Case study of the upgrade of an existing office building for low energy consumption and low carbon emissions

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Abstract

This case study evaluates the best energy efficiency measures of an existing two-story office building from the late 1960s located in Vancouver. Natural gas was used for heating and electricity was used for lighting, cooling and other needs. The building was simulated to match both metered data and bills. The energy model allowed identifying the parameters to reduce the energy consumption and mitigate the impact on CO_2-eq emissions. On-site renewable energy supply was simulated. The return on investment (ROI) of the retrofit strategies (building envelope and renewable energy) was calculated to determine the profitability. From the parametric study, the insulation of the wall and roof, the airtightness and window replacement have the most impact on energy saving and allowed reducing 45% of the total annual energy consumed. These improvements can save more than 70 tons of CO_2-eq per year from reducing the natural gas consumption. The return on investment of upgrading the building envelope was 7.7 years in Vancouver. Net zero energy building performance was possible with the addition of photovoltaic solar panel and solar heating to supply the total energy needs of the building, with an ROI of 11.6 years. If we changed the building location to Montreal, the same optimized building envelope reduces the energy consumption by 39%, and the energy saving increases to 56% when using the electric heating system usually already in place. Overall, building envelope upgrades are solutions to consider to improve energy saving in northern climate.

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1. Introduction

Building upgrades is an excellent opportunity to reduce energy consumption and greenhouse gas emissions [1-4]. In recent years, improving the energy efficiency of a building is a research topic of high interest [5-8]. Most studies focus reduction of the operational energy [9-11]. Building retrofit targets selected building components, such as the heating ventilation and air-conditioning system (HVAC) [9, 12-15]; the energy management systems [2]; the building envelope [1, 9, 15] and specific building envelope elements, such as the wall [16-19], the thermal mass [20], the airtightness [21], the insulation [12, 21], the lighting of the building [2, 12, 22]. Economic benefits, especially reduction in energy costs and attractive return on energy retrofit investment, are the main driver for energy retrofits decision [2]. Thus the economic analysis is an important part of a building upgrade study.

The energy saving from the office building retrofits varies on a case-by-case basis. In a multi-objective optimization of an office building in Germany, the reduction in operational energy reached a plateau at one-third reduction of operational energy [23]. Retrofit of office buildings in Italy was found to reduce the primary energy by at least 40% [24]. Retrofit energy saving in four existing class A commercial office building downtown Toronto in Canada reached 0.9% to 18% energy saving with LEED and BOMA certification [25]. Energy retrofit measures allowed 29-31% electricity saving and 19-32% natural gas saving in low-rise office building in Edmonton, Ottawa and Vancouver [12].

As there are many retrofit options available, energy simulations are required and different tools are available to analyze scenarios. The key to success in a case study is having a confidence in those simulation tools by calibrating or validating them. Several studies focus of the validation of models [26, 27], but surprisingly, there are not many complete cases studied with a validation of an energy model, improvement of the model and with an economic analysis of the improvement. The validation of a model can be done through three processes i) inter-model comparison or ii) empirical and iii) analytical. Model validation is a necessity, but a complex process and it is important to gain confidence in a model that leads you to a parametric study for retrofitting strategies [28], meaning having the possibility to change model input [29]. Detailed model calibration allows a better building prediction [29]. Often the software's user, especially in absence of information on old buildings, make assumptions based on his experience, which leads to high degree of uncertainty [30]. The calibration relies as well on the level of the experiment and measurement accuracy. In order to simplify the calibration process, some researchers [31] are trying multistage calibration, which consists in dividing the entire building into different sub-models and calibrates them separately to obtain an accurate model. The process depends on the objectives of the study, each model is treated differently.

This study investigates the retrofit of an existing office building in Canada from the late 1960s to reduce the annual operational energy, to determine the on-site energy production to reach net zero energy standard and the return of investment (ROI) for a building located in Vancouver. In the current code requirements and policy in Vancouver, Canada, the public policies focus on reducing the operational energy from buildings. [32]. Older traditional buildings from the 1950s to 1970s were not insulated, not airtight, which meant high energy consumption [12]. To address these issues, a numerical approach has been adopted to simulate the energy consumption of the office building pre-retrofit conditions, based on both bills and metered data. A sensitivity and parametric study was undertaken to assess and identify the most important parameters affecting the energy performance and the greenhouse gas emissions, as single and combined parameters. Net zero energy is gaining policy attention and the government of British Columbia is aiming to have all new construction net-zero energy ready by 2032 [33]. The profitability of on-site renewable energy measures for net zero energy building was estimated with the return on investment (ROI). In order to see the effect of the location on energy consumption, retrofit measures renewable energy production and ROI, the building was hypothetically moved from Vancouver to Montreal to assess the robustness of the upgrade measures.

2. Building Energy Model

2.1 Case study

The case study is a two-story office building built in 1969 of a building science consulting firm office located in Vancouver, in British Columbia (Figure 1) [34]. This building was selected because of the quantity and quality of data collected by the consulting firms on his own office, actually their old office and they moved location. Building energy consumption data is often sensitive and not easy to access. This building is a typical two-story office building found in the building typology in Canada [12] and in the United States [15]. The energy simulation was calibrated by both historical energy billed and metered data, for both electricity and natural gas [34]. The exterior wall assembly was made of painted concrete block and gypsum board. The façade surrounding the windows are made of stucco, wood sheathing, fibreglass batts in wood studs, and gypsum board. It is assumed that the structure is made of concrete. Table 1 presents the architectural details and Table 2 the mechanical parameters. Additional data given by the building science consulting firm is given in supplementary electronic materials.

