Electricity Consumption and Demand Forecasting for Office Buildings' Electrification in Canada

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Abstract

Predicting electrical energy and demand increase due to building electrification is crucial in understating building-grid interaction and future growth planning for the utility generation, transmission, and distribution infrastructure.

This article presents the results of a simulation study addressing the electrification of three representative office archetypes to forecast the increase in electrical energy (kWh) and demand (kW). The archetypes used for this study are small, medium, and large offices, representing vintages from pre-1980, 1980-2010, and newer buildings compliant with Canada's National Energy Code for Buildings 2011, 2015, and 2017. The office building electrification scenarios have been studied for seven Canadian cities to understand the regional and climatic variations across the nation.

The electrical energy and demand for the office archetypes with conventional natural gas space and hot water heating are calculated, followed by the same archetypes' full space and hot water heating electrification. The increase in electrical energy and demand is calculated. This current study finds that with the full building electrification of office archetypes, there is a potential for a 25-162% increase in the annual electrical energy (kWh) and a 15-210% increase in demand (kW) across different Canadian locations. This results in the projected office electrical energy use between 101-232 kWh/m^2 (compared to 71-109 kWh/m^2 for natural gas heated baseline) and peak demand between 40-120 W/m^2 (compared to 32-50 W/m^2 for natural gas heated baseline).

Introduction

Building electrification is typically achieved by converting the primary fossil fuel-run hot water and space-heating technologies in residential and commercial buildings to electrical systems (Nathan, 2021; Di Cosola, 2021). Most common building heating electrification is achieved using electric air source heat pumps, including ductless mini-split or central systems, replacing natural gas and other fossil fuel-powered furnaces. Electric furnaces and resistance heaters are older technologies and can contribute to building electrification. Water heating through heat pump water heaters and electric resistance heaters significantly contribute to electrification (Blonsky, 2019).

Electric heat pumps are currently used for space heating in about 10% of homes and 15% of commercial spaces in the USA (EIA, 2019). In the states with mandates to reduce carbon emissions, studies estimate that 50–75% of heating will need to be electrified by 2050 (EIA, 2019; Mai et al., 2018; Weis et al., 2019). As electricity usage grows and changes, the electric grid will need to change with it to deliver economically competitive and reliable electricity (Falchetta, 2020; Jeuland, 2020).

The current study explores a simulation study addressing the electrification of three representative office archetypes (small, medium, and large) to forecast the increase in electrical energy (kWh) and electrical demand (kW). The office archetypes chosen for this study represent various vintages from pre-1980, 1980-2010, and new buildings compliant with Canada's National Energy Code for Buildings (NECB) 2011, 2015, and 2017. The office building electrification scenarios have been modeled for seven Canadian cities to understand the regional and climatic variations across the nation. The office building-related energy use is estimated using conventional natural gas. The post-electrification scenarios are modeled, and the increased electrical energy and demand have been forecasted. This study is part of a larger investigation aimed at developing detailed hourly load profiles of Canadian office buildings with full space and hot water electrification, and the results presented in the current study estimate the percentage and per unit area increase in electrical energy and demand for the office archetypes in Canada.

Methodology

The office buildings used for this study were developed using Natural Resources Canada (NRCan) Building Technology Assessment Platform (BTAP). BTAP is a software tool that uses OpenStudio to create building models and EnergyPlus to perform detailed energy simulations. In addition, BTAP can provide detailed costing for the energy and building systems (BTAP, 2024). BTAP offers the flexibility to apply the changes described by the policy or code to the building models to determine the

impact on their energy consumption and related capital and operating costs.

For this study, three commercial office archetypes in BTAP are used. The commercial office archetypes are based on the U.S. DOE reference building archetypes (Commercial Reference and Buildings, 2024).

Three commercial office archetypes have been used for this study, presented in Table 1.

Table 1: BTAP Office Archetypes.

Building Name	Floor Area (m^2)	Building Floors
Large Office	46,320	12
Medium Office	4,982	3
Small Office	511	1

The graphical rendering of the commercial office archetypes used for this study is presented in Figure 1.

