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

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Overview

- **Introduction & Background**
- **Literature Review**
- **Research Objectives**
- **Energy Consumption Analysis**
- **Feasibility Analysis**
- **Development of Building Energy Model**
- **Impact of Time-of-Use Electricity Tariff**
- **Conclusions**
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- **Next Steps**
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- **Publications**

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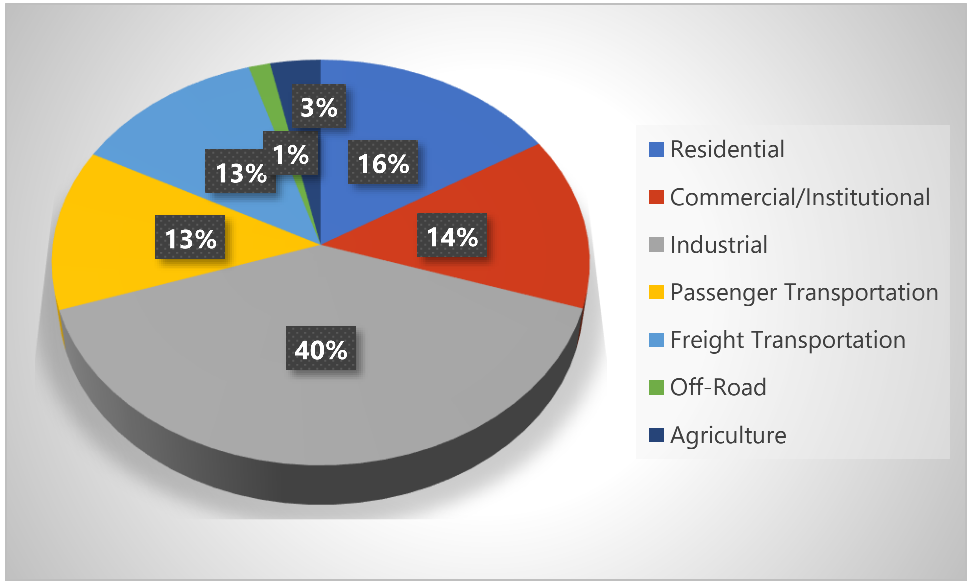
Introduction & Background

- On average, buildings contribute to more than 30% of the global energy consumption
- In Canada, buildings consume more than 25% of country's total energy consumption.
- In 2020, approximately 30% [1].
- Space heating accounts for approximately 60% of energy consumed by buildings [2].
- In residential buildings 61% [3]
- In commercial and institutional buildings 57% [4]



Energy consumption by sector in 2020

Energy consumption by end use in 2020, Commercial/Institutional buildings

Energy consumption by end use in 2020, Residential 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

Introduction & Background (Contd.)

- In educational buildings, natural gas serves as the primary fuel for space heating [5]

Space heating by energy source in educational buildings, 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

- In Atlantic Canada, refined products fulfil a significant proportion of energy demands [1], due to
  - limited access to alternative sources
  - infrastructure constraints
  - comparatively higher costs

Introduction & Background

- Space heating stands as a major area for improving energy efficiency in buildings.
- Electrification of space heating systems has been a potential solution.
- Energy tariffs and consumption patterns have a direct impact on energy costs.
- Building energy modeling (BEM) allows for detailed analysis of energy performance, aiding in optimization and decision-making.
    - Based on various theoretical approaches
    - Various modeling techniques and tools
- Building energy systems (BES) encompass heating, ventilation, lighting, insulation, renewable energy, and control systems, crucial for achieving efficiency and environmental goals.

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Literature Review

Summary of literature review

Research Area	Reference	Inputs gathered
Energy consumption by buildings	[7]	Energy consumption in educational buildings
	[1]	Energy consumption in Canada by sector and by building type
	[8]	Key energy statistics around the world, including the energy consumption by buildings
Electrification of space heating	[9]	Technologies used in net-zero buildings
	[10]	Electrification of buildings, opportunities and potential barriers
	[11]	Electrification of heating in residential and commercial buildings
	[12]	Electrification of heating in commercial and institutional buildings
Benchmarking	[13]	Energy use by the S. J. Carew building at the Memorial University of Newfoundland
	[14]	Benchmarking data snapshots for all building types
	[15]	Energy use intensity by property type in Canada

Literature Review (Contd.)

Summary of literature review (Contd.)