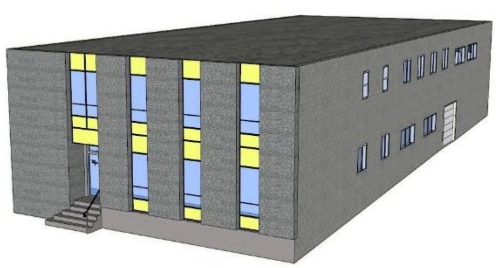


Figure 1: Northwest elevation of the two-storey building from 3D models [34]

Table 1 : Architectural input of the office building [34]

Type	Value
Total floor area	922 m^2
Total roof area	463 m^2
Gross exposed wall area, North	90 m^2
Gross exposed wall area, South	90 m^2
Gross exposed wall area, East	92 m^2
Gross exposed wall area, West	204 m^2
Window percentage, North	19.5%
Window percentage, South	16.3%
Window percentage, East*	1.5%
Window percentage, West	9.0%
Infiltration rate (0.29 cfm/ft2)	1.76 ACH
Overall Roof R-Value	1.97 RSI
Overall Wall R-Value	0.44 RSI
Occupancy density	0.07 people/m^2

*Note that the East wall contains a shared portion with the neighboring building and is modelled as adiabatic

Table 2: Mechanical inputs [34]

System type	Direct expansion unitary system
Heating	
Fuel	Natural gas
Heating efficiency	80%
Setpoint temperature	20 °C
Setback temperature	17 °C
size factor	1.0
Cooling	
Fuel	Electricity
Cooling COP	3.1
Setpoint temperature	22 °C
Setback temperature	26 °C
Size factor	1.0
Domestic hot water	
Fuel	Natural gas
Mains supply temperature	10 °C
Delivery temperature	55 °C
Equipment efficiency	80%
Consumption rate	1.4 L/m^2.day
Ventilation	
Minimum outside air	2.5 L/s.person
Mechanical ventilation	0.22 L\s\m^2
Natural ventilation cooling temperature	30 °C

2.2 Energy simulation

For building's renovation, the choice of the building and the energy simulation software is an important element in the evaluation and the choice is also oriented toward data availability. There are several tools of energy simulation in North America and more particularly in Canada. Some of the most used software are DOE-2, eQuest, EnergyPlus, EE4, SIMEB, Design Builder, TRNSYS and RETScreen [35, 36]. In this current study, the software used for the energy simulation of this building is SIMEB, software developed by Hydro-Quebec, the electricity provider in Quebec [37]. This software allows estimating the energy consumption of the modelled building, considering the efficiency of energy economy measures, analyzing and comparing with consumption. The pre-retrofit office building operation was previously modelled with Design Builder by the building consulting firm [34]. The energy model for the office building was calibrated to match the metered data and the one-year historical billed energy by varying the unknown mechanical and electrical input parameters. The calibrated model results are very close to the metered data with only 0.5% annual difference.

The RETScreen software is also used in this study to estimate the additional cost of the improvements brought to the building. It was chosen because it is the commonly used and reliable for energy projects in North America. The software estimates the return on investment (ROI) of such a project and financing options [38]. The ROI calculates the number of years to recover the investment cost. The most important parameters of the simulation are detailed in Table 3. The SHGC is the solar heat gain coefficient, which expresses the ratio between the energy of solar origin that penetrates into the building through the window and the incidental solar energy on the window that becomes a thermal gain and an incidental solar energy on the window.

This building has a poor thermal performance. The exterior walls are having an effective R-value of less than R-3. The roof is a low-sloped built up asphalt roof with minimal insulation. Table 3 below provides a summary of the exterior walls and roof in terms of construction and thermal performance. Overall effective U- and R-values for the wall and roof were calculated using area-weighted U-values from the detailed area calculations. These overall effective walls and roof U-values were calculated to be 2.3 W/m2·K (R-2.5) and 0.51 W/m2·K (R-11.2) respectively. The remaining data necessary to the simulation are in the supplementary electronic materials (Tables S1 and S2). Mechanical and electrical inputs are available in supplementary tables S3 and S4.

Table 3: Most important data used for the simulation, based on pre-retrofit conditions

Modelling data	Value
Insulation of the shell	
Roof	RSI = 1.97 m²K/W
Walls	RSI = 0.88 m²K/W
Floor	No value
Windows	U = 5.91 W/m²K and SHGC = 0.85
Airtightness	1.76 ACH
Air conditioning	
Saver cycle of the new air	None

The validation of the building model simulated with SIMEB is critical in order to reflect the reality and allows performing parametric study with confidence. This is an inter-model validation process. Furthermore, this stage is necessary so that energy-saving measures are reliable. For that purpose, the data of simulation obtained in this study using SIMEB software has to reach the same or close to energy consumption as those who were obtained by the previous study. Figure 2 presents the total energy consumption (i.e. gas and electricity) obtained with the Design Builder software from January 1 , 2006, through May 31 , 2011. Data analysis through that period indicates that approximately 31% of the building's energy is from gas, and 69% from electricity.

