Feasibility Study for Green Roof Application on Queen's University Campus

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Executive Summary

Increasing worldwide environmental concerns have led to the development of environmentally friendly construction practices. Green roof technology is one possibility for reducing the environmental impact of a building. Queen's Physical Plant Services is considering installing a green roof on part of the new Queen's Centre in an effort to enhance the university's image as an environmentally conscious institution. PPS has thus enlisted the help of our consulting team to investigate the environmental benefits and the financial feasibility of green roofs.

The investigation done has incorporated literature research, site visits, expert consultations and university information. It has studied the effects of green roofs on the physical and biological environment, the costs associated with materials and installation, and any financial incentives for green roof implementation.

The main benefits of green roofs are their ability to regulate the temperature in and around buildings, improve energy efficiency in buildings, reduce the urban heat island effect, retain storm water, and increase the lifespan of a roof. Further, their secondary benefits include their ability to provide therapy to humans, provide space for agricultural use, improve public perception of a company or institution, improve the aesthetic environment, increase property value, reduce noise inside a building, and provide habitat for airborne species.

Financially, a case study was performed to assess the financial feasibility of a hypothetical green roof. The roof was assumed to cost $70,000 to construct, install and maintain. It was assumed that the building ordinarily would use 90,000kWh of energy for cooling purposes annually, and that the green roof would reduce this usage by 15%. The price of electricity was assumed to be 11c/kWh, with an annual increase of 7%, for the 30 years that the roof was assumed to last for. These assumptions were based on average values found in the literature and quoted by experts. The results of the case study showed an NPV of -$33,838 and an ROI of 100%, with a break-even point of about 21 years.

A sensitivity analysis was also performed and showed that the NPV and ROI were very dependent on the percent reduction in energy cost, the initial capital investment required, and the cooling energy required annually. Thus, it was concluded that, although the financial case study did not show a green roof as being a wise financial investment, there are in fact combinations of variables that would result in a positive NPV and high ROI, which would indicated a sound financial investment.

A further incentive for Queen's to install a green roof is that it can earn a point under the Leadership in Energy and Environmental Design (LEED) rating system for doing so. LEED points can improve the public's perception of the institution's environmental awareness. This study has therefore concluded that the benefits of green roofs, combined with their possible financial incentives, render them a promising investment for Queen's University.

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1 Introduction

In today’s society, sustaining the environment is becoming an increasingly important issue. Consumers, businesses and institutions are making an effort to be environmentally conscious for the sake of the planet. In addition, businesses and institutions have the incentive of appearing more environmentally conscious to the public, and are beginning to forgo immediate economic gains for the sake of engaging in more environmentally sustainable activities.

A green roof by definition is any man made building that has been covered with plants. They are widespread in Europe, and gaining popularity in North America. They are known to reduce heat island effects and insulate buildings, thus decreasing heating and cooling costs. They have the added feature of being aesthetically pleasing and visible to the public. Further research is also showing them to have many other benefits, such as air quality improvement and storm water management. Rating systems have been developed to reward companies for abiding to certain environmental guidelines, which is an additional incentive for the use of structures like green roofs.

Currently, Queen’s is considering the installation of a green roof on the new Queen’s Centre. Queen’s also hopes that as an added benefit the green roof will reduce air conditioning costs in the building it covers. Construction of the centre is to begin in May of 2006, and Queen’s Physical Plant Services has requested the help of our consulting team to research green roofs.

2 Objectives

The objective of this study is to determine whether the environmental benefits and financial incentives of a green roof on a Queen's University roof are sufficient to render the green roof a sound investment. Specifically, the following topics will be investigated:

- The types of green roofs and what differentiates them
- The environmental benefits provided by green roofs
- Extra costs incurred by the construction and maintenance of green roofs
- Expected energy savings resulting from the presence of green roofs

3 Green Roofs Background

3.1 History of Green Roofs

Although green roofs are a relatively new technology in North America, their origins can be traced back into the distant past. The most famous early green roof is the Hanging Gardens of Babylon, which is known as one of the seven wonders of the ancient world. The gardens, most likely built around 600 B.C. covered an area of 2000m^2, and consisted of a water-tight foundation, asphalt panels, bricks and mortar on top of a column structure[39]. The garden was made up of trees, blooming bushes, climbing plants, and spice gardens, leading historians to believe that the roof garden existed for aesthetic purposes (Figure 1). While the ancient green roofs of Rome and Italy were impressive in their extravagance, diversity, and construction, the roots of modern green roofs lie in Iceland and Scandinavia. In these cold, European climates, green roofs, or sod roofs as they are commonly called, arose centuries ago from the lack of natural resources that made it necessary to construct buildings out of local materials of sod and stone. The roofs were typically made up of two to three layers of peat sod atop of a small layer of short branches and twigs. Natural vegetation would grow relatively quickly, and the roofs were sloped to allow for water run-off, since the roofs were not water-tight. Although primitive, these green roofs provided heat storage and insulation, and are the inspiration for today's green roofs[16].

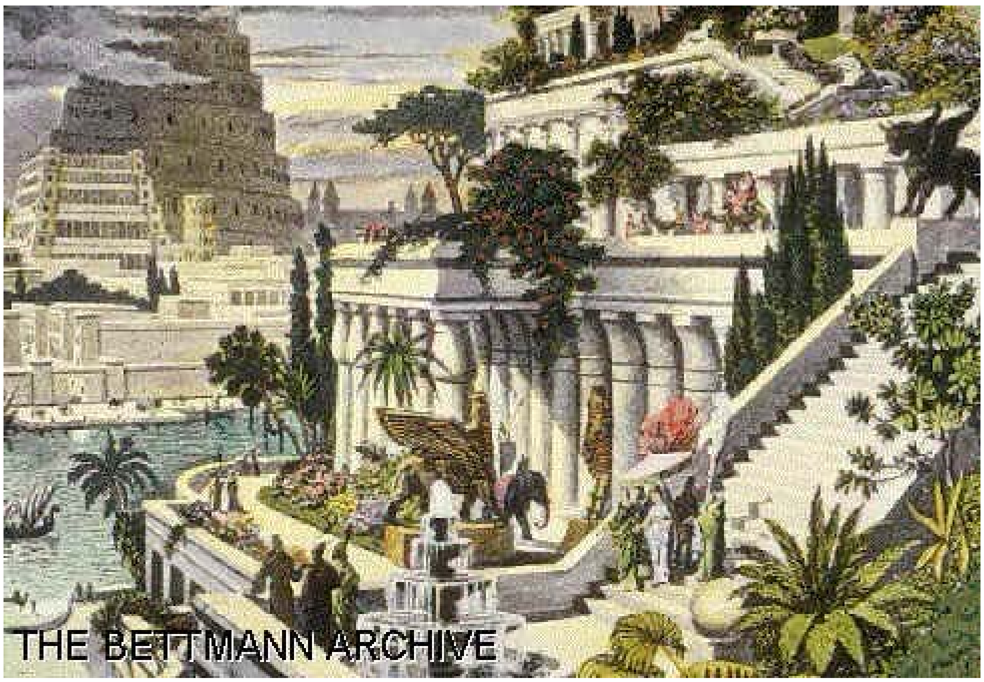

Figure 1. An artistic impression of the Hanging Gardens of Babylon [39]

The twentieth century brought a few isolated green roofs. The most impressive examples are[16]:

- The Casino Patio in Bern, Switzerland built in 1936, which still exists with 20 chestnut trees.
- Derry & Toms department store in Kensington High Street, London (U.K.), planted in 1930's. It covers 6000 m^2

However, the cost of constructing green roofs, as well as fear of structural damage, kept green roof implementation to these isolated examples. The 1950s and 1960s brought cautious advances, but green roofs were still not common, because of the following reasons:

- Flat roofs were not usually built to take large loads
- Green roofs were expensive to construct
- A larger structure would be required to hold a green roof
- Insufficient information about construction, materials, and maintenance existed

In the 1970s, building trade shows exhibited the importance of green roofs and their construction. Manufacturers developed new technologies, which in turn pushed more research and development in universities and industry. The German FLL (Landscaping and Landscape Development Research Society), which was founded in 1975 for the improvement of environmental conditions through the advancement and dissemination of plant research and its planned applications[16], released specific guidelines for the construction and use of guidelines, and from then on the construction of green roofs has been increasing. They are widespread in Europe, and gaining popularity in North America[32].

3.2 Definition

While green roofs have slowly become a very common component of buildings in Europe, they are only beginning to emerge now as a common practice in North America. The most common definition of a green roof is "a building who's roof is either partially or completely covered in plants" [44]. Other definitions go on to add that they must be a stable living ecosystem that make the urban environment more liveable, efficient and sustainable[19], however the main goal is always environmental enhancement. Common synonyms include eco roofs and vegetated roofs.

3.3 Types of Green Roofs

There are two main types of green roofs; Intensive and Extensive.

Intensive roofs tend to be more than 15 cm deep which allows for the growth of larger plants such as trees and shrubs. With the large soil thickness and height of the plants, there is more structural loading imposed by an intensive roof. As such, they require more maintenance, a watering schedule, irrigation and feeding. This extra weight and maintenance is what makes these roofs more costly. The plants chosen for an intensive roof tend to be chosen based on visual appeal.

Extensive roofs on the other hand, contain smaller plants, including shrubs, sedums (low laying ground covers), and herbs. They are self sustaining except for bi-yearly maintenance where the beds are weeded and fertilized. They tend to have lower construction and maintenance costs. Due to the low level of all the plants, they are often subjected to more weather such as wind and frost. As such, when choosing the plants used for an extensive roof, plants that are common to the area and can withstand the harsh conditions are desired. Extensive roofs are more environmentally effective than intensive roofs.

When choosing between an intensive and extensive roof, the main question is whether the roof is to be visited regularly by people. If the answer is yes than an intensive roof is required. By nature, intensive roofs are more visually appealing and therefore lend well to daily public visits.

Green roofs can be placed on both old and new buildings. However, due to the added weight requirements, it is advised that a feasibility study be completed on any old buildings to ensure that it can withstand the extra structural loading[41].

Some experts split green roofs into an intensive and semi-intensive category. The semi-intensive category is a way to bridge the large gap between a fully extensive roof and a fully intensive roof.

Below is a chart that summarizes the differences between extensive and intensive green roofs.

Table 1: Comparison of Different Types of Green Roofs[17]

	Intensive	**Extensive**
Depth of Material	More than 15cm	Less than 15 cm
Accessibility	Accessible	Inaccessible
Fully Saturated Weight	290-967.7 kg/m^3	72.6-169.4 kg/m^3
Plant diversity	High	Low
Cost	High	Low
Maintenance	High	Low

Table 2: Comparison of Advantages and Disadvantages of Intensive and Extensive Roofs

Intensive advantages	**Extensive Advantages**
Greater plant diversity and options	Lightweight
Visually appealing	Low maintenance
Good insulation	Low cost
Used as open space	Works on older roofs
Potential for higher energy savings	Easier to replace
More storm water retention	Often no irrigation or drainage system

Intensive Disadvantages	**Extensive Disadvantages**
High weight loading	Little plant choice
Necessary irrigation/drainage systems	No recreational access
High cost	Unattractive
High maintenance	Less storm water retention
High replacement cost	
More expertise required	

Within the different types of green roofs, different green roof systems or technologies can be used. The three most common systems are: complete, modular and pre-cultivated vegetative blankets. The following are described in turn below.

<u>Complete systems</u>**:** This type of system can be added to the roof either during or post construction, and consists of all the different components of the roof from the roof membrane to the plants. While this roofing system offers the greatest amount of choice in terms of membranes, mediums and plants used, it does contribute to the highest structural loading which means a higher building cost.

Figure 2 is a diagram illustrating the different components in a complete system.

