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THE ENERGY EFFICIENCY IMPROVEMENT OF A BUILDING IN ORDER TO ACHIEVE A BUILDING WITH NET ZERO CONSUMPTION

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Abstract: *This paper focuses on the retrofit of a building to become a net-zero energy building. It needs less energy and the energy is supplied by a renewable energy production near the building. The studied building is located in Vancouver (BC). The study shows that the airtightness and the insulation of the building envelope are the most important parameters in energy saving. It has been found that with a new air-saving cycle based on the enthalpy of the air makes, we can reduce the energy consumption. All these measures allow a 45% reduction in energy consumption and the remaining energy requirements are met by photovoltaic panels and an air-solar collector. The return on investment (ROI) of such a project is about 14.4 years. The study shows as well that the same energy retrofits in Montreal (QC) is not profitable. This is due in part to lower energy prices in Quebec. Changing gas heating to electric heating is more realistic.*

Keywords: *Energy Retrofit, Building envelope, Net-Zero, Airtightness, Insulation*

INTRODUCTION

The construction sector represents a big part of the energy consumption in the country. It is one of the most polluting sectors behind transport and industry. The quantity of rejected CO_2 is strongly bound to the heating consumption of buildings. Indeed, according to the Ministry of the sustainable development of Quebec, we can observe the same evolution between annual heating degrees day of and the greenhouse gas (GHG) emissions of buildings. Even if this heating consumption depends strongly on the outside temperature, other elements can influence it, such as energy efficiency. Improvements in energy consumption are encouraged by the Quebec government through voluntary programs and certifications but also by new methods of construction and less energy-consuming technologies. Beside those voluntary programs and certifications, there are standards to be respected for new buildings in Quebec. Construction of sustainable buildings, more environment-friendly in construction phases and of use, is a way to reduce GHG emissions in Quebec. Nowadays, the renovation of buildings is also an important sector in construction to be considered in terms of energy efficiency, since more than 55% of the building stock has to be retrofitted. During the renovation process, an energy simulation is necessary. It is completed through many steps: creation of a building model (made with information about building and input data), validation of this model, and measure of the impact of every data input to determine the best efficiency energy measures (Bensenouci Ahmed, (2016)). The validation of the model is the comparison between billed consumption and consumption obtained with a simulation of the building model. Validation of the model is a very important step for the retrofit of a building, to trust the simulated model.

Objectives

The objectives of this paper are:

- Study of the energy performance of an existing commercial building in order to improve its energy efficiency. This will be performed through stepwise approach numerical simulations:

1. Validation of the numerical model with the real building's data ;
2. Identification of the important parameters which can affect energy efficiency of the building, and

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3. Parametric study with the identified important parameters.

- Determination of sustainable building's characteristics in general and net zero buildings in particular, because of its important energy saving;

- The profitability of the building's renovation in a net zero building.

Net zero building

A sustainable building is a building, which is resistant in time and durable (Voir vert. (2012)). A sustainable building can also be a more successful building in terms of energy efficiency. Savings also concern the consumption in water and greenhouse gas emissions. A net zero building is a sustainable building because its low energy demand is provided by renewable energy.

NUMERICAL SIMULATION

Building description and Inputs

The choice of the building is an important step of the study because the energy simulation requires a lot of information and is very often complicated to obtain for confidentiality reasons.

The most important are:

- Location of the building
- Orientation
- Characteristics of the envelope
- Heating, Air Conditioning and Ventilation Systems
- The type of lighting
- The frequency of occupation
- Internal electrical loads

The chosen building is the RDH offices (Figure 1), a consulting company in construction, which provided us with plans and technical information for this study (Chris Moning, (2011)). This information was able to be shared due to the courtesy of Graham Finch. The building is located in Vancouver, British Columbia.