Research Area	Reference	Inputs gathered
Building energy modelling	[16]	Benefits and drawbacks of various approaches to BEM (WB, BB and GB modelling)
	[17]	Benefits of dynamic modeling over steady-state BEMs
Simulation software	[18]	Benefits and drawbacks of a range of BEM software
	[19]	Use of TRN-SYS as a BEM
	[20]	Use of IDA-ICE as a BEM
	[21]	Comparison of various BEM tools introduced and managed by Natural Resources Canada
	[22]	Use of OpenStudio as a BEM
Approach for BEM	[23]	Practically using OpenStudio for BEM simulation

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Research Objectives

- Buildings in Canada, including educational buildings consume a significant amount of energy, indicating opportunities in optimizing energy use.
- Building energy modeling can be a valuable tool for simulating building performance.
- Research should encompass all conceivable scenarios, encompassing potential future alterations.
- Objectives
  - Development of Building Thermal Model
  - Analysis of Energy Consumption and Efficiency
  - Feasibility of Electric Resistive Heating
  - Influence of Programmed Heating Methods
  - Implications of Time-of-Use Electricity Billing

Case Study

- Core Science Facility Building, Memorial University
- Opened to public in 2021
- Floor area of 40,817m^2 [6]
- Teaching rooms, research laboratories, and office spaces specifically designated for the Department of Electrical and Computer Engineering
- Two primary sources of energy, electricity, and hot water
- Temperatures in
    - The primary circuit~138°C
    - The secondary circuit ~83°C
    - Return ~ 55-65°C

Core Science Facility Building, MUN

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Energy Consumption Analysis

- Collection of energy consumption data
- Energy consumption analysis
- Calculation of Energy Use Intensity (EUI)
- Benchmarking
- Cost estimation for electric resistive heating system
- Calculation of potential savings

Energy Consumption Analysis (Contd.)

- Collection of energy consumption data
  - Electricity
  - Diesel oil #2
- Energy Consumption analysis & EUI
- Benchmarking
  - S. J. Carew Building, MUN [16]
    - 25,412m^2, 23,000MMBTU & 5,500,000kWh
    - EUI of 1.73GJ/m^2
  - National median for universities [17]
    - EUI of 1.04GJ/m^2

Oil consumption and cost in 2022 [6]
Electricity consumption and cost in 2022 [6]

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
TOTAL	12,706,138	1,333,283.81

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

Energy Consumption Analysis (Contd.)

- Cost estimation for electric resistive heating system
- Calculation of potential savings
  - Consumption data and cost from building energy consumption records
  - Energy in diesel based on heating value

Cost estimate for electric resistive heating system [24]

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

Current cost of oil for heating ($)	= 1,825,891.37
Diesel oil consumption (liters)	= 1,100,109
Energy in one liter of diesel (kWh)	= 10
Approximate energy for heating (kWh)	= 11,001,090
Current electrical tariff ($/kWh)	= 0.11
Projected cost of electricity ($)	= 1,210,119.9
Potential saving ($/yr)	= 615,771