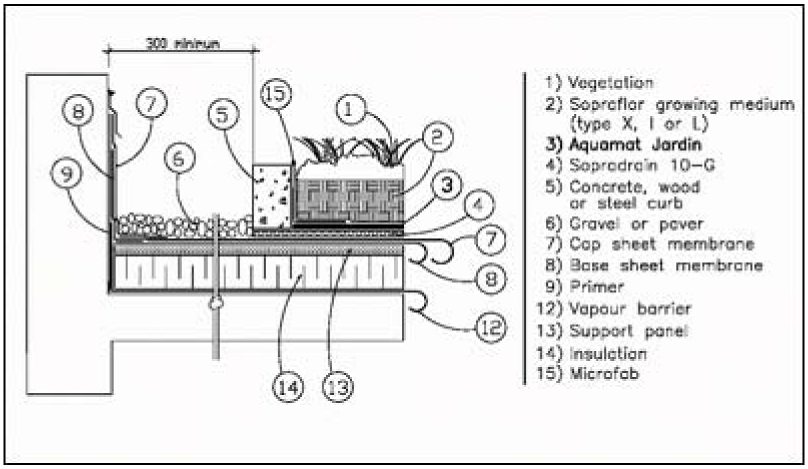

Figure 2. Different layers of a complete system[37]

Modular Systems**:** These systems are not built into the roof but are rather placed on an existing roof. The plants are typically grown in trays off site and are transported to the roof when they are fully grown. The depth and type of soil is flexible, however, deep soil layers are not common. Typically, a modular system will be within the depth range of 7.5 cm to 30cm. Figure 3 shows a diagram of a modular system.

Figure 3. Modular green roof systems[14]

Pre-cultivated Vegetative Blankets: This type of system is similar to a modular system as it is also grown off-site. The main difference is in how the blankets are installed. They typically come in rolled up interlocking tiles that can be placed on any roof. These blankets are very thin and do not offer much flexibility in terms of barrier and plant choices. Their limited height makes them a very lightweight option. Figure 4 is a figure illustrating the different layers.

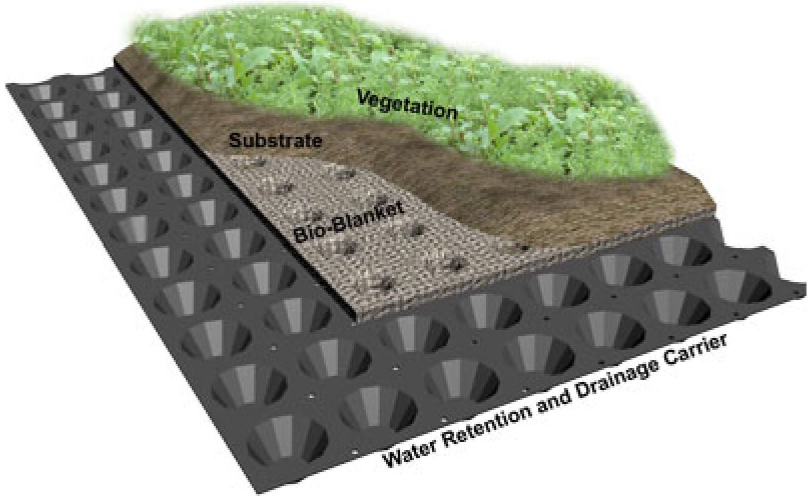

Figure 4. Pre-cultivated blanket layers[11]

Table 3 is a comparative summary of the three systems available.

Table 3: Comparison of Available Green Roof Systems

	Complete Systems	**Modular Systems**	**Pre-cultivated Blankets**
Maintenance/repair	difficult	Easy	easy
Installation	more involved installation	quick and easy	quick and easy
System	layer combinations	pre-planted	pre-planted
Weight	high to moderate	moderate	low
Flexibility	high	moderate	low
Companies	Soprema Hydrotech Roofscapes	GreenGrid Green Roof Block	Xero Flor Canada Elevated Landscape Technologies

4 Primary Benefits

There are seven main benefits to having a green roof. They include increased energy efficiency, an increase in air quality, a decrease in heat island effect, temperature regulation both on the roof and surrounding areas, stormwater retention an increase in roof lifespan and a LEED point. The following section will examine each of these in detail.

4.1 Energy Efficiency

Investigating the potential for green roofs to reduce energy demands is important for two reasons. First, reducing energy demands of a building lowers the air-conditioning costs for that building. Second, reducing energy demand reduces the strain on the earth's fragile environment by reducing pollution. This section discusses the ways that green roofs reduce energy demands on the buildings they cover. There are three major ways that green roofs help to reduce energy consumption: by adding insulation; by providing shade; and by protecting roofs from wind-chill.

Intuitively, adding a layer of soil and a layer of plants to a roof adds insulation to the building it covers. Insulation slows down the rate of heat transfer between the inside and the outside of a building. This rate of heat transfer depends on the temperature difference between the inside and the outside air. A well-insulated building will absorb less heat in the hot summer months, and will lose less of its cooled air, thus reducing air-conditioning costs. A study at the University of Waterloo found that buildings with green roofs typically have indoor air temperatures that are 3-4^{o}C lower than the air outside. Additionally, extra insulation from green roofs will cause buildings to lose less heated air in the winter[42].

Plants also prevent solar energy from reaching the roofs by providing shade. Solar energy that reaches the surface of the roof heats it up, which heats up the air just above the roof by convection. This increases the temperature difference between the inside and outside of the building, and therefore increases the rate of heat transfer between the inside and outside air. By shading a roof with plants, the solar energy is prevented from reaching the roof in the first place. Thus, the increase in temperature difference does not occur and the heat transfer rate does not increase.

The last way that green roofs increase energy efficiency in green roofs is by blocking them from the wind. In the winter, wind chill plays a crucial role in lowering inside temperatures of buildings. Even in airtight buildings, wind reduces the effectiveness of ordinary insulation. By protecting a building from wind chill, heating demand can be reduced by 25% [30].

4.2 Air Quality

Before discussing the ways in which green roofs can improve air quality, a summary of what constitutes air quality, and the current air quality situation, from both a global and local perspective is given

4.2.1 Global Air Quality

In December of 1997, Canada met with more than 160 other countries in Kyoto, Japan, to discuss the climate change challenge. These countries have recognized the urgent need to reduce greenhouse gas (GHG) emissions[13]. The "greenhouse effect" is the term commonly used to describe the earth's natural regulation of its temperature. Some of the solar energy that warms the earth's surface and surrounding air is radiated back through the atmosphere. However, some of this energy is absorbed by greenhouse gases, which form a protective "blanket" around the earth. By delaying the radiation of heat back out of the atmosphere, GHGs maintain the earth at a temperature 30^{o}C higher than it would be otherwise. Without the presence of GHGs, the average temperature of the earth's surface would be -18^{o}C[13].

GHGs include gases such as water vapour, carbon dioxide, ozone, methane and nitrous oxide. While the gases do occur naturally, human activities also produce them. For instance, carbon dioxide is emitted from the burning of coal, oil and natural gas: methane and nitrous oxide are produced by farming activities and changes in land use. Further, long-lived industrial gases that do not occur naturally are being produced. The levels of these gases in the atmosphere are increasing at an unprecedented speed. CO_2 emissions account for over 60% of the increased GHG emissions. With the current rates of emissions continuing, the CO_2 levels in the atmosphere will double or even triple from their pre-industrial levels before the end of the 21st century. The result of this increase in GHGs is the warming of the earth's surface and lower atmosphere. It is known as the "enhanced greenhouse gas effect." Computer simulation models predict that the enhanced greenhouse gas effect will increase the earth's average temperature by 1.4^{o}C to 5.8^{o}C by the year 2100[43].

This seemingly small rise in temperature will cause a significant change in cloud cover, precipitation, wind patterns, and the duration of seasons. These changes in the earth's climate are currently having and will continue to have severe consequences. Unfortunately, some climate change is unavoidable now because of past and current emissions. After 150 years of industrialization, global warming has momentum and will not stop immediately even if emissions were completely eradicated. However, reducing emissions can slow the rate of global warming, and the global community has committed to make this happen. Canada has committed to reducing GHGs to 6% below its 1990 levels between 2008 and 2012[13].

Green roofs can help reduce global warming in two major ways. The first of these is by distributing additional biomass in cities. Through photosynthesis, plants convert CO_2, water and solar energy into oxygen and glucose, thus reducing CO_2 emissions into the atmosphere. While a single green roof will not remove sufficient CO_2 to have any impact on global warming, many green roofs and parks can have an impact. The second way that green roofs can reduce GHG emissions is by decreasing the air-conditioning demand of buildings. By decreasing the temperature of a building, which can be done by a green roof, the building can lower its air-conditioning requirements[30]. Air conditioning places high demand on power plants, which release pollutants during their operation. Further, hydrofluorocompounds (HFCs) are refrigerants that are commonly used in air-conditioners, and according to Greenpeace International, are one of the most potent greenhouse gases ever invented and they contribute more to global warming than originally thought[15].

4.2.2 Local Air Quality

Perhaps of more interest to an institution such as Queen's University is the effect that green roofs have on local air quality. A major problem in Canadian urban centres is the brownish-yellow haze known as smog. While less of a problem in smaller cities, wind movement causes smog to travel. Especially in the hot summer months, smog can be a problem in rural areas far from major urban centres. Smog is particularly dangerous to the elderly and those with existing heart and respiratory problems. However, high levels of smog can be dangerous to even the healthiest people. Smog is a mixture of two main components: airborne particles and ground level ozone[12]. The contaminants that create smog are released when fossil fuels are combusted to operate vehicles, power plants, factory boilers and homes. They are also released by industrial processes, the evaporation of liquid fuels and the use of solvents and other volatile products such as oil-based paints[3].

Ground level ozone: Ozone forms when nitrogen oxides (NO_x) react with volatile organic compounds (VOCs). This process occurs more quickly when the ambient temperature is higher[1]. According to Environment Canada[12], recent studies have shown that every major urban centre in Canada has high enough ground-level ozone levels to pose a health risk. Other than immediate human health effects, ozone also poses a threat to vegetation and natural and synthetic materials. Further, it is a GHG, and thus contributes to climate change.

Airborne Particulates: Airborne particles are droplets of liquid that are small enough that they remain suspended in the air. They pose a health risk to the respiratory systems of humans. Recent studies also show that every major urban centre has high enough particulate matter in the air to pose health risks to humans[12].

While Kingston is not a major city, its proximity to industrial cities such as Toronto and Hamilton increases its smog levels. However, according to the Ontario Ministry of the Environment[2] over 50% of Ontario's smog comes from the U.S. Kingston, being a city on the border, has over 80% of its smog coming from the U.S. Environment Canada gives an index of air quality. Figure 5 shows Kingston's air quality index by month in 2005, and Figure 6 shows the air quality index and what it means.

