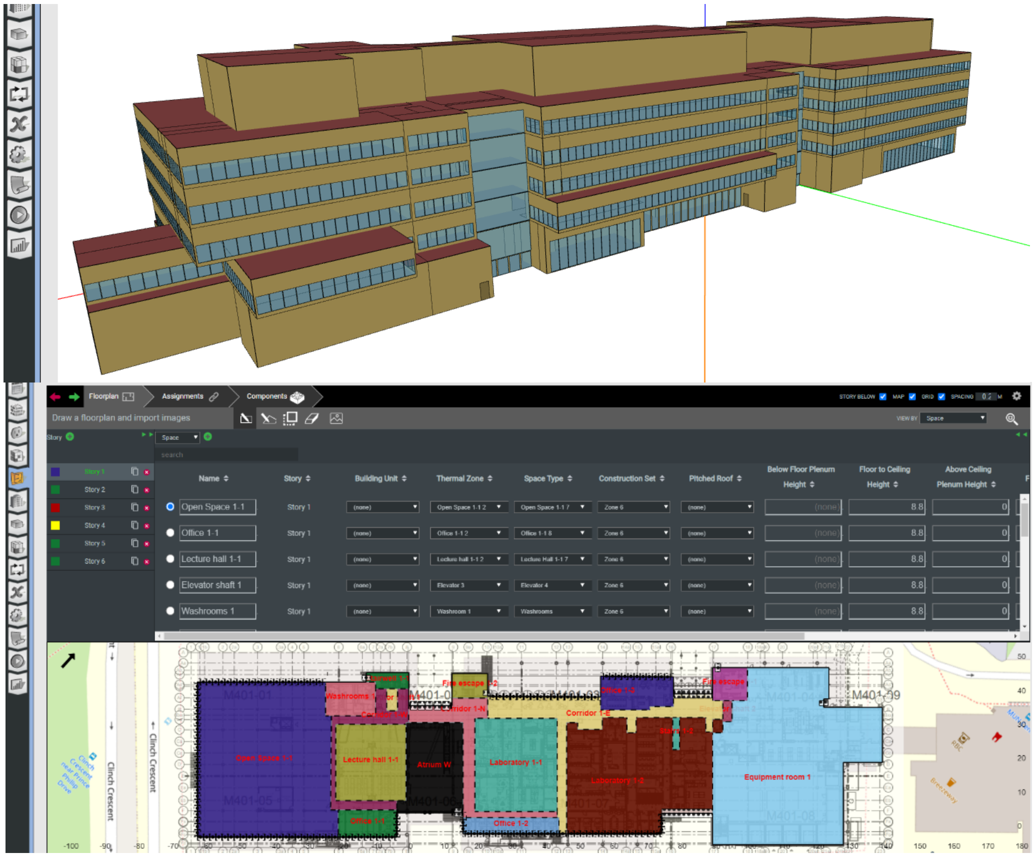

Figure 4.7. Building geometry of CSF building (above) and the floor plan, space and thermal zone allocation for Floor 1 (below)

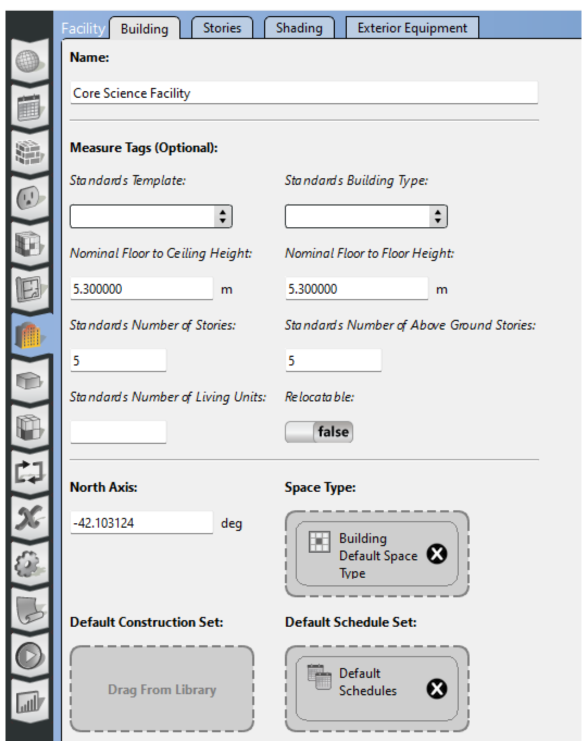

Figure 4.8. Information in the Facility tab

In the "Spaces" tab, the allocation of default schedule sets and various loads, including lighting, electrical equipment, infiltration, and occupancy, specific to individual spaces, was completed. Then the development of the HVAC system was completed under the HVAC systems. HVAC system modeling in OpenStudio has been streamlined with the integration of the ASHRAE Advanced Energy Design Guides (AEDG) [25]. By using this facility, users can effectively design and simulate energy-efficient HVAC systems for buildings in a number of quick steps. This process encompasses the definition of system types, selection of equipment, and customization of system parameters. The HVAC system for the CSF building was modeled with the inclusion of a hot water loop utilizing a boiler for heating, a chilled-water loop with an electric chiller for cooling, and an air loop for each floor of the building. In the initial phase of model development, an oil-fired boiler was chosen to reflect the current scenario, while during the second iteration of the simulation, this was subsequently replaced with an electric boiler. The sizing of the hot water boiler was determined based on the parameters outlined in Table 4.4, and temperature control parameters were set according to the specifications in Table 4.2. Adiabatic piping was employed for all system loops, assuming negligible heat loss through the transfer lines. Default values were considered for all other system parameters. While Figures 4.9, 4.10, and 4.11 illustrate the hot-water loop, chilled water loop, and air loop for floor 1, respectively, that were taken into account in this study, parameters for hot water loop, chilled water loop and air loop that were automatically sized by OpenStudio are indicated in Table 4.5.

Table 4.4. Boiler parameters for heating system

Parameter	**Unit**	**For oil fired boiler**	**For electric resistive boiler**
Boiler capacity	Mega-Watt (MW)	18	15.5
Boiler efficiency	%	82	95

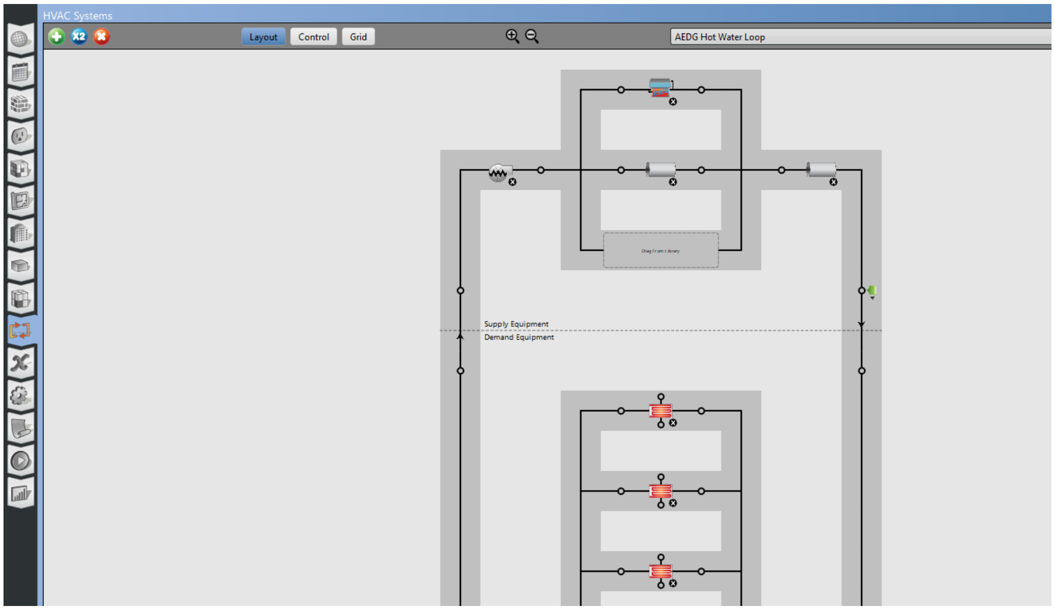

Figure 4.9. Hot-water loop (Only a section with key components is shown)

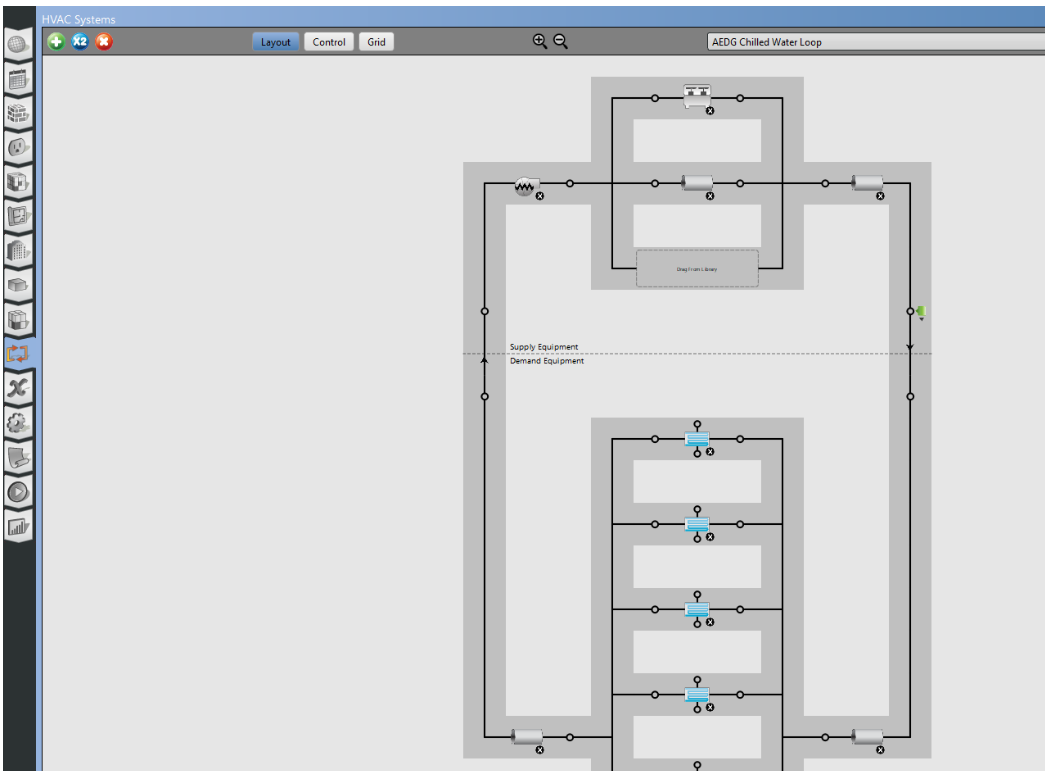

Figure 4.10. Chilled-water loop (Only a section with key components is shown)

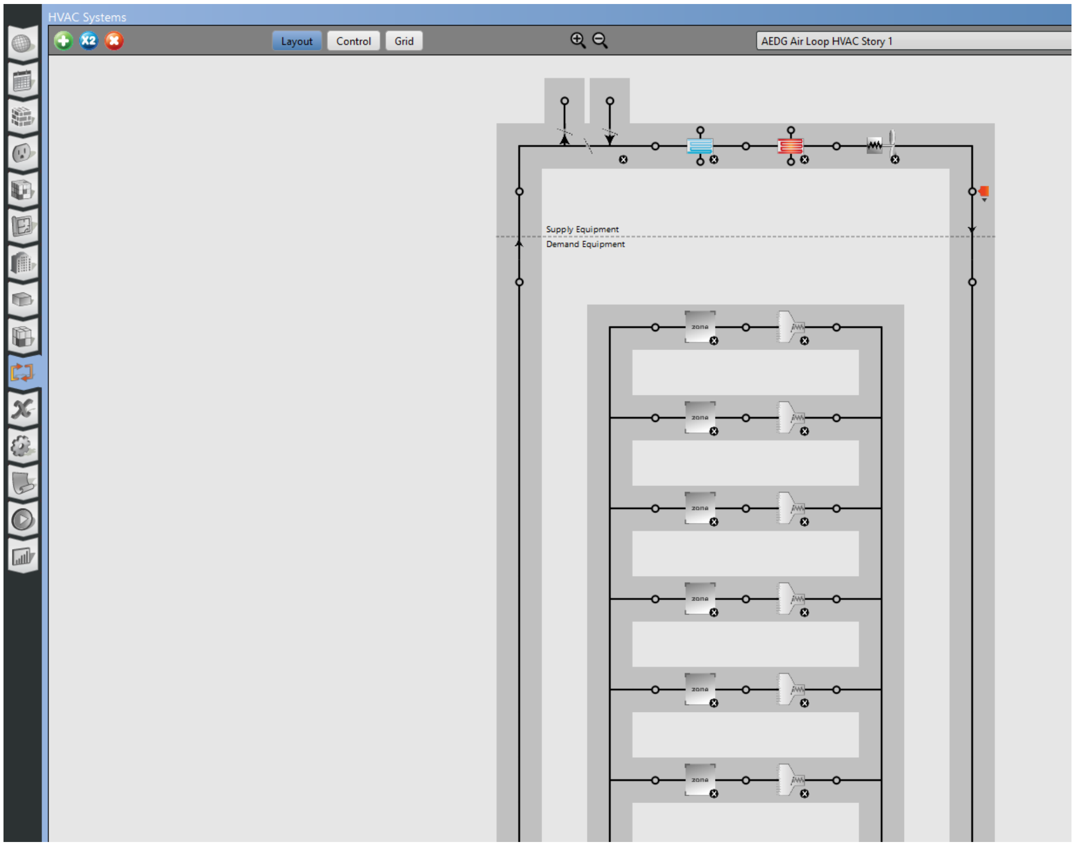

Figure 4.11. Air loop for floor 1 (Only a section with key components is shown)