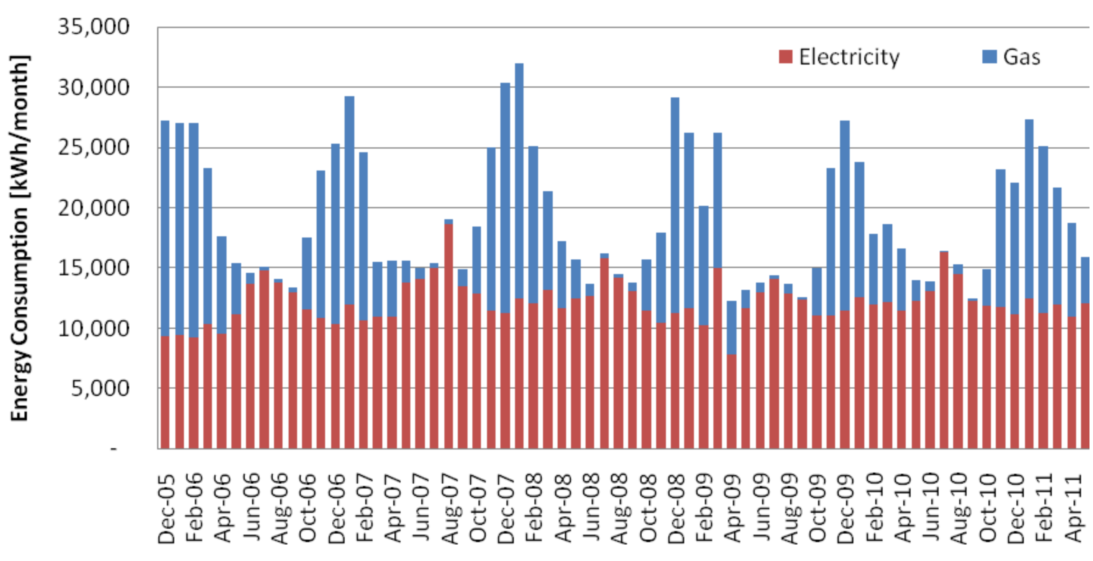
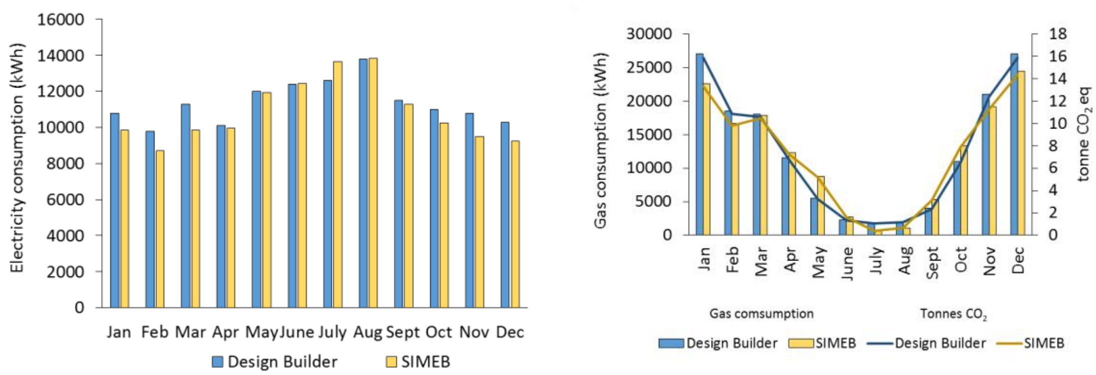


Figure 2 – Total energy consumption from January 1 , 2006, through May 31 , 2011 [34].

Figure 3 presents the monthly gas and electricity consumption obtained with Design Builder and those obtained with SIMEB in the pre-retrofit conditions. Seasonal trends are observed in both the gas and electrical energy consumption of the building. The gas consumption is only for the heating consumption. The trends of gas are influenced by heat generation and the domestic hot water heater (DHW). The electricity consumption combines the consumption in DHW, electrical loads, lighting and of the systems of ventilation and cooling systems. There is no big difference between the two models SIMEB and Design Builder, based on the total annual average, which is about 252 W/m²/yr; the difference on the total is 4% for the electricity and 3% for the natural gas. The seasonal differences are due for example because SIMEB consider a minimum insulation and the case study building was less insulated. The SIMEB model was considered validated and acceptable to simulate the energy performance of the retrofitting scenarios of this building.



a) b)

Figure 3: Validation of the pre-retrofit energy consumption with two simulation software: a) electricity consumption, b) gas consumption

3. Improvement in the building energy performance

A sensitivity analysis is performed to analyze the impact of the various parameters of the energy simulation on buildings. Once the model is validated, the value of every input was modified to analyze its effects on the building consumption. However, a study of every parameter is not enough, because some simulation parameters are complementary. For example, an improvement of the insulation of walls or another component of the envelope will not allow saving enough energy, if we do not modify the airtightness of the envelope. The sensitivity study shows that the most important inputs to reduce the annual consumption of RDH's building is airtightness of the envelope, wall insulation, roofing insulation and U-Value of Windows. The reduction of multiple parameters is known to be less than the sum of the individual saving [12]. The comparison of the saving of CO_2 equivalent was calculated using the generation intensity factor of 587.4 g CO_2 eq/kWh for gas use in British Columbia in 2015 [39]. There is no consumption of gas for residential heating purposes in Quebec since 2015 and there is no direct CO_2 emission from the hydroelectricity generation. Indirect CO_2 emission from energy transport and services were not considered.

3.1 Inputs of the sensitivity analysis

The sensitivity analysis was done for every input available on SIMEB software (Table 4). All the data have a different impact on the annual consumption. The sensitivity analysis shows the most important data for the improvement of the energy efficiency of the office building. The sensitivity study shows that the most important inputs to reduce the annual consumption is the airtightness of the envelope and the insulation of walls, roof and windows. Parameters based on occupants, such as set point temperature, were not the most influential on the overall annual energy consumption.

Table 4: Simulation inputs used for the sensitivity analysis

Building elements	Inputs
Envelope insulation	Walls Windows Roof Floor slab
Heating	Number of boilers Boiler power Heating coil capacity Heating efficiency Modulation of the burner Heating setpoint Flow control of the pump Type of peripheral heating Type of terminal heating
Cooling	Setpoint temperature Cooling coil capacity Cooling efficiency
Ventilation	Flow rate of ventilation Supply flow of the fans Restarting the fans in idle period if the set point is not respected Option of control of the fresh air by a CO_2 probe

3.2 Single parameter study

Wall insulation

The value of the thermal resistance of the insulation of walls is 0.44 m^2K / W, which is R-2.5. However, the minimal value of the thermal resistance of the insulation of walls in the SIMEB software is 0.88 m^2K / W (R-5), which was used. Increasing the thermal resistance of the insulation of walls allows to reduce heating consumption, but makes increase the consumption in cooling, as shown in Figure 4. However, savings in heating are more important than the increases of consumption in cooling, especially in cold climate, so the total consumption of the building decreases with the increase of the thermal resistance of walls. A wall insulation of 4.88 m^2K/W (R-27) obtained by simulation is an optimum value that allows to reach an annual consumption of 233 828 kWh (Figure 4) and deemed complied with the 2015 National Building Code [40]. A decrease of 15 % for the consumption and a saving of 27 tons of CO_2 equivalent can be obtained with this insulation.