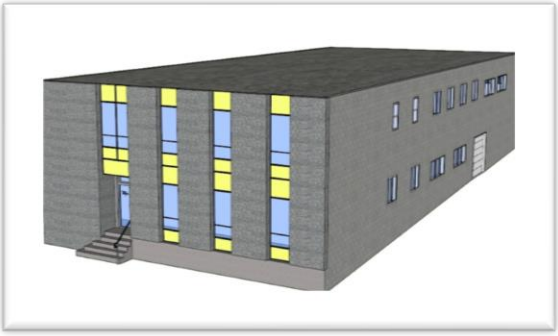

Figure 1: RDH building in Vancouver

The RDH's offices were built in 1969 and energy performance analysis of the building was performed by RDH which consists of various scenarios of energy renovation with the aid of Design Builder software. Table 1 presents the architectural details and Table 2 the mechanical parameters.

Table 1: Architectural inputs for RDH office building

	Value	Units
Total floor area	922	m²
Total roof area	463	m²
Gross exposed wall area, North	90	m²
Gross exposed wall area, South	90	m²
Gross exposed wall area, East	92	m²
Gross exposed wall area, West	204	m²
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	m²·°C/W
Overall Wall R-Value	0.44	m²·°C/W
Occupancy density	0.07	people/m2

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Table 2: Mechanical inputs

	Value	Units
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/ m².day
Ventilation		
Minimum outside air	2.5	L/s.person
Mechanical ventilation	0.22	L/s. m²
Natural ventilation cooling temperature	30	°C

Software selection

For building's renovation, the selection of the energy simulation software is an important element in the evaluation. The choice is also oriented toward data availability. There are several tools of energy simulation in North America. Some of the most used software are DOE-2, eQuest, EnergyPlus, EE4, SIMEB, Design Builder and Retscreen (Ma municipalité efficace. (2018)). The software eQuest was envisaged but it requires a very precise detailed information. It turns out that this software is not adapted because of the lack of some RDH's building information.

In this current study, the software used for the energy simulation of this building is SIMEB, a software developed by Hydro-Québec (HydroQuébec. (2012)). This software allows us to estimate the energy consumption of the modelled building. It permits to consider the efficiency of various economic measures of energy added to the building.

Some of simulation data used by RDH with Design Builder for the numerical modelling have been reused for SIMEB. However, some of the inputs required by SIMEB are unknown by RDH such as:

- Floor slab insulation
- Maximum load of the water heater
- Number and power of the boiler
- Capacity of the serpentines of heating and cooling systems
- types of terminal heating

For the floor slab insulation, no input has been chosen. The maximum load of the water boiler is the default value with SIMEB (i.e. 1.29 W/m^2). The automatic sizing was also chosen for the capacity of the heating and cooling serpentines. The automatic sizing calculates the necessary capacities compared with the needs for the modelled building. The value is 2.1 kW for heating and 3.6 kW for cooling. The type of terminal heating has been selected in consideration of the heating source, gas. The most appropriate is the hot water serpentine. The power of the boiler is selected to reach the same consumption obtained by RDH with Design Builder. We ended up by using a 500 kW power in the current simulation.

Other inputs from SIMEB have not been used for the numerical modelling with Design Builder by RDH such as:

- Modulation of the boiler burner
- Type of control of the temperature at the exit of the boiler
- Type of control of the flow of the boiler pump
- The presence or not of peripheral heater
- The restart or not of the ventilators in unoccupied period if the setpoint temperature is not respected
- Use of an option of control of the new air by a CO_2 probe
- Type of regulation of the ventilator debit
- Use or not of a saving cycle of the new air

RDH building has been built in 1969, so, the saving options have not been used for the numerical modelling with SIMEB, but the modulation of the burner of the boiler has been used.

Retscreen software is also used in this study to estimate the additional cost of the improvements brought to the building. It also allows to estimate the return on investment of such a project. The Retscreen software was selected because it is the commonly used software and reliable in the energy projects in North America (Ressources Naturelles Canada. (2017)).

The most important parameters of the simulation are detailed in Table 3.