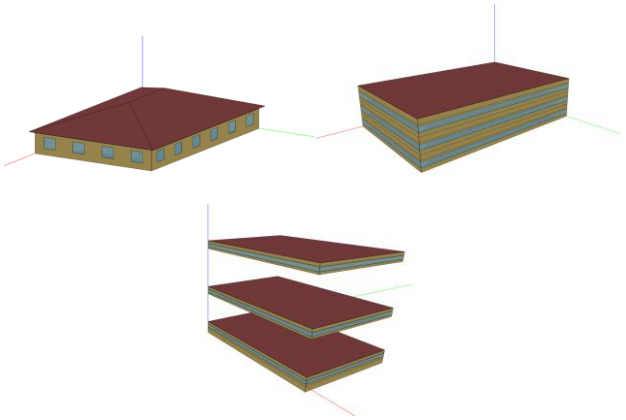

Figure 1: BTAP Small, Medium, and Large Office Geometry.

The key building characteristics for the small, medium, and large office archetypes are shown in Table 2 (summarized from Commercial Reference Buildings, 2024).

The climate has a major impact on a building's energy performance. Standards and codes like ASHRAE Standards 90.1 (2022) and NECB (2011, 2015, 2017) prescribe, among many things, the minimum requirements for certain thermal properties of building envelope components, such as U-values. The NECB has divided Canada into six climate zones – 4, 5, 6, 7a, 7b, and 8. Zone 4 is the warmest zone, so buildings here typically require less insulation than those in Zone 8, the coldest zone (NECB, 2017).

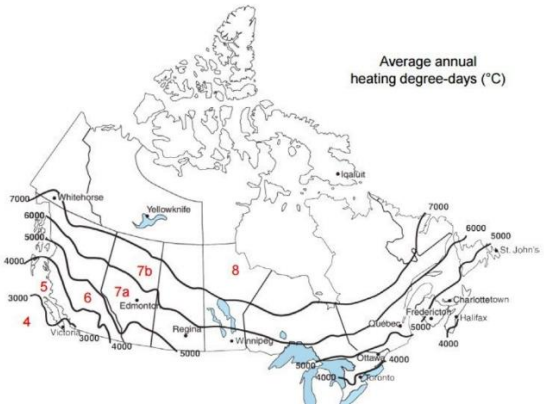

Figure 2: Canadian Climate Zones per NECB.

Table 2: Construction Characteristics of Office Archetypes.

Building Name	Small Office	Medium Office	Large Office
Total Floor Area (m^2)	511	4,982	46,320
Building Shape	Rectangle	Rectangle	Rectangle
Aspect Ratio	1.5	1.5	1.5
Number of Floors	1	3	12 plus basement
Window Fraction (Window to Wall Ratio)			
South	0.244	0.33	0.38
East	0.198	0.33	0.38
North	0.198	0.33	0.38
West	0.198	0.33	0.38
Thermal Zoning	core zone with four perimeter zones on each floor		
Floor to Ceiling Height (m)	3.1	2.7	2.74
Wall Type	Steel-frame	Steel frame	Mass wall
Roof Area (m^2)	598.8	1,661	3,563
Foundation Type	Mass Floor	Mass Floor	Basement
Foundation Area (m^2)	511.0	1,661	3,563

For this study, seven Canadian cities have been chosen to represent a wide range of climate zones, and for each city, five vintages are modeled for each office type (i.e., small, medium, and large). In addition, for the reference or baseline scenario, natural gas has been used as the primary fuel for space and hot water heating. In contrast, for the proposed (electrification) scenario, the space and water heating fuel has been converted to electricity. A total of 210 models have been run in BTAP to quantify the existing and post-electrification energy and demand. The summary of the scenarios is shown in Table 3.

Table 3: Summary of Simulation Scenarios.

City	NECB Climate Zone	Building Type			Building Vintages					Ref. Fuel	Prop. Fuel
		Small Office	Medium Office	Large Office	BTAP1980TO2010	BTAPPRE1980	NECB2011	NECB2015	NECB2017	Natural Gas	Electricity
Vancouver	4										
Halifax	5										
Toronto	6										
Edmonton	7a										
Calgary	7a										
Montreal	7a										
Whitehorse	7b										

Results

The results of this study are presented below based on the building type (small, medium, and large offices), climate location, and vintages.

Small Offices

Table 4 summarizes small office electrification scenarios and presents the increase in energy (kWh) and demand (kW) for small offices of different vintages across seven Canadian cities.

