

ENERGY EFFICIENCY

Potential for Improving Energy Efficiency

Adding a green roof to a building changes the thermal performance of the roof assembly. The drainage, growing medium and vegetation layers installed over the waterproof roofing membrane have the following four main effects:

1. Reduced absorption of incident solar radiation by the roofing membrane
2. Increased thermal insulation value of the roof assembly
3. Increased thermal mass of the roof assembly
4. Increased evaporative cooling of the roof assembly

This document describes the study conducted to estimate the annual savings in heating and cooling energy consumption that can be achieved by installing a green roof on a typical commercial office building located in the Region of Waterloo.

Methodology

To estimate the building energy performance benefits of installing a green roof, simulations were conducted using EE4/DOE-2 building energy simulation software. Empirical results provided by the National Research Council of Canada (NRC) were also used to complement the simulated results. The following steps outline the methodology used to prepare the energy performance results:

1. Definition of a typical commercial office building (i.e. the reference building) using the MNECB prescriptive building standards.
2. Preparation of a model of the reference building using EE4/DOE-2 building energy simulation software.
3. Simulation of the reference building to determine the base case heating and cooling energy consumption.
4. Simulation of the reference building with a perfectly insulated roof to approximate the best case heating and cooling energy consumption savings for a green roof.
5. Modification of the results (based on empirical and simulated data) to estimate the actual heating and cooling energy consumption savings for the reference building with a generic green roof system.

Description of Reference Building Model

The reference building was based on a typical low-rise commercial office building designed to the prescriptive requirements of the Model National Energy Code for Buildings (MNECB) for Ontario, Region A. Weather data for Toronto, Ontario was used since it was the closest location to Waterloo with an available weather file.

It was assumed that the building used natural gas as the primary heating fuel. The energy cost rates assumed for the analysis were: Electricity=\$0.12/kWh, Natural Gas=\$0.370/m³.

Table 1 presents selected parameter values for the 1-storey reference building.

Table 1: 1-Storey Reference Building Parameters

Parameter	Value
Space Use:	Office
Heating Setpoint:	22°C [with 18°C set-back]
Cooling Setpoint:	24°C [with 35°C set-up]
Building Length:	40 m
Building Width:	40 m
Building Area:	1600 m ²
Building Height:	3.5 m
Model Zones:	North, East, South, West, Core
Floor Description:	Uninsulated shallow slab
Wall U-Value:	0.550 W/(m ² ·C)
Window U-Value:	3.200 W/(m ² ·C)
Window SHGC:	0.64 [energy neutral in EE4]
Window to Wall Ratio:	25% [equal on all sides]
Roof U-Value:	0.470 W/(m ² ·C)
HVAC System Type:	Packaged VAV [hot water heating, DX cooling]
Boiler Thermal Efficiency:	80%
Cooling Efficiency:	8.5 EER [with outdoor air economizer]
Occupant Density	25 m ² /person
Receptacle Power	7.5 W/m ²
Lighting Power Density	18 W/m ²
Minimum Outdoor Air Rate	0.4 L/s/m ²
Operating Schedule	MNECB Schedule A
Service Water Heating	90 W·person

Base Case Simulation Results

The annual energy consumption results for the reference building are presented graphically in **Figure 1** and numerically in **Table 2**. Energy consumption is categorized by end-use.

Annual Energy Consumption Summary
(1-Storey, MNECB Reference Building)

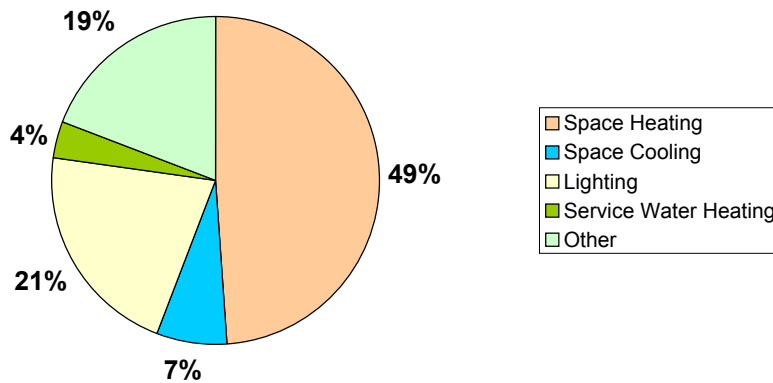


Figure 1: Annual Energy Consumption by End-Use

Table 2: Annual Energy Consumption for 1-Storey Reference Building

End-Use	Annual Energy Consumption	% of Total	Energy Source
Space Heating [MJ]	700153	49%	Natural Gas, Electricity
Space Cooling [MJ]	99360	7%	Electricity
Lighting [MJ]	305439	21%	Electricity
Service Water Heating [MJ]	51698	4%	Electricity
Other [MJ]	272740	19%	Electricity
Total [MJ]	1429390	-	-
Total / Floor Area [MJ/m ²]	893.4	-	-