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Table 3: Most important data used for the simulation

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

The R-value for wall insulation given by RDH is 0.44 m²K/W but the minimum value for software SIMEB is 0.88 m²K/W, this may affect the analysis or the validation. So, the consumption can be different if we compare the results with Design Builder and those obtained with SIMEB.

Model Validation

The validation of the building model simulated with SIMEB is useful to make sure that the model corresponds to the reality and permits us to perform parametric study with all confidence. Furthermore, this step is necessary, so that energy-saving measures are reliable. For that purpose, the simulation data obtained in this study using SIMEB software must reach the same (or close to) energy consumption as those which were obtained by RDH using Design Builder. Gas consumption includes only heating consumption. Electricity consumption combines domestic hot water consumption (DHW), electrical loads, lighting consumption and ventilation and cooling consumption.

Figure 2 and 3 represent the monthly consumption in electricity and gas using SIMEB and RDH's results given by Design Builder. If we compare monthly consumption obtained with SIMEB and those obtained by RDH with Design Builder, we can observe differences. For electricity consumption, maximum difference is obtained during winter (between October and March) whereas during summer (between April and September), differences are lower. The maximum difference is observed in March with a value of 12.83%. The lower difference is observed in June with a value of 0.18%. This can be explained by hypothesis and default value. Also lighting consumption is higher during the winter. For gas consumption, maximum difference is obtained during summer (between May and October) whereas during winter (between November and April), differences are lower. The maximum difference is observed in July with a value of 61.5%. The lower difference is observed in March with a value of 1.02%. This can be caused by default values used for heating sizing.

Annual electricity consumption simulated by SIMEB represents a 4.36 % difference compared to the consumption obtained by RDH, whereas, annual gas consumption represents only 3.09 % difference with the consumption obtained by RDH. This difference can be explained by the fact that some RDH data were not used with SIMEB and some SIMEB inputs have been supposed. All data are not available, so we have to set some hypothesis and use default values (Maroua BEN HASSINE. (2015)).

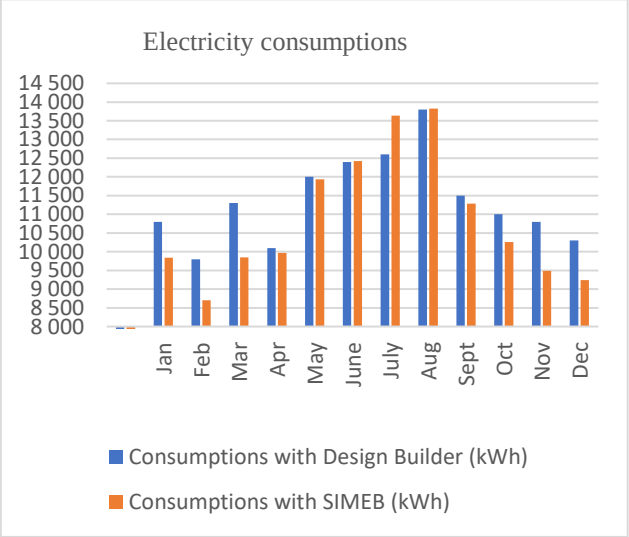

Figure 2: Electricity consumption of RDH building

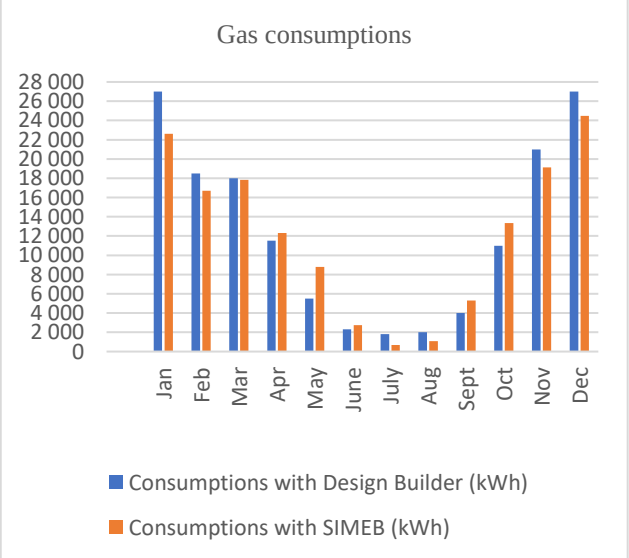

Figure 3: Gas consumption of RDH building

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With this low difference between total energy consumption, the SIMEB model is validated and can be used to further improve the energy performance of this building.