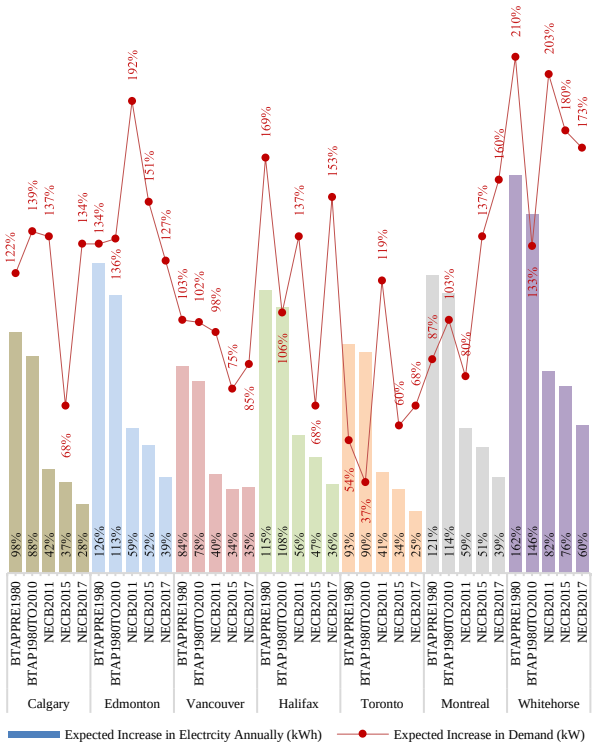

Figure 3: Energy and Demand Increase in Small Offices.

Table 4: Summary of Small Offices Electrification Scenarios.

City	Vintage	Increase in Elect. Annually (kWh)	Increase in Demand (kW)
Calgary	BTAPPRE1980	98%	122%
	BTAP1980TO2010	88%	139%
	NECB2011	42%	137%
	NECB2015	37%	68%
	NECB2017	28%	134%
Edmonton	BTAPPRE1980	126%	134%
	BTAP1980TO2010	113%	136%
	NECB2011	59%	192%
	NECB2015	52%	151%
	NECB2017	39%	127%
Vancouver	BTAPPRE1980	84%	103%
	BTAP1980TO2010	78%	102%
	NECB2011	40%	98%
	NECB2015	34%	75%
	NECB2017	35%	85%
Halifax	BTAPPRE1980	115%	169%
	BTAP1980TO2010	108%	106%
	NECB2011	56%	137%
	NECB2015	47%	68%
	NECB2017	36%	153%
Toronto	BTAPPRE1980	93%	54%
	BTAP1980TO2010	90%	37%
	NECB2011	41%	119%
	NECB2015	34%	60%
	NECB2017	25%	68%
Montreal	BTAPPRE1980	121%	87%
	BTAP1980TO2010	114%	103%
	NECB2011	59%	80%
	NECB2015	51%	137%
	NECB2017	39%	160%
Whitehorse	BTAPPRE1980	162%	210%
	BTAP1980TO2010	146%	133%
	NECB2011	82%	203%
	NECB2015	76%	180%
	NECB2017	60%	173%

For the small offices, the following observations are made:

- Conventional natural gas-heated small office archetype electrical energy use intensity (EUI) ranges between 81-109 kWh/m^2.
- Conventional natural gas-heated small office archetypes' peak electrical demand ranges between 32-49 W/m^2.
- With full electrification, an annual electrical energy (kWh) increase of between 25% to 162% is observed.
- With full electrification, an annual peak demand (kW) increase of 37% to 210% is observed.

- Post-electrification office electrical energy EUI ranges between 121 to 232 kWh/m^2.
- Post-electrification office peak electrical demand ranges between 65 to 120 W/m^2.

Medium Offices

Table 5 presents the energy (kWh) and demand (kW) increase for medium offices of different vintages across seven Canadian cities.

The range of increase in energy and demand is shown in Figure 4. For the medium offices, the following observations are made:

- Conventional natural gas-heated medium office archetype electrical EUI ranges between 71 to 94 kWh/m^2.
- Conventional natural gas-heated medium office archetypes' peak electrical demand ranges between 33 to 49 W/m^2.
- With full electrification, an annual electrical energy (kWh) increase of between 28% to 101% is observed.
- With full electrification, an annual peak demand (kW) increase of 13% to 108% is observed.
- Post-electrification office electrical EUI ranges between 101 to 164 kWh/m^2.
- Post-electrification office peak electrical demand ranges between 42 to 84 W/m^2.

Large Offices

The summary of the increase in electrical energy and demand for large office electrification is shown in Figure 5. For the large offices, the following observations are made:

- Conventional natural gas-heated large office archetype electrical EUI ranges between 71 to 94 kWh/m^2.
- Conventional natural gas-heated large office archetypes' peak electrical demand ranges between 29 to 49 W/m^2.
- With full electrification, an annual electrical energy (kWh) increase of between 44% and 78% is observed.
- With full electrification, annual peak demand (kW) increases of 14% to 141% are observed.
- Post-electrification office electrical EUI ranges between 95 to 148 kWh/m^2.
- Post-electrification office peak electrical demand ranges between 37 to 81 W/m^2.