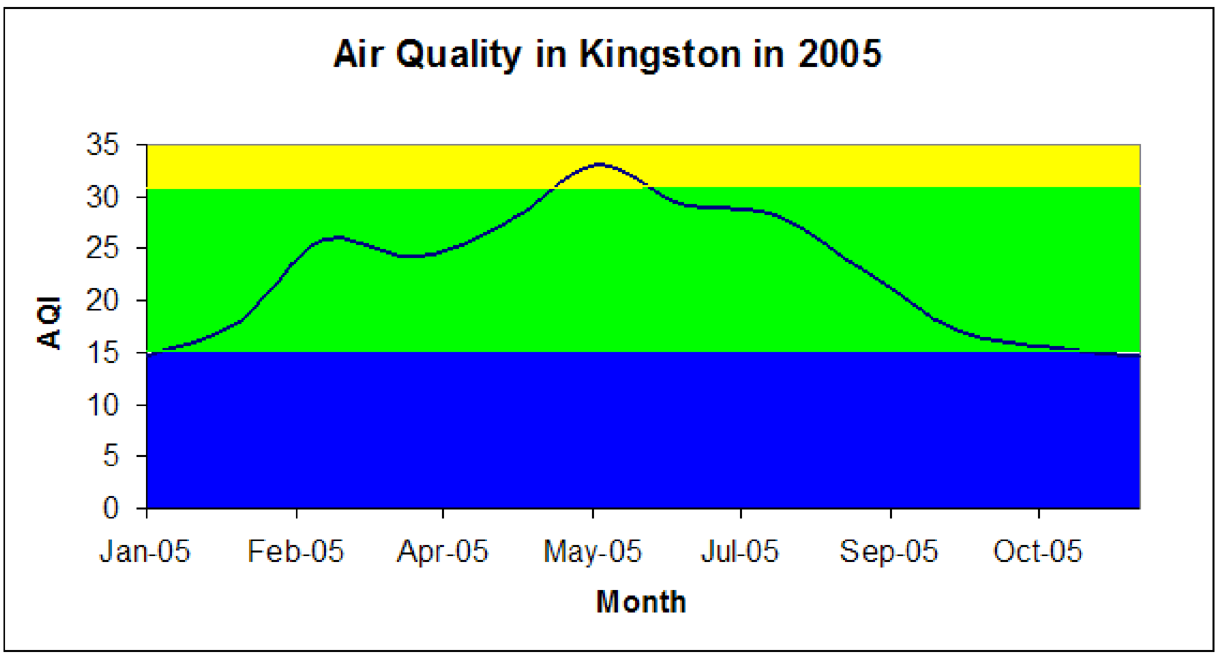

Figure 5. Air quality in Kingston by month in 2005 [28]

AQI	Colour
0-15 Very Good	
16-31 Good	
32-49 Moderate	
50-99 Poor	
100+ Very Poor	

Figure 6. Air quality index [28]

These graphs show that the air quality in Kingston was not a significant problem in 2005, with the exception of the month of May, during which the air quality level was moderate. However, according to the city of Kingston, 2005 had three times as many smog days by June 28^{th} when compared to 2004[3]. Also, in the year 2000, Kingston had 44 days during which the AQI reached the moderate level, and 2 days during which the AQU was poor[28]. According to the Ontario Ministry of Environment[28], when Kingston does have little to moderate smog in the air, it is primarily composed of ground-level ozone.

Green roofs can help the local air quality by reducing smog and by producing oxygen. Smog reduction occurs in two ways: reducing the particulate matter in the air, and lowering the ambient temperature.

Green roofs filter the air moving across them. They remove particulate matter as it passes. According to the Green Roofs for Healthy Cities website[16], 1 m^2 of grass can remove between 0.2 and 2 kg of particulate matter. Also, the City of Toronto study[19] found in a literature search that 2,000 m^2 of un-mowed grass on a roof could trap up to 4,000kg of particulate matter in its foliage, thus removing it from the air[1].

It was previously mentioned that ozone is formed more quickly at higher temperatures. The City of Toronto study also looked at a study done in the city of Los Angeles that investigated the reduction of smog by the lowering of temperatures. The Los Angeles study found that avoiding NO_x production through air conditioning by lowering the temperature inside buildings, as well as reducing NO_x by cooling the ambient city temperature by up to 3 ^oC, Los Angeles could reduce its smog output by 25%. Thus, green roofs, by lowering the ambient temperature surrounding the buildings, reduce the need for air conditioning and slow the ozone-forming NO_x and VOC reactions. Both of these reduce work to reduce smog levels[1].

Plants on green roofs produce oxygen through the previously mentioned process called photosynthesis. According to Green Roofs for Healthy Cities, 1.5 m^2 of un-mowed grass provides enough oxygen per year to supply a single human with their yearly oxygen intake requirement[16]. With the growing ecological problem of deforestation, this is a valuable benefit of green roofs.

4.3 Temperature Regulation and the Urban Heat Island Effect

There are four fundamental climate levels: climatic zones, regional climate, local climate, and microclimate. Climatic zones, which are characterized by their broad, geographic bands, are affected by land mass and large bodies of water. Global warming, which is a growing world problem, is an example of a significant change to a climatic zone. Regional climates refer to the variations within climatic zones, and local climates, such as the urban heat island effect, are subdivisions of regional climates[30].

Since climatic zones, regional, and local climates are relatively large scale, they require significant combinations of changes to affect them. However, microclimates, which are smaller and site-specific, are directly influenced by the elements on or around the site. Changing theses elements can produce a significant change in the site's microclimate. An example of a microclimate is the air just above a building, which has a different microclimate than the air at the base of the building. The microclimate above this roof can be changed by altering certain factors. Many studies have shown that the air temperature above a roof can be altered by placing a layer of soil and plants on the roof[30].

According to Callaghan and Peck[30], a lot of radiated solar energy is reflected by building materials such as concrete and asphalt, which raises the local temperature. The amount of heat radiated can be reduced by green roofs. When sunlight falls on a leaf of a plant, it is used in the following ways: 2% is absorbed and used in photosynthesis to create biomass and oxygen; 48% passes through the leaf and is stored in the plant's water system, 30% is used as heat in transpiration, and only 20% is reflected. Since less solar energy is radiated back into the air when plants are present, green roofs reduce air temperatures surrounding them.

The urban heat island effect describes the excess warmth of urban areas compared to their non-urbanized surroundings. Urbanization causes surface and atmospheric modifications that generally lead to an urban thermal climate that is warmer than the surrounding rural areas, particularly at night[30]. Studying the urban heat island effect is important because it has many implications, including atmospheric pollution and internal climates of buildings. As discussed in Section 4.2, GHG production increases with increasing temperatures. Thus, GHG production will be higher in cities where the urban heat island effect takes place. However, perhaps of more interest to building owners, is the fact that urban heat islands cause the internal temperature of buildings to be higher. This increases the need for expensive and polluting air conditioning.

The “island” designation is given to the urban warming due to the near-surface air temperature profile in cities and their surrounding rural areas that resemble an island. This can be seen in Figure 7.

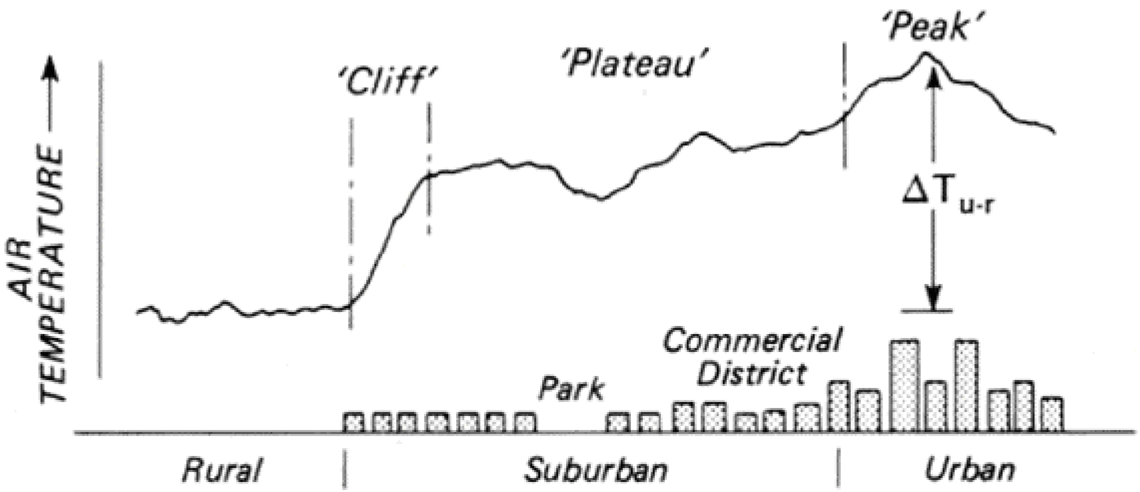

Figure 7. Generalized cross-section of an urban heat island[1]

In Figure 7, the most defining characteristic of an urban heat island is the “cliff,” or the sharp temperature rise, near the rural/suburban border. The urban heat island has a “plateau”, where it has a relatively constant temperature over parks, residential, and smaller-scale commercial districts, and then it reaches a maximum, or “peak”, which would occur over city centres. It is important to note that there would likely be several plateaus and peaks found over large metropolitan areas. The difference between the maximum “peak” temperature and the baseline rural temperature is known as the heat island “intensity.”

According to Callaghan and Peck[30], the heat island effect is mainly due to the large amount of hard and reflective surfaces in cities. In rural areas where there is more green space, a large amount of solar energy is absorbed and transformed into biomass and latent heat by vegetation, rather than being reflected back into the air. In the absence of this vegetation, the energy is radiated off of the surfaces, thus increasing the near surface air temperature. Further, buildings, transportation and industrial operations in urban areas emit large quantities of heat, which also increases the temperature in these urban areas[1].

As research on the topic of urban heat islands has increased, methods to reduce the effects have been proposed. These include designs that would exploit natural sources of cooler air from surrounding rural areas and lakes, increasing parks in cities, designing urban structures that would circulate air, and increasing vegetation or other sources of water in cities to increase evaporation. It has been found that tree planting programs in metropolitan areas have had beneficial effects on air temperature, aesthetics and GHG production[1]. However, due to limited space in cities, tree planting is not often a viable option.

Green roofs create the opportunity to increase vegetation and soil in cities, thus providing the required evaporative surface for natural energy consumption, without using up valuable space. They can significantly reduce the near-surface air temperature, thus reducing air-conditioning costs and pollution.

4.4 Stormwater Retention

Stormwater is the precipitation that falls on impervious surfaces, flowing to the lowest point as surface runoff. The majority of the stormwater that conveys from a rooftop within an urban setting washes into the municipal storm sewer system. This can cause strain on the drainage system during storm events and can lead to a number of problems including flooding, sewage backup, congestion of waterways, and water quality issues. As the stormwater flows over impervious surfaces it has the potential to obtain pollutants such as gasoline, motor oil, bacteria, fertilizers and pesticides before entering the receiving water.

Locally green roofs can potentially alleviate overloading of municipal sewer systems by stabilizing water flow and reducing stormwater runoff from 70% to 90% annually[31]. During a 15 month period from 2002 -2003, a study in Portland, Oregon was conducted on the effects of green roofs on stormwater retention. It was found that an extensive green roof with a growing medium of 10-12 mm could retain 69% of total rainfall[36].

A green roof company, Hydrotech, has a tool on its website for calculating water retention capabilities of a green roof based on its size and soil depth[20]. Assuming Queen's would install a 280 m^2 extensive green roof with a soil depth of 15 cm, it could expect 70% water retention. The spreadsheet calculation can be found in Appendix B. If Queen's were to install an intensive green roof of the same size but having a soil depth of 40 cm, it could expect 80% water retention. Since 40 cm of soil will be costly and much heavier than 15 cm of soil, and only provide a 10% increase in water retention, the extensive roof that has 15 cm of soil makes more sense for Queen's from a stormwater retention standpoint.

4.5 Roof Lifespan

The vegetation placed on top of a roof prolongs the life span of the roof in three ways. Firstly, it protects the layers and outer membrane of the roof from ultra-violet rays (Figure 8). This essentially slows down the wear of the roofing material. Secondly, it protects the roof from punctures, rips and other physical damage. This damage is mainly bestowed on the roof by people, debris and weather.