Building Energy Performance Improvement

A sensitivity analysis study was performed to evaluate the impact of various parameters of the energy simulation of buildings. Once the model is validated, the value of every input is modified to analyze its effects on building consumption. However, a study of every parameter is not enough because some simulation data are complementary. For example, an improvement of the insulation of walls or another component of the envelope will not allow to save 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 is the airtightness of the envelope and the insulation of walls, roof and windows.

Wall Insulation

The value of thermal resistance of wall insulation is 0.44 m²K/W that corresponds to an R-value of R-2.5. However, the minimal value of the thermal resistance of wall insulation in the SIMEB software is 0.88 m²K / W (R-5). It is this value which was used in SIMEB. Increasing the thermal resistance of the wall insulation allows to reduce heating consumption but unfortunately, increases the cooling consumption. However, savings in heating are more important than the increases of cooling consumption, so total consumption of the RDH building decreases with the increase of the wall thermal resistance. Results are presented in Figure 4. A wall insulation of 4.88 m²K/W allows to reach an annual consumption of 233 828 kWh.

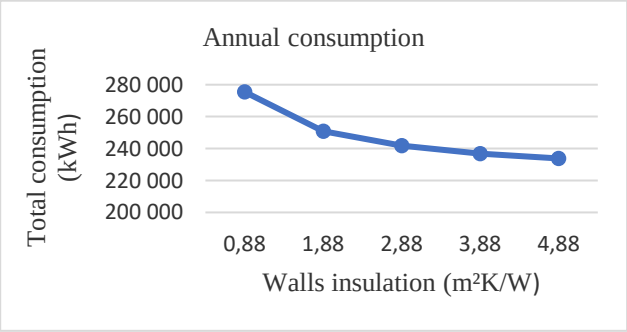

Figure 4: Impact of wall insulation on total consumption

Roofing Insulation

The roof's thermal resistance is 1.97 m²K/W, which gave us an R-Value of 11 (i.e. R11). Increasing the roof insulation will allow to reduce heating consumption but increase cooling consumption. Results are presented in figure 5. A roof insulation of 4.97 m²K/W allows to reach an annual consumption of 267 004 kWh.

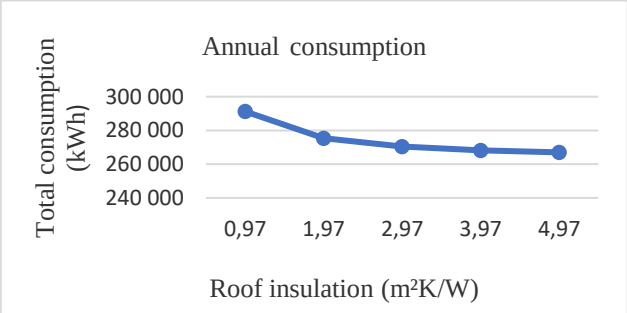

Figure 5: Impact of roof insulation on total consumption

Window U-Value

Windows are defined by two parameters: global thermal transmission in W/m²K and CARS. CARS is the coefficient of sun rays contributions which expresses the ratio between the energy of solar origin which penetrates into the building through the window and the incidental solar energy on the window which becomes a thermal gain and an incidental solar energy on the window. Windows settled in the RDH's building have a value of global thermal transmission of 5.9 W/m²K and CARS of 0.85. SIMEB software proposes several types of windows to model a building. Some windows characteristics are listed in table 4 below.