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Feasibility Analysis

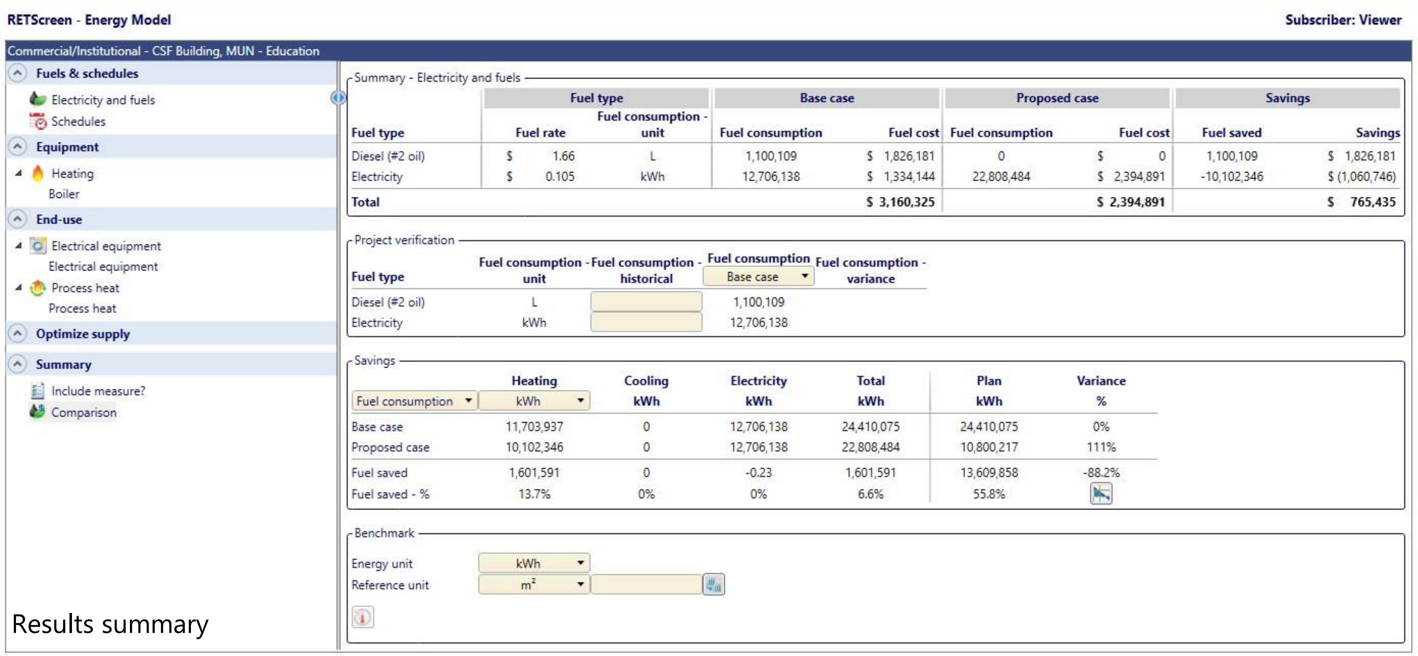
- RETScreen Expert
- For performance analysis, benchmarking and feasibility analysis
- Feasibility study based on the location, building type, footprint, actual and projected energy consumption.
- Potential savings in switching to electric resistive heating

Facility information on RETScreen

Feasibility Analysis

- Parameters for the feasibility analysis
- Results
  - Energy saved 1,601,591kWh/ year
  - Reduction in energy consumption 6.6%
  - Savings in cost 765,435CA$/ year
  - Reduction in energy costs 24.2%
  - GHG reduction 2,665tCO_2/ year

Parameters considered for the feasibility study



Summary - Electricity and fuels

Fuel type	Fuel rate	Fuel consumption - unit	Base case: Fuel consumption	Base case: Fuel cost	Proposed case: Fuel consumption	Proposed case: Fuel cost	Savings: Fuel saved	Savings
Diesel (#2 oil)	$ 1.66	L	1,100,109	$ 1,826,181	0	$ 0	1,100,109	$ 1,826,181
Electricity	$ 0.105	kWh	12,706,138	$ 1,334,144	22,808,484	$ 2,394,891	-10,102,346	$ (1,060,746)
Total				$ 3,160,325		$ 2,394,891		$ 765,435

Project verification

Fuel type	Fuel consumption - unit	Fuel consumption - historical	Fuel consumption Base case	Fuel consumption - variance
Diesel (#2 oil)	L		1,100,109	
Electricity	kWh		12,706,138	

Savings

Fuel consumption	Heating kWh	Cooling kWh	Electricity kWh	Total kWh	Plan kWh	Variance %
Base case	11,703,937	0	12,706,138	24,410,075	24,410,075	0%
Proposed case	10,102,346	0	12,706,138	22,808,484	10,800,217	111%
Fuel saved	1,601,591	0	-0.23	1,601,591	13,609,858	-88.2%
Fuel saved - %	13.7%	0%	0%	6.6%	55.8%	

Benchmark

Energy unit	kWh
Reference unit	m^2

Results summary

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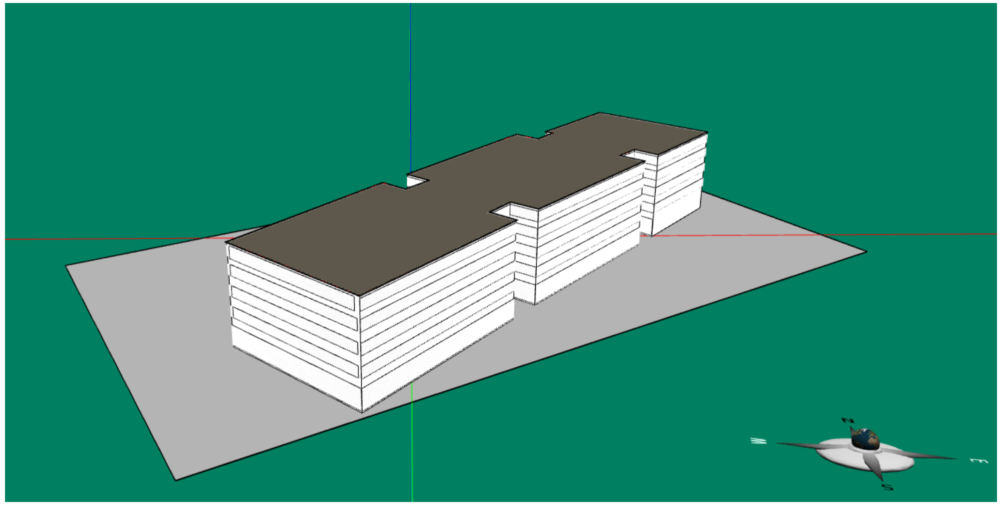
Development of a Building Energy Model