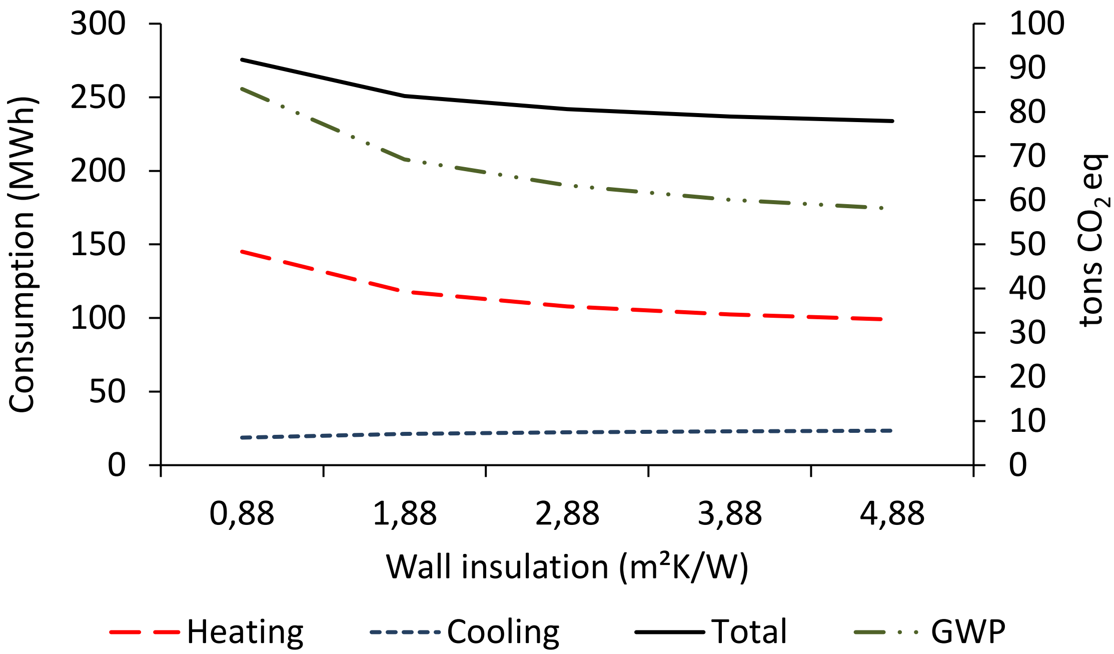


Figure 4: Impact of wall insulation on total consumption ton

Roofing Insulation

The roof is part of the building envelope of the building. The roof's thermal resistance is RSI of 1.97 m^2K/W, which gave us an R-Value of 11 (R11). Increasing the thermal resistance of the roof insulation reduces the consumption for heating but increases the consumption for cooling. A roof insulation of 4.97 m^2K/W (R-28) is an optimum value obtained by simulation that allows us to reach an annual consumption of 267 004 kWh (Figure 5). This represents a decrease of 8% for the consumption and a saving of 16 tons of CO_2 equivalent.

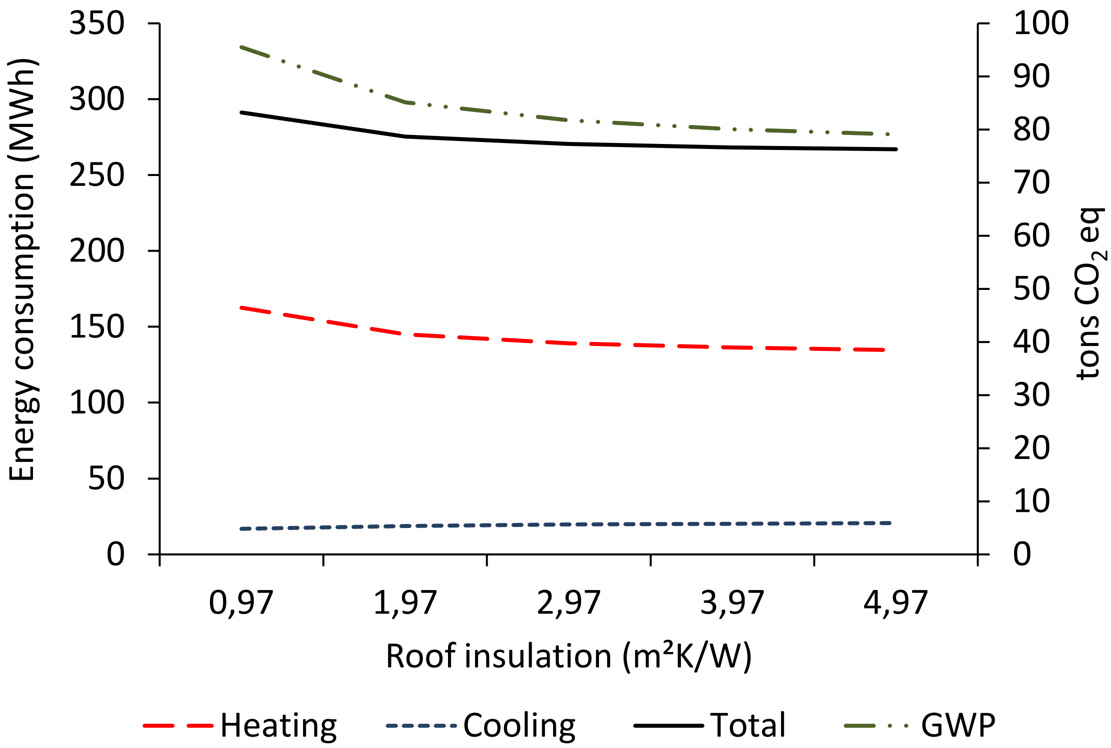


Figure 5: Impact of roof insulation on total energy consumption

Window U-value

Window energy efficiency is defined by two parameters: global thermal transmission in W/m2K (i.e. U Coefficient or U-Value) and SHGC. Windows settled in the simulated building have a value of global thermal transmission of 5.9 W/m2K and SHGC of 0.85. The windows consist of clear, 3 mm single panes in non-thermally broken aluminum window frames. The windows occupy 8.9% of the exterior wall area and vary in size in shape. SIMEB software proposes several types of windows to model a building. Every type of window corresponds to a global thermal transmission and different SHGC (see supplementary electronic materials Table S5 for more details) [37].