Table 4: Windows characteristics on SIMEB

Type of window	Coefficient U (W/m²K)	CARS
Standard double clear	3.52	0.62
Effective double clear with argon	3.04	0.62
Standard double tinted	3.52	0.42
Effective double tinted with argon	3.04	0.42
Standard double clear low E	2.89	0.5
Effective double clear with argon low E	2.16	0.5
Standard double tinted low E	2.89	0.3
Effective double tinted with argon low E	2.16	0.3
Standard triple clear	2.76	0.54
Effective triple clear	2.34	0.54

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When the global thermal transmission of windows increases, it means that the window allows to pass more heat, but when CARS is increased, it means that contribution of solar energy through the window is important. Simulations performed by RDH on all types of windows listed on Table 4 showed that windows effective double tinted filled with argon and with low emissivity allow the biggest reduction on the total consumption of the building, we can reach a total consumption of 269 580 kWh, so this represents an annual reduction of 5 819 kW.

Building Envelope Airtightness

The airtightness measures the tightness of the building to the outside air. If the rate of airtightness increases, an important quantity of air circulates between the building and the outside what causes heat losses in winter and thermal earnings in summer. The unit of the airtightness of the building is the quantity of Air Change per Hour (ACH). A good airtightness is essential so that the envelope insulation is effective. The rate of airtightness defined by RDH is 0.29 cfm/pi ² or 1.76 ACH. ASHRAE defines that a tight building corresponds to a rate of airtightness of 0.1 cfm/pi² to 75 Pascal (0.61 ACH), an average building has generally a rate of waterproofness of 0.3 cfm/pi ² and a rate of 0.6 cfm/pi ² corresponds to a building with a lot of infiltration of air. 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 RDH's building and so the annual consumption is 245 772 kWh. Results are presented in Figure 6 below.

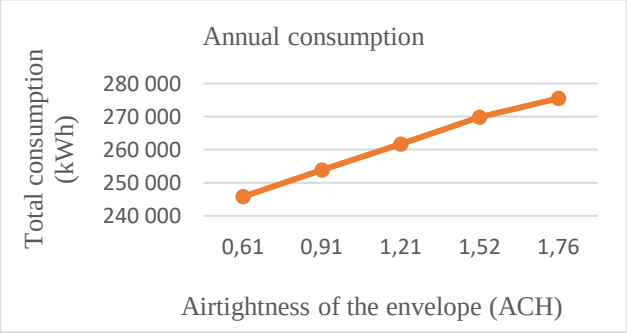

Figure 6: Impact of airtightness on annual consumption

Roof insulation and airtightness of the envelope

Consumption was measured for every value of roof insulation and airtightness of the envelope. The criterion to select the improvements to be brought to the building is to choose the simulation data which allows the biggest total energy saving. A roof insulation of 4.97 m^2K/W and the airtightness of 0.61 ACH (or 0.91 ACH) allows to reach the minimal annual consumption which is 239 032 kWh.

Walls insulation and airtightness of the envelope

The same method is applied to find the values of wall insulation and airtightness of the envelope which allow the biggest saving energy. A wall insulation of 4.88 m^2K/W and the airtightness of 0.61 ACH allows to reach the minimal annual consumption which is 189 998 kWh.

Windows insulation and airtightness of the envelope

A window insulation of 2.16 W/m²K with a CARS value of 0.3 (so 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 choices of windows on the facades of the building according to their orientation could allow to realize 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. It is necessary to pay attention that the solar heat gain does not increase the consumption in air conditioning. To limit this increase of consumption, it is possible to install some flaps or sun visors on the building windows.

Boiler efficiency

Boiler efficiency used by RDH for the numerical modelling is 80%. Increase the boiler efficiency allows to decrease heating consumption but have no influence on the other consumption. We can increase the efficiency by choosing a certified boiler ENERGY STAR. Results presented in Figure 7 show that the efficiency of 95% allows to reach a total consumption of 252 794 kWh.