Table 5: Summary of Medium Offices Electrification Scenarios.

City	Vintage	Increase in Elect. Annually (kWh)	Increase in Demand (kW)
Calgary	BTAPPRE1980	59%	73%
	BTAP1980TO2010	52%	67%
	NECB2011	33%	44%
	NECB2015	35%	46%
	NECB2017	37%	35%
Edmonton	BTAPPRE1980	77%	95%
	BTAP1980TO2010	68%	87%
	NECB2011	44%	62%
	NECB2015	46%	63%
	NECB2017	48%	65%
Vancouver	BTAPPRE1980	51%	47%
	BTAP1980TO2010	45%	43%
	NECB2011	28%	13%
	NECB2015	30%	13%
	NECB2017	31%	13%
Halifax	BTAPPRE1980	67%	92%
	BTAP1980TO2010	62%	91%
	NECB2011	34%	41%
	NECB2015	35%	42%
	NECB2017	39%	46%
Toronto	BTAPPRE1980	62%	47%
	BTAP1980TO2010	60%	45%
	NECB2011	31%	16%
	NECB2015	32%	17%
	NECB2017	35%	18%
Montreal	BTAPPRE1980	79%	80%
	BTAP1980TO2010	74%	76%
	NECB2011	41%	47%
	NECB2015	43%	47%
	NECB2017	46%	27%
Whitehorse	BTAPPRE1980	101%	108%
	BTAP1980TO2010	90%	104%
	NECB2011	59%	93%
	NECB2015	62%	95%
	NECB2017	61%	108%

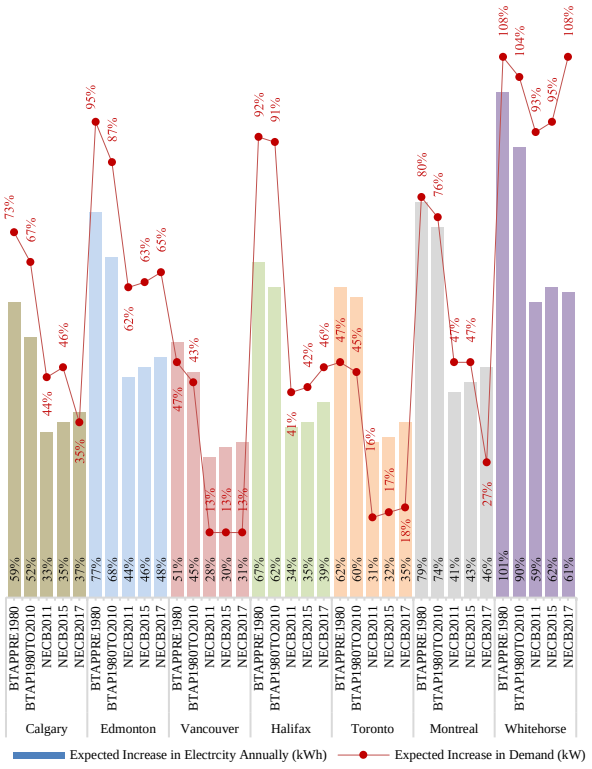

Figure 4: Energy and Demand Increase in Medium Offices.

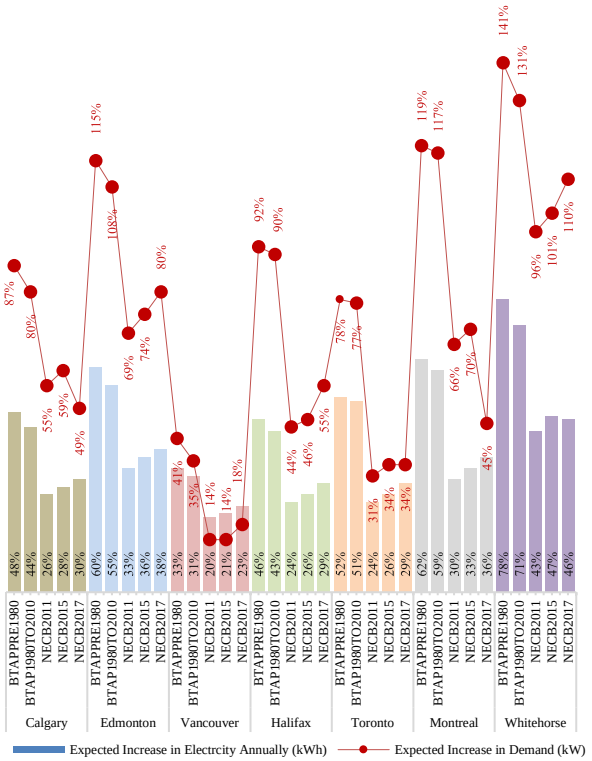

Figure 5: Energy and Demand Increase in Large Offices.