Table 4.5. AEDG HVAC system parameters auto sized by OpenStudio

Loop	Parameter description	Unit	System parameter
AEDG chilled water loop	Variable pump water flow rate	gal/min	849.54
	Electric chiller cooling capacity	ton	428.6
	Water flow rate	gal/min	849.54
	Reference COP		2.93
AEDG hot water loop	Variable pump water flow rate	gal/min	425.02
	Water flow rate	gal/min	425.02
Air loop for Floor 1			
Outdoor Air System	Maximum outdoor airflow rate	CFM	21,525
	Minimum outdoor air flow rate	CFM	Auto
Coil cooling: Water	Air flow rate		21,525
	Water flow rate	gal/min	150.31
Coil heating: Water	Heating capacity	Btu/hr	186,371.60
	Water flow rate	gal/min	19.13

Once the modeling of HVAC system was completed, system parameters such as cooling thermostat and heating thermostat schedules for individual spaces were added under the Thermal zones tab.

The results from the simulation can be customized using the "Output variables" tab, although no adjustments were made to the settings for this study. To easily identify errors in the models, troubleshooting measures from the Building Component Library (BCL) were implemented under the "Measures" tab. During the initial simulation runs aimed at rectifying model errors, the run period and simulation steps were reduced in the simulation settings to expedite the process and minimize the time required. After rectifying the model errors adequately, the timestep was increased to 4, adhering to the minimum recommended by OpenStudio, and the run period was extended to encompass an entire calendar year.

4.3 Results and discussion

In OpenStudio, the energy consumption simulation results are expressed in Joules (J). The outcomes for the simulation, considering both the existing system and the electric resistive boiler system, are listed in Tables 4.6 and 4.7, respectively, while the actual consumption data is presented in Table 4.8 (adapted from [26]).

Table 4.6. Simulation results (existing system)

Month	Energy Consumption in Joules	
	Space heating- No.2 diesel oil	**Electricity**
January	3.23E+12	1.41E+12
February	2.93E+12	1.27E+12
March	2.51E+12	1.41E+12
April	1.83E+12	1.37E+12
May	1.19E+12	1.45E+12
June	4.58E+11	1.48E+12
July	1.26E+11	1.63E+12

August	1.61E+11	1.56E+12
September	5.15E+11	1.43E+12
October	1.29E+12	1.43E+12
November	2.20E+12	1.36E+12
December	3.33E+12	1.41E+12
Total	1.98E+13	1.72E+13

Table 4.7. Simulation results (with electric resistive heating)

Month	**Energy Consumption in Joules**	
	Space heating- Electricity	**Other uses- Electricity**
January	2.99E+12	1.41E+12
February	2.88E+12	1.27E+12
March	2.32E+12	1.41E+12
April	1.64E+12	1.37E+12
May	1.04E+12	1.46E+12
June	4.00E+11	1.48E+12
July	1.49E+11	1.63E+12
August	1.46E+11	1.56E+12
September	3.73E+11	1.43E+12
October	1.04E+12	1.43E+12
November	2.23E+12	1.37E+12
December	3.06E+12	1.41E+12
Total	1.83E+13	1.72E+13

Table 4.8. Actual energy consumption

Month	**Electricity consumption (kWh)**	**Oil consumption (liters)**
January	938,238	143,447
February	855,079	163,802
March	960,000	151,847
April	932,419	117,433

May	1,001,842	72,558
June	1,116,581	60,246
July	1,239,224	25,221
August	1,301,140	34,303
September	1,151,270	44,295
October	1,096,985	42,079
November	1,047,888	106,251
December	1,065,471	138,628
TOTAL	12,706,138	1,100,109

The actual energy consumption and simulation results can be converted to Gigajoules (GJ) to facilitate comparison, utilizing the following formulas.

LHV of diesel (MJ/litre) = 38.18

Diesel consumption/January (litres) = 143,447

Energy consumption (heating/Jan) (GJ) = 5,476.81

Electricity consumption/January (kWh) = 938,238

Electricity consumption/ January (GJ) = 3,377.66

Comparison between the actual and simulation results are presented in Tables 4.9 and 4.10 respectively, for space heating and electricity.

Table 4.9. Comparison of fuel consumption for space heating

	Energy Consumption (GJ)		
Month	**Actual**	**Simulation results (Fuel oil)**	**Simulation results (Electricity)**
January	5476.81	3128.52	2976.22
February	6253.96	2955.37	2918.21
March	5797.52	2490.05	2384.31
April	4483.59	1751.43	1549.46
May	2770.26	1181.74	1074.15
June	2300.19	466.44	321.71
July	962.94	133.75	133.26
August	1309.69	156.07	162.26
September	1691.18	552.97	327.86
October	1606.58	1275.47	991.93
November	4056.66	2261.33	2188.28
December	5292.82	3278.99	3022.45

Table 4.10. Comparison of electricity consumption (for purposes other than space heating)

	Energy Consumption (GJ)		
	Actual	**Simulation results (other than for space heating)**	
Month		With space heating using fuel oil	With space heating using electricity
January	3377.66	1410.69	1413.74
February	3078.28	1272.23	1274.51
March	3456.00	1413.63	1414.42
April	3356.71	1371.98	1373.37
May	3606.63	1454.85	1455.86
June	4019.69	1479.04	1479.36
July	4461.21	1625.72	1625.66

August	4684.10	1559.93	1559.89
September	4144.57	1427.71	1427.96
October	3949.15	1429.06	1430.70
November	3772.40	1364.67	1365.58
December	3835.70	1407.47	1409.11

Comparison between the two simulation results is given in Figure 4.12.

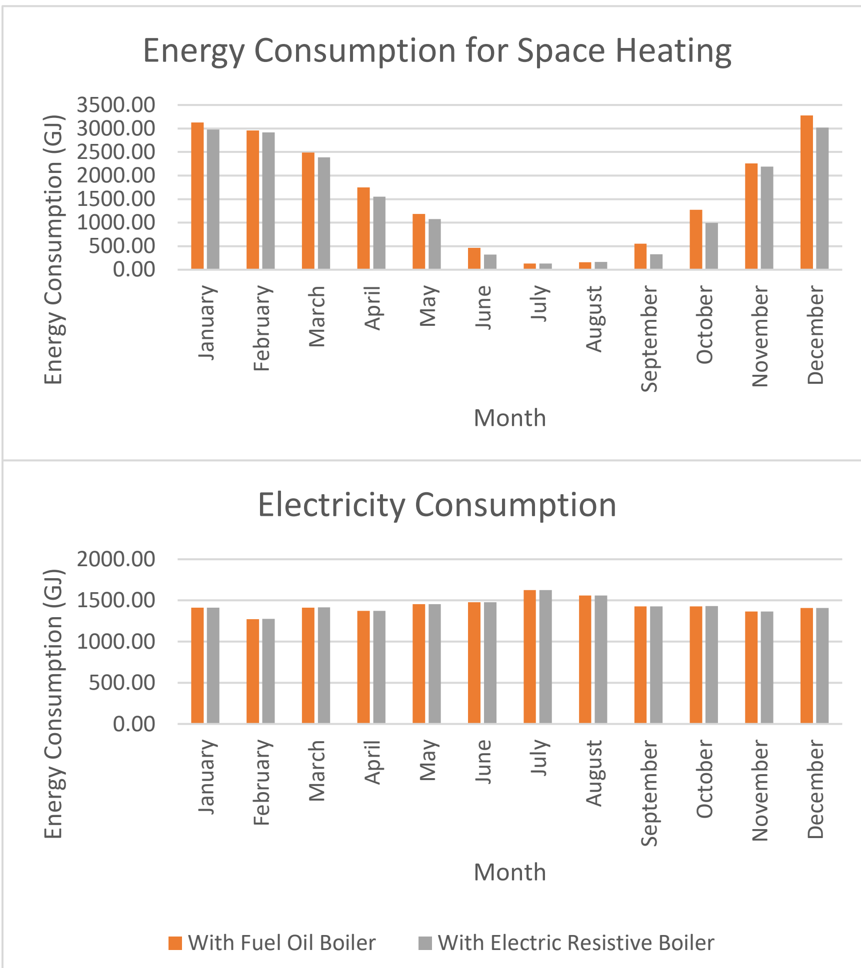

Figure 4.12. Comparison of simulation results, energy for space heating (above) and electricity (below)

The graphical representation of energy consumption for space heating and other end uses considering all three scenarios is represented in Figure 4.13 (above) and (below), respectively. While both Figures 4.12 and 4.13 illustrate an identical consumption pattern of electricity in both simulations, they also reveal a slight difference in energy consumption for space heating under electric resistive heating. Electric resistive heating exhibits approximately 7% less energy consumption, further to the improved efficiency and lower boiler capacity considered for the study.

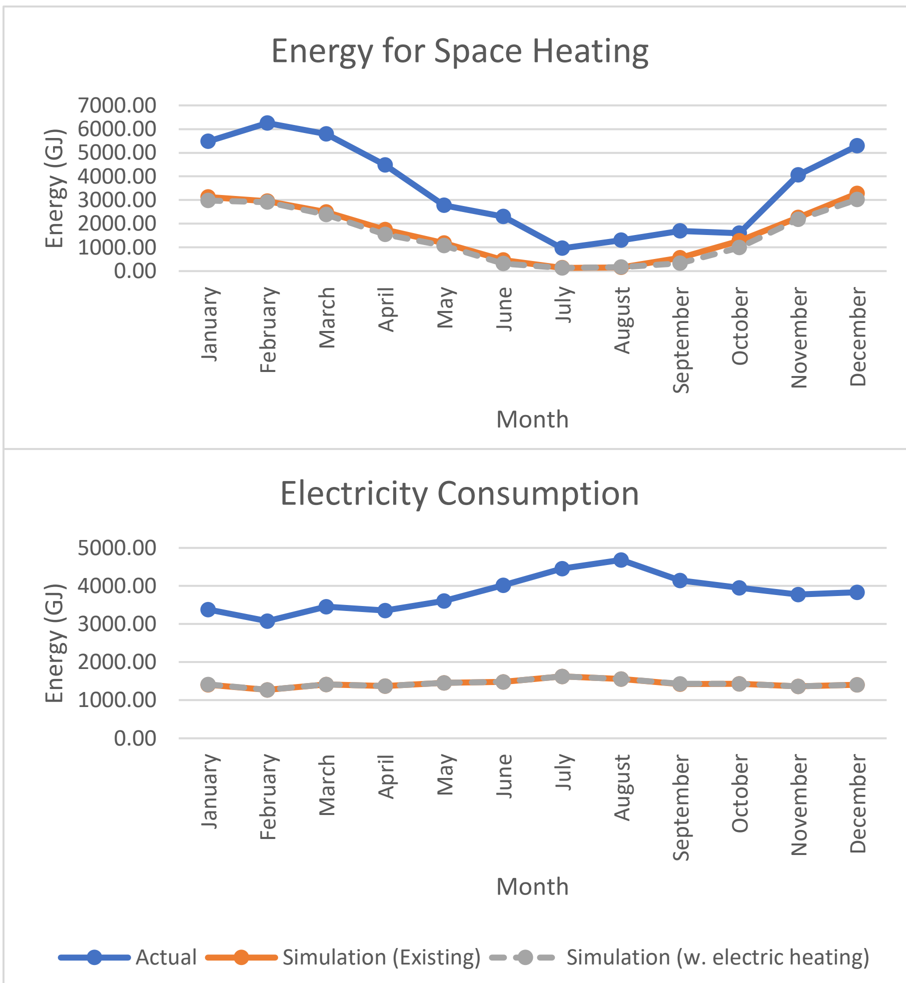

Figure 4.13. Comparison of energy consumption for space heating (above) and electricity for other end uses (below)

Electric boilers can modulate their output almost instantaneously in response to fluctuations in temperature or changes in demand for space heating or hot water. This rapid responsiveness allows for precise control, ensuring that the boiler operates at its optimal capacity, neither overproducing nor underproducing heat. In comparison, oil-fired boilers can experience less efficiency during frequent on/off cycling or during periods of low demand, as they may need to cycle on and off to maintain temperature, resulting in a modulation that is less effective than an electric resistive boiler. While this study did not account for dynamic heating loads such as fluctuating occupancy, OpenStudio incorporates passive heating elements such as solar heat gains and radiation from equipment in its simulations. This inclusion allows for the consideration of dynamic conditions that may impact heating within the modeled environment. Therefore, this difference in energy consumption can be attributed to this inherent distinction between the two technologies.