Space heating is the single largest energy consuming end-use, accounting for nearly 50% of total energy consumption in the reference building. Lighting is the second largest end-use (at 21%), other miscellaneous loads (e.g. plug loads) is third largest (at 19%), and space cooling follows (at 7%). Service water heating is the smallest energy consuming end-use, accounting for about 4% of the total.

However, electricity costs are typically higher than natural gas costs. Since heating is provided primarily by natural gas and cooling is provided by electricity, a reduction in cooling energy consumption offers more energy cost savings than a similar reduction in heating energy consumption. The total annual energy cost for the reference building is estimated to be approximately \$32,805. The heating energy cost is about \$8,675 (26%) and the cooling energy cost is about \$3,310 (10%).

These results put the energy consumption by end-use for a typical office building in the Region of Waterloo into perspective. Due to the cold climate, energy consumption for space heating is very high relative to space cooling. This means that there is greater potential to reduce total energy consumption by pursuing measures that reduce heating energy use rather than cooling energy use.

Maximum Possible Energy Savings

The model for the base case reference building was adjusted to eliminate all energy flows through the roof (i.e. no heat gains or losses through the roof). In effect, this simulates a building with a roof that is perfectly insulated. This model was used to approximate the maximum energy consumption savings that could possibly be achieved by the addition of a green roof. The reference building with a perfectly insulated roof is referred to as the “ideal roof” case.

This approach assumes that the best case scenario for a green roof (in terms of energy performance) is to eliminate all heat gains and losses through the roof. However, heat gains are beneficial when the building is in heating mode and heat losses are beneficial when the building is in cooling mode. This would only be an issue during certain days in the spring and fall when one of two situations may occur:

1. the outdoor air temperature is low, the building is in heating mode and the roof is heated by the sun. In this case, heat gains would offset energy consumption.
2. the outdoor air temperature is high, the building is in cooling mode and the roof is evaporatively cooled. In this case, heat losses would offset energy consumption

Since these situations would rarely occur over the course of a typical year, they are ignored in the analysis (since they are not expected to influence the results significantly).

In addition to achieving savings by reducing the heating and cooling loads on the building, the HVAC (Heating, Ventilating and Air-Conditioning) systems could potentially be resized based on the reduced loads (particularly if the building was new construction). This provides a further potential for energy savings since proper sizing optimizes operating efficiency. Thus the first values are typical for retrofit construction whereas the “resized” values are typical of new construction.

The results for the reference building with an ideal roof for both the base case HVAC system and the resized HVAC system are presented in **Table 3**. The % difference numbers indicate the % change in energy consumption relative to the reference building.

Table 3: Annual Energy Consumption for 1-Storey Reference Building (Ideal Roof)

End-Use	Reference Building with Ideal Roof (Base Case HVAC)		Reference Building with Ideal Roof (Resized HVAC)	
	Energy Consumption	% Difference	Energy Consumption	% Difference
Space Heating [MJ]	435651	-38%	429004	-39%
Space Cooling [MJ]	92880	-7%	81720	-18%
Lighting [MJ]	305439	0%	305439	0%
Service Water Heating [MJ]	51698	0%	51698	0%
Other [MJ]	272740	0%	272740	0%
Total [MJ]	1160245	-19%	1127011	-21%
Total / Floor Area [MJ/m ²]	725.2	-19%	704.4	-21%

The differences in space heating and space cooling energy consumptions per unit of roof area between the “reference building” and the “ideal roof” case represent the energy consumptions for each end use that is attributable to the energy flows through the roof. As shown, energy consumption for lighting, service water heating and other (e.g. plug loads) is unaffected by the roof. **Table 4** presents a summary of the maximum possible annual energy consumption savings normalized per unit of roof area.

