CSF Building Energy Consumption Analysis and Cost Estimate of Electric Resistive Heating System

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***Abstract*— This paper 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 2.15GJ/m2, compared to the National median reference of 1.04GJ/m2 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

I. 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 2,626.28Peta Joules (PJ) (approximately 729.52 Tera-Watt hours) claiming 24.66% of total end use demand in Canada, with a projected energy consumption of 3,011.66PJ (approximately 836.57TWh) 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 I and II 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 kWh/m^2 for newly constructed buildings up to 220kWh/m^2 or more for buildings that were constructed before 1960 [1].

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 III and IV respectively (Reproduced from [5]).

TABLE I. TABLE 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 II. ENERGY CONSUMPTION BY END USE IN 2020 (RESIDENTIAL BUILDINGS)

	Energy use, PJ	As a %
Space heating	871.3	61.00
Water heating	258.2	18.08
Appliances	210.5	14.74
Lighting	52.6	3.68
Space cooling	35.7	2.50
Total	1428.3	100

TABLE III. 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 IV. 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.

II. 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]. Table V summarises the contribution of each fuel type for space heating (Adapted from [7]).

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 V. SPACE HEATING BY ENERGY SOURCE IN EDUCATIONAL BUILDINGS IN 2020

	Energy Use, PJ	As a %
Natural Gas	77.3	85.2
Electricity	9.0	10.0
Light Fuel Oil and Kerosine	1.3	1.5
Heavy Fuel Oil	0.0	0.0
Steam	0.0	0.0
Coal and Propane	3.1	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 environmental 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 the 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 suggest that the heat pump system performance can vary significantly in extreme cold climates [15], [16].

III. 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 (MUN), which serves as a central hub for connecting various other buildings and departments.

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°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.

Fig. I. Core Science Facility Building

IV. 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 VI (Adapted from [17]) summarises the electricity consumption by CSF building and the cost of electricity during this period. Likewise, Table VII (Adapted from [17]) indicates the oil consumption for heating water for the CSF building and the related cost of oil.

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 VIII. The energy use intensity is calculated considering a Lower Heating Value (LHV) of 38.18 MJ/litre of diesel and the floor area of CSF building, which is 40,817m^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 VI. ELECTRICITY CONSUMPTION AND COST IN 2022

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 VII. OIL CONSUMPTION AND COST IN 2022

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

TABLE VIII. ENERGY USE INTENSITY OF CSF BUILDING PER YEAR

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 enrolment 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/m2 for source EUI and site EUI, respectively [19]. It can be observed from the values given in Table VIII 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 VIII. One of the main objectives of this thesis is to find out the means of reducing the energy consumption of the building. In this regard, one potential solution considered in this study is adopting electric resistive heating for space heating.

In accordance with Reference 20, the Engineering Building at MUN, encompassing an area of 25,412m^2, consumes approximately 23,000 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.

V. COST ESTIMATION FOR ELECTRIC RESISTIVE HEATING

Based on the data provided in Tables VI and VII, 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 18MW 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.

A. *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 IX.

The proposed electric resistive boilers consist of two units, each with 15.5MW capacity, and each unit can effectively replace one 18MW 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 IX. Furthermore, the cost indicated in Table IX includes the additional cost of demolition of an existing boiler that has been non-functional.

B. *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 VII 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 10kWh 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.

TABLE IX. COST ESTIMATE FOR ELECTRIC RESISTIVE HEATING 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

VI. CONCLUSIONS

In this paper, the energy consumption of building in Canada was analysed, taking the Core Science Facility (CSF) building at the Memorial University 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 2.15GJ/m^2, indicates a higher energy demand than the national average of 1.04GJ/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 modelling will allow for a more comprehensive evaluation of potential energy savings.

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