While the simulation results exhibit a consumption pattern similar to the actual data, there are also some deviations from the energy consumption values calculated using past data. This variance may arise from several disparities between the actual conditions and the OpenStudio model.

In the absence of specific details about the construction materials used in the CSF building, readily available materials optimized for Climate Zone 6 were employed in the OpenStudio model. These materials are designed to perform efficiently in the specified climate conditions. It is important to note that the actual construction materials used in the building may differ, especially in terms of properties such as insulation. Consequently, these discrepancies can influence the energy consumption patterns of the building throughout the year. The utilization of climate-specific materials in the model serves as an approximation, and the actual energy performance may vary based on the real-world construction details. The OpenStudio model also omitted the consideration of internal windows and doors as a simplification measure in the simulation. This resulted in the assumption that all internal surfaces are entirely sealed, whereas, in reality, substantial air leakages can occur through the glass surfaces, seals, and doors, leading to a higher energy consumption.

Furthermore, the second level of the CSF building is linked to the University Center (UC), facilitating substantial airflow between the two structures. The interchange of air between these interconnected buildings can cause heat loss from the CSF building, as warm air escapes into the cooler UC. This can produce a comparable impact during the summer season, wherein the influx of warm outdoor air into the CSF building would lead to increased energy consumption for space cooling to lower the temperature of the building envelope. This heat loss necessitates additional energy consumption, as the heating system in the CSF building must compensate for the dissipated heat. Moreover, the UC features several openings to the outdoors, potentially leading to infiltration and exfiltration, resulting in additional energy losses. Notably, for the simulation in OpenStudio, neither the interconnection nor the heat loss has been taken into account, potentially resulting in an estimated energy consumption that is lower than the actual values.

The CSF building, as well as the UC, accommodates numerous occupants throughout the year. Acknowledging the behavior of occupants is recognized as a pivotal factor contributing to the observed performance gap between actual and simulated energy consumption in buildings [27], [28]. Additionally, fluctuations in occupancy levels within a day influence space heating requirements, introducing variations in heating needs and potential inefficiencies. Maintaining a comfortable indoor environment involves striking a balance between the heating system and external conditions, and varying occupancy levels can impact the energy consumed for space heating. Thus, it is crucial to consider building occupancy levels in building energy modeling. Occupancy information for CSF building is not currently available and determining occupancy levels poses significant challenges, especially for buildings with dynamic occupancy patterns like the CSF building. Modeling dynamic occupancy levels is not currently feasible in BEM simulations; therefore, occupancy levels were not factored into this study, which can lead to a disparity in the energy requirements given by the simulation.

The HVAC system modeled in OpenStudio adhered to ASHRAE's Advanced Energy Design Guidelines (AEDG), providing a framework for designing energy-efficient HVAC systems. It is important to note that the actual HVAC system in the CSF building may have a different configuration and potentially lower efficiency, leading to higher energy consumption than indicated by the simulation results.

The energy demand from different equipment utilized across the building was not accessible for this study, posing a challenging task for data compilation. Additionally, the dynamic nature of occupancy levels introduces variations in actual loads and operating times. Consequently, guidelines for electrical equipment usage in an office building situated in climate zones 4-8 were employed for the simulation. This approach may lead to a lower estimated energy consumption value than the actual consumption. The CSF building also accommodates numerous plants and equipment that consume a substantial amount of energy, a factor not taken into account in the simulation. For instance, the ground floor and penthouse, functioning as plant rooms, were modeled as office spaces due to the lack of available data on the actual energy demand from these areas.

The hot water supply and return lines for the CSF building are channeled from the Department of Earth Science building, covering a substantial distance of around 160 meters between the two structures. In the simulation, no consideration was given to any energy loss within this section, as the model employed adiabatic piping with negligible heat losses. This contrasts with real-world conditions where significant losses might occur between the measuring point and the entry points of the pipes into the CSF building.

4.4 Conclusions

In this study, a comparative analysis was conducted between the existing space heating system at the CSF building and a proposed electric resistive space heating system using simulations in OpenStudio. The study suggests that, beyond the evident improvement in boiler efficiency, a further reduction in energy consumption, approximately 7%, can be achieved by transitioning to electric resistive heating. Simulated results also indicate that the building's energy consumption pattern closely aligns with actual consumption, although the calculated values are lower than the observed actual consumption. However, it is important to acknowledge that certain assumptions considered in the model development which can deviate from the actual conditions, such as construction materials, building occupancy, infiltration and exfiltration, interconnected buildings, energy usage by equipment and lighting, HVAC system energy consumption, and transmission losses through piping, can significantly influence energy consumption for space heating and electricity. These unaccounted variables contribute to the higher actual energy consumption of the building. An extensive survey focused on gathering operational data for the building can provide the groundwork for refining both this building energy model and the simulation results.

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CHAPTER 5. IMPACT OF FUTURE TIME OF USE BILLING ON ENERGY CONSUMPTION COSTS.

Preface

A version of this manuscript has been submitted for publication in the International Energy Journal (http://www.rericjournal.ait.ac.th/index.php/reric). The principal author developed the OpenStudio simulation models, carried out the analysis, drafted the initial manuscript, and later refined it incorporating feedback from the co-author, Professor M. Tariq Iqbal. Professor Tariq Iqbal played a key role in selecting the topic and outlining the scope, scrutinized and rectified the obtained results, and actively participated in the preparation, review, and revision of the manuscript.

Abstract

Globally, buildings contribute to about 30% of the total energy demand, and in Canada, more than half of this consumption is 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 regular operational patterns of the building 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 and utilizing the MUN CSF building as the case study. The findings indicate that transitioning from the current oil-fired hot water boiler employed for space heating to electric resistive heating, which proves cost-effective under a Flat-Rate tariff, might not yield any financial savings and could potentially result in increased energy costs under a Time-of-Use tariff. The simulation results, indicating an

energy cost of CA$1,029,089 under the Flat-Rate tariff extracted from historical data and CA$1,980,110 under the Time-of-Use tariff reasonably derived from the current tariffs in effect in Newfoundland and Ontario, suggest that the energy cost under Time-of-Use tariff can nearly be doubled when compared to a Flat-Rate tariff, with the same amount of energy consumed and a similar usage pattern.

Keywords- OpenStudio, Educational Building, Space Heating, Thermal Modeling

5.1 Introduction

5.1.1 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].

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 5.1 (adapted from [7]), 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, p. 69], [10]. The energy consumption of educational facilities in Canada as of 2020 is outlined in Table 5.1 (adapted from [9, p. 69], [10]).

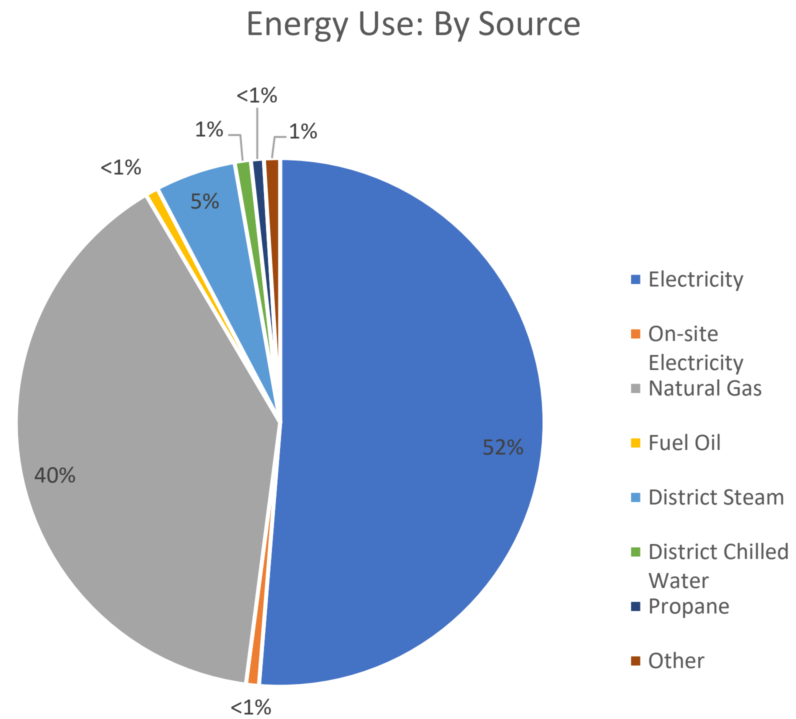

Figure 5.1. Energy Use in Commercial and Institutional Buildings by Source

Table 5.1. Energy consumption by educational facilities, in Peta Joules (PJ)

	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

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, p. 1]. 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 5.2 (adapted from [12, p. 45], [13, p. 46]. 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].

Table 5.2. Energy consumption (in PJ) by educational buildings in Atlantic Canada

	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 reveals 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].

5.1.2 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 is essentially composed of two elements for residential and small commercial consumers: a consumer charge and a flat rate per kWh. On the other hand, large commercial and industrial consumers also pay a demand charge along with a flat rate, and the flat rate per kWh varies based on the consumer class. A flat electricity tariff (FR) offers simplicity and predictability, while providing consumers with a straightforward understanding of their electricity costs and eliminates complexities associated with variable rates. However, a major drawback is its lack of incentive for energy conservation during peak hours, potentially leading to inefficient usage patterns. Additionally, this model may not accurately reflect the actual costs of electricity generation and distribution, posing challenges in promoting sustainability and encouraging responsible energy consumption behaviors [19]. In comparison, a tariff that can be viewed as a variation of the flat-rate tariff but fluctuates based on time blocks, Time-of-Use (TOU) electricity tariff introduces a variable pricing structure based on the time of day, offering potential benefits and drawbacks. The advantage lies in incentivizing consumers to shift energy-intensive activities to off-peak hours, promoting load balancing and overall grid efficiency. It also reflects the actual cost of electricity production during different times. However, a challenge is the complexity for consumers in managing and adapting their energy usage to fluctuating rates. Additionally, certain industries or households may face difficulties in adjusting their activities to align with TOU schedules, potentially leading to increased costs during peak periods [20].

A more recent approach to electricity tariff structures is the real-time electricity pricing (RTP) model, aiming to minimize the net difference between the actual costs associated with electricity generation, transmission, and distribution trade and its tariffed revenue [19]. This dynamic pricing structure provides consumers the opportunity to adjust their usage during periods of low demand or lower prices, effectively reducing peak loads enhancing the grid reliability [21]. However, when compared to TOU, RTP encompasses a broader spectrum of market price variations, creating challenges for consumers in effectively managing and predicting costs [22]. This dynamic pricing structure may lead to volatile bills, affecting the predictability of budgets for households and businesses.

5.1.3 Building Energy Modeling

Building Energy Modeling (BEM), applicable to both new constructions and existing structures, offers a comprehensive and anticipatory evaluation of a building's energy efficiency. By incorporating data related to architectural design, materials, Heating, Ventilation and Air Conditioning (HVAC) systems, lighting, and occupant behavior, energy models replicate the dynamic interactions within a building, quantifying energy consumption and ensuring thermal comfort [23], [24]. These models prove invaluable in evaluating the influence of diverse technologies, insulation approaches, and the integration of renewable energy, providing insights for decision-makers to attain optimal energy performance. Serving as potent tools, building energy models enable the prediction, analysis, and implementation of strategies to curtail energy usage, reduce operational expenses, and fulfill sustainability objectives.

Building energy models can be primarily categorized as either steady-state or dynamic. Steady-state models overlook the transient impact of variables, whereas dynamic models have the capacity to monitor peak loads and effectively capture thermal effects, such as those resulting from setback thermostat strategies [2]. The selection between these approaches depends on the specific requirements of the analysis. Steady-state models, being computationally efficient, are suitable for quick assessments where transient effects are less critical, making them well-suited for short-term analyses and initial screening. On the other hand, dynamic models provide a more accurate representation of a building's behavior over time, capturing transient effects, seasonal variations, and interactions among different components. Although dynamic simulations are more complex and computationally intensive, they are invaluable for providing a more accurate representation of a building's behavior over time. This accuracy is instrumental in facilitating well-informed decision-making processes.

