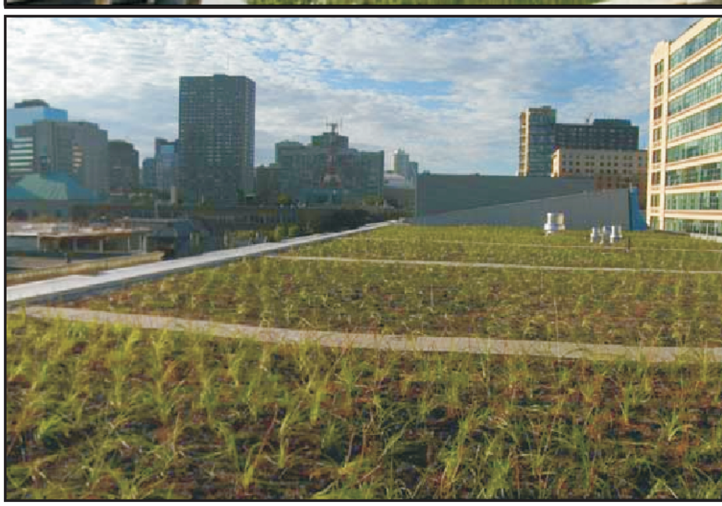
An Economic Analysis of Green Roofs:

Evaluating the costs and savings to building owners in Toronto and surrounding regions



Prepared by: Toronto and Region Conservation

July 2007

AN ECONOMIC ANALYSIS OF GREEN ROOFS:
Evaluating the costs and savings to building owners in Toronto and surrounding regions

A report prepared by:

Toronto and Region Conservation

under the

Sustainable Technologies Evaluation Program

In partnership with:

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NOTICE

PUBLICATION INFORMATION

Reports conducted under STEP are available at www.sustainabletechnologies.ca. For more information about the study, please contact:

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THE SUSTAINABLE TECHNOLOGIES EVALUATION PROGRAM

The Sustainable Technologies Evaluation Program (STEP) is a multi-agency program, led by the Toronto and Region Conservation Authority (TRCA). The program helps to provide the real world data and analytical tools necessary to support broader implementation of innovative environmental technologies within a Canadian context. The main program objectives are to:

- monitor and evaluate clean water and clean air technologies
- identify and address potential implementation barriers
- provide recommendations for guideline and policy development
- promote broader use of effective technologies through research, education and advocacy.

Technologies evaluated under STEP are not limited to physical structures; they may also include preventative measures, alternative urban site designs, and other innovate techniques that help promote more sustainable forms of living.

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EXECUTIVE SUMMARY

Background

The Greater Toronto Area (GTA) faces many of the environmental problems that are common in highly populated, urbanized municipalities, such as combined sewer overflows, air pollution, smog, and heat build-up. These problems stem largely from a lack of green space and abundance of impervious surfaces. Green roofs help to address these issues by replacing dark, impervious roofs with vegetated systems that retain stormwater runoff, enhance biodiversity, improve air quality, lower building energy use and create more attractive cityscapes.

Since 2005, the City of Toronto has been developing a green roof policy, which was approved by council in February 2006, and includes a commitment to greening new and existing roofs on municipal buildings where feasible and developing a pilot incentives program to assist with the capital costs of green roof construction. Various other municipalities in southern Ontario and across North America are considering or have already implemented such policies. Obtaining reliable local cost data is a key step in determining the nature and magnitude of government incentives that should be offered to encourage green roof industry development.

While significant progress has been made in the areas of green roof research and policy development in the GTA, building owners remain reluctant to build green roofs partly due to concerns that green roofs require higher capital and maintenance costs than conventional roofs, without the demonstration of offsetting benefits to the proponent. While there is general agreement that initial green roof costs are greater, what remains uncertain is the magnitude of this cost differential and the key life cycle factors that affect conventional and green roof costs.

Objectives

The primary aim of this study was to estimate the life cycle costs and savings associated with building and owning a green roof in the GTA. Costs related to structural modifications, materials and labour for installation, and long-term maintenance are discussed for both new and retrofit installations. The study focuses in particular on extensive installations which have been planted or seeded, and are above buildings that are heated during cold weather, but not necessarily air-conditioned. Cost variables included in the analyses were limited to those incurred by, or accruing to building owners or developers as these were the factors that were thought to most influence the decision to construct a green roof. An earlier study by the University of Ryerson (2005) addressed the economic value of the many public benefits offered by green roofs.