- Energy3D
- Based on three inputs, location, geometry and construction materials
  - Location considered- Halifax, NS
  - Geometry based on mechanical drawings
  - Construction materials



Energy3D model

Properties of the construction materials considered

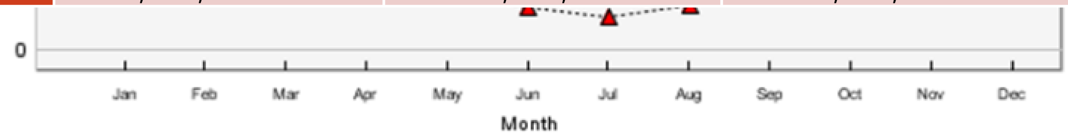
Building component	Property	Value considered (unit)	Reference for value considered
External wall	Wall thickness	0.3 (m)	Mechanical drawings
	Insulation	33 (h.ft^2.°F/Btu)	Insulation building code 2021 [25]
Windows	Tint	Clear	Observation
	Insulation	0.48 (Btu/h.ft^2.°F)	Energy3D standard for double-glass windows
Roof	Insulation	55 (h.ft^2.°F/Btu)	Insulation building code 2021 [25]

Development of a Building Energy Model (Contd.)

- Simulation results for space heating
- Comparison with actual consumption
  - Simulation mimics real consumption patterns.
  - Deviation in consumption values
- Factors contributing to the deviations
  - Exclusion of Penthouse
  - Length of hot water piping
  - Interconnection with the University Center
  - Occupancy rates and behavior
  - HVAC system
  - Degradation of equipment

Comparison between simulation results and actual data

Month	Consumption from simulation (kWh)	Diesel oil #2 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



Simulation result, Energy consumption for heating

Development of a Building Energy Model (Contd.)

- Enhanced BEM using OpenStudio
  - St. John's, Newfoundland
  - Climate Zone 6A
  - Construction materials for Zone 6A

Steps to be followed in OpenStudio

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

Development of a Building Energy Model (Contd.)

- Lack of data
  - Construction materials
  - HVAC system
  - Operational data and occupancy
- Multiple parameters and operational scenarios
  - Standards and guidelines
  - Observations
  - Assumptions

Properties of the construction materials [26]