5.2 Building for the Case Study

This study focuses on the Core Science Facility (CSF) building, covering a total floor area of 40,817 square meters (m^2) across five floors. Situated on the Memorial University of Newfoundland (MUN) campus in St. John's, Newfoundland and opened to public in 2021, the CSF accommodates teaching rooms, research laboratories, and office spaces primarily designated for the Department of Electrical and Computer Engineering within the Faculty of Engineering and Applied Science at Memorial University. Additionally, the building houses various plant and equipment, including a cryogenic facility operated and maintained by the Department of Technical Services [25]. The CSF relies on two energy sources: electricity and hot water for space heating, with the hot water sourced from the central heating plant in the university's Utility Annex (UA). 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.

Figure 5.2. The CSF Building

The data shows that in the calendar year 2022, the CSF facility utilized 12,706,138 kilo watt 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. A suggestion has been put forth to substitute one of the oil-fired boilers with two electric resistive boilers, each featuring a relatively 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. This study explores the potential implications of switching from a FR tariff to TOU, using the CSF building as an example.

5.3 Methodology

5.3.1 Development of the Building Energy Model

For this study, a BEM created using OpenStudio version 3.6.1 was taken into account. 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 [28], [29]. Furthermore, this study involved making certain assumptions and utilising standard parameters due to the lack of data on building operations. Crucial details like construction materials, occupancy patterns, lighting, and equipment loads were unavailable, mainly because the building is relatively new, and no comprehensive survey has been conducted to date to encapsulate such information. 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 [30]. Additionally, predefined schedules in OpenStudio for Large Office

Buildings were utilized for equipment usage and occupancy densities, considering that a portion of the building serves as office spaces for faculty staff and students. Table 5.3 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 5.3 offers a depiction of the BEM when viewed from the North.

Table 5.3. 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		

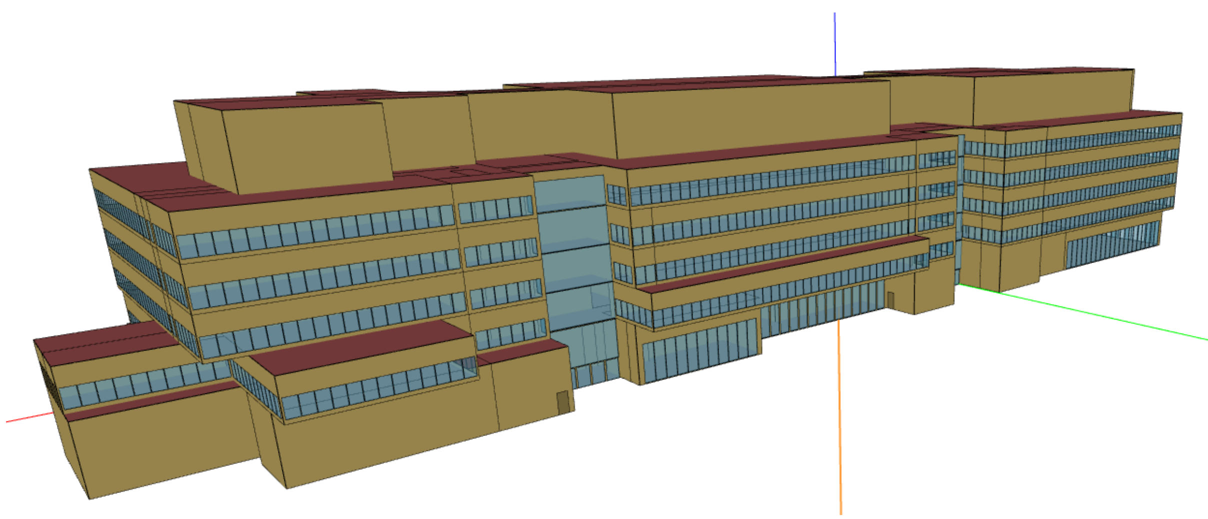

Figure 5.3. OpenStudio model of the CSF building

For the simulation of the model, various parameters, including the load profiles, intensity and the Heating, Ventilation and Air-Conditioning (HVAC) system operation for various space types allocated within the building envelope were considered. The HVAC system was simulated using the ASHRAE Advanced Energy Design Guides (AEDG) from OpenStudio's Building Component Library (BCL) [31], which allows users to effectively design and simulate energy-efficient HVAC systems for buildings through a simple and straightforward process. Figure 5.4 illustrates the floor plan of the first floor with different space types, while Table 5.4 provides a summary of the parameters taken into account for space heating and ventilation. Figure 5.5 illustrates the schedule for HVAC availability based on the AEDG.

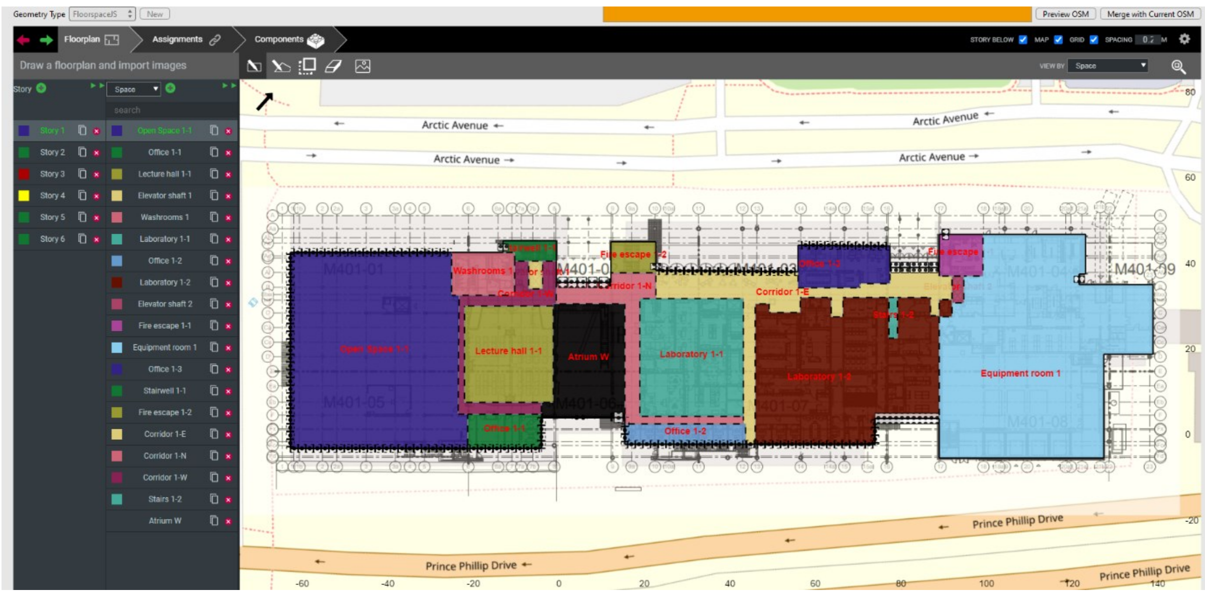

Figure 5.4. Floor plan for floor 1

Table 5.4. 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

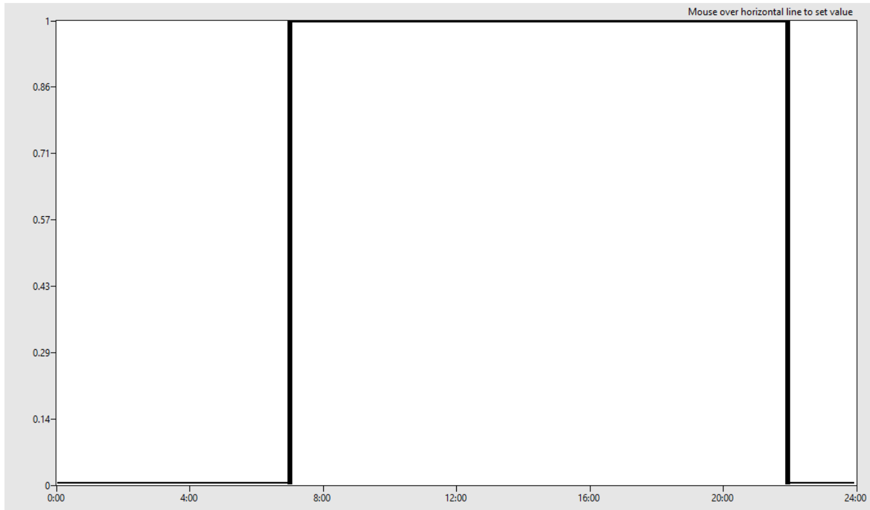

Figure 5.5. AEDG HVAC availability schedule

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 Figures 5.6 and 5.7 respectively, with the occupancy schedule for the building shown in Figure 5.8.