Approach

The life cycle costs of green roofs were estimated based on a variety of information sources, including literature, industry surveys, key informant interviews and supplier interviews. The literature review was the sole source of information on green roof energy savings and roof membrane longevity, and also provided important capital and life cycle cost information to supplement the interview and survey results. Cost data for local green roofs were collected through a survey distributed to individuals with knowledge of, or access to green roof cost data. Survey respondents consisted of green roof suppliers and installers, building managers or their representatives, and architects.

Telephone interviews were also conducted with representatives from several major Canadian companies that supply and/or install green roofs in order to obtain cost estimates of products currently on the market. All interviewees were asked to provide a per square foot cost range for their green roof systems, as well as a saturated weight. The weights helped to inform a discussion of the structural implications of building new and retrofit green roofs. Conventional roof cost and weight data were obtained from local literature (City of Toronto, 2005; Peck and Kuhn, 2002) and interviews with two representatives from development groups involved in construction of industrial buildings. Conventional roof costs obtained from these sources were also compared with estimates from green roof suppliers interviewed whose cost quotations included the underlying base roof (*i.e.* conventional roof).

Data obtained from industry surveying was entered into a spreadsheet database to facilitate price comparisons, identify trends, and determine averages. Information not available through surveying was estimated based on the literature review and key informant interviews. Data from surveys and other information sources were used as inputs to a life cycle costing tool developed by the Athena Sustainable Materials Institute. Cost analyses were conducted for a green and conventional roof on a model one-storey office building in Waterloo, Ontario. The data sources, assumptions and input values are clearly stated. The relative importance of individual inputs on life cycle costs was determined through alternative scenario analysis.

Costs

Installation and Labour

Figure 1 summarizes the installed capital cost of extensive green roof systems as obtained from two key literature sources (Peck and Kuhn, 2002 and GRHC, 2005), industry surveys, and supplier interviews. German averages from two other literature sources (Philippi, 2006; Beattie and Berghage, 2004) are also shown for comparison.

Lower German costs (shown in Figure 1) are a result of the well-developed green roof market in that country. There was significant cost overlap among the other sources of cost data. Capital costs for Canadian data sources range from a low of $6.00 to a high of $21.00 per square foot, not including the base roof. Key factors influencing green roof capital costs include the following:

- Size and complexity of the installation
- Building height (difficulty of transporting materials to roof on very tall buildings)
- Use of special features for enhancing aesthetics and safety of accessible green roofs (*e.g.* edging, walking paths, safety fencing)
- Local availability of materials

- Availability of labour-reducing technologies (*e.g.* growing media blower truck)
- Abundance of experienced local labour (*i.e.* installers, horticulturalists, architects)
- Market competition
- Availability of ready-made modular or complete systems (versus more expensive custom designed solutions)
- Need for structural modifications to increase load-bearing capacity on the roof