Table 4: Maximum Possible Annual Energy Consumption Savings

End-Use	Base Case HVAC	Resized HVAC
Space Heating [MJ/m ²]	165.3	169.5
Space Cooling [MJ/m ²]	4.1	11.0
Total [MJ/m ²]	169.4	180.5

Figure 2 provides a graphical representation of the maximum possible energy consumption savings for space heating. The gray shaded area represents the space heating energy consumption due to non-roof load components. This energy consumption cannot be affected by the green roof. The light orange shaded area represents the space heating energy consumption due to the roof of the reference building and is the maximum savings that could possibly be achieved with the base case HVAC system. The dark orange shaded area represents the additional savings that could be achieved with a resized HVAC system.

Figure 3 provides a graphical representation of the maximum possible energy consumption savings for space cooling. The gray shaded area represents the space cooling energy consumption due to non-roof load components. This energy savings cannot be affected by the

green roof. The light blue shaded area represents the space cooling energy consumption due to the roof of the reference building and is the maximum savings that could be possibly be achieved with the base case HVAC system. The dark blue shaded area represents the additional savings that could be achieved with a resized HVAC system.

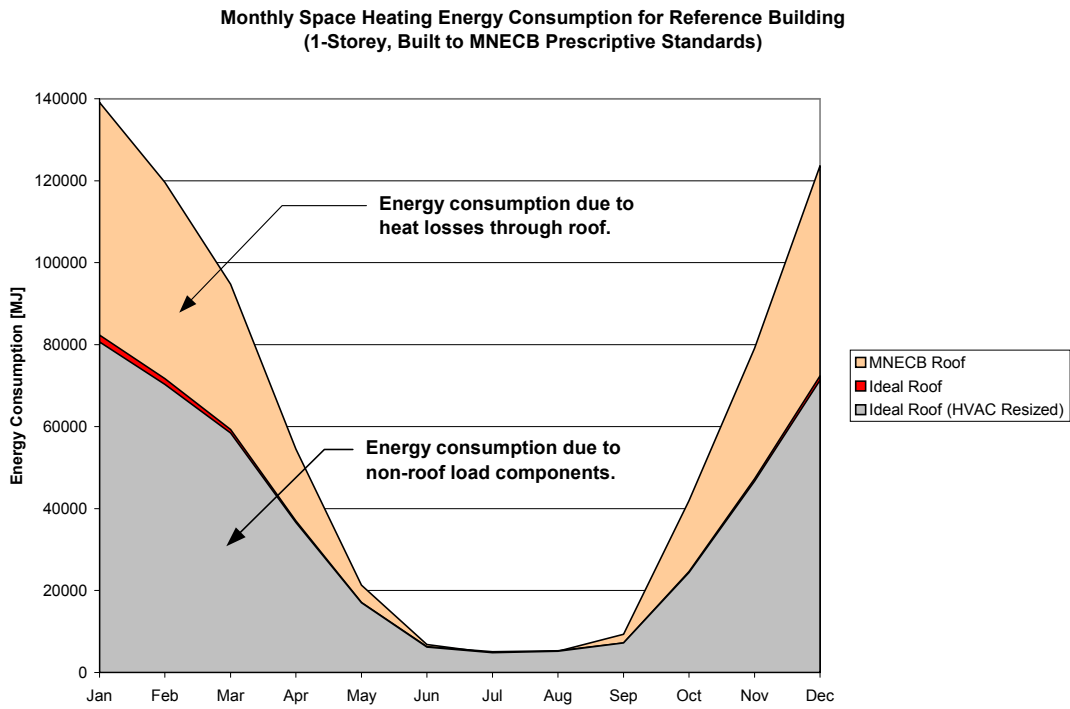


Figure 2: Space Heating Energy Consumption Reduction Potential

**Monthly Space Cooling Energy Consumption for Reference Building
(1-Storey, Built to MNECB Prescriptive Standards)**

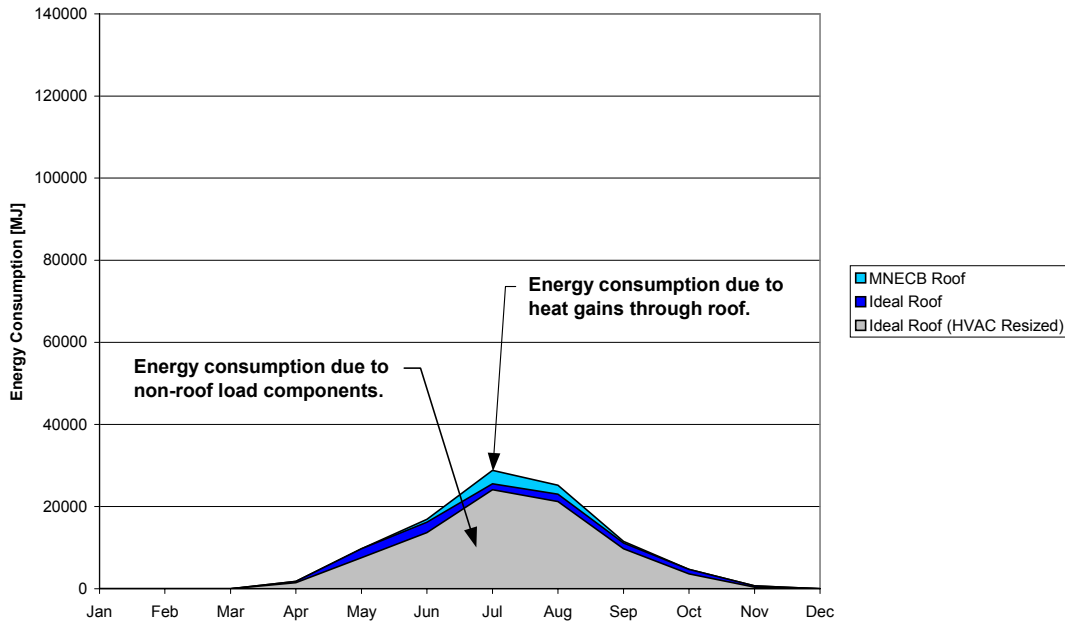


Figure 3: Space Cooling Energy Consumption Reduction Potential

Actual Savings

The actual savings in energy consumption achieved by installing a green roof is less than the maximum potential savings described in the previous section. The following analysis is based on the addition of a generic extensive green roof with 150 mm (6”) of growing medium.