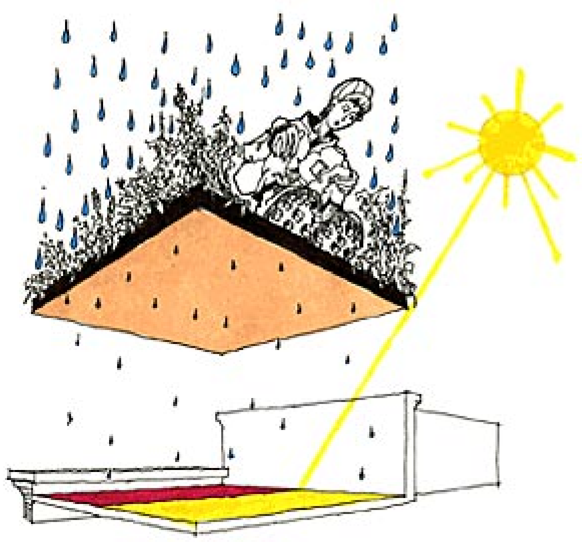

Figure 8: UV rays are absorbed with a green roof in place [34]

Finally, the green roof protects the roof from extreme temperature changes as the plants absorb much of the heat and use the energy for photosynthesis in summer months. This is beneficial because it minimizes the typical damage from expansion and stresses on the roofing material. It has been shown in previous studies that roofing temperatures can reach 80^{o}C with a black roof while the green roof in the same environment had a maximum temperature of 27^{o}C. The green roof can also protect the roof in harsh winter conditions by protection from frost and ice formation[21].

The graph below shows a comparison of temperatures between a green roof and a typical gravel roof in Philadelphia. Clearly, the temperature fluctuation with a green roof is much less severe.

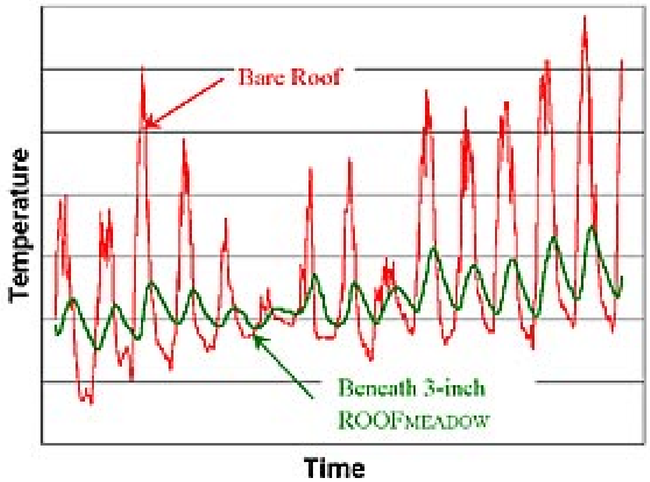

Figure 9: Temperature comparison with and without green roof [34]

The combined result of these three factors is an increase in the life span of the roof. Most companies claim that the roof will last at least twice as long as a typical roof. Not only is this a cost saving for the building owner (because the roof would have to be replaced less often), but is also beneficial to society because it will reduce landfill wastes[34]. With Canada only recently installing their first green roofs, not much data has been acquired on roof lifespan. However, a case study example performed on the roof of a Kensington High Street Building in London shows promise towards a significant lifespan improvement. The green roof installed in 1938 was examined 50 years later and found to be in full functioning form. This can be compared to the average roof lifespan of 25-30 years[21].

4.6 LEED

Leadership in energy & environmental design (LEED) is a rating system that has been developed in the United States and is now being implemented in Canada by the Canada Green Building Council (CGBC). LEED's main goal is to create nationwide standards, requirements and prerequisites for a "green" building. Points are given out in each different category and add up to a total score that will determine which level of LEED you can achieve. The four levels of

LEED are: certified, silver, gold and platinum. Each higher level represents a more environmentally friendly and efficient building.

Points are given out in 6 main categories. By design, the LEED program is primarily geared towards new buildings. The six categories are as follows.

1. Sustainable sites
2. Water efficiency
3. Energy and atmosphere
4. Materials and resources
5. Indoor environmental quality
6. Innovation and design process

A green roof can help a building owner obtain one LEED point in the sustainable site category. There is also potential for a green roof to earn points in other categories. The intent of the roof is to reduce the heat island effect while also helping to minimize the thermal gradient effect on the climate and human/animal habitat. The requirement is that 50% of your roof be covered with a green/vegetated roof. As such, any Queen's building that is 50% covered with a green roof would be able to receive one LEED point as long as documentation is provided and has been stamped by the architect, civil engineer or installation company.

5 Secondary Benefits

The following section will describe further benefits to Queen's that may be incurred with the implementation of a green roof. Some of these benefits, while called secondary, are just as important as many of the primary benefits. However, due to their nature, it is more difficult to quantitatively assess their worth as they have more social benefits than monetary value.

A poll was completed throughout the Queen's community to assess how highly the students value a green campus. It was found that 91% of students polled would be willing, theoretically, to pay a fee to help Queen's increase its green practices. While only 46% of students took into account the "greenness" of a school when choosing which university to attend, 82% are aware of the green practices currently on Queen's campus, such as the living wall in the Beamish Munro building. When asked how import it was to students that Queen's makes an effort to be as green as possible, the average answer was a 4 out of 5 and 96% said that they supported Queen's in the implementation of green roofs. This poll demonstrates that the average student is aware of the green practices on campus, supports the green practices and would like to see more in the future. The questions asked and final results can be found in Appendix A

5.1 Therapy

The presence of greenery in cities, homes and offices has long been known to have positive psychological effects on humans. A study conducted by the human-environment research lab showed that communities with higher amounts of green space had a "greater sense of community, reduced risk of street crime, lower levels of violence and a better capacity to cope with life demands."[22] Studies around the world, in places such as the Netherlands, have shown that green space is positively related to mental and personal health. They found that it was not necessary for people to be immersed in the green space for improvements in mental health. Viewing it from the street, office or classroom would still have positive effects[40].

While studies have been done on this topic, it is difficult to quantitatively measure people's well being while keeping all outside test variables constant. The physical benefits are thought to come from better air quality, less temperature fluctuation in the building and humidity control, where as the mental benefits are thought to come from the visual, audio (blowing in the breeze) and olfactory joys of plants[17].

Other benefits range from improving the attention span of children with ADHD, decreasing hospital patient recovery time, increasing student scoring on attentional testing, lowering heart rate and blood pressure, and increasing ease of stress management. A further study by the University of Michigan proved that "the experience of nature, whether passively observed or actively participated in, is an important component of psychological well being."[23]

Not only does it help with personal well being, it can also increase the productivity of workers. In 1990, a company in Germany found that there was a significant difference between the sick days taken in one of its buildings compared to another. The only difference that could be found was that one building had a green roof while the other one did not[27].

All the studies mentioned above, draw the same major conclusion. While the exact numbers are not known, green space has been shown to improve a person's mental and physical well being.

5.2 Agriculture

Some green roofs not only house plants, shrubs and other vegetation, but also grow flowers, fruits, vegetables and herbs. As mentioned by Green Roofs for Healthy Cities (GRHC), growing food on green roofs provides opportunities such as the support of local economy in terms of growing, processing and distributing food, fresher produce for the city as well as some income to help sustain the cost of the green roof. An example of this is the Fairmount Waterfront Hotel in Vancouver which has a green roof that grows herbs, flowers and vegetables. They estimate that by growing their own produce, they save $30,000 per year in costs.

Figure 10: Herbs can be grown on green roofs

However, there are difficulties with growing food on the roof. First, it would need extra maintenance in comparison to an extensive roof. This would mean extra man-hours to sustain the growing crops. Secondly, with the harsh winter that Kingston often incurs, unless there is a glass dome or another cover, the garden would only be valuable in the summer and spring months. Finally, there would be additional structural costs involved in the design of the building to support the extra medium needed for food growth[5].

5.3 Public Relations

It is well said by the Green Grid Company, that green roofs are “a great way of showing that you care.”[14] From the Queen’s poll, it is clear that the community is interested in the university pursuing more green initiatives. David Robinson, the assistant manager of Mountain Equipment Co-op (MEC), described how the green roof is an excellent conversation piece when meeting with clients, consumers and investors[32]. MEC has been part of the Doors Open Toronto for the past three years and has seen a steady increase in citizens interested in the building for its green roof and other environmentally friendly qualities.

In Europe, there are many government subsidies for green roofs as well as awards for creativity. While North America is not as advanced as the European countries with their green roof policies, they are slowly being incorporated. The most recent event in Ontario was the announcement by mayor David Miller of a new policy to start the implementation of green roofs on Toronto city buildings[4]. They are also starting to look into policies that would encourage others to implement green roofs.

If the direction that Europe has taken is any indication of where North America will be in 20 years, like Germany, there may soon be regulations requiring buildings to install green roofs where possible[21]. While the benefits of green roofs are only starting to be recognized in Canada, they are quickly gaining popularity and recognition.

5.4 Property Value

As mentioned before, not many studies have been completed in Canada on green roofs and therefore the data available is limited. However, one survey completed in Manchester, Connecticut[21] claimed that the addition of green space and trees to a property increases its value by an increase of 6%. This survey matches the results found by greenroofs.org that saw an increase of 6-15% in the value of homes with green roofs.

5.5 Aesthetics

Green roofs have been credited with the ability to significantly improve the beauty of buildings and to appeal to the senses of people. A green roof is a way to differentiate your building from the rest and can also help mask the ugliness of a typical roof. The following figure demonstrates the visual difference between the common gravel roof and a green roof.

Figure 11: Aesthetically pleasing roofs can be used as public space [14]

5.6 Noise Reduction

The different layers used in a green roof can contribute to noise reduction. The Federal Technology Alert report states that the soil used in green roofs can absorb traffic and other common outdoors noises[14]. It is possible to reduce noise levels anywhere from 10 decibels to 46 decibels with a minimum of a 20 cm deep soil layer. This benefit is more applicable to buildings close to highways and airports and is therefore not as important to the implementation of a green roof by Queen's University.

5.7 Airborne Species

Whether intensive or extensive, green roofs can provide habitat (food, shelter, water and breeding grounds) for many different species. The kind of species that will find shelter will range from bees, butterflies, spiders, beetles and ants to birds and ducks. It must be noted that green roofs will not fully replace the habitat lost when a building is constructed. However, it will help replenish the lost space and as stated in the federal technology alert report, help "reconnect fragmented habitats"[41].

Species will use the space because it offers shelter from human noise and activity, traffic noise as well as an escape from predators. As the new Queen's Physical

Figure 12: Wildlife on green roofs [21]

Education center will be quite high, some species may not be able to reach the top of the buildings. However, studies have shown that many different animals can use the green space on top of high buildings. Examples of this range from butterflies found on gardens of 20 storey high buildings, bees on the 23rd floor and squirrels, woodpeckers and blue jays as high as 19 floors. In order to attract local species, it is important to use similar flora found in the surrounding ground level area[21].

While green roofs are not a perfect replication of the area at ground level, it does significantly outperform a typical roof in terms of habitat for wildlife.

5.8 Summary of Benefits

The following section summarizes the benefits discussed above as they pertain to the Queen's University's new Physical Education Center. Many of the secondary benefits do not have associated cost savings. As such, the following three criteria were used to rank the benefits:

1. Cost savings for Queen's University
2. Benefits of a green roof to Queen's
3. Most highly valued benefits as seen by the Queen's community

The following table depicts which benefits fall into which of the above three categories. Some benefits have been highlighted in more than one color while others that fit into neither category have been left blank. The top benefits can be easily viewed as those with more than one color highlighted.

Table 3: Summary of main benefits as they pertain to Queen's University

Summary of Benefits	**Cost savings to Queen's**	**Benefit to Queen's University**	**Valued by the Queen's community**
Temperature Regulation			
Energy Efficiency			
Air Quality			
Storm water management			
Roof Lifespan			
Therapy			
Agriculture			
Public Relations			
Property Value			
Noise Reduction			
Airborne species Habitat			

6 Materials and Installation

6.1 Structural

The structural requirements differ between intensive and extensive green roofs. Intensive green roofs have a typical soil base of 20 – 60 cm, therefore producing large stresses on the roof under saturated soil conditions. They are more elaborate with trees and shrubs contributing to the loads, requiring greater structural stability of a heavily reinforced structure. Occupancy live loads must be considered and safety measures taken such as the installation of guard rails and unobstructed pathways for human access.