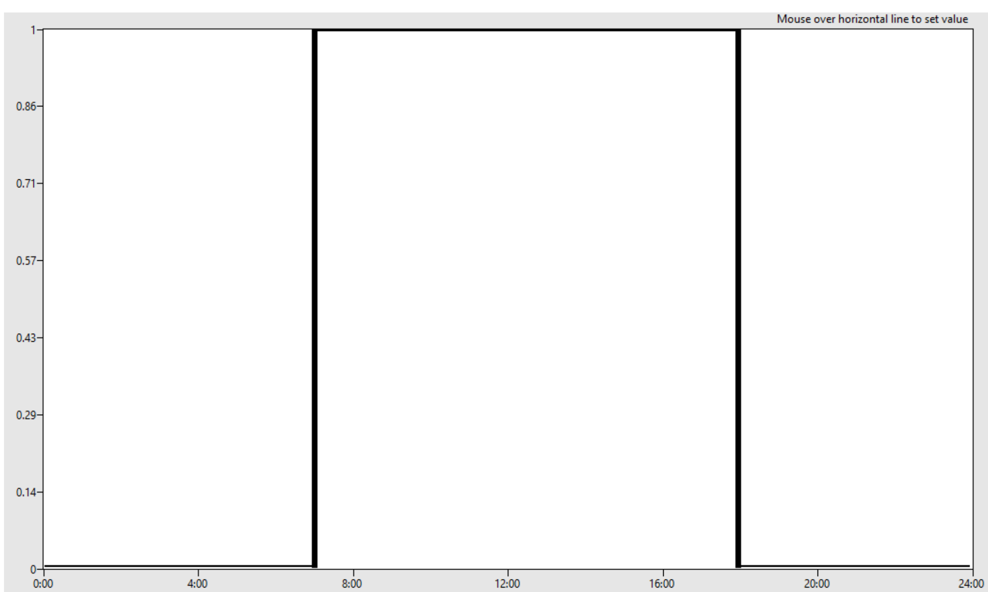

Figure 5.6. Equipment and lighting profile for Office

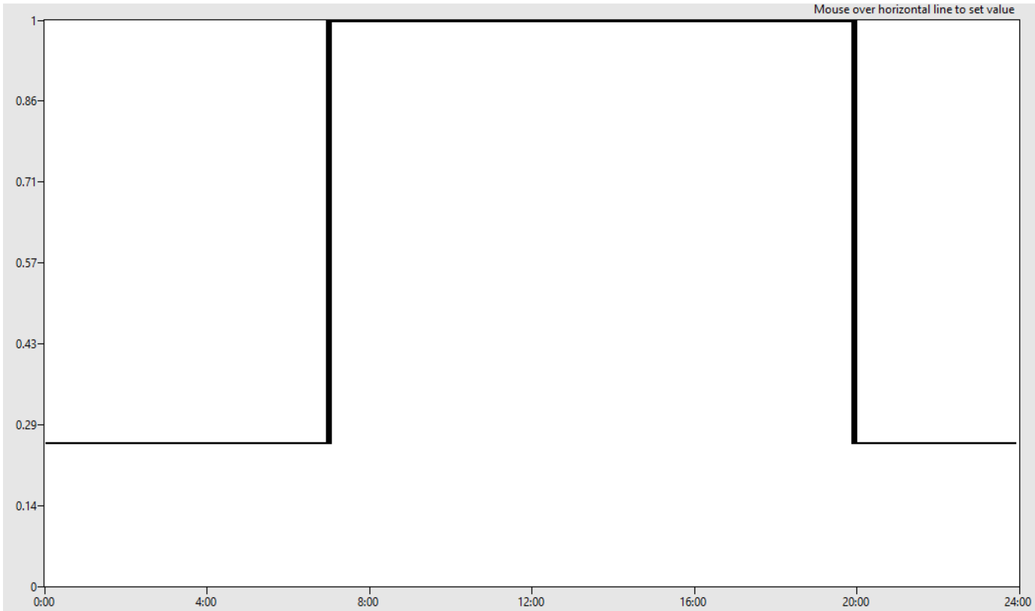

Figure 5.7. Equipment and lighting profile for Laboratory

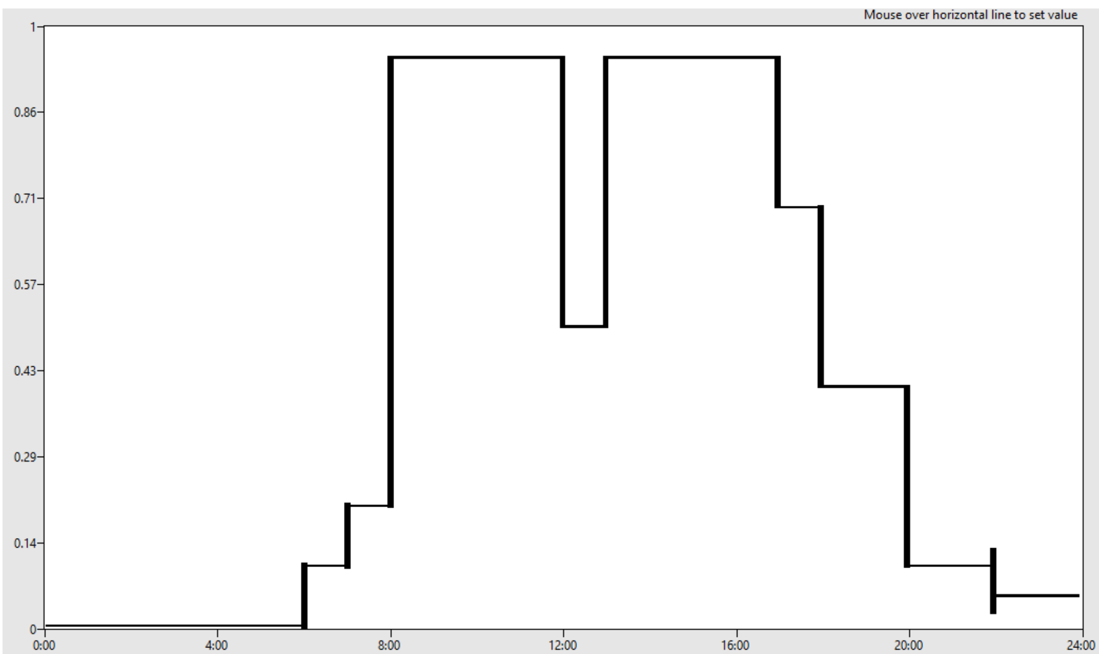

Figure 5.8. Building occupancy schedule

5.3.2 Selection of Energy Tariff

Historical data of the CSF building indicates that in 2022, the average tariffs have been 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], [32]. In Ontario, 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 at around 8.2 ¢/kWh. [33].

Table 5.5 illustrates the current TOU tariff structure in Ontario (adapted from [16]).

Table 5.5. TOU tariff structure in Ontario

TOU tier	Rate (¢/kWh)	Winter period (Nov 1 to Apr 30)	Summer period (May 1 to Oct 31)
Off-peak	8.7	Weekdays 19.00-07.00 Weekends and holidays all day	Weekdays 19.00-07.00 Weekends and holidays all day
Mid-peak	12.2	Weekdays 11.00-17.00	Weekdays 07.00-11.00 and 17.00-19.00
On-peak	18.2	Weekdays 07.00-11.00 and 17.00-19.00	Weekdays 11.00-17.00

In contrast, Newfoundland employs a block tariff system for industrial consumers with a demand exceeding 1,000 kilo-volt amperes (kVA), as outlined in Table 5.6 (adapted from [34]).

Table 5.6. Electricity tariff for industrial customers

Charge Type	Unit	Cost ($)
Basic customer charge	Per month	85.12
Demand charge- Winter months	Per kVA	7.82
Demand charge- Summer months	Per kVA	5.32
Energy charge- First 75,000kWh	Per kWh	0.10982
Energy charge- Beyond 75,000kWh	Per kWh	0.09305

For the purpose of simplifying the computational model and improving comparability, a TOU tariff was utilized, incorporating the two tariff structures detailed in Tables 5.5 and 5.6, without considering the Harmonised Sales Tax (HST). Table 5.7 provides a summary of the tariff structures adopted for the simulation.

Table 5.7. 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

5.4 Results and Discussion

The outcomes from the two simulations 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 5.8.

Table 5.8. 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 5.9.

Table 5.9. 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

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 CSF facility and the TOU is derived from tariff structures currently in practice in Newfoundland and Ontario. In addition to the 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 indicates that the demand charge accounts for approximately 25% of the total energy bill.

Electricity costs under TOU tariffs can be significantly higher than flat rates 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 model encourages consumers to shift their energy-intensive activities to off-peak hours, promoting energy efficiency and reducing strain on the grid. However, failure to adjust consumption habits to align with lower-priced periods can result in elevated electricity costs under TOU tariffs.

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 from historical data 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, a third model was developed, incorporating a No.2 diesel oil fired boiler with a thermal efficiency of 82%. The results are presented in Table 5.10. 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 diesel (per liter)	= 38.18 MJ
1kWh of electricity	= 3,600,000 J

Table 5.10. Actual consumption and simulation results for existing system

	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 FR tariff, and TOU tariff, is presented in Table 5.11.

Table 5.11. Comparison of energy costs

		Cost ($)	Total Energy Cost ($)
Existing System	Electricity (at $0.105/kWh)	502,161.93	1,355,733.06
	Space Heating (with No.2 diesel oil, at $1.66/liter	853,571.13	
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 results depicted in Table 5.11 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 price in Newfoundland. The market for diesel oil has exhibited notable volatility, with data indicating substantial fluctuations in consumer prices in 2023 alone [35]. 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 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 taken into account 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.

The simulation results exhibit a consumption pattern similar to the actual patterns; however, a notable disparity in the energy consumption values is evident when comparing the simulation results with the actual data. Several factors can contribute to this deviation. In the OpenStudio model for the CSF building, generic materials optimized for Climate Zone 6 were used due to the lack of specific construction details. These materials are designed to optimize the efficiency in the specified climate conditions. However, it should be noted that the actual building may have used different materials, particularly in terms of insulation properties, impacting its energy consumption patterns. The model's use of climate-specific materials is an approximation, and the real energy performance can vary based on actual construction details. Additionally, the model was simplified by not considering internal windows and doors, assuming full sealing, whereas in reality, air leakages through these elements can contribute to higher energy consumption.

Moreover, the connection between the second level of the CSF building and the UC allows substantial airflow between them, causing heat loss during winter as warm air escapes into the cooler UC and potential heat gain in summer due to warm outdoor air entering the CSF building. This unaccounted-for heat exchange requires additional energy consumption for heating or cooling to maintain indoor temperatures. The UC, with its openings to the outdoors, introduces potential infiltration and exfiltration, leading to additional energy losses. The OpenStudio simulation did not consider these interconnections and heat losses, potentially underestimating the actual energy consumption.

Both the CSF building and the UC experience varying occupancy levels throughout the year. Occupant behavior significantly influences the observed gap between actual and simulated energy consumption. Daily fluctuations in occupancy impact space heating requirements, introducing inefficiencies. Balancing the heating system with external conditions for a comfortable indoor environment becomes crucial, and varying occupancy levels can affect energy consumption for space heating. While occupancy information for the CSF building is currently unavailable, modeling dynamic occupancy levels is also a challenge in BEM simulations. This study did not account for occupancy levels, potentially leading to discrepancies in the simulated energy requirements.

The HVAC system in the OpenStudio model was aligned with ASHRAE's Advanced Energy Design Guidelines (AEDG) for energy-efficient design. However, the actual HVAC system in the CSF building may differ, potentially having lower efficiency and resulting in higher energy consumption than the simulation results. Furthermore, access to energy demand data for various building equipment was challenging, leading to the utilization of OpenStudio guidelines for electrical equipment in office buildings (climate zones 4-8) for simulation. The dynamic nature of occupancy levels introduces variations in loads and operating times, further influencing the accuracy of the simulation results. Additionally, energy-consuming plants and equipment in the CSF building, not considered in the simulation, for example the ground floor and penthouse which serve as plant rooms but modeled as office spaces, contribute to potential discrepancies in estimated energy consumption values.

The hot water supply and return lines for the CSF building extend approximately 160 meters from the Department of Earth Science building. The simulation assumed adiabatic piping with negligible heat losses, disregarding potential energy losses during the actual transmission between the two structures, which can significantly differ from real-world conditions.

5.5 Conclusions

This study involved a comparative analysis using a building energy model created 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 a 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 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.

Simulated results indicate a close resemblance between the building's energy consumption pattern and actual usage patterns, although the calculated values are comparatively lower than the actual usage. It is important to recognize that certain model assumptions, including construction materials, occupancy, infiltration, interconnected buildings, equipment and lighting energy usage, HVAC system performance, and transmission losses through piping, may deviate from actual conditions, significantly impacting energy consumption. These unconsidered variables contribute to the building's higher actual energy consumption.

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. 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.

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CHAPTER 6: CONCLUSIONS, CONTRIBUTIONS AND FUTURE WORK

6.1 Conclusions

The first section of this thesis explored the energy consumption patterns exhibited by buildings in Canada, with a particular focus on the Core Science Facility (CSF) at the Memorial University of Newfoundland as a prominent case study. A comprehensive analysis of a year's worth of actual consumption data uncovered notable variations in energy usage when compared to the national median reference for university buildings. Specifically, the current Energy Use Intensity (EUI) at CSF, standing at approximately 2.15 gigajoules per square meter (GJ/m^2), signified a higher energy demand than the national average of 1.04 GJ/m^2 for university facilities. This discovery underscores the imperative need for implementing energy efficiency enhancements within the CSF. To further delineate the financial implications of improving energy efficiency, a detailed cost estimate was conducted for the conversion of the heating system to electric resistive heating. This encompassed an evaluation of upfront procurement and installation expenses, coupled with operational costs. The findings of this cost estimate presented a clear overview of the financial considerations inherent in undertaking such a transition. Notably, straightforward calculations indicated a substantial potential for financial savings through the adoption of electric resistive heating. The outcomes of this initial investigation laid the groundwork for subsequent chapters, informing the development of a comprehensive building energy model. Moreover, it set the stage for a thorough exploration of the feasibility of transitioning to electric resistive heating, a critical aspect addressed in the ensuing sections of the thesis. The study's findings, therefore, not only shed light on the existing energy consumption scenario but also provided essential insights crucial for the in-depth analysis and exploration conducted in the subsequent phases of the research.

In the second section of the research, an in-depth examination was conducted to assess the viability of transitioning the space heating system of the CSF building from its current oil-fired boiler system to electric resistive boilers. This analysis utilized RETScreen Expert for a comprehensive evaluation. Additionally, to enhance the understanding of the building's thermal dynamics, a thermal model for the CSF building was developed using Energy3D. The feasibility study suggested that the proposed transition could lead to substantial cost savings. Specifically, the analysis indicated a potential annual reduction of approximately $765,435 in fuel costs, representing a noteworthy 24.2% of the total energy expenditure incurred by the CSF building in 2022. Furthermore, the study highlighted an anticipated 6.6% decrease in energy consumption, coupled with a substantial gross annual reduction of 2,665 metric tons of carbon dioxide emissions.

The next section focused on a comparative analysis between the existing space heating system at the CSF building and the proposed electric resistive space heating system, utilizing building energy modeling and simulations conducted in OpenStudio. The findings suggested that, beyond the evident improvement in boiler efficiency, a further reduction in energy consumption, approximately 7%, can be achieved by transitioning to electric resistive heating. The simulated results also revealed a close alignment between the building's energy consumption pattern and the actual consumption, albeit with calculated values being lower than observed actual consumption. This deviation can be accounted to a number of variables that were not considered in the building energy model, which included factors such as construction materials, building occupancy, infiltration and exfiltration rates, interconnected buildings, energy usage by equipment and lighting, HVAC system energy consumption, and transmission losses through piping.

The final section of this study undertook a comparative analysis to evaluate the impact of various tariff structures. This analysis utilized the building energy model created with the OpenStudio application as a foundational framework, subsequently enhancing it to scrutinize the effects of different tariffs. The findings suggested that the transition from the current oil-fired hot water boiler for space heating to electric resistive heating, economically viable under a Fixed Rate (FR) tariff, might not yield financial savings and could potentially incur additional energy costs under a Time-of-Use (TOU) tariff. The simulation results, incorporating an energy cost of CA$1,029,089 under the historical FR tariff and CA$1,980,110 under the derived TOU tariff (based on prevailing tariffs in Newfoundland and Ontario), indicate a substantial disparity. Specifically, the energy cost under a TOU tariff can nearly double compared to an FR tariff, assuming the same energy consumption and usage patterns. Despite the inherent benefits of electric resistive boilers, such as enhanced efficiency and rapid responsiveness, coupled with operational strategies like improved thermal insulation, load shifting to off-peak hours, and the use of energy-efficient equipment, it remains uncertain whether these measures alone can completely offset the potentially high energy costs associated with a TOU tariff.