According to NRC data [1], green roofs are most effective at reducing heat losses during the shoulder seasons (spring and fall), while during the winter heat losses are close to the same as those of a similar reference roof without vegetation, growing medium, etc. This is explained by the fact that, during the late fall, the growing medium becomes saturated with water and eventually freezes. This creates a nearly solid layer of ice that has very little insulating value.

Also according to NRC data, the reduction in heat gains during the summer months are up to 95% of the maximum potential reduction. This means that for the months of June, July and August the cooling energy consumption reductions are substantial.

Table 5 shows the percent reductions in heat losses and gains for a generic green roof relative to a reference roof. These values were used to predict the savings in energy consumption.

Table 5: NRC Empirical Results (% Reductions in Heat Losses and Gains) [1]

Month	Heat Loss % Reduction	Heat Gain % Reduction
January	7%	-
February	4%	-

Month	Heat Loss % Reduction	Heat Gain % Reduction
March	9%	-
April	22%	100%
May	61%	97%
June	65%	95%
July	-	93%
August	-	91%
September	62%	97%
October	25%	100%
November	11%	100%
December	15%	-

Table 6 presents the predicted energy consumption savings for the reference building when a generic extensive green roof is added (with base case HVAC systems). The annual savings predicted for heating are 20.2 MJ/m² (5% of total heating energy consumption) and for cooling are 3.7 MJ/m² (6% of total cooling energy consumption). The corresponding annual energy cost savings are about \$0.250/m² for heating and \$0.123/m² for cooling.

Table 7 presents the predicted actual energy consumption savings for the reference building when a generic extensive green roof is added and HVAC systems are resized. The annual savings predicted for heating are 20.8 MJ/m² (5% of total heating energy consumption) and for cooling are 10.4 MJ/m² (17% of total cooling energy consumption). The corresponding annual energy cost savings are about \$0.257/m² for heating and \$0.347/m² for cooling.