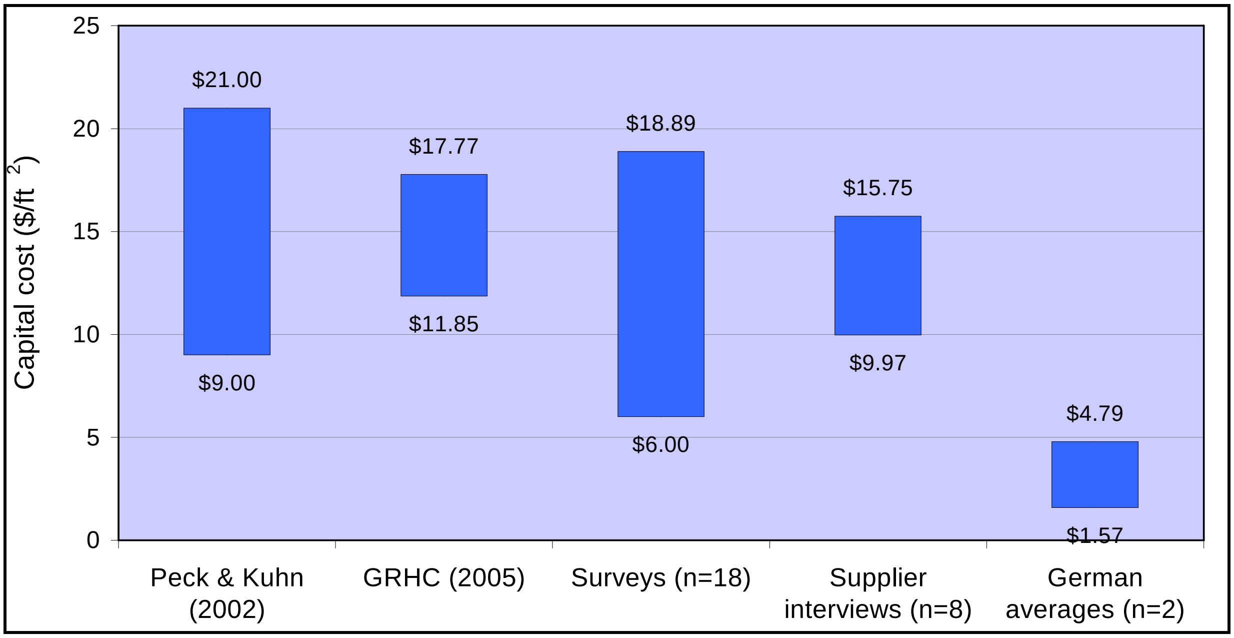

Figure 1: Summary of installed capital cost of extensive green roof systems from various sources

Among the 18 new and retrofit installations surveyed, only one respondent indicated that structural modification of the building design was required to accommodate the green roof. In this instance, the structural modification of the original building design increased the capital cost by 29%. The lack of structural modification costs listed for retrofit installations surveyed is likely due to the tendency for building owners to choose other non-green roof options if upon consultation with a structural engineer, it is determined that structural modifications are required.

Building Structural Modification

Depending on the version of the Ontario Building Code (OBC) in place at the time of building construction, many buildings may have been constructed with a load-bearing capacity as much as 18 lbs/ft^2 higher than what is required by the current version of the OBC (Peck and Kuhn, 2002). The removal of ballast or other surfacing aggregates – which can weigh between 10 and 12 lbs/ft^2 - may also allow for some additional weight to be accommodated (City of Portland, 2000; MAPC, 2005). Suppliers interviewed quoted green roof weights ranging from 8 to 50 lbs/ft^2, with several systems weighing less than 30 lbs/ft^2.

The additional cost associated with accommodating higher loads due to a green roof will vary widely based on building structure. In a tall building, the addition of weight associated with a green roof adds relatively little stress to the columns which are already capable of supporting significant weight. Conversely, one-storey industrial buildings occupying a larger ground area have more widely spaced column supports with lower load bearing capacities. The larger spans between columns mean that supporting additional weight on the roof is a greater challenge unless the structural roof framing is strong and rigid. Accommodating a green roof on these buildings would normally require structural support. Less expensive strategies to avoid or minimize building structural modifications are mainly targeted towards transferring weight or designing for heavy garden elements over load bearing members. While these strategies can help to minimize costs associated with a retrofit, a site-specific assessment by a structural engineer would still be required to determine whether they are viable options for a given building.

Roof Maintenance

Maintenance costs required for a green roof normally include services such as watering, weeding, pruning, application of organic fertilizer and occasional removal of invasive or undesirable plants and re-planting as needed. Drains and gutters must be inspected and cleared more frequently than on a roof without a garden, due to the build up of plant debris.

Maintenance costs are generally higher during the first two years of operation than in subsequent years as the garden is becoming established. Literature estimates of annual maintenance costs during the first two years ranged from \$0.25 to \$4.10/ft^2 (Peck and Kuhn, 2002). Survey respondents rarely cited maintenance as a cost because most installations surveyed were less than 2 years old and were, therefore, still covered under the installer's maintenance warranty. The oldest green roof installation surveyed cited an annual maintenance cost of \$0.50/ft^2, which is paid out to a green roof maintenance company and covers a minimum of 4 visits annually.

Informant interviewing indicated that an independent maintenance company would likely charge a minimum of \$250 per site visit and that 5 visits annually would be recommended to cover basic needs. In instances where the building manager already has a landscape maintenance contract in place, or employs an in-house landscaper, the maintenance work could likely be carried out by these staff for a lower added cost.