6.2 Contributions

1. Two complete Building Energy Models (BEM) for the CSF building were developed using Energy3D and OpenStudio software, considering the energy consumption throughout a whole year. The results derived from these models closely aligned with the actual energy consumption patterns observed in the building. These models can serve as a foundation for conducting studies on energy consumption and energy efficiency in the CSF building.
2. The completion of a feasibility analysis utilizing RETScreen Expert software assessed the transition from a fuel oil-fired boiler to an electric resistive heating boiler for space heating. The analysis indicated significant cost and energy savings associated with the transition, taking into account historical energy tariffs.

3. The BEM in OpenStudio underwent additional developments to integrate various electricity tariff structures, primarily focusing on Flat-Rate (FR) and Time-Of-Use (TOU) tariffs. The simulation results suggested that the expected financial benefits from the transition might not materialize if a TOU tariff is applied in Newfoundland. These BEMs can be further refined to analyze diverse scenarios under various alternative tariff structures.
4. The analysis of energy consumption, incorporating data spanning a year for the CSF building, revealed that the building's Energy Use Intensity (EUI) is notably higher not only than the average EUI for university buildings in Canada but also in comparison to the S. J. Carew building, an older counterpart at MUN. These results underscore the potential for improving energy efficiency within the CSF building.
5. Literature on energy consumption in educational buildings in Canada is limited. The results of this study can establish a benchmark for evaluating the energy consumption of educational buildings and highlight key considerations when transitioning from one energy source used for space heating to another.

6.3 Future Work

The work carried out in this research can be further extended in numerous ways, which are outlined below.

1. The BEM was designed to include as many thermal zones as possible while maintaining simplicity to minimize the computing power needed for simulations and reduce simulation times. Further enhancements to the BEM can be made by incorporating all thermal zones and additional spaces not addressed in this study, such as plenums, to improve its accuracy.

2. This study was devoid of inputs from a comprehensive survey covering building occupancy, electricity usage, operational schedules, infiltration/exfiltration rates, and construction details. Such data could enhance both the building energy model and simulation results, ensuring a more precise representation of the intricate factors influencing energy consumption in the CSF building.
3. Data on the HVAC system specifics, the complete space heating mechanism, distances of transmission lines (piping), and operational schedules were unavailable for this study. The inclusion of this information could significantly enhance the BEM, playing a crucial role in evaluating energy requirements and devising an optimized operational strategy for the building.
4. Further refinement of the BEM can be pursued to pinpoint an optimal operational strategy and energy saving measures for the building.
5. The tariff structures embedded in the BEM can be expanded and refined to include a variety of tariffs expected to be employed in Newfoundland. This enhancement would enable the analysis and projection of energy costs associated with the CSF building under different tariff scenarios.
6. A sensitivity analysis can be conducted for the considered tariffs, providing an additional layer of refinement to the simulation results.

6.4 List of Publications

"CSF Building Energy Consumption Analysis and Cost Estimate of Electric Resistive Heating System." Presented at the 32nd Annual Newfoundland Electrical and Computer Engineering Conference (NECEC), Nov. 14, 2023. Authors: Chamila Jayanuwan Liyanage, Mohammad Tariq Iqbal.

"Thermal Modeling and Electric Space Heating of a University Building in Newfoundland." Published in European Journal of Engineering and Technology Research Volume 9, Issue I, 2024 (2024). pp 37-46, doi:10.24018/ejeng.2024.9.1.3145. Authors: Chamila Jayanuwan Liyanage, Mohammad Tariq Iqbal.

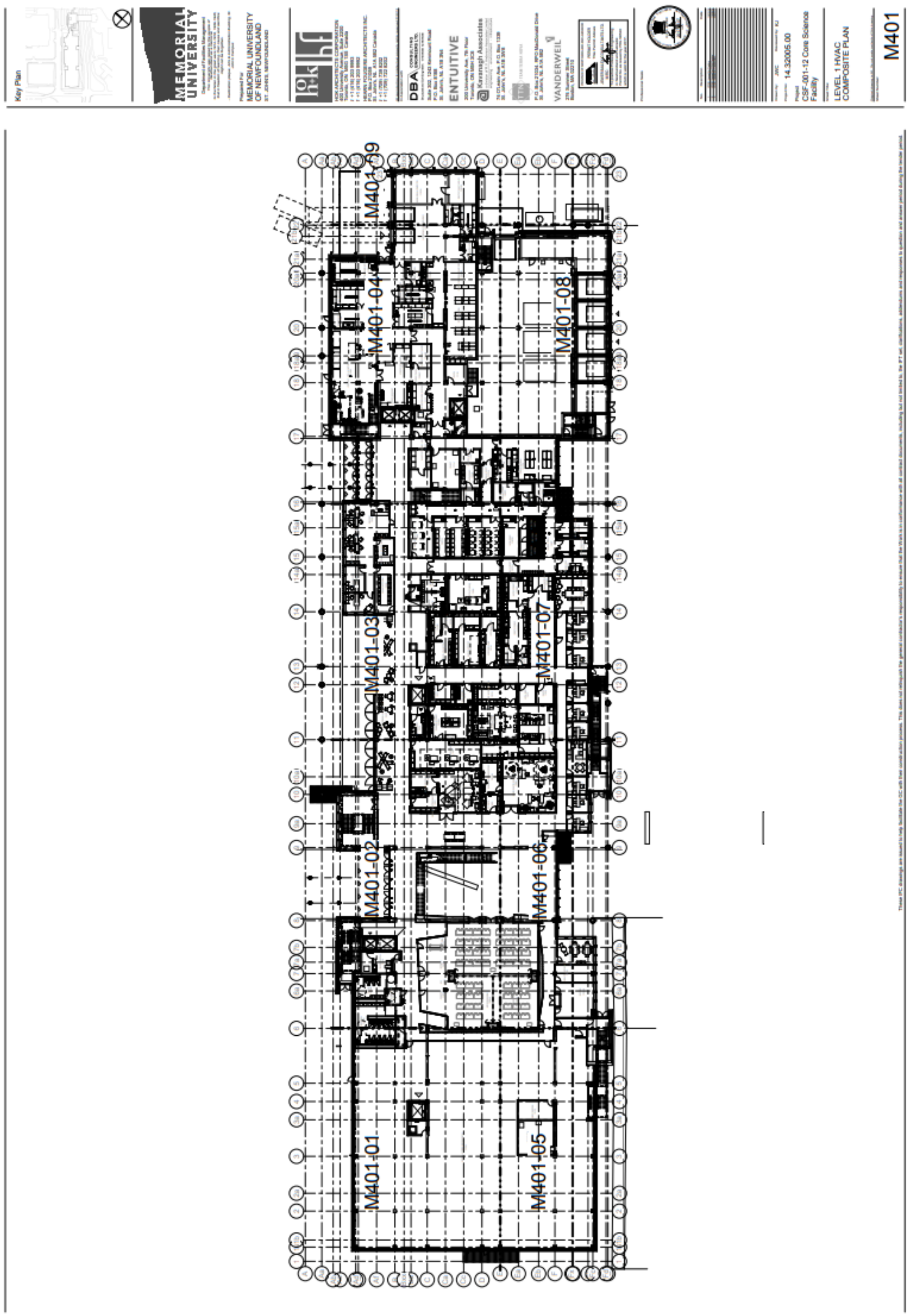
"A Comparison of Programmed Controlled Existing System vs. Electric Resistive Heating for a University Building in Newfoundland." Accepted for publication in European Journal for Energy Research. Jan 26, 2024. Authors: Chamila Jayanuwan Liyanage, Mohammad Tariq Iqbal.

"Impact of Future Time of Use Billing on Energy Consumption Costs in a University Building in Newfoundland." Submitted for publication in International Energy Journal. Feb 22, 2024. Authors: Chamila Jayanuwan Liyanage, Mohammad Tariq Iqbal.

LIST OF APPENDICES

Appendix I- Floor Plans of CSF Building

Floor 1



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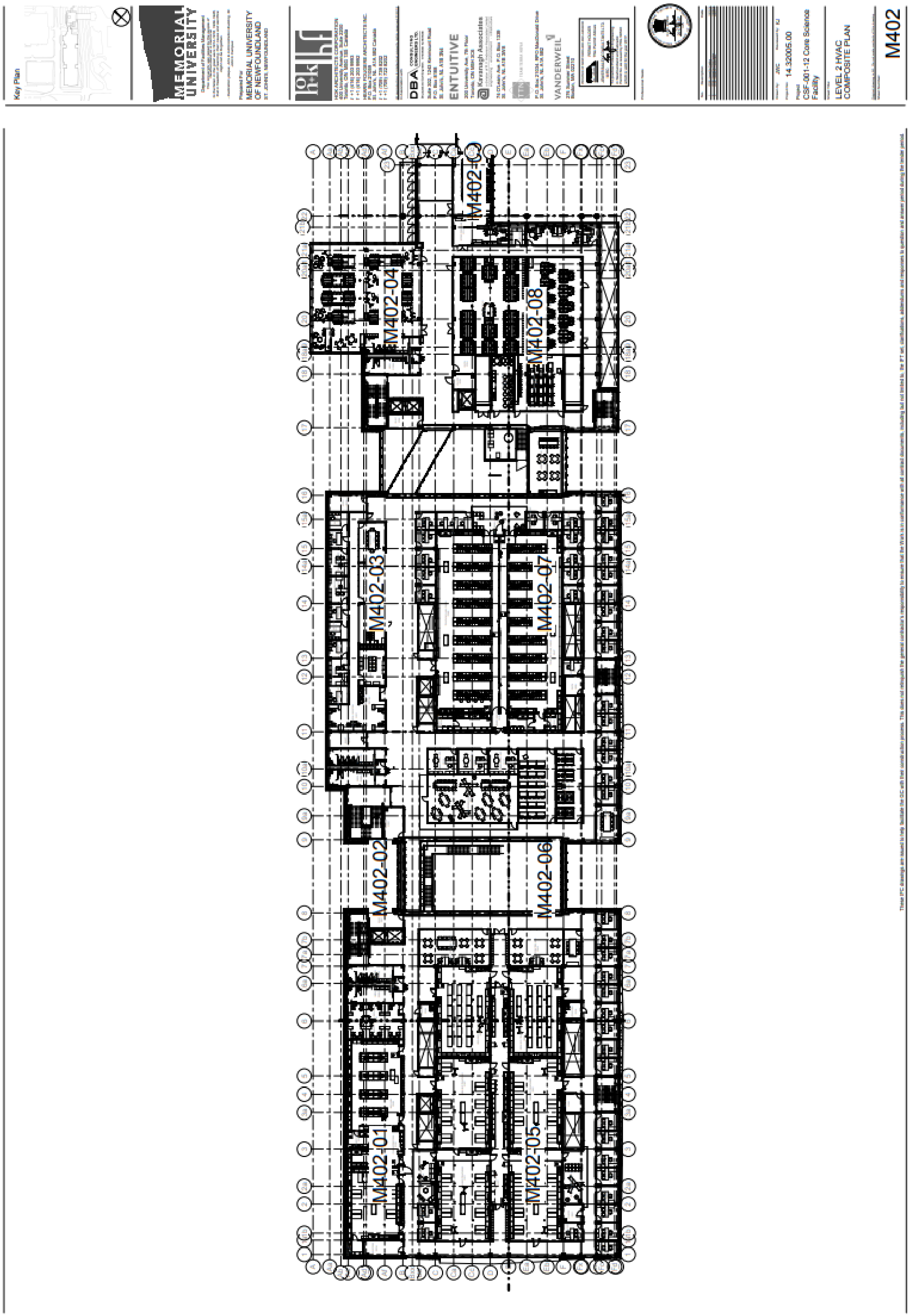