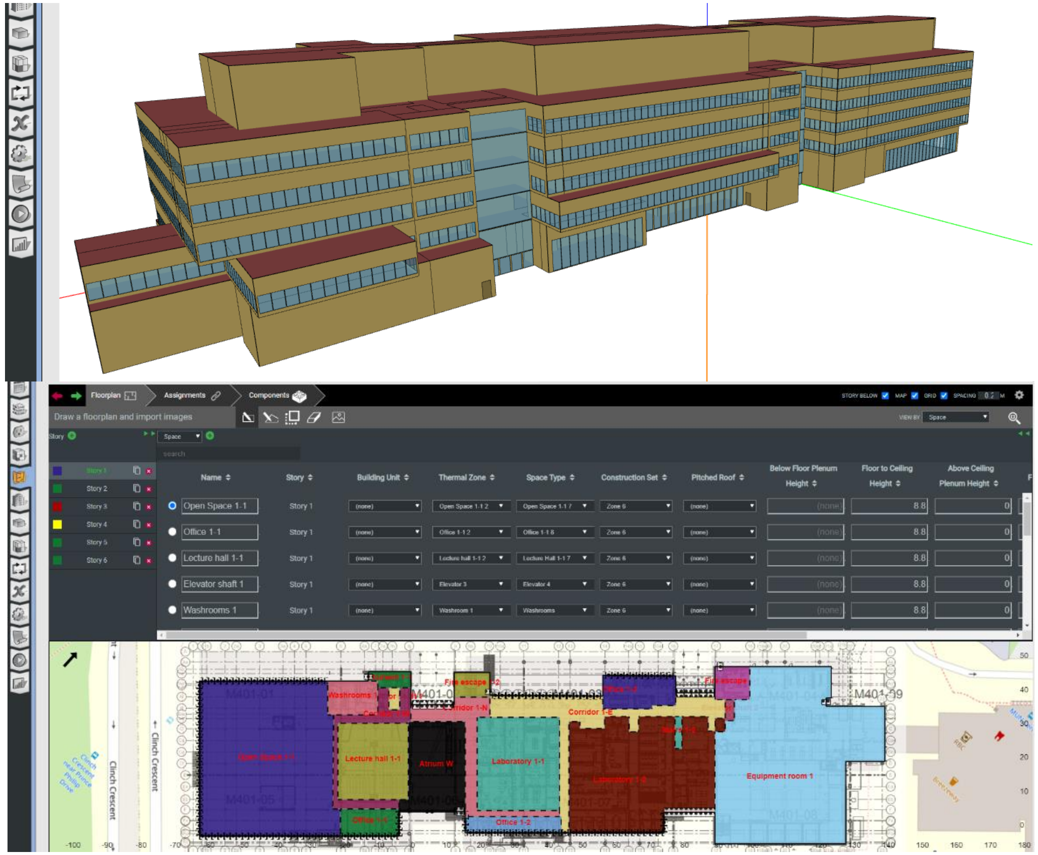
Component	R Value	U Value	Unit	SHGC	VLT
Main Building					
Exterior Walls	13.34		ft^2.h.R/Btu		
Roof	30.48		ft^2.h.R/Btu		
All windows and glass doors		0.45	Btu/ft^2.h.R	0.4	0.51
All solid doors		N/A		N/A	N/A
Penthouse (Equipment room in top floor)					
Exterior Walls	18.07		ft^2.h.R/Btu		
Roof	30.48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

System parameters

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

Development of a Building Energy Model (Contd.)

- Development of the building envelop
  - Based on the mechanical drawings and google maps
  - Space types and thermal zoning
  - Allocation of schedules and loads



Building geometry and space allocation in Floor 1

Development of a Building Energy Model (Contd.)

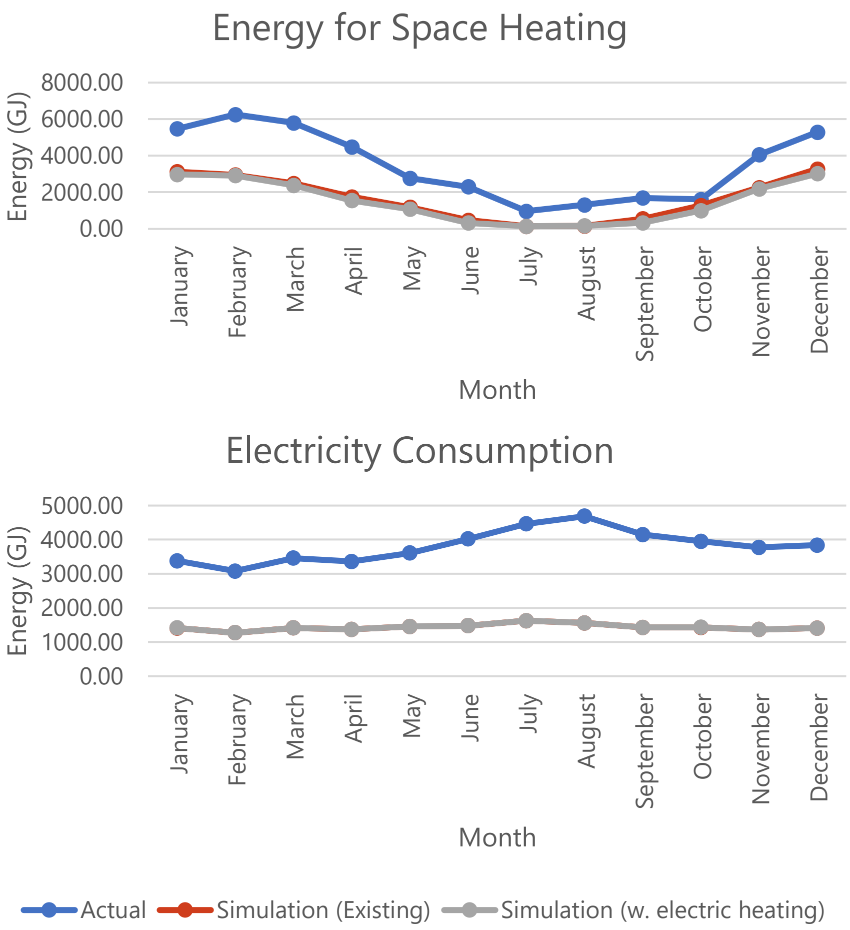
- Development of the HVAC system
  - Based on ASHRAE's Advanced Energy Design Guidelines
  - Enabled rapid system development and simulations
  - Allocation of thermal setpoints for heating, cooling, humidity and freeze protection