Extensive green roofs have a typical soil base of 5 – 15 cm, only 25% of that of an extensive green roof. These roofs are typically designed for limited human access due to the lack of maintenance required. Therefore the loads of an extensive green roof are less than that of an intensive green roof.

When designing the structural supports for the roof the following factors are taken into consideration; dead loads (D), live loads (L), wind loads (W) and temperature loads (T). Dead loads include the self weight of the building medium, permanent materials of construction and stationary equipment. Live loads include loads produced by intended use, snow, ice and rain. Upon the calculation of each load they are substituted into the total factored load equation.

$$w_f = \alpha_D D + \gamma\Psi(\alpha_L L + \alpha_W W + \alpha_T T)$$

where w_f = total load

Load factors, α , shall be taken as follows:

$$\alpha_D = 1.25$$
$$\alpha_L = 1.50$$
$$\alpha_W = 1.50$$
$$\alpha_T = 1.25$$

The importance factors, γ , shall not be less then 1.00

The load combination factor, Ψ , shall be taken as 0.60 when all L, W and T are acting on the structure.

Therefore

$$w_f = 1.25D + 0.60(1.50L + 1.50W + 1.25T)$$

For both intensive and extensive green roofs the wind load (W) and temperature load (T) will be the same value. The live loads of an intensive green roof will include the weight of the soil medium and vegetation (plants, trees, and shrubs), which are greater than that of the extensive green roof. The greater live load of the intensive roof will require a greater dead load, due to designing a stronger structure to resist the live loads. Therefore the total factored load for the intensive green roof will be greater than that of the extensive roof, requiring a greater capital cost.

6.2 Cross Section of a Green Roof

Intensive and extensive green roofs consist of multiple layers in order to provide a growing surface and drainage of excess water on top of the roof, as depicted in Figure 13.

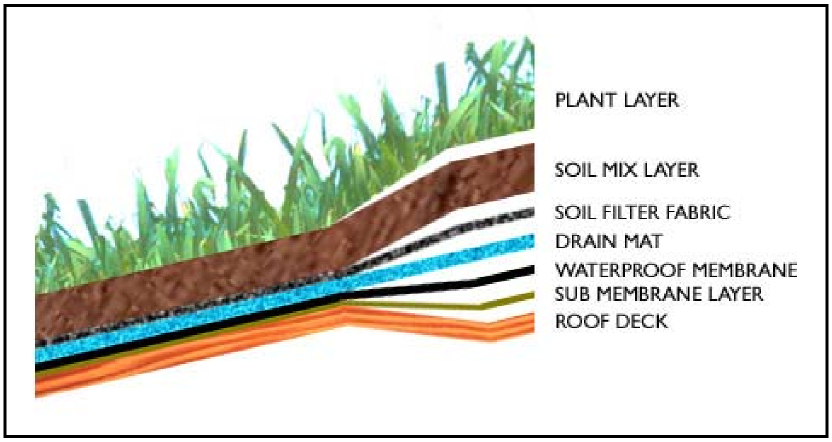

Figure 13. Green roof cross-section [29]

6.2.1 Vegetation Layer

The vegetation layer is composed of succulent or cacti like plants which survive under minimal hydration. When choosing a vegetation medium for an extensive green roof a maximum root depth of 10cm should be considered to minimize the soil medium depth. Sedums are commonly used for vegetation coverage because of their ability to store water in their leaves for extended periods of time in preparation for drought conditions. Native drylands and tundra grasses are suitable for use due to being able to survive harsh climate conditions that can be experienced upon a rooftop and require minimal maintenance. Intensive green roofs have endless vegetation possibilities to accommodate the vision of the stakeholders. Considerations have to be taken into initial and upkeep costs, irrigation and overall weight of the materials.

6.2.2 Soil Medium

The optimum soil conditions consist of ½ solid particulate matter, ¼ water and ¼ oxygen. Lightweight expanded shale or clay that is heated to over 1000^{o}C in order to expand and maximize the porosity is used as aggregate. This increase in the porosity increases the soils capacity to retain water and nutrients. The heating process also improves the aeration and drainage for optimum plant growth[36]. The addition of compost to the soil provides a high quantity of organic material and nutrients to the soil for enhanced vegetation growth.

Engineered soils play an important role in the design of a green roof. It is important that the soil medium meet the demanding physical, chemical, and biological design requirements associated with stormwater drainage. This includes moisture retention, porosity, hydraulic conductivity and maximum water capacities properties[31].

6.2.3 Soil Filter Fabric

Between the soil medium and the drainage mat is a soil filter fabric (geotextiles). This retains the soil and keeps the roots of the vegetation from penetrating the drainage layer and potentially clogging the drainage layer thus reducing its effectiveness. Geotextiles are permeable fabrics which are engineered to retain a specific grain size from passing through.

6.2.4 Drainage Mat

The drainage mat diverts any excess rain water that is not absorbed by the soil medium or vegetation to roof top drains. The water is then able to run off site to a soak-away pit or stormwater system.

6.2.5 Waterproof Geomembrane

Geomembranes are impermeable layers that protect the roof deck from infiltration of water. Multiple sheets of geomembranes can be welded together using a hot rubberized fluid application, this adheres the sheets to make one continuous impenetrable layer protecting the roof deck.

6.3 Installation

The installation of a green roof must meet the German FLL standards, currently the only internationally recognized building standards for green roofs. It is imperative that any stormwater that is not absorbed by the roof is drained properly. In the event that water breaches the waterproof geomembrane, this non-drained water can cause extensive damage since it cannot evaporate.

To ensure the conformity of the geomembrane, it can be tested with an Electric Field Vector Mapping (EFVM) to detect leaks. This test is performed immediately after the geomembrane has been installed by moistening the geomembrane and running a current through two probes. A leak is detected when the current from the EFVM is grounded to the roof deck, depicted in Figure 14 & 15.

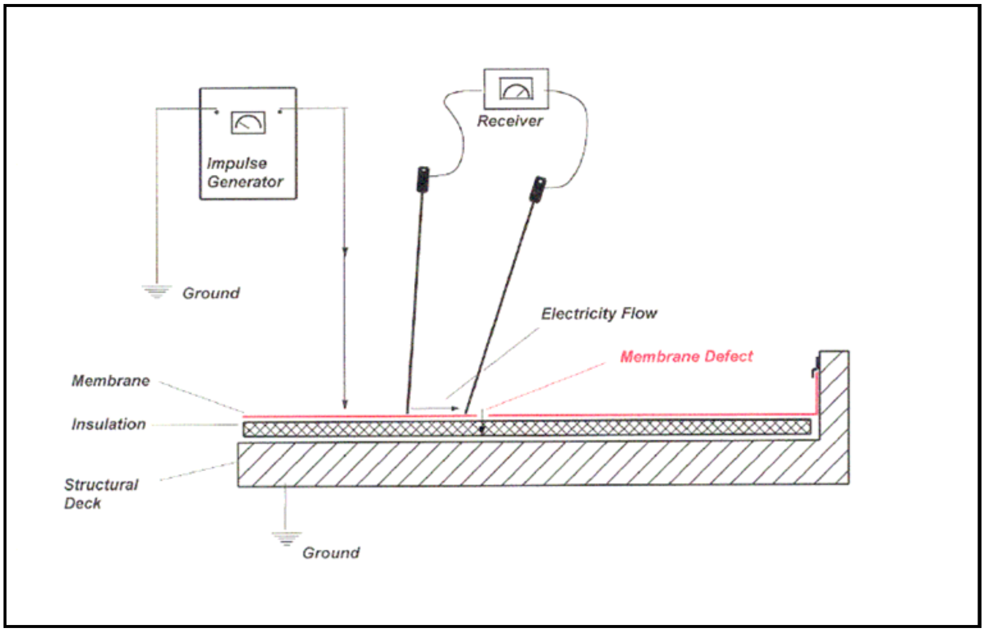

Figure 14. Electric Field Vector Mapping Technology [38]

Figure 15. Electric Field Vector Mapping in practice [38]

The leak test is performed as follows:

- An examination wire is set up in a rectangular loop around the test area and is connected to a pulse generator
- Every three seconds, a pulse is delivered for a one second duration

- An electric potential difference is created between the wet layer of medium and the grounded roof deck. If there are any leaks, the electric current will flow from the medium through the puncture hole to the roof deck
- Using a receiver and two probes, the direction of the current can be determined, and by moving them across the test area, the puncture can be pinpointed

Because of the high electrical resistance of the roof medium, the current is relatively small. However, it is the current direction that is used to find the leak in the membrane, therefore the magnitude of current is not important[38].

Recommended for absence of precipitation is the installation of an external water source or irrigation system. This ensures that the growth medium receives adequate nutrients and moisture under all climate conditions.

6.4 Maintenance

The amount of maintenance required for a green roof depends on which type is installed; intensive or extensive. Since at this point extensive appears to be a more suitable option for Queen’s university, it will be the focus of the following analysis.

Most companies that install green roofs claim that there is little to no maintenance required for extensive green roofs. To determine the validity of this claim, David Robinson the assistant manager of Mountain Equipment Co-op (MEC) was contacted to see how much maintenance their extensive roof required. The approximate cost of maintaining their green roof was $5000/yr. This included the hiring of a company called Ecoman to do maintenance on the roof 4 or 5 times a year. The company sets up an irrigation system (for the summer months only), adds organic fertilizer (however this is not necessary), adds new plants if requested, takes out unwanted plants that have blown in such as poplar trees, and clears out overgrowing plants.

Figure 16: Extensive roof on MEC building in Toronto

Currently, Queen's roofs are visited minimally to clear off debris and for inspection purposes. With the addition of a green roof, the roofs would need to be visited more often, but provided Queen's maintained the roof themselves, no extra money would be expended.

6.5 Challenges

In terms of the construction of green roofs, one of the challenges is that there is currently no national design standard for green roofs. Though the German FLL exists, the design of green roofs needs to be integrated into the National Building Code of Canada (NBCC), or have a code of its own in order to properly define the design requirements for Canadian green roof construction.

7 Financial Analysis

There are a few reasons for which an exact financial analysis is not possible. First, the energy savings that will result from a green roof are very sensitive to factors individual to each green roof and building. Second, the building has not yet been constructed, and therefore has no existing energy costs to reduce. However, using basic assumptions, including literature research, information provided by green roof companies, and information provided by Queen's Physical Plant services, reasonable estimates of a range of required capital investment and subsequent savings can be made.

7.1 Capital Investment

The cost of the green roof and its installation will vary greatly based on the design chosen by Queen's. A representative from Soprema, a reputable green roof company in Canada, has supplied information on the prices of Soprema's products[10]. Soprema is the company that built and installed the extensive green roof on top of MEC's Toronto store. This green roof is likely similar to one that Queen's would consider, so it is not unreasonable to assume that Queen's might install a Soprema green roof, or one that is similar in price. Thus, the capital investment estimate is based on Soprema's prices.

The prices of the components of a Soprema green roof can be found in Appendix C, and in more detail in the Electronic Appendix. Because the combinations of the components, the installation costs, and the size of the green roof affect the price, it is difficult to make an exact calculation of the capital required for a Soprema green roof. However, Chris Elliot[10] provided an estimation of the cost of a green roof per square foot over and above the cost of the "conventional roof" that lies underneath it. Mr. Elliot estimated this cost to range from $30-$50 per square foot, which can be converted to $320-$540 per square meter. This estimate is for a higher end Soprema green roof. Marie Bovin, another representative for Soprema, quoted in the Montreal Gazette[24] that a green roof costs $11-$15 per square foot, which can be converted to approximately $120-$160 per square meter. It is clear that there is a wide range of possible green roof installation costs. For the purpose of this financial analysis, the green roof cost for materials and insulation is assumed to range from $160/m² to $430/m². The green roof at Queen's is not expected to reach $540/m² since Queen's will likely purchase an extensive, inaccessible green roof that will not be the most expensive roof available. Also, Queen's is unlikely to install the bare minimum green roof, so the minimum cost is assumed to be at least $160/m².