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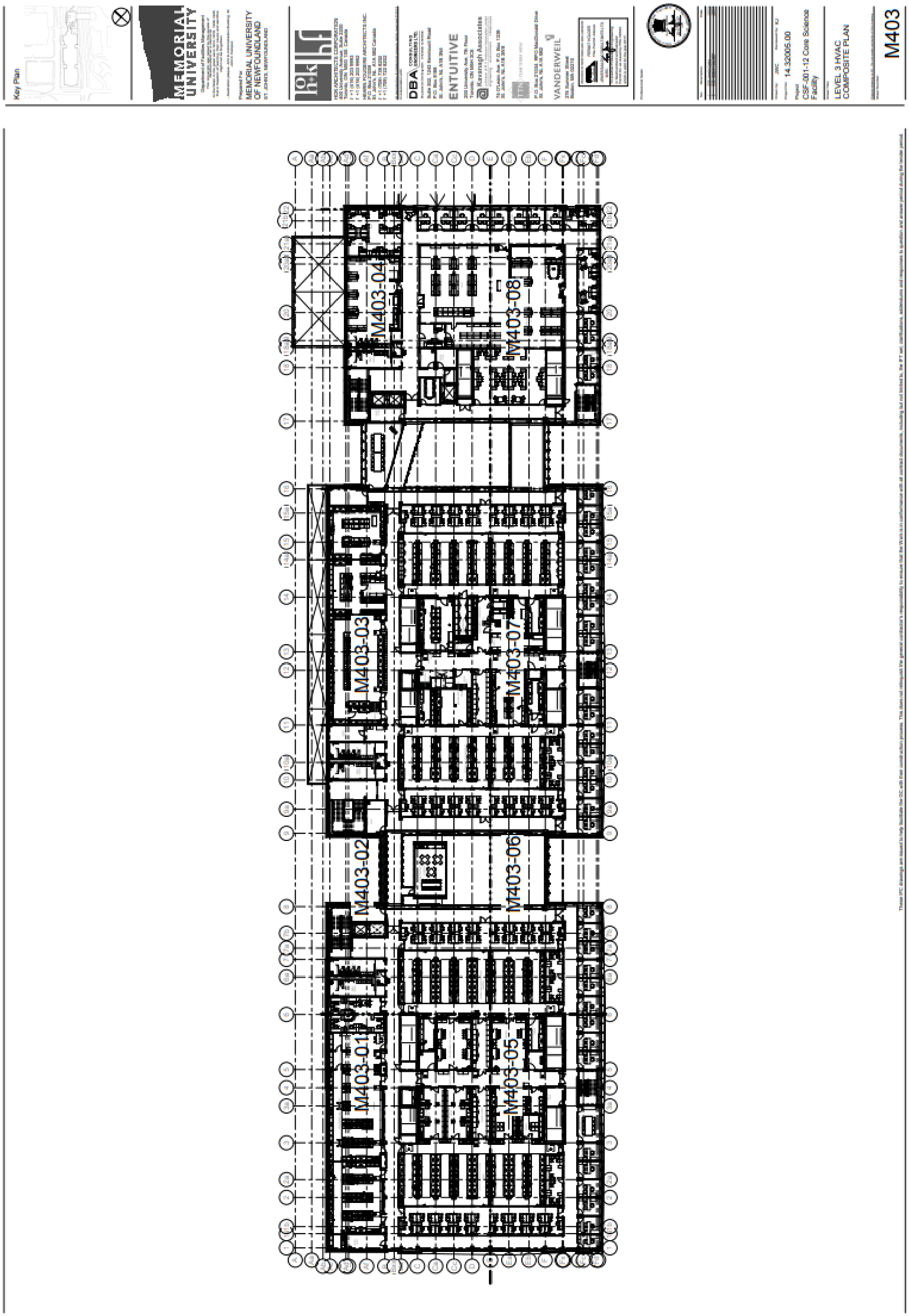

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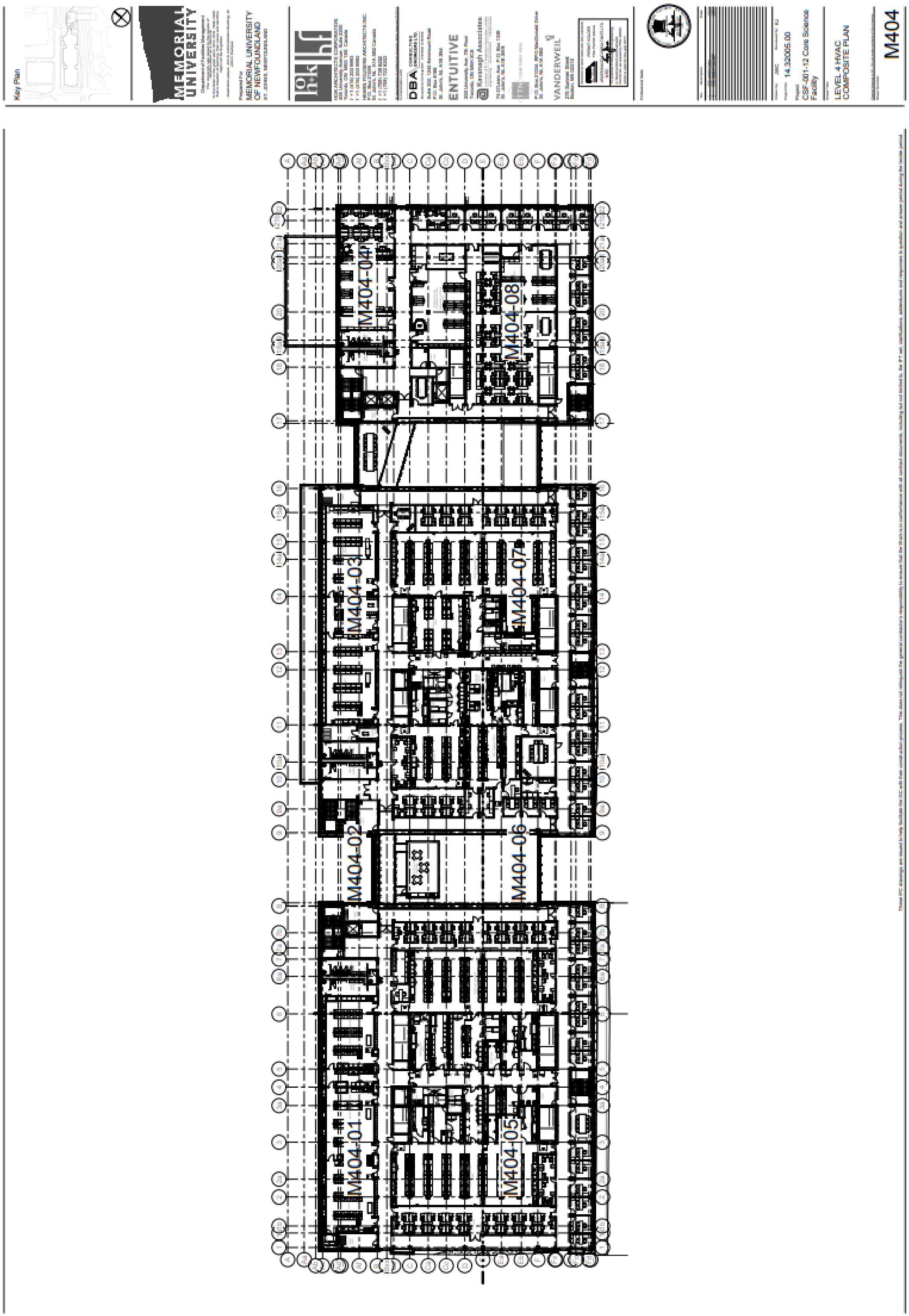
LEVEL 3 HVAC COMPOSITE PLAN
M403

Floor 4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VANDERWEIL
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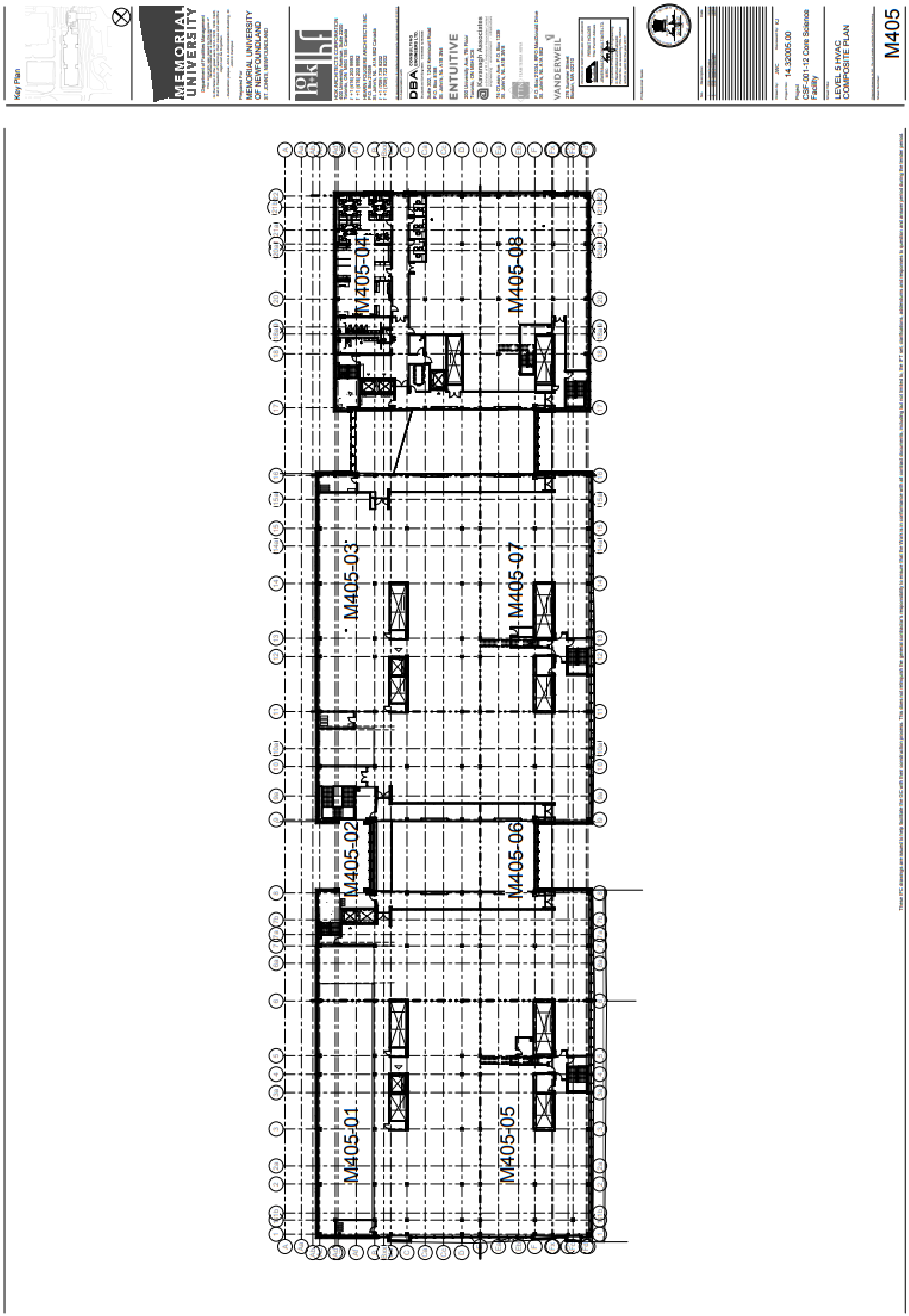
M404-07
M404-08
LEVEL 4 HVAC COMPOSITE PLAN
M404