Table 6: Summary of Large Offices Electrification Scenarios.

City	Vintage	Increase in Elect. Annually (kWh)	Increase in Demand (kW)
Calgary	BTAPPRE1980	48%	87%
	BTAP1980TO2010	44%	80%
	NECB2011	26%	55%
	NECB2015	28%	59%
	NECB2017	30%	49%
Edmonton	BTAPPRE1980	60%	115%
	BTAP1980TO2010	55%	108%
	NECB2011	33%	69%
	NECB2015	36%	74%
	NECB2017	38%	80%
Vancouver	BTAPPRE1980	33%	41%
	BTAP1980TO2010	31%	35%
	NECB2011	20%	14%
	NECB2015	21%	14%
	NECB2017	23%	18%
Halifax	BTAPPRE1980	46%	92%
	BTAP1980TO2010	43%	90%
	NECB2011	24%	44%
	NECB2015	26%	46%
	NECB2017	29%	55%
Toronto	BTAPPRE1980	52%	78%
	BTAP1980TO2010	51%	77%
	NECB2011	24%	31%
	NECB2015	26%	34%
	NECB2017	29%	34%
Montreal	BTAPPRE1980	62%	119%
	BTAP1980TO2010	59%	117%
	NECB2011	30%	66%
	NECB2015	33%	70%
	NECB2017	36%	45%
Whitehorse	BTAPPRE1980	78%	141%
	BTAP1980TO2010	71%	131%
	NECB2011	43%	96%
	NECB2015	47%	101%
	NECB2017	46%	110%

It has been found that with the full building electrification of office archetypes, there is a potential for a 25 to 162% increase in the annual electrical energy (kWh). This is attributed to converting space and hot water heating to electricity. In addition, it has been observed that the highest increase in energy is prevalent among the older vintages (typically pre-1980) and in the climate zones with higher heating degree days.

Additionally, an increase of 14 to 210% in demand (kW) across different Canadian locations is observed for the office archetypes. This is attributed to the increase in the coincident demand for space and hot water heating, lighting, office equipment, and cooling demand. It has been observed

that the offices in Canadian locations with milder climates (Zone 4) designed per the most recent NECB standards show the smallest electrical demand increase. Generally, the highest electrical demand increase has been observed among the older vintage and in the climate zones with higher heating degree days. However, the electrical demand trends show more variation due to a complex interaction between the lower lighting power density thresholds, higher cooling and heating system efficiencies, and higher envelope performance in the newer vintages. In addition, it has been observed that the office building size has a non-linear correlation with the electrical demand, likely due to the increased interior volume and dynamic thermal interaction between building zones.

For Canadian locations, where electricity might be the main energy source for space heating and DHW, building electrification might have a smaller impact on the increase in electric demand and consumption.

Conclusion

This article presents the results of a simulation study addressing the electrification of three representative office archetypes to forecast the increase in electrical energy (kWh) and demand (kW) across various climate zones in Canada. The electrical energy and demand for the office archetypes with conventional fossil fuel space and hot water heating are calculated, followed by the same archetypes' full space and hot water heating electrification. The increase in electrical energy and demand is estimated.

A separate investigation will explore a detailed analysis of the building thermal performance in relation to the building's interior volume and floor area.

This results in the projected office energy use between 101 to 232 kWh/m^2 and demand between 40 to 120 W/m^2.

It has been found that with the full building electrification of office archetypes, there is a potential 25% to 162% increase in annual electrical energy (kWh) and 15% to 210% increase in demand (kW) across different Canadian locations.

This results in the projected office energy use between 101 and 232 kWh/m2 (compared to 71 to 109 kWh/m2 for the natural gas-heated baseline) and demand between 40 and 120 W/m2 (compared to 32 to 50 W/m2 for the natural gas-heated baseline).

This study is part of a larger ongoing investigation into developing detailed hourly load profiles for Canadian office buildings. Overall, this research underscores the importance of energy simulations to predict energy and demand increases due to the electrification of Canadian office buildings, offering valuable insights for electrical utilities, building designers, and energy infrastructure planners for the built environment.

Acknowledgment

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