When the global thermal transmission of windows increases, the window allows more heat to pass. When SHGC is increased, the ratio between the energy of solar origin which penetrates into the building through the window and the incidental solar energy on the window is important and so the contribution of solar energy through the window is important. Simulations performed on all types of windows showed that the type allowing the biggest reduction on the total consumption of the building is the high-performance windows double tinted filled with argon and with low emissivity. A total consumption of 269 580 kWh represents an annual reduction of 5 819 kW, which corresponds to a decrease of 2% of the total consumption.

Building envelope airtightness

The airtightness measures the tightness of the building to outside air. If the rate of airtightness increased, an important quantity of air circulates between the building and the outside, which causes heat losses in winter and thermal heat gain in summer. The unit of the airtightness of the building is the quantity of air change per hour (ACH). The airtightness is essential to ensure that the insulation of the envelope is effective. The initial rate of airtightness measured by the building science-consulting firm was 1.76 ACH and allowed user thermal comfort. American Society of Heating, Refrigerating and Air-Conditioning (ASHRAE) defines that a tight building corresponds to a rate of airtightness of 0.61 ACH, which is also very close to the requirement of 0.6 ACH for a passive house [41]. An average building has generally a rate of airtightness of 1.82 ACH; a rate of 3.64 ACH corresponds to a building with a lot of infiltration of air and thus energy losses. When the value of the rate of airtightness decreases, the annual consumption in heating decreases, whereas the consumption in cooling increases. Savings in heating allow to reduce the total consumption of the building to 245 772 kWh (Figure 6). This change impacts a lot the total consumption, which represents the reduction of 11% in total energy consumption and 19.6 tons of CO_2 eq. Even if the energy simulation shows that the value of 0.61 reduce annual consumption, this value is actually hard to achieve. Thus it is not necessary to simulate lower values of ACH.

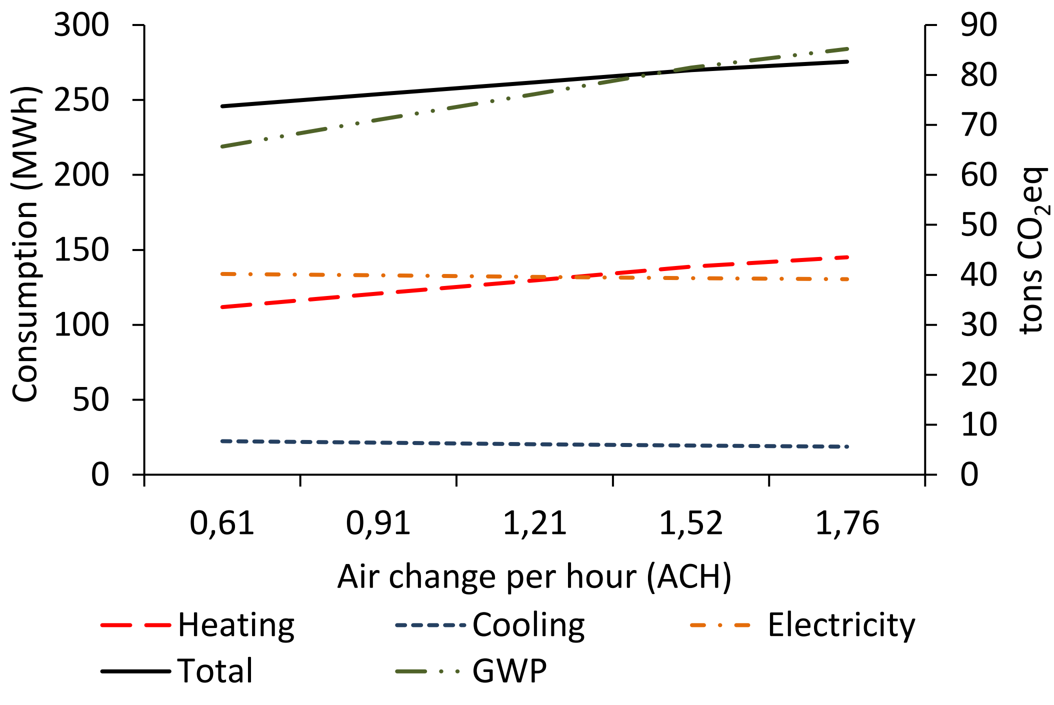


Figure 6: Impact of airtightness on annual energy consumption

Boiler efficiency

Boiler efficiency used for the numerical modelling is 80% with Design Builder. Increase the boiler efficiency allows decreasing the heating consumption. This has no influence on the other consumption. We can increase the efficiency by choosing a certified boiler ENERGY STAR. The efficiency of 95% allows to reach a total consumption of 252 794 kWh, whereas the efficiency of 70% causes the consumption of 296 041 kWh (Figure 7).