Savings

There are several benefits of green roofs that can translate into long-term savings to building owners and developers. Only quantifiable benefits relating to energy efficiency and roof longevity were included in the life cycle cost analysis. Other benefits relating to the public image of building green or tenant roof access are recognized but not explicitly included in the analysis as these will vary substantially from one building to the next, and are not easily defined in dollar value terms.

Energy Consumption

Estimates of the building energy savings provided by a green roof were obtained from several sources. Monitoring by the National Research Council (NRC) indicated a 75% reduction in energy demand for space conditioning in the spring and summer on a field roofing facility in Ottawa (Liu, 2002). Energy modelling conducted by the City of Waterloo (2004) for a 17,222 ft^2 extensive green roof on a one-storey office building indicated annual savings of $400 and $554 in heating and cooling energy costs, respectively. Martens and Bass (2006) reported significantly greater energy savings associated with roof greening for single story buildings than for 2 or 3 story buildings. During a July day in Toronto, a green roof with dimensions of 820 ft by 820 ft was found to bring about energy savings of 73%, 29%, and 18%, for 1, 2, and 3 story air conditioned buildings, respectively.

Membrane Longevity

Green roofs have the potential to increase the lifespan of the roofing membrane by providing protection from thermal stress caused by high temperatures and diurnal fluctuations (Liu and Baskaran, 2004). NRC monitoring conducted in 2002 and 2003 at the Eastview Community Centre in Toronto reported maximum conventional roof membrane temperatures above 60°C and a median daily temperature fluctuation of more than 45°C. By contrast, the membrane below the adjacent garden experienced a maximum temperature of only 40°C and temperature fluctuation of less than 15°C (Liu, 2006). A similar trend was noted during experiments at the NRC Ottawa Field Roofing Facility.

German literature indicates that, based on observation of installations in Germany, green roofs will at least double the lifespan of the roofing membrane to 40 or 50 years (Porsche and Kohler, 2003; Krupka, 2001). Porsche and Kohler (2003) also note that membranes beneath some older green roof installations in Berlin have even lasted 90 years without requiring replacement. Literature estimates of conventional roof longevity ranged from 10 to 30 years. A 15-year lifespan was most commonly cited in the literature reviewed (TMIG, 2006; Peck and Kuhn, 2002; Johnston and Newton, 2004; Porsche and Köhler, 2003).

Life Cycle Cost Analysis

Life cycle costs of a green roof and conventional roof alternative were calculated using a costing tool developed by the Athena Sustainable Materials Institute. Capital and long term cost (and savings) data used as inputs to the tool were based on the best information obtained from surveying, interviewing and review of other green roof studies.

Specifications of the building used in the life cycle analysis were the same as the reference building used in a green roof feasibility study conducted by the City of Waterloo (2004), which included a full energy savings calculation and translated the energy savings into a dollar amount. The reference building is a new, one-story 17,222 ft^2 office building, using electricity for cooling (at a rate of $0.12/kWh) and natural gas for heating (at a rate of $0.010/$ft^3$). It was assumed that structural modifications would not be required. For the base scenarios, the conventional and green roof life spans were assumed to be 15 and

30 years respectively, and the LCC was run for a 30 year investment period. The discount rate of 6.5% was used.

Life cycle costs of six alternative scenarios were also calculated to illustrate the cost impact associated with changes in assumptions. Figure 2 presents the results of the LCC analysis. The base case and alternative scenarios are presented as the ratio of green to conventional roof LCCs and as the percentage change from the base case. To simplify, results were calculated based on the green and conventional roof cost minimums only. Scenario results are summarized in the following sections.

Extended Green Roof Membrane Scenario

Increasing the life of the green roof membrane from 30 to 45 years reduced the green-to-conventional roof LCC ratio from 1.56 in the base case to 1.37 (a 12% decrease). The impact was less significant than anticipated because the costs for conventional roof replacements that occur at 15 and 30 years are much lower than the initial installation cost when converted to present value dollars.

Non-air Conditioned Building Scenario

Eliminating the summer cooling energy savings from green roofs increased the LCC ratio by 2% relative to the base case. This scenario did not consider capital cost savings associated with downsized HVAC system requirements in a green roofed building because these data were not available. The cost impact of this scenario would have been greater had this consideration been incorporated.