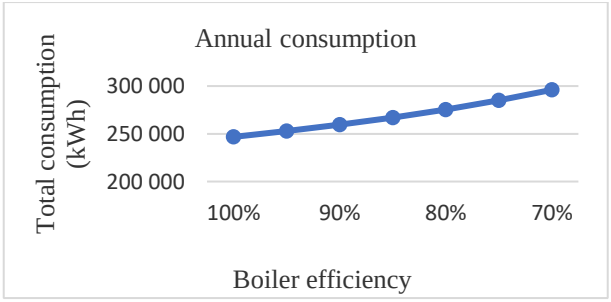

Figure 7: Impact of boiler efficiency on annual building consumption

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 if the outside temperature is lower than the temperature of resumption. A regulation according to the enthalpy means that the outside

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air is used as long as the enthalpy of the outside air is lower than the enthalpy of the air of resumption. The saving cycle of the new air according to the temperature of outside air causes an increase of the 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).

Global energy savings

The sensitivity test shows the most important for the 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

Results obtained with SIMEB and combined parameters allowed us to calculate total energy savings, based on the basic building and optimized building (Table 5). The basic one is the building simulated with original data and the optimized one is the building simulated with energy efficiency measures. Only heating requires gas. Cooling consumption is a part of electricity consumption. The optimized building requires a higher electricity consumption than the basic, this is due to the improvement of the envelope, which increases the cooling needs.

Table 5: Energy savings

Type of consumption	Basic building (kWh)	Optimized building (kWh)	Energy savings
Heating consumption	144 967	17 247	-88%
Cooling consumption	18 720	23 110	23%
Gas consumption	144 967	17 247	-88%
Electricity Gas Consumption	130 449	133 989	2,70%
Total consumption	275 416	151 236	-45%

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. 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.

In Table 6, additional costs of the renovation are calculated with Retscreen (Ressources Naturelles Canada. (2005)). Detail for the envelope retrofit shows 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 cost of the price of the total price of the retrofit. Improving the windows and the roof efficiency cost a lot for a limited result.

Table 6: Detail energy savings of the envelope retrofit

Improvement	Additional costs ($)	Energy savings (kWh)
Wall	35 000	41 673
Windows	16 367	5 921
Roof	26 093	8 497
Envelope Airtightness	3 900	29 729

Renewable energy

A net zero building requires to supply the energy needs with on-site production of renewable energy, which is easier once the energy consumption is reduced by energy efficiency measures. For gas consumption, a solar heating system of the air is the best solution. Improvement of the envelope and the airtightness of the building allowed a strong fall in demand in heating and allows to fill 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. Electricity production by 226 photovoltaic panels 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 made, it is important to assure a follow-up of the energy performances of the building.

Table 7 presents the annual consumption to be filled and the appropriate sources of renewable power production. The supplied energy was calculated using Retscreen software and the Vancouver solar radiation data.

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Table 7: Supplied energy for the building

Type of consumption	Annual consumption (kWh)	Renewable power production	Supplied energy (kWh)
Gas consumption	17 247	Solar heating of the air	17 472
Electricity consumption	133 989	Photovoltaic panels	134 315

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. Additional costs, the return on investment and savings due to the renovation of the envelope and installation of renewable sources of energy were estimated with Retscreen software (Table 8).

Table 8: Annual savings due to the energy performance

Measures of efficiency energy	Additional costs ($)	Savings ($)
Envelope retrofits	81 360	9 452
Photovoltaic panels	234 112	12 594
Solar heating of the air	7 280	1 726

The return on the invested own capital considers the flows of money of the project from the beginning, but also the financial lever (function of the level of debt), what makes it a much better financial indicator of the project than the simple return. 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.

The debt ratio is the most influential value on the return on investment. The more the ratio is low, the more the project will be profitable quickly. Duration of the project is 25 years (approximately the life expectancy of a solar panel) and the duration of the loan of 10 years. The return on own capital for a 50 % debt ratio is of 16 years. Other values for the debt ratio are presented in the table 9.