Table 6: Predicted Green Roof Savings for Retrofit (i.e. Base Case HVAC)

Month	Heating [MJ]	Cooling [MJ]
January	3784	0
February	2024	0
March	3175	0
April	3853	0
May	2558	0
June	345	684
July	-317	3003
August	-105	1959
September	1310	348
October	4326	0
November	3621	0
December	7691	0
Annual	32264	5994
Annual/Roof Area [MJ/m²]	20.2	3.7

Table 7: Predicted Green Roof Savings for New Construction (i.e. HVAC Resized)

Month	Heating [MJ]	Cooling [MJ]
January	3897	0
February	2082	0
March	3250	0
April	3946	360
May	2622	2090
June	414	3078
July	-106	4338
August	0	3592
September	1310	1740
October	4378	1080
November	3681	360
December	7850	0
Annual	33324	16638
Annual/Roof Area [MJ/m²]	20.8	10.4

Conclusions

The addition of a green roof to the reference building appears to offer minor savings in building energy consumption. The predicted annual savings for heating energy per square meter of roof area are 20.2 MJ/m² (a 4.6% reduction in heating energy consumption). The predicted energy cost savings are about \$0.250/m² (a 1.2% reduction in total energy costs). HVAC system resizing has little effect on heating energy consumption.

The predicted annual savings for cooling energy are 3.7 MJ/m² (a 6% reduction in cooling energy consumption). The predicted energy cost savings are about \$0.125/m² (a 0.6% reduction in total energy costs). If the HVAC systems are resized as a result of the addition of the green roof, the savings can increase to 10.4 MJ/m² (\$0.346/m²).

The heating energy savings for the reference building (with resized HVAC systems) are shown graphically in **Figure 4**. The orange shaded area represents the savings.

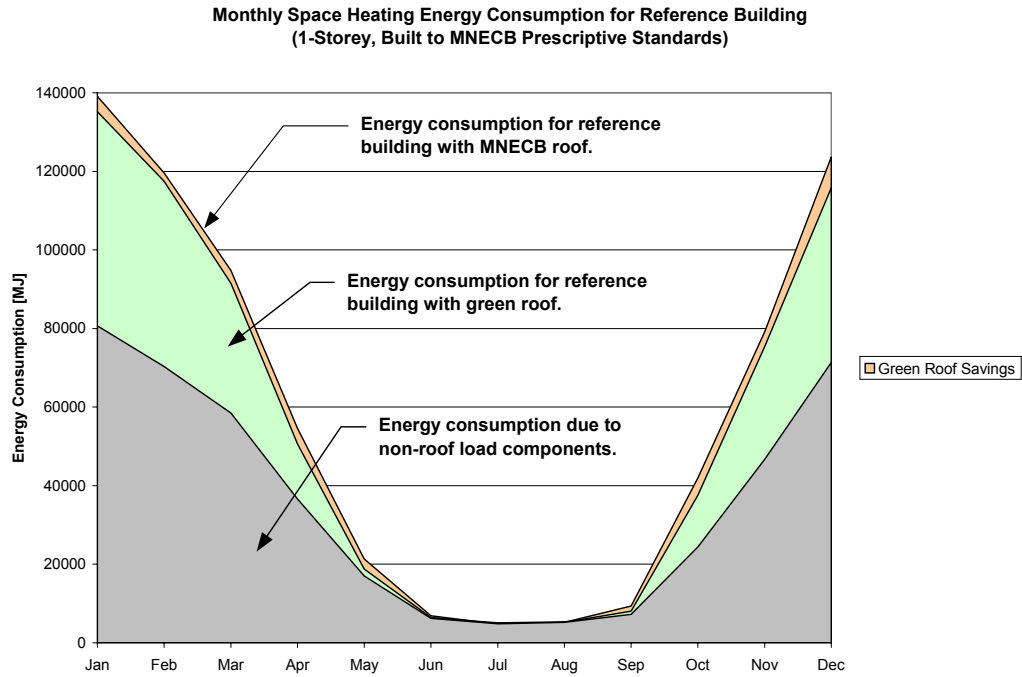


Figure 4: Green Roof Savings (HVAC Resized)

The cooling energy savings for the reference building (with resized HVAC systems) are shown graphically in **Figure 5**. The blue shaded area represents the savings.