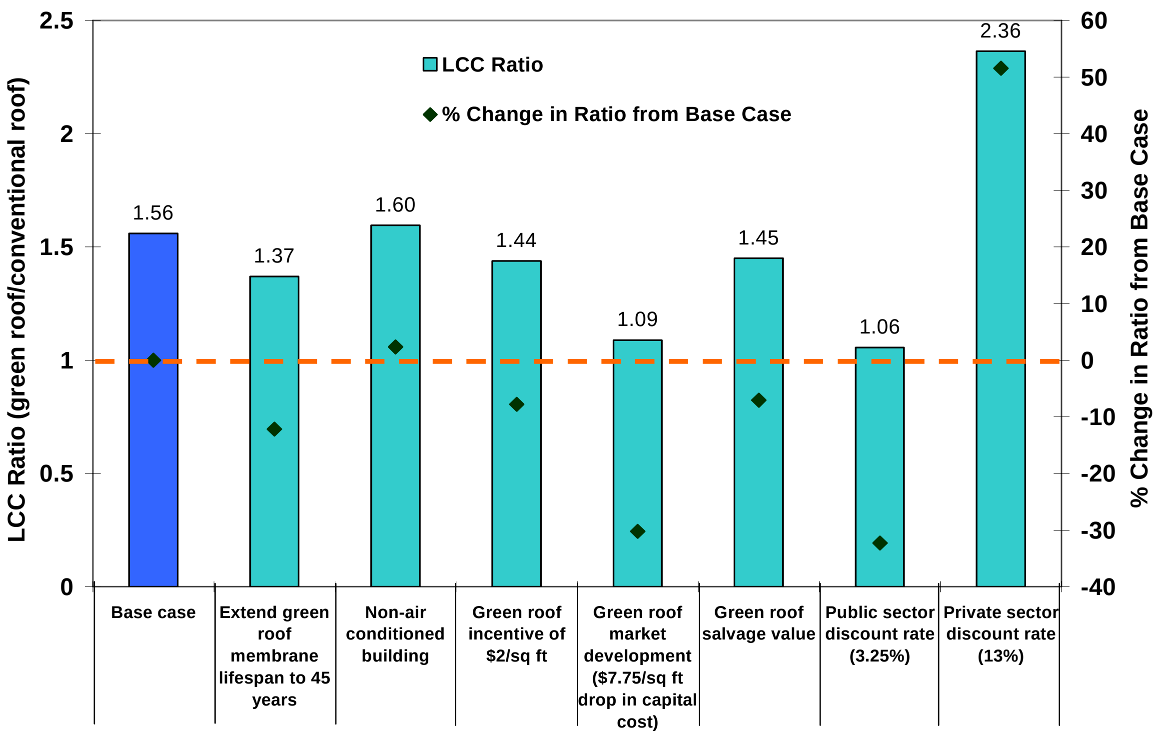

Figure 2: Ratio of green roof to conventional roof LCC for all scenarios (based on minimums)

Municipal Incentive Program Scenario

The installed cost of the green roof was subsidized by $2/ft^2. The subsidy reduced the LCC ratio from 1.56 in the base case to 1.44 (a decrease of 8%), making the investment a more attractive option to building owners.

Green Roof Market Development Scenario

Reducing the installed cost of the green roof (including the cost of the underlying base roof) from a minimum of $23.75/ft^2 to 16.00/ft^2 substantially narrowed the cost gap between the green and conventional roof LCC, bringing the ratio down to 1.09. Relative to the other scenarios, market development yielded the second lowest cost differential between green and conventional roofs.

Green Roof Salvage Value Scenario

This scenario involved assigning a salvage value to green roof materials once the roof membrane needed replacing (30 years). Accounting for salvage value of the green roof caused the LCC ratio to fall to 1.45 from 1.56 in the base case.

Public vs. Private Discount Rate Scenario

LCCs were calculated based on discount rates of 3.25% and 13%, representing public and private sector rates respectively. The LCC ratio fell to 1.05 when the public sector rate was applied, and increased to 2.36 with use of the private sector rate. These results indicate that green roofs will tend to be more affordable for investors such as those in the public sector, who tend to look for lower risk investments with more modest rates of return.