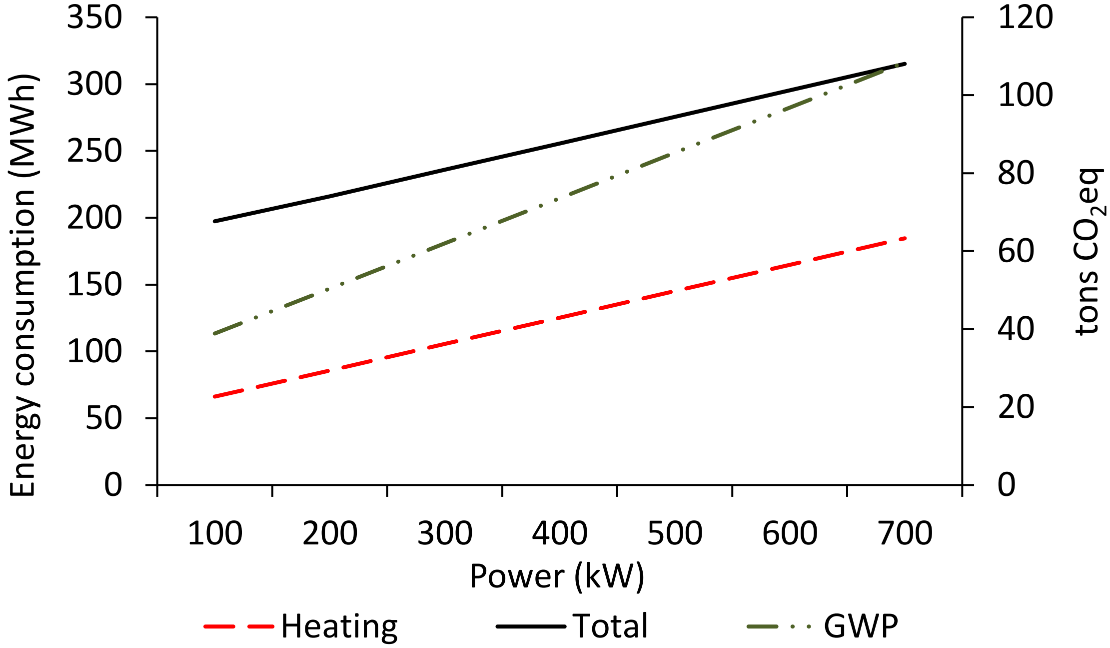


Figure 7: Impact of boiler efficiency on annual building energy consumption

Air conditioning: saving cycle of the new air

The regulation of the saving cycle is used to reduce mechanical air conditioning. A regulation according to the temperature means that the outside air is used as long as the outside temperature is lower than the recovery temperature. A regulation according to the enthalpy means that the outside air is used as long as the enthalpy of the outside air is lower than the enthalpy of the air of recovery. The saving cycle of the new air according to the temperature of outside air causes an increase of the total annual energy consumption (with an annual consumption of 280 225 kWh instead of 275 501 kWh). Whereas the saving cycle of the new air working with the enthalpy of the outside air allows to reduce the total annual consumption of the building (with an annual consumption of 267 021 kWh instead of 275 501 kWh). The regulation of free cooling used to reduce the heat load on the mechanical system is carried out by enthalpy measurements. Indeed, the outside air is used for free cooling as long as its enthalpy is lower than that of the indoor air.

3.3 Multiple parameter study

Roof insulation and airtightness of the building envelope

Energy consumption was simulated for every value of roof insulation and airtightness of the envelope. If we increase the R-value for roof insulation and decrease the value of airtightness, annual heating consumption decreases whereas annual cooling consumption increases. The criterion to select the building upgrade is to choose the simulation data which allows the biggest total energy saving. A roof insulation of 4.97 m^2K/W (R-28) and the airtightness of 0.61 ACH (or 0.91 ACH) reached the minimal annual consumption which is 239 032 kWh.

Wall insulation and airtightness of the building envelope

The same method is applied to find the values of wall insulation and airtightness of the envelope, which allow the biggest energy savings. A wall insulation of 4.88 m^2K/W (R-27) and the airtightness of 0.61 ACH allows to reach the minimal annual consumption which is 189 998 kWh. This reduction can save the production of 50 tons of CO_2 equivalent gas, which is not negligible gain for CO_2 mitigation.

Window insulation and airtightness of the building envelope

A window insulation of 2.16 W/m^2K with a SHGC value of 0.3 (effective double tinted with argon low E) and the airtightness of 0.61 ACH allows to reach the minimum annual consumption which is 239 193 kWh. A study of different types of windows on the facades of the building according to their orientation could achieve more energy savings due to an effective insulation in the north and in the east and windows, which allow an important solar heat gain to the south and on the west. The solar heat gain from the windows must not increase the air conditioning consumption. To limit this increase of consumption, it is possible to install flaps or sun visors on the windows of the building.

Global energy savings

The sensitivity test shows the most important choices to allow a reduction of energy consumption of the building are:

- Improvement of the airtightness of the envelope,
- Improvement of the building insulation,
- Energy efficient equipment,
- A saving cycle of the new air.

The results of the building simulated with SIMEB with the combined parameters allow calculating the total energy savings on the building's annual consumption, based on the basic building and optimized building (Table 4). The basic one is the building simulated with original data and the optimized one is the building simulated with four energy efficiency measures: insulation of the roof and wall, the improvement of windows and the airtightness of the envelope. Building retrofits of the building envelope has more impact in northern climate [1], while it is not the most common retrofit chosen in southern cities in United States [2]. The electricity consumption is the total of the electrical need (lighting, etc.) and the cooling of the building. The optimized building requires higher electricity consumption than the basic, this is due total improvement of the envelope, which increases the cooling needs. The cooling of the basic building is only 18 720 kWh, while the optimized building is about 23 110 kWh. The optimized building requires a lower gas consumption than the basic one, because the improvement of the envelope decreases the heating needs (Table 5). The heating savings are important in this study. The total consumption of the optimized building is 45% lower than the basic one, which is comparable to the results of a classical university office building [6]. These changes can save a total of 75 tons of equivalent CO_2 gas by reducing only the heat consumption. To compare with another study, the electricity energy saving of a two-story building reached 20% by applying heat recovery, daylighting, lighting load reduction, boiler efficiency economizer and preheat upgrades, in Edmonton, Ottawa and Vancouver. The natural gas saving of these three cities were 30%, 32% and 19% respectively [12]. Upgrading the building envelope had more impact on the energy saving.