It is also being assumed that the cost of maintaining the roof will be negligible compared to the capital investment. This is based on the fact that a MEC representative commented that very little additional maintenance is required for MEC's green roof [32]. Further, most reputable companies offer lifetime warranties to repair any damage that occurs in the roof. Finally, because Queen's is a university, it could potentially have students maintain the roof as part of an educational program.

Because the Queen's green roof will be approximately 275m² in size (see Appendix D for calculation), the green roof materials and installation will cost anywhere from $45,000 to $120,000. The lifespan of the roof is expected to be 30 years (an approximate average of life spans quoted in the literature).

7.2 Energy Savings

Most of the literature research done has indicated that the savings in energy resulting from a green roof will be in cooling costs. According to an NRCC study, green roofs are more effective at preventing heat gain in the summer than heat loss in the winter[25]. This is because green roofs reduce heat gain through shading, insulation, evapotranspiration and thermal mass. They reduce heat loss only through insulation and decreased radiation heat losses. A recent study by Karen Liu[26] has found that in certain situations green roofs can be as effective at preventing heat loss in the winter as preventing heat gain the summer, and therefore reducing heating costs. However, this requires that the green roof be specifically designed for winter use. It must have a deeper soil and larger, winter plants, to increase insulation. For the purpose of this financial study, it is assumed that Queen's will likely invest in an extensive green roof, thus resulting in cooling energy savings, and not in heating energy savings.

The percent reduction in cooling energy costs is difficult to estimate, since it is dependent on many factors, including the design and layout of the building, the insulation in the walls of the building, and the size and design of the green roof itself. Intuitively, it would seem that an intensive green roof would insulate a building more than an extensive green roof, due to the higher soil thickness required for an intensive green roof. However, while this can be true, there are many factors that affect the insulation value of a green roof, including soil thickness, density and moisture content[8], so the soil thickness alone is not necessarily an indication of insulation value. Some studies have found extensive green roofs to be better insulators than intensive green roofs, and they attribute this to the fact that the insulation value of mixed grass, which is commonly found on extensive green roofs, is higher than that of low-growing sedum, which would be found on an intensive green roof[30]. For the purpose of this study, green roof specifications have not been chosen, and it is assumed that different combinations of characteristics will result in different energy savings. Therefore, estimates for energy reduction percentages have been found in the literature and from experts in the field, and will be used in this study. The following energy percent reduction estimates have been found:

- Don Cruikshank of the company that installed the Ottawa War Museum green roof estimated up to 10% cooling energy reduction[6]
- An Environment Canada Study estimated 25% reduction[24]
- Callaghan and Peck estimated 50-70% savings, based on how much the indoor air temperature was lowered[30]. However, this study also assumed that vertical gardens were insulating the walls of the building, providing increased energy savings. Therefore this estimate is likely high

It should also be noted that a green roof over a one story building will reduce energy costs more than a green roof on top of a multiple story building. Since the Queen’s building will be multiple stories, it will likely experience cooling energy savings on the low end of the above estimates. Therefore, a conservative estimate of the cooling energy savings for the Queen’s building is between 5% and 25%. This financial study will investigate the feasibility of a green roof that provides savings in this range.

7.3 Energy Price

Ken Hancock of Physical Plant Services provided some information on the annual energy expenditure of Queen’s. He said that Queen’s uses approximately 70 million kWh of energy per year, and that approximately 10% of this energy is used for air conditioning. He also said that about 50% of the buildings at Queen’s are air conditioned, and that the buildings that are air conditioned use more energy[18]. It is known that Queen’s has approximately 100 buildings. Putting this together, it is reasonable to assume that 90 000kWh are used for cooling one air conditioned building per year (see Appendix E for calculation). Mr. Hancock has also provided information regarding the prices that Queen's has been paying for electricity for the past few years. This information is as follows[18]:

- 2 years ago, Queen's was on contract with Ontario Power Generation and was paying 7c-8c per kWh
- Last year, Queen's paid market prices of over 10c per kWh, meaning Queen's experienced a 20% increase in electricity price
- Electricity costs more in the summer than it does in the winter. Last summer electricity costs rose to 11.6c per kWh for Queen's
- Over the past 5 years, the average yearly increase in electricity price has bee 7%

7.4 Financial Case Study

Most of the assumptions made thus far have been that variables will fall within ranges. A financial analysis in which all of the variables are varied over their ranges is not possible within the scope of this project. Instead, a financial case study has been done for assumed, exact values of variables, which are either the averages over the ranges, or are reasonable approximations of what would apply to Queen's. Following is a list of the variable values that are used in the financial case study:

- The green roof is 280 m^2 and will have a lifespan of 30 years
- Materials and installation of the roof cost $70,000, and maintenance cost is negligible
- The green roof will result in a 15% reduction in cooling costs for the building
- The building requires 90,000kWh of cooling energy every year
- The current summer electricity price is 11c/kWh, and a yearly increase of 7% will occur consistently over the 30 years.

7.4.1 Simple Payback Period

The simple payback period gives the time it takes for a venture to begin turning a profit. However, it assumes that the yearly cash flows are equal, and also does not take the time value of money into account. Since electricity prices are likely to increase every year, the yearly cash flows will not be equal. Further, the money invested in the project today will be worth a different amount later in time. Therefore, the simple payback period is not a good indicator for this financial analysis.

7.4.2 Breakeven

Breakeven, which is defined as when the total sales equal the totals costs, gives an idea of when profit will be achieved[9]. In this financial case study, the total cost is the initial investment, and the total sales are the cumulative savings in cooling costs resulting from the green roof. The breakeven point for this project is approximately 20 years. This is a relatively long time before breakeven occurs.

7.4.3 Net Present Value

Net Present Value (NPV) is used to determine the profitability of an investment or project. It describes the present value of the future cash flow of a project with a certain discount rate. The discount rate is the rate at which future cash flow is discounted because of the time value of money (a dollar today will be worth less in the future) [9]. A venture will be profitable if it has a positive NPV, and so NPV is likely a good indicator of whether or not green roofs will be a financially advisable investment for Queen’s. The NPV value for the financial case study is found to be -$33,838. Since this is a negative amount, investing in this green roof is not advisable.

7.4.4 Return on Investment

Return on investment, or ROI, is the primary measure of profitability for investors. ROI is equal to the net income divided by the investment[9]. The net income in this financial case study is the sum of the yearly energy savings. The investment is the initial capital required for green roof materials and installation. The ROI has been calculated to be 100%, indicating that the green roof will be profitable.

The calculations for this financial case study were performed in Microsoft Excel and can be found in Appendix F.

7.5 Sensitivity Analysis

A sensitivity analysis is important for this project because of the uncertainty of the values of the variables. It was noted that changing the percentage of energy savings, the initial capital investment, and the annual energy use changes the NPV and ROI significantly. Spreadsheets were made to perform calculations that return NPV and ROI for varying values of these variables within their approximate ranges. In these sensitivity analyses, the initial energy cost was kept constant at 11 cents/kWh, and the annual increase in electricity price was kept constant at 7%. The other variables not being tested for sensitivity were also held constant. First, an analysis was done to examine the effect of percent energy savings on the NPV and ROI of a green roof that costs $70,000 and when the cooling energy usage of the building is 90,000kWh. The constant values were input into the top of the "Sensitivity % Savings" spreadsheet, which calculates NPV and ROI at each of the specified percent energy savings values. Figures 16 and 17 show graphs of the results.