System-derived parameters for HVAC chilled water loop, hot water loop and Floor 1 air loop

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

Development of a Building Energy Model (Contd.)

- Comparison of simulation results
  - Simulations followed the actual consumption patterns
  - EUI of 0.87GJ/m^2
  - Indicated approx. 7% savings in energy under electric resistive heating
- Potential reasons for the deviations
  - Assumptions for construction material properties
  - Steps taken to simplify the model
  - Interconnection with the University Center
  - HVAC system
  - Electrical and lighting loads
  - Transmission losses
  - Operational schedules



Comparison of simulation results with actual data

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Impact of Time-of-Use tariff

- Refinement of OpenStudio models
  - Adoption of tariff structures
  - Building operational schedules
- Tariff Selection

Tariff structures considered

Simulation	Tariff tier	Rate	Winter period (Nov 1 to Apr 30)	Summer period (May 1 to Oct 31)
FR	FR	10.50 ¢/kWh	Throughout the day	Throughout the day
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

Impact of Time-of-Use tariff (Contd.)

- Simulation results
  - Maximum demand ~5.6MW
  - Demand charge 25% of the total energy costs (under TOU)
- Comparison of various simulation results
  - Existing system
  - Electric resistive heating with Flat Rate tariff
  - Electric resistive heating with Time-of-Use tariff
- Possible significant rises in energy expenses with TOU tariffs.

Simulation Results

		Cost ($)	Total Energy Cost ($)
Existing System	Electricity (at $0.105/kWh)	502,161.93	1,355,733.06
	Space Heating (with FO#2, at $1.66/liter	853,571.13	
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

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Conclusions

- Current energy use intensity of the CSF building at 2.15 GJ/m^2 is higher than the national median of 1.04 GJ/m^2 , and that of a similar but older S. J. Carew building at 1.73 GJ/m^2
- Space heating is the main energy consumer. Simple calculations revealed savings in excess of $600,000/ year
- Transition to electric resistive heating indicates a potential savings of 24.2% in cost, 6.6% in energy consumption and 2,665 tCO_2 GHG reductions
- The thermal model and BEM validated approach taken.
- Financial savings, though potential and lucrative under a Flat-Rate tariff may not yield under a Time-of-Use tariff.
- Current operational practices employed under a Time-of-Use tariff could lead to significantly higher energy expenses, even higher than the current cost.

Contributions

- Two types of BEMs that can be used for conducting studies on energy consumption and energy efficiency of CSF building
- Feasibility analysis on RETScreen further strengthened the significant energy, cost, and GHG savings from the transition to electric resistive heating.
- BEMs developed with OpenStudio can be employed to assess diverse operational approaches under both Flat Rate and Time-of-Use tariff models, with the potential for adaptation to additional tariff structures.
- The results from the energy consumption analysis and benchmarking underscore the potential for improving energy efficiency within the CSF building
- This study establishes a benchmark for assessing energy consumption and transitioning space heating sources, particularly in Canadian educational buildings, an area where existing literature is limited.

Future Works

- Refinement of the BEM to improve accuracy
- Completion of a comprehensive energy survey for the CSF building.
- Research and utilization of operational data, such as HVAC system, occupancy patterns, volume, and operational schedules.
- Finding an optimal operational strategy and energy efficiency measures for the CSF building.
- Analysis and projection of energy costs associated with the CSF building under different tariff scenarios.
- A sensitivity analysis for the considered tariff structures.

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Publications

- Liyanage CJ, Iqbal MT. 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); 2023 Nov 14.
- Liyanage CJ, Iqbal MT. Thermal Modeling and Electric Space Heating of a University Building in Newfoundland. Published in the European Journal of Engineering and Technology Research. 2024; Volume 9, Issue I. pp 37-46, doi:10.24018/ejeng.2024.9.1.3145
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Thank You!