Table 5: Primary energy savings

Type of energy consumption	Basic building (kWh)	Optimized building (kWh)	Energy savings
Gas heating	144 967	17 247	88%
Electricity	130 449	133 989	2.70% gain
Total	275 416	151 236	45%

RETScreen calculated the additional cost and saving for the improvements, from an initial to an upgrade value (Table 6). The insulation of the walls and roof were panels, as proposed for flat roofs. The new windows were effective double tinted with argon low emissivity. These results show that 83% of this saving was due to the increase of the insulation of the wall and to the very good airtightness of the building. This represents only 48% of the total price of the retrofit cost. Improving the windows and the roof efficiency cost more for a limited result, while the airtightness measures offers the best energy saving/additional cost ratio.

Table 6: Detail energy savings of the combined envelope retrofit

Improvements	Additional costs ($)	Energy savings kWh	Tons of CO_2 eq.	Energy saving/ additional cost
Wall Initial values: 0.44 R SI Upgrade values: 4.88 R SI	35 000	41 673	24	1.19
Windows Initial values: 5.9 W/m²K Upgrade values: 2.16 W/m²K	16 367	5 921	3	0.36
Roof Initial values: 1.97 R SI Upgrade values: 4.97 R SI	26 093	8 497	5	0.33
Envelope Airtightness Initial values: 1.76 ACH Upgrade values: 0.61 ACH	3 900	29 729	17	7.62
Combined improvements	124 265	81 360	75	1.53

3.3 Renewable energy and net zero building

A net zero building produces as much clean energy as it consumes [42], which is easier once the energy consumption is reduced by energy efficiency measures. The addition of on-site renewable energy measured was modelled with RETScreen [38]. The capacity of the solar heating system is 9.1 kW and the installed surface is 13 m². The incoming air is sucked in dimples with a great turbulence for maximum heat transfer. For the gas consumption, a solar heating system of the air is a good renewable solution. A solar thermal collector collects heat by absorbing sunlight. The improvement of the envelope and the airtightness of the building allowed a strong fall in demand in heating and what allows filling the remaining needs easily. However, these improvements also caused an increase of the electric consumption because of a bigger need for cooling, supplied by the installation of photovoltaic panels. The table 7 presents the annual consumption and the appropriate sources of renewable power production. The supplied energy was calculated using RETScreen software and the Vancouver solar radiation data. Electricity production by the 226 photovoltaic panels with a life cycle efficiency of 16% represents a surface of 433 m^2 (the roof surface is 497 m^2). The solar collector replaces gas consumption and has a surface of 13 m^2. When the renovation of the building is done, it is important to assure a follow-up of the energy performances of the building.

Table 7: Supplied energy for the building

Type of energy consumption	Annual consumption (kWh)	Renewable power production	Supplied energy (kWh)	Decrease of tones CO_2 eq.
Gas	17 247	Solar heating of the air	17 472	10.1
Electricity consumption	133 989	Photovoltaic panels	134 315	NA

3.4 Annual saving and return on investment (ROI)

Reducing energy needs allows a reduction of operating costs, but there are additional costs for the installation of measures of efficiency energy proposed. Additional costs, the return on investment and savings due to the renovation of the envelope and to the installation of renewable sources of energy were estimated with RETScreen software (Table 8). To measure the profitability of such a project, the return on capital is better than the simple return, because the first one indicates the number of years which it is necessary to get back amounts invested in the project by the investor due to the flows generated. The return on the invested capital takes into account the flows of money of the project from the beginning, but also the financial lever (function of the level of debt), that makes it a better financial indicator of the project than the simple return. With no debt, the ROI is 7.5 years for the retrofit of the building envelope and 11.6 years for the retrofit with the renewable energy production, in Vancouver (Table 9).

Table 8: Annual savings due to the energy performance

Measures of efficiency energy	Additional costs ($)	Annual savings ($)
Envelope retrofits (wall, roof, windows and airtightness)	81 360	9 452
Photovoltaic panels (226 for a surface of 433 m²)	234 112	12 594
Solar heating of the air (for a surface of 13 m²)	7 280	1 726

Several data influence the return on own capital: inflation rate, life cycle of the project, debt ratio, interest rate on the debt, duration of the loan, capital costs, possible subsidies and the annual savings [38]. The debt ratio is the most influential value on the return on investment. The lower is the ratio, the lower is the debt, the more the project will be profitable quickly. The returns on investment take into account the duration of the project of 25 years (approximately the life expectancy of a solar panel) and the duration of a loan of 10 years. The return on capital for a 50% debt ratio (an interest rate of 7%) is of 13.7 years while considering the renewable energy production and 7.9 years when considering only the building envelope. Other values for the debt ratio are presented in the table 9.

Table 9: Return on investment of the office upgrade scenario in Vancouver (in years)

Debt ratio	Return on investment			
	Building envelope		Building envelope and renewable energy	
0%	7.5 years		11.6 years	
	Interest rate 2%	Interest rate 7%	Interest rate 2%	Interest rate 7%
10%	7.7	7.9	11.7	12.0
50%	7.1	8.7	12.2	13.7
90%	4.3	10.5	12.6	15.4

3.5 The application of the study to Montreal, Quebec

The impact of the building location on consumption, upgrade measures, and return on investment was also performed by moving the building from Vancouver to Montreal, in simulations. The numerical modelling was performed by changing the weather input files in SIMEB and RETScreen from Vancouver to Montreal, to evaluate the relevance of the choices of the improvement of the building. For an office building in Montreal with natural gas, the total consumption is 28% higher than in Vancouver, due to a 50% increase in the heating consumption in a colder winter climate (Table 10). In Vancouver, electricity costs 0.094$/kWh and gas costs 0.074$/kWh, whereas for Montreal electricity costs 0.08 $/kWh and gas costs 0.033 $/kWh, at the commercial rate. Even though the consumption is 28% higher in Montreal, the energy bill is 21% lower because of the lower energy price for the basic building (Table 11). If we consider the same energy efficiency measures applied on the building envelope in Vancouver then, the energy needs are reduced by 39% in Montreal, as compared to 45% in Vancouver.