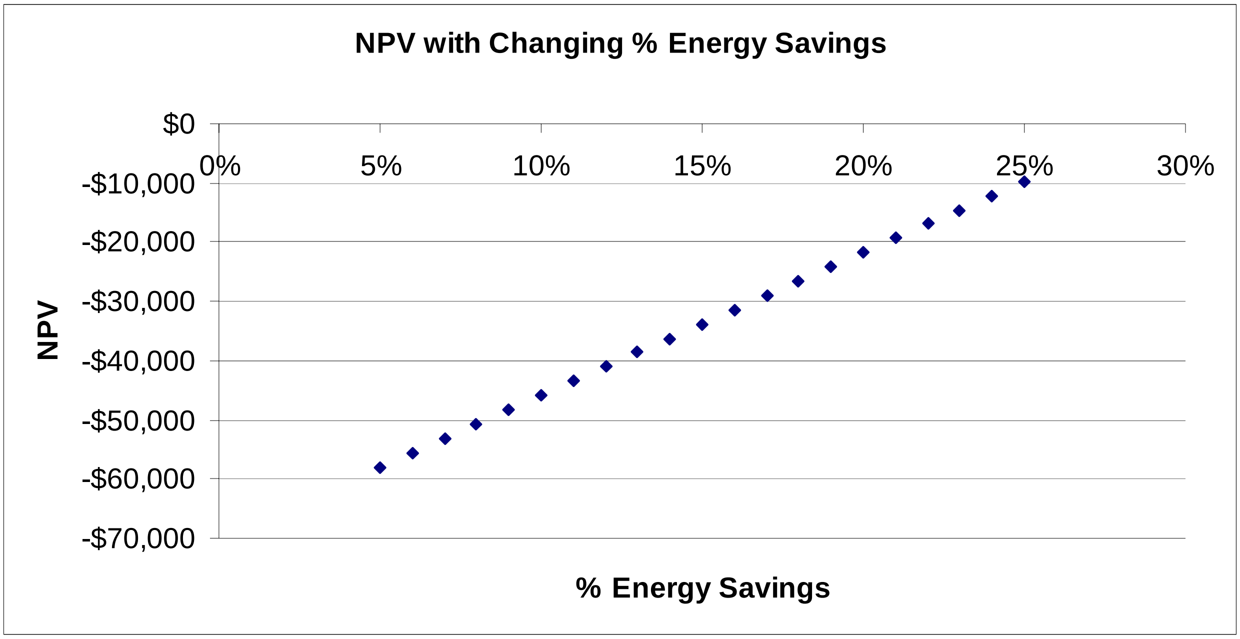

Figure 17. NPV values at varying percent reductions in energy costs

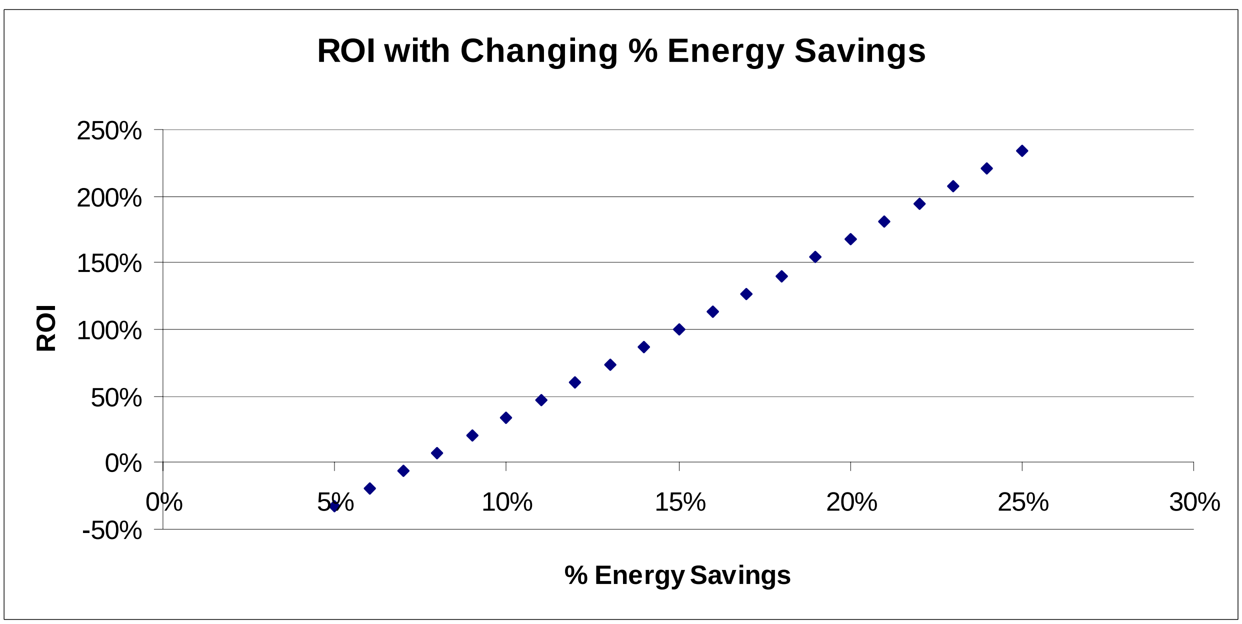

Figure 18. Return on investment with varying percent reductions in energy costs

The sensitivity analysis shows that, at the financial case study values of initial capital ($70,000), annual cooling energy usage (90,000kWh), initial electricity price (11cents/kWh) and an annual 7% increase in electricity price for 30 years, the NPV is never positive over the 5%-25% range of energy cost savings. This indicates that financially, a green roof project with these specifications is not a good investment. However, it should be noted that decreasing capital investment to $50,000 gives a positive NPV for a roof that provides energy savings of 20% or higher. This might be a target roof for Queen's to achieve. The return on investment looks promising for most of the energy saving percentages (not below 8%). This is likely due to the long lifespan of the green roof, and so Queen's would probably not see this high return on investment for quite a few years (recall the breakeven of 20 years in the financial case study).

The next sensitivity analysis was performed by changing the initial capital investment, and keeping the other variables constant at their financial case study values. Figures 18 and 19 show the NPV and ROI, respectively, with varying capital investment.

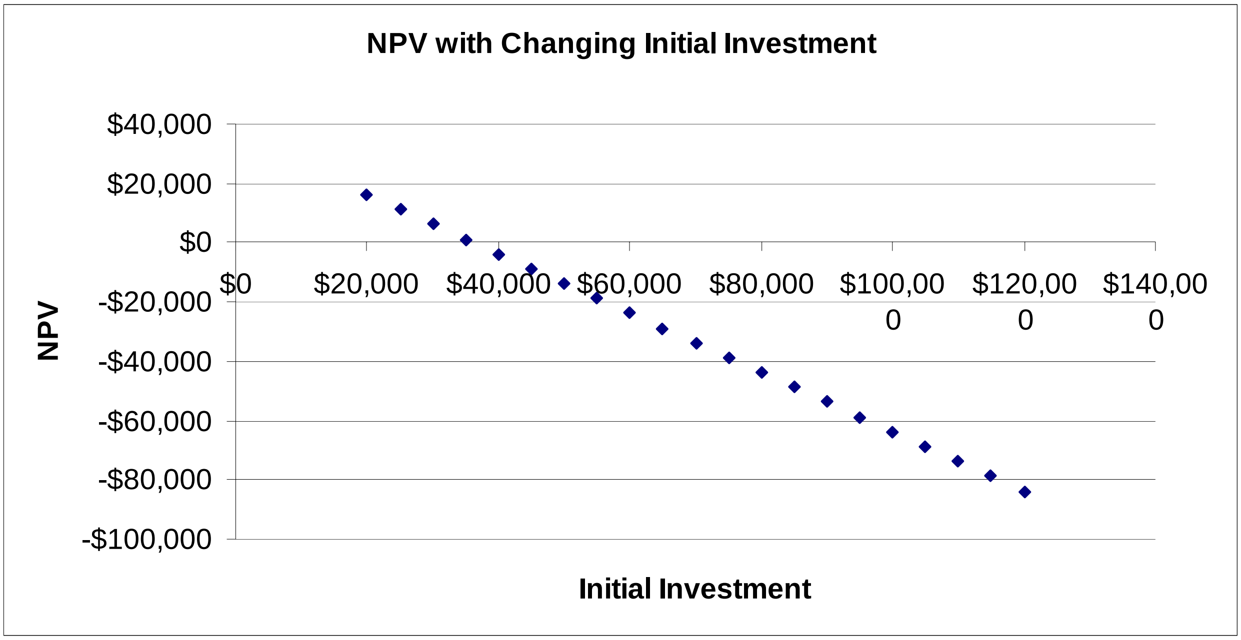

Figure 19. NPV values at varying initial capital investments

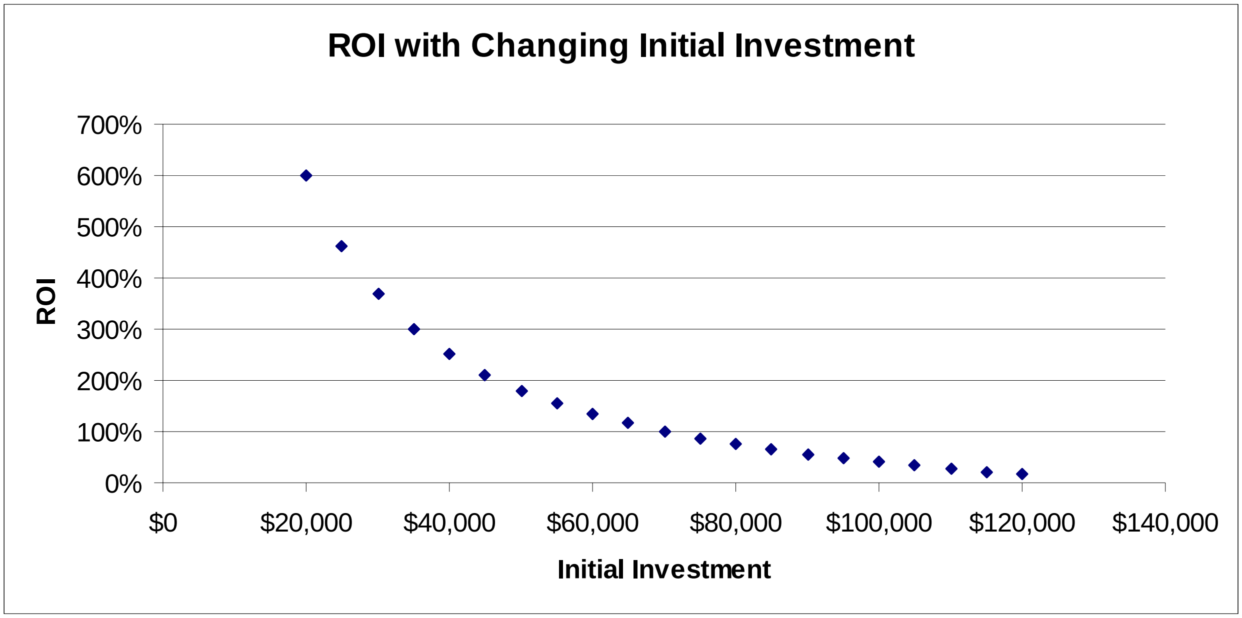

Figure 20. Return on investment with varying initial capital investments

Figure 18 shows that the NPV is positive, and therefore the venture is financially advisable, if the capital investment is less than approximately $38,000. As the project becomes more expensive, the NPV becomes more negative. Figure 19 shows that the ROI is very large when the investment is relatively cheap, and then it decreases to zero as the initial investment becomes more expensive.

The final sensitivity analysis was performed on the cooling energy use assumption. The assumption of the annual cooling energy use for the new building was a very rough approximation, and will not likely be the exact value seen by Queen's. Figures 20 and 21 show the results of the sensitivity analysis.

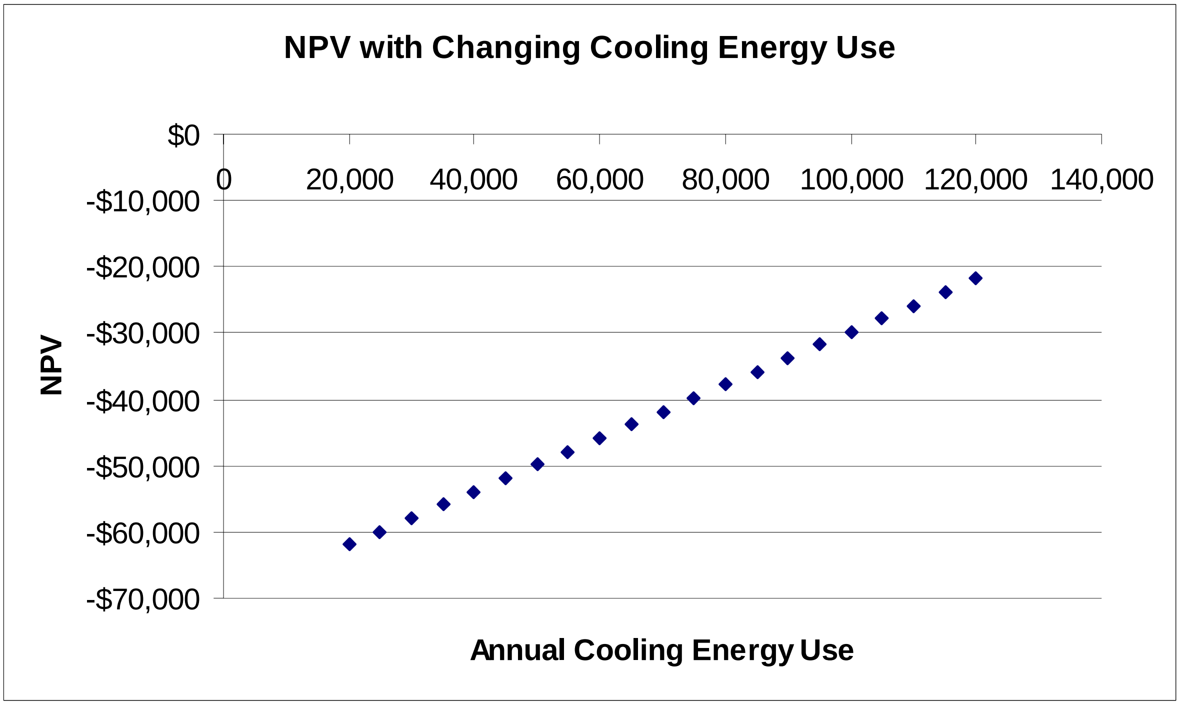

Figure 21. NPV values at varying initial capital investments

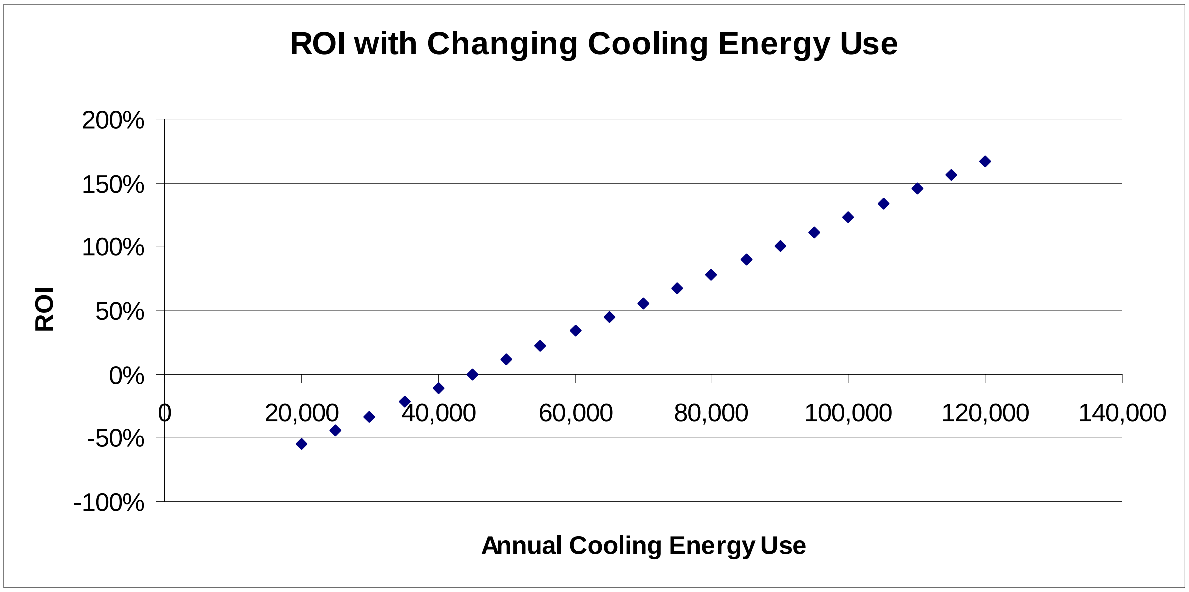

Figure 22. Return on investment with varying initial capital investments

It can be seen in Figures 20 and 21 that as the annual cooling energy use required increases, the NPV and ROI both increase. This makes intuitive sense, because reducing a certain percentage of a higher number results in a higher reduction and therefore increased cost savings.