Floor 5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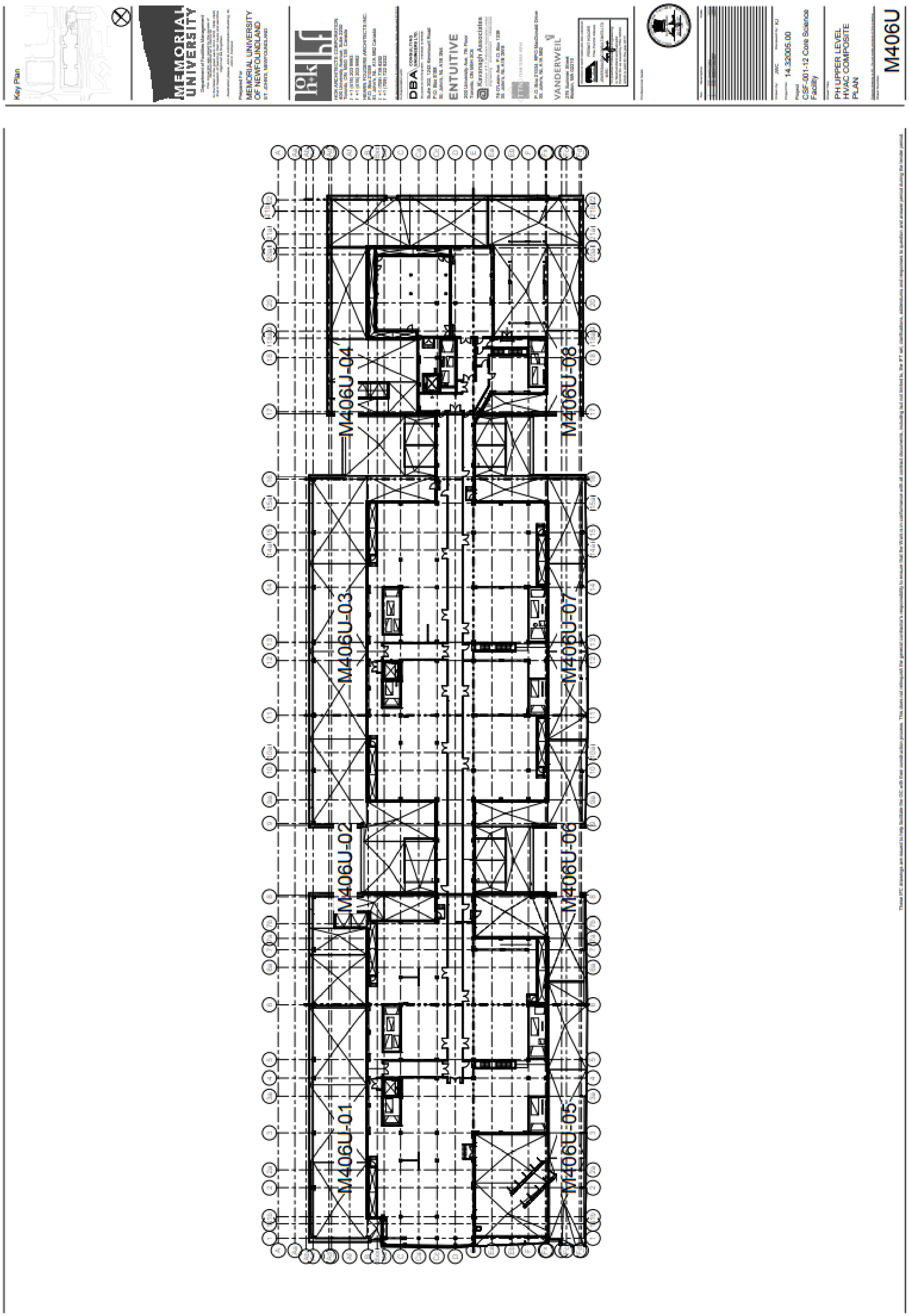
Penthouse


Key Plan
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ST. JOHN'S, NEWFOUNDLAND
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ENTUITIVE
Kavanagh Associates
VANDERWEIL
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CSF-001-12 Core Science Facility
PH UPPER LEVEL HVAC COMPOSITE PLAN
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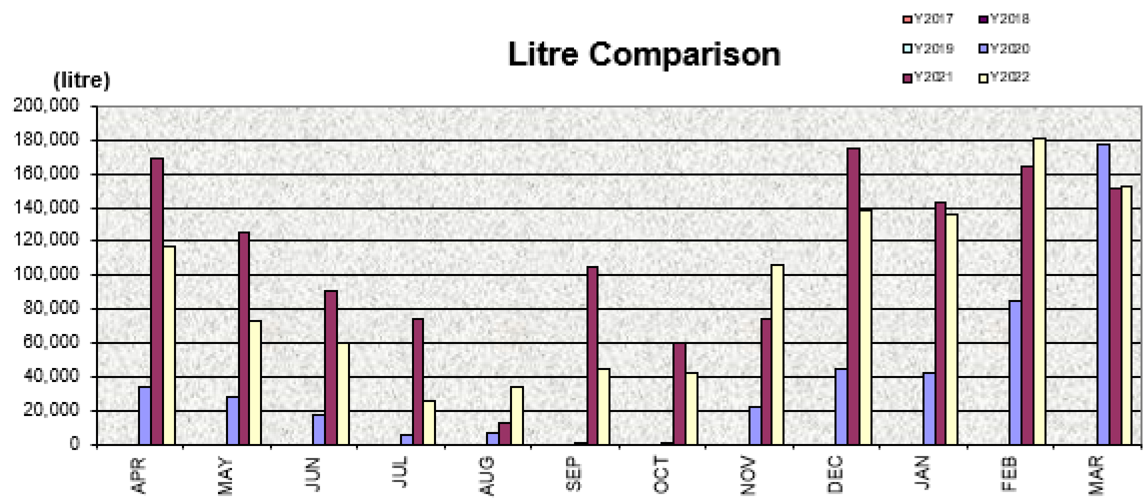
Appendix II- Energy Consumption Data for CSF Building for 2022

Consumption Data- Diesel fuel oil #2

Facility Energy Summary, Core Science Facility 40,817.0 m²

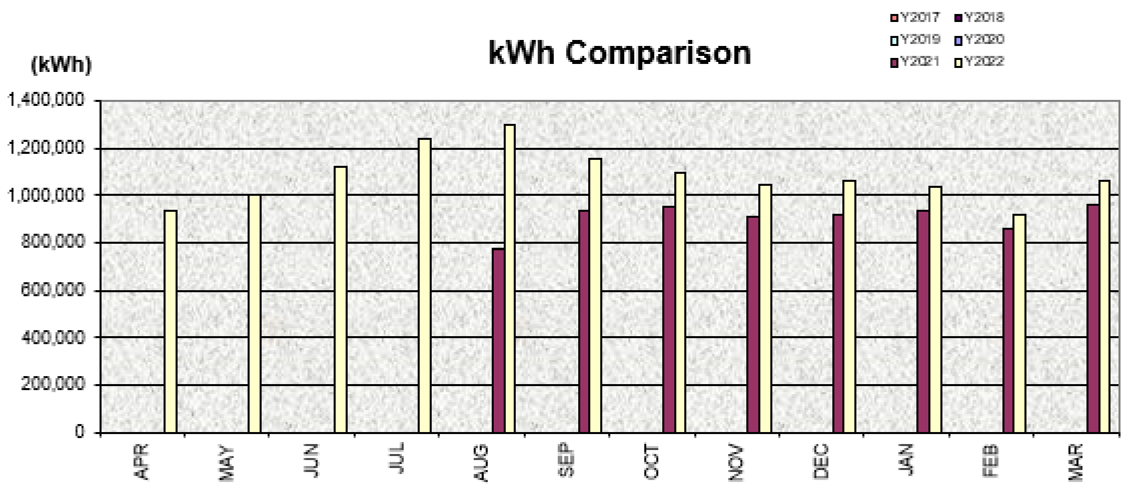
299.8 kWh/m² oil 177.6 kWh/m² elec 477.4 kWh/m² total

MONTH	Y2017 Litres	Y2018 Litres	Y2019 Litres	Y2020 Litres	Y2021 Litres	Y2022 Litres
APR	0	0	0	33,577	169,354	117,433
MAY	0	0	0	28,321	125,642	72,558
JUN	0	0	0	17,593	90,808	60,246
JUL	0	0	0	4,900	73,903	25,221
AUG	0	0	0	6,794	11,979	34,303
SEP	0	0	0	8	104,746	44,295
OCT	0	0	0	130	60,090	42,079
NOV	0	0	0	21,953	74,783	106,251
DEC	0	0	0	44,525	174,832	138,628
JAN	0	0	0	42,597	143,447	136,161
FEB	0	0	0	85,264	163,802	180,862
MAR	0	0	0	177,796	151,847	152,815
TOT	0	0	0	463,457	1,345,232	1,110,851
kWh Equiv.	0	0	0	4,215,534	12,236,028	10,104,136
						15,055
					1.606	24,184



Consumption Data- Electricity

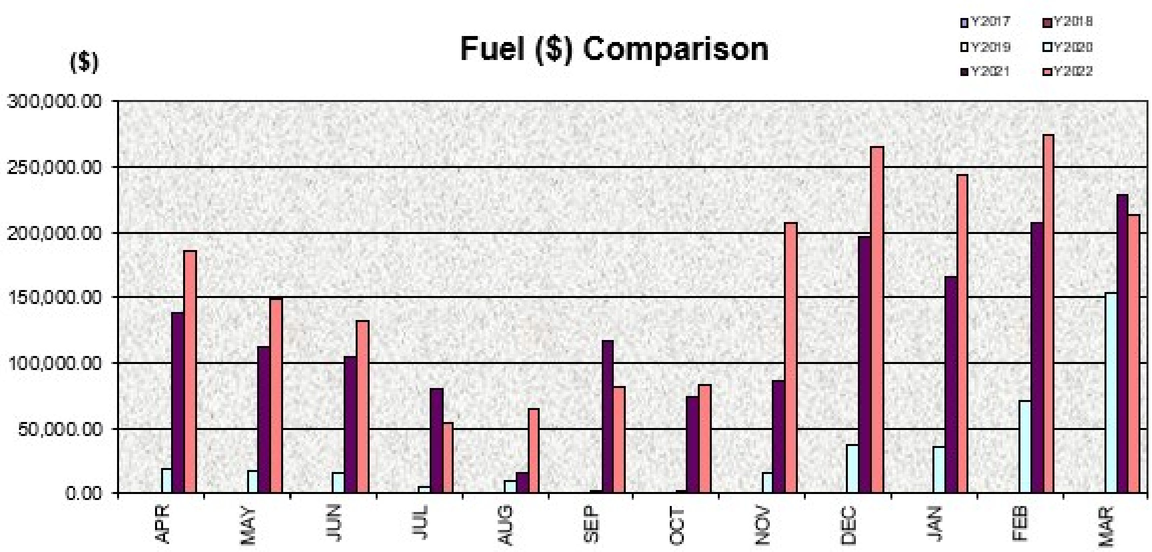
MONTH	Y2017 kWh	Y2018 kWh	Y2019 kWh	Y2020 kWh	Y2021 kWh	Y2022 kWh
APR	0	0	0	0	0	932,419
MAY	0	0	0	0	0	1,001,842
JUN	0	0	0	0	0	1,116,581
JUL	0	0	0	0	0	1,239,224
AUG	0	0	0	0	777,250	1,301,140
SEP	0	0	0	0	939,154	1,151,270
OCT	0	0	0	0	951,072	1,096,985
NOV	0	0	0	0	912,918	1,047,888
DEC	0	0	0	0	915,062	1,065,471
JAN	0	0	0	0	938,238	1,039,436
FEB	0	0	0	0	855,079	917,404
MAR	0	0	0	0	960,000	1,059,268
TOT	0	0	0	0	7,248,773	12,968,928
						0



Energy Costs- Diesel fuel oil #2

Facility Energy Summary, Core Science Facility

MONTH	Y2017 FUEL$	Y2018 FUEL$	Y2019 FUEL$	Y2020 FUEL$	Y2021 FUEL$	Y2022 FUEL$
APR	0.00	0.00	0.00	19,576.53	137,970.33	186,022.67
MAY	0.00	0.00	0.00	17,514.73	112,180.11	149,521.34
JUN	0.00	0.00	0.00	16,368.67	105,097.87	132,538.90
JUL	0.00	0.00	0.00	5,889.02	80,750.73	54,695.58
AUG	0.00	0.00	0.00	9,195.48	15,228.11	64,563.66
SEP	0.00	0.00	0.00	8.04	117,503.48	81,541.38
OCT	0.00	0.00	0.00	99.25	73,648.36	82,818.29
NOV	0.00	0.00	0.00	15,644.37	86,103.74	207,351.45
DEC	0.00	0.00	0.00	37,493.49	195,868.83	264,963.69
JAN	0.00	0.00	0.00	35,438.33	166,594.97	244,573.48
FEB	0.00	0.00	0.00	70,343.81	207,250.91	275,093.15
MAR	0.00	0.00	0.00	154,240.69	228,028.54	213,762.92
TOT	0.00	0.00	0.00	381,812.41	1,526,225.98	1,957,446.51
5%	0	0	0	19,091	76,311	97,872



Energy Costs- Electricity

MONTH	Y2017 ELEC $	Y2018 ELEC $	Y2019 ELEC $	Y2020 ELEC $	Y2021 ELEC $	Y2022 ELEC $
APR	0.00	0.00	0.00	0.00	0.00	95,471.55
MAY	0.00	0.00	0.00	0.00	0.00	102,834.86
JUN	0.00	0.00	0.00	0.00	0.00	115,952.03
JUL	0.00	0.00	0.00	0.00	0.00	128,663.04
AUG	0.00	0.00	0.00	0.00	82,105.72	134,127.86
SEP	0.00	0.00	0.00	0.00	98,045.13	119,218.06
OCT	0.00	0.00	0.00	0.00	99,941.67	116,203.27
NOV	0.00	0.00	0.00	0.00	95,615.07	107,139.62
DEC	0.00	0.00	0.00	0.00	98,364.61	114,135.94
JAN	0.00	0.00	0.00	0.00	102,320.81	112,738.01
FEB	0.00	0.00	0.00	0.00	94,450.09	98,052.53
MAR	0.00	0.00	0.00	0.00	102,766.68	116,487.04
TOT	0.00	0.00	0.00	0.00	773,609.78	1,361,023.81