Table 10: Consumptions for Vancouver and Montreal.

	Basic building			Optimized building envelope		
Energy Consumption	Vancouver	Montreal	Montreal (all electric)	Vancouver	Montréal	Montréal (all electric)
Gas (kWh)	144 967	216 084	0	17247	71 698	0
Electricity (kWh)	130 449	135 866	239 610	133 989	140 255	154 124
Total (kWh)	275 416	351 950	239 610	151 236	211 953	154 124

Table 11: Energy costs for Vancouver and Montreal

	Basic building		Optimized building envelope		
Energy bills	Vancouver	Montréal	Vancouver	Montréal	Montréal (all electric)
Gas bills ($)	10 728	7 130	1 276	2 366	
Electricity bills ($)	12 262	10 870	12 595	11 220	12 330
Total bills ($)	22 991	18 000	13 871	13 586	12 330

In Montreal, most buildings are already heated by electricity, buildings are connected on the grid supplied with hydroelectricity. Thus the electric building in Montreal was modeled with SIMEB by using an electric boiler, which is an electric serpentine with the efficiency of 100%, meaning a coefficient of performance of 100% [43]. For the capacity of the serpentine, an automatic sizing was chosen to supply the total heating needs of the building. Even in the colder climate with no building upgrade, the energy use is reduced by 13% by using an electric heating. The building envelope upgrades in Montreal for the all-electric building reduce the electricity consumption by 36%, compared to the basic building heated by electricity, and by 56% for the building using both natural gas and electricity, like the base case in Vancouver. The electricity needs of the optimized electric only building in

Montreal is consuming only 2% more energy than the building in Vancouver with the optimized building envelope, and the electricity bill is 11% less. The case of retrofit to the all-electric building in Vancouver was not evaluated, because buildings are usually demolished and rebuilt when deciding to change to an electric building [44], which is actually what happened to this case study building. The return on investment of the optimized building in Montreal was calculated using various debt ratio. The ROI of the building envelope was nearly 15 years and adding on-site renewable energy increases the ROI to 22.6 years (Table 12), for the building with both natural gas and electricity, as in the case of Vancouver. The increase in number of years is due to the lower cost of energy. If financing is needed, installing renewable energy on an office building Montreal with both natural gas and electricity is not profitable. However, other motivations can justify the installation, especially resilience toward extreme events having the potential to damage the electricity transport lines.

Table 12: Return on investment of the office upgrade scenario in Montreal

Debt ratio	Return on investment			
	Building envelope		Building envelope and renewable energy	
0%	14.9 years		22.6 years	
	Interest rate 2%	Interest rate 7%	Interest rate 2%	Interest rate 7%
10%	15 years	15.4 years	22.8 years	23.4 years
50%	15.6 years	17.5 years	23.7 years	More than 25 years
90%	16.2 years	19.5 years	24.5 years	More than 25 years

The use of a geothermal heat pump can also be a solution to reduce the consumption of the building. A classical geothermal heat pump in Quebec has an average between 3 and 5 in heating mode [45]. With this performance the efficiency in heating mode, and even in cooling mode, is gone improved. Furthermore, a direct expansion system [46] can also be used to reduce the installation part and decreased the return of investment. Installing water heat pumps in office building in China was also found to create 70% HVAC energy saving [13]. Moreover, additional building improvement is possible by using higher insulation for the walls, roof, windows, and floor; shades in the windows to limit heat gains in the summer and reduce air conditioning, water and energy-efficient appliances.

Thus, this case study shows that upgrading an existing office building in Vancouver can be profitable. However, this building was actually sold and demolish during the time this study was performed; while it is not the trend in most cities in North America and many building owners select energy efficiency measures to retrofit their building [2]. Buildings are demolished as a lower rate in Montreal. As the energy source for heating of most new buildings in Vancouver is mostly hydroelectric, the carbon payback is over 100 years, and with the very fast reconstruction rate, lower carbon goal will not be achieved, which suggest to reevaluate current policies to encourage new construction [44]. Material conservation is a guiding principle for low energy, low-carbon building and considered in the material credits of the LEED standard value [47]. The upgrade of existing office building must part of the building energy strategy and policy [1, 3, 4].

4. Conclusion

This case study of a two-story office building in Vancouver shows that characteristics of the envelope are one of the most important parameters in the reduction of the building consumption, based on a sensitivity analysis and a parametric study. The improvement made on the building envelope in terms of airtightness and insulation allows to reduce of 45% of the annual energy consumed and saved 75 tons of CO_2 gas equivalent. Net zero building performance is possible with the addition of solar collectors to heat the air and photovoltaic panels. It is important to highlight that the return on investment (ROI) of such a project is influenced by the building energy consumption, but also with the energy price in the studied city. The ROI to upgrade the building envelope is 7.7 years in Vancouver, while it is 14.9 years in Montreal. Installing on-site renewable energy is more profitable in Vancouver with a ROI of 11.6 years and a ROI of 22.6 years in Montreal.

To validate such a study, it is essential to realize measures of the real performances of the building with occupants. Only the follow-up of the performances allows making sure of the viability of a net zero and to obtain a certification which will allow to identify this building as a net zero building. Furthermore, an analysis of sensibility could be interesting to estimate the robustness of the scenario of renovation in front of economic fluctuations, such as the energy price.

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