Table 9: Return on investment

Debt ratio	Return on investment
10%	14.4 years
50%	16.4 years
90%	18.4 years

The Impact of the location on the Approach Study: Quebec

The impact of the building location on consumption, upgrade measures, and return on investment was also performed in this study. The numerical modelling were performed by changing the weather input files in SIMEB and Retscreen from Vancouver to Montreal, to evaluate the relevance of the energy efficiency measures. For Montreal, the total consumption is 28% higher than in Vancouver, due to a 50% increase in the heating consumption (Table 10).

Table 10: Consumptions for Vancouver and Montreal

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

In Vancouver, electricity costs 0.094$/kWh and gas costs 0.074$/kWh, whereas for Montreal electricity costs 0.08 $/kWh (Ministère de l'énergie et des ressources naturelles. (2014)) and gas costs 0.033 $/kWh (Ministère de l'énergie et des ressources naturelles. (2014)). Even though the total consumption for Montreal is 28% higher than for Vancouver, the energy bills are 21% lower, because of the lower energy price in Montreal than in Vancouver. If we consider the same efficiency energy measures done in Vancouver then, the energy needs are reduced of 39%.

The return on investment of the optimized building in Montreal was calculated using Retscreen using various debt ratio. Results show that the return on investment is higher than 25 years for any debt ratio. So the upgrade of energy efficiency of a commercial building is not economical in Montreal. Moreover, additional improvement is possible in Montreal by using higher insulation for the walls, roof and windows. Changing gas

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heating to electricity heating is a more realistic renovation in Montreal and this choice was already made.

Table 11: Energy bills for Vancouver and Montreal (basic building)

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

DISCUSSION OF THE RESULTS

Results are from simulation and it is necessary to expect that real consumption is not quite identical because every software has its own limitations. Furthermore, the consumer's behaviour may influence the real energy consumption of buildings as well.

Simulations do not consider some characteristics of the net zero building such as:

- Improvement of the floor insulation which can allow to reduce heating losses and heating consumption
- Operating costs of the solar collector which can increase the annual expenses and the return on investment
- Systems of shade on windows to limit heating gains in summer and decrease air conditioning consumption

To reach a net zero building we must consider:

- Decreasing the water consumption,
- Using ENERGY STAR equipment,
- Ecological impact of the life cycle of materials used.

CONCLUSION

The presented results are from the simulation and so real consumption is not quite identical, the modelling of a building may not reflect the reality.

The study concerning the search for the best measures of energy efficiency for the building's renovation allow us to establish a scenario of energy renovation of the RDH's building to improve its energy efficiency of the building. However, improvements do not allow to reach a net zero building because the energy consumption remains too high, due to the heat loss through the envelope, through the floor. To reach a net zero building, it is important to consider other elements such as: decreasing the water consumption, using low-energy equipment, the ecological impact and the life cycle of the used materials.

The measures of energy efficiency and installation of renewable energy are interesting. The improvement made on the building envelope in terms of airtightness and insulation allows to reduce of 45 % the annual energy consumed due to an investment at 133 553 $. This reduction of energy use allows to save 9 124 $ annually. Furthermore, installation of photovoltaic panels and a solar collector allow to fill the remaining energy needs. It is important to know that the return on investment is influenced by the energy consumption of the building but also by the energy price in the studied city. A lower energy price such as the city of Montreal does allow to reach a return on investment below 25 years for this kind of building.

To validate such a study, it is essential to realize measures of the real performances of the building. Only the follow-up of the performances allows to make sure of the viability of a net zero and so to obtain a certification which will allow to identify this building as a net zero building.

RECOMMENDATIONS

To complete this study, it is necessary to proceed to a life-cycle analysis with SimaPro to verify that improvements on the building and its use does not increase its carbon footprint.

Furthermore, an analysis of sensibility could estimate the robustness of the scenario of renovation in front of economic fluctuations, such as the energy price.

Finally, this study concerns the renovation of a building, a next study could compare a scenario of renovation with the construction of a new building.

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