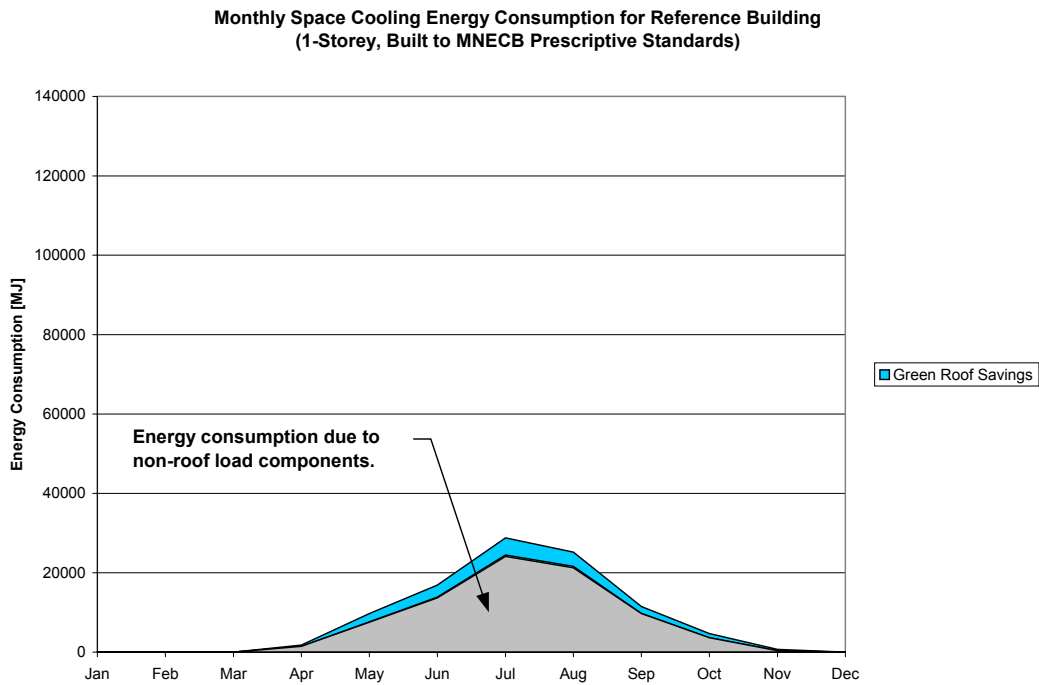


Figure 5: Green Roof Savings (HVAC Resized)

[1] Liu, K., Baskaran, B., "Thermal Performance of Green Roofs Through Field Evaluation", Greening Rooftops for Sustainable Communities: Chicago 200

Waterloo Public Library – Sample Green Roof Demonstration Site

Assessment of Energy Savings

Adding a green roof to a building changes the thermal performance of the roof assembly. This can provide an overall reduction in energy used for heating and cooling interior spaces, and as a result, reduce building operating costs.

In general, a green roof has the following four main effects on a building:

1. Reduced absorption of incident solar radiation by the roofing membrane
2. Increased thermal insulation value of the roof assembly
3. Increased thermal mass of the roof assembly
4. Increased evaporative cooling of the roof assembly

Typically, green roofs can achieve more energy savings during the cooling season. This means that buildings located in hot regions (i.e. cooling dominated climates) represent a better opportunity for significant savings. Buildings located in colder regions (i.e. heating dominated climates) such as the region of Waterloo, have a lower potential for savings.

As part of the green roof feasibility study, an estimate of the heating and cooling energy savings associated with adding a green roof on the Waterloo Public Library was conducted using information developed through energy simulations (see appendix) and preliminary plans prepared for the demonstration site.

The existing roof assembly at the Waterloo Public Library generally consists of layered built-up-roofing over one inch of rigid board insulation on a pre-cast concrete slab structural deck. There are three levels of roof – a lower roof, a middle roof and a penthouse roof. The total roof area is approximately 24 000 ft². Below the roof assembly, most spaces have suspended (i.e. drop-down) ceilings that create an air plenum. This effectively increases the overall thermal insulating value.

The plans for the proposed green roof retrofit indicate that the existing roof membrane and insulation will be removed. The green roof system will be installed over a layer of new insulation (one inch of rigid board insulation). The overall U-value of the finished assembly below the green roof is estimated to be close to 0.470 W/m²·C (R-12).

The proposed green roof covers about 70% of the roof area (about 16 500 ft²). It is assumed that 75% of the space below the green roof will be conditioned (i.e. heated and cooled with mechanical systems). Based on this area of 12 375 ft², the maximum potential savings for heating energy would be 23 GJ/year and the maximum potential savings for cooling would be 4 GJ/year. At current energy prices, this corresponds to a savings of less than \$290/year for heating and less than \$145/year for cooling.

In conclusion, the addition of a green roof to the Waterloo Public Library offers some savings in building energy consumption. The total annual operating cost savings are expected to be approximately \$450/yr.