7.6 Financial Analysis Tool

The Financial Analysis tool used for this analysis has been included with this report for the use of Queen’s Physical Plant Services. It is easy to use, and provides NPV and ROI for a wide variety of variables. In the NPV_ROI sheet, one can simply enter all the variable values (capital investment, yearly cooling energy use, percent energy savings, initial electricity price, yearly percent increase in electricity price and discount rate), and obtain the NPV and ROI values for a project with those specifications. Further, looking down the column of cumulative savings for the initial capital investment value gives the breakeven point.

7.7 Financial Summary and Recommendations

It is difficult to conclude definitively whether or not installing a green roof on top of the new Queen’s Centre academic building will be a good financial investment. The NPV and ROI values depend on variables that are very uncertain at this stage, and only ranges in which they will probably lie can be estimated. However, through the sensitivity analysis conduced using the Financial Analysis tool developed for this project, it was observed that certain variable values do in fact produce high NPV and ROI values. It is recommended that Queen’s try to install a green roof that results in a positive NPV and a large ROI, since this should be possible. In order to do this, Queen’s will likely have to install an extensive green roof, since, in comparison to intensive green roofs, extensive green roofs are cheaper to install and maintain, and provide similar energy savings.

8 Conclusion

The objective of this project was to determine whether the benefits of a green roof make installing one a good investment for Queen's. Based on the research done, the implementation of a green roof will have many benefits for Queen's University and the Queen's community. The green roof will serve to show that Queen's University is taking initiative in sustainable development and will keep Queen's on equal footing with other universities that have or will be implementing green roofs themselves. While the implementation of an extensive roof will not serve as a possible gathering spot for students, it will serve as a habitat for many insects and animals and will still be able to be visited by future investors, interested students and staff. Research of past green roofs used in Canada reveal an energy cost reduction of 5-25% and a comparable or longer roof lifespan. There are also benefits to the Kingston area such as a decrease in storm water run off, better air quality and a reduction in the heat island effect.

Financially, the implementation of a green roof could cost between $45,000-$120,000 and has a break even point of 18-19 years. Although a higher installation cost is required, the maintenance cost will be quite low. With the many variables and lack of knowledge on details such as the size of the building, it is difficult to say whether the green roof would be a financially sound investment. In many situations the NPV analysis showed a positive value while in others it was negative. However, based on the explained benefits and possibilities of a positive NPV the extensive green roof is recommended as a sound investment.

Thus, the conclusion of this report is that installing a green roof on part of the new Queen's Centre is indeed a wise investment for the University.

9 Recommendations

It is recommended that Queen's University install an extensive green roof onto the new Queen's Center. It is recommended that the green roof cover a minimum of 50% of the roof span in order to reap the full benefits of the green roof as well as to achieve one LEED point for the building.

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Appendix

Appendix A

Questions asked to students in Green Roof Poll

1. Would you be willing to pay an extra $15 for Queen's to add environmentally friendly services and practices? Yes or No.

2. When choosing universities, did/would the greenness of a school influence your decisions? Yes or No

3. Did you know there is a living wall in the ILC? Yes or No.

4. Would you support Queen's in the implementation of a green roof on the new physical education center? Yes or No.

5. On a scale of 1-5, how important is it to you that Queen's tries to be as green as possible? 1 is low, 5 is high.

Results

Q1	Q2	Q3	Q4	Q5
1	2	1	1	4
1	2	2	1	5
1	2	1	1	4
1	2	2	1	3
1	2	1	1	4
1	2	1	2	3
1	1	1	1	4
2	1	1	1	4
1	1	1	1	4
1	1	1	1	5
1	2	1	1	3
1	1	2	1	4
1	1	1	1	4
1	2	1	1	2
1	2	1	1	3
1	1		1	4
1	2	1	1	4
1	1	1	1	4
1	1	1	1	3
1	2	1	1	4
1	1	2	1	4

1	2	1	1	4
1	1	1	1	4
2	2	1	1	2
1	1	2	1	3
1	1		1	5
1	2	1	1	5
1	2	1	1	4
1	2	1	1	4
2	2	1	1	2
2	2	1	1	3
1	1	1	1	5
1	1	1	1	5
2	2	2	2	1
2	2		2	1
1	2	1	1	4
1	1		1	5
1	2	1	1	3
1	2	1	1	4
1	1	1	1	4

Total YES	34	17	30	37	
Total NO	6	23	6	3	
Percent Yes	**85**	**42.5**	**83**	**92.5**	
					3.675 <=Avg

Notes:
Yes is denoted with a 1
No is denoted with a 2
Blank spaces for question 3 represent someone who does not attend Queen's
All 1's given for question 5 were from commerce students

Appendix B

A picture of the spreadsheet calculator that can be used to calculate the potential rain water retention by a green roof.

American Hydrotech, Inc.
Garden Roof Assembly
Storm Water Management

Rainwater retention and run-off calculator

Variables...

3,000	Enter Roof area in square feet
8	Enter Soil depth in inches
1	Enter (1) if roof slope is < or = 1:12 (<10%). Enter (2) if roof slope is > than 1:12 (>10%).

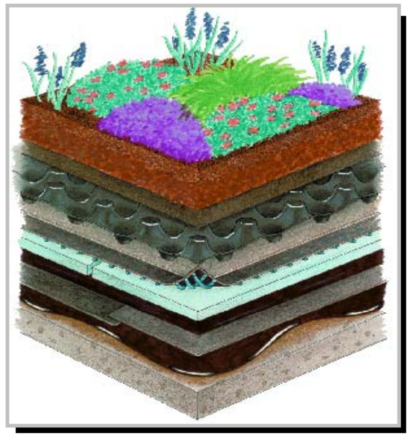
Water retained (approximate) on Hydrotech's Garden Roof Assembly…

1.5	gallons/second
88	gallons/minute
5,292	gallons/hour
70%	% water retained on roof

Water run-off (approximate)…

0.6	gallons/second
38	gallons/minute
2,268	gallons/hour

Notes:
Value represents average national rainfall intensity with appropriate safety factor.
Calculator is based on testing performed in accordance with German National Building Standards.



Example: Consider the above depicting an Intensive Garden Roof Assembly with 8" of soil. The dry weight of the assembly would be approximately 50 LB. / S.F. The wet weight (saturated weight) of the assembly would be approximately 78 LB. / S.F. One inch of water weighs 5.2 LB. The difference between the two is 28 LB., so the equivalent of over 5 inches of rain would have to fall to saturate the assembly!

Appendix C

Soprema Green Roof Systems

The following price information was provided by Chris Elliott, a Soprema representative.

Sopradrain 10G - 2m X 12.5m - $275.00/roll
Aquamat Jardin - 4' X 100' - $1,700.00.roll
Microfab - 3.25' x 300' - $350.00/rl
Sopraflor X (Extensif) - Blk cu M - $155.00
Sopraflor I (Semi - intensif) - Blk cu M - $150.00
Sopraflor L (Light) - Blk cu M - $145.00

Further information including specifications and technical data sheets can be found in the electronic appendix, and also at Soprema's green roof website: http://www.soprema.ca/sopranature-en.asp.

Appendix D

Calculation of the size of the green roof on top of the new academic building of the Queen's Centre.

According to Eric Neuman of PPS, the building dimensions are 39.9m in length by 13.8m in width by 17m in height. Assuming the green roof covers 50% of the roof, the calculation for the area of the green roof is as follows:

Roof area = 13.8m x 39.9m = 550.6 m^2
550m^2 / 2 = 275

Appendix E

Estimation of the annual energy usage of a hypothetical air-conditioned building at Queen's

Assumptions
70 million KWh used per year for entire university
100 buildings at Queen's, 50 of which are air conditioned
The 50 air conditioned buildings use more energy than the 50 non air conditioned buildings (assume 25 – 45 split), so the 50 air conditioned buildings are using 45 million KWh per year

45 000 000/50 = 900 000
Each air conditioned building is using 900 000 KWh of energy per year

10% of energy use goes to air conditioning
900 000 x 0.1 = 90 000 KWh

Appendix F

Financial case study results.

Capital Investment	$ 70,000
Yearly cooling Energy (kWh)	90,000
energy cost year 1 ($/kWh)	$ 0.11
energy cost increase	7%
discount rate	8%
% Energy Savings	15%

Year	Energy Price	Energy Cost	Cash Flow	Cumulative Savings
0			-$70,000	
1	$ 0.110	$ 9,900.00	$1,485	$1,485
2	$ 0.118	$ 10,593.00	$1,589	$3,074
3	$ 0.126	$ 11,334.51	$1,700	$4,774
4	$ 0.135	$ 12,127.93	$1,819	$6,593
5	$ 0.144	$ 12,976.88	$1,947	$8,540
6	$ 0.154	$ 13,885.26	$2,083	$10,623
7	$ 0.165	$ 14,857.23	$2,229	$12,851
8	$ 0.177	$ 15,897.24	$2,385	$15,236
9	$ 0.189	$ 17,010.04	$2,552	$17,787
10	$ 0.202	$ 18,200.75	$2,730	$20,517
11	$ 0.216	$ 19,474.80	$2,921	$23,439
12	$ 0.232	$ 20,838.03	$3,126	$26,564
13	$ 0.248	$ 22,296.70	$3,345	$29,909
14	$ 0.265	$ 23,857.47	$3,579	$33,487
15	$ 0.284	$ 25,527.49	$3,829	$37,317
16	$ 0.303	$ 27,314.41	$4,097	$41,414
17	$ 0.325	$ 29,226.42	$4,384	$45,798
18	$ 0.347	$ 31,272.27	$4,691	$50,489
19	$ 0.372	$ 33,461.33	$5,019	$55,508
20	$ 0.398	$ 35,803.62	$5,371	$60,878
21	$ 0.426	$ 38,309.88	$5,746	$66,625
22	$ 0.455	$ 40,991.57	$6,149	$72,774
23	$ 0.487	$ 43,860.98	$6,579	$79,353
24	$ 0.521	$ 46,931.25	$7,040	$86,392
25	$ 0.558	$ 50,216.43	$7,532	$93,925
26	$ 0.597	$ 53,731.58	$8,060	$101,985
27	$ 0.639	$ 57,492.79	$8,624	$110,608
28	$ 0.684	$ 61,517.29	$9,228	$119,836
29	$ 0.731	$ 65,823.50	$9,874	$129,710
30	$ 0.783	$ 70,431.14	$10,565	$140,274
		NPV	**-$33,838**	
		Saved Sum	**$140,274**	
		ROI	**100%**	