Results obtained for the base and alternative scenarios demonstrate that the differential between conventional and green roof LCC is most affected by factors that impact capital or replacement costs. These factors include: (i) roof membrane longevity, (ii) market transformation, and (iii) discount rates. Variations in annual costs and savings associated with maintenance and energy use reduction did not have a strong impact on the LCC.

Of course, these LCC calculations only apply to buildings with the same specifications as the reference building described earlier. Changes in these specifications could have a significant impact on the LCC. The cost estimates provided in this study do not replace the need for a site specific cost assessment, as circumstances vary widely. Those considering a green roof must carefully consider the various conditions that apply in their particular case. It is hoped that this study provides information and data that help facilitate this process.

Recommendations

Market Development

- GTA municipalities wishing to aggressively support green roof infrastructure should provide an incentive to reduce the capital cost of green roof projects, as green roofs are currently cost-prohibitive for many building designs and uses.
- A direct financial incentive of $4 - $7 per square foot is needed in order to decrease capital costs enough to make green roofs an attractive option, and thus spur market growth.
- Offering an incentive of more than $8/ft^2 could potentially stunt market growth, as it may lead suppliers to keep costs high rather than striving to develop solutions that reduce prices charged to potential clients.
- The use of other creative policies and incentives may help to stimulate market growth without some of the pitfalls of a direct financial incentive. Examples include reduced size of end-of-pipe facilities or expedited application approvals for owners proposing a green roof.

Further Research

- Further research is needed to investigate the effectiveness of innovative strategies (*e.g.* weight transferring structures, creative green roof design) aimed at minimizing the need for large investments in structural modifications on new and retrofit commercial or industrial roofs.
- While it will be several years before data on the longevity of local green roofs will be available, laboratory simulations of the conditions experienced by a membrane beneath a green roof could be an effective way of quantifying expected life spans in the GTA.
- There is evidence that less quantifiable benefits of green roofs associated with the amenity and public relations value of green roofs can translate into substantial cost savings to building owners. These benefits should be further investigated and their value estimated in economic terms to provide a more comprehensive life cycle cost for green roofs to building owners than was provided in this study.
- Results from this study and other research specifically addressing the public values of green roofs (e.g. Ryerson University, 2005) should be combined and re-examined to determine the extent to which the cost of green roofs borne by owners is offset by their overall societal value.

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1.0 GREEN ROOFS AND THE GREATER TORONTO AREA

As one of the most populous urban areas in North America, the Greater Toronto Area (GTA) faces many of the environmental problems that are common in highly urbanized municipalities. These include water contamination, air pollution, smog, and heat build-up. These unfortunate by-products of urbanization stem largely from the loss of green space and abundance of impervious surfaces such as roads, parking lots and rooftops. Within the City of Toronto, rooftops alone make up approximately 21% of the total land area (Ryerson University, 2005). The creation of urban green spaces such as rooftop gardens will reduce the total impervious cover in the GTA and create vibrant new habitat for plants, animals and insects. This additional greenspace provided by a green roof is beneficial to the urban environment not only for its stormwater management benefits, but also as a means of increasing biodiversity, reducing building energy use, minimizing the urban heat island effect, improving air quality, and enhancing the aesthetic quality of cities.

For all of these reasons, the green roof industry in the GTA has gained significant momentum over the past decade, with the encouragement of several stakeholder groups, including municipal governments, the National Research Council, Green Roofs for Healthy Cities, the TRCA, and several universities and colleges. Since the fall of 2005, the City of Toronto has taken several steps to further encourage broader adoption of green roofs. A green roof strategy was developed through multi-stakeholder workshops and two documents were published discussing the benefits, costs and implementation barriers for green roofs in Toronto.

Recommendations derived from the above noted research have been used to develop a City of Toronto green roof policy, approved by council in February 2006. The new policy includes a commitment to greening new and existing roofs on municipal buildings whenever feasible, and the development of a pilot incentive program which provides financial incentives for green roof implementation. The success of this pilot program will be evaluated in order to determine whether a full-scale green roof incentive program should be adopted by the City. Other municipalities in southern Ontario, such as Waterloo, Mississauga, and Markham, are considering or have already implemented green roof policies, and several other North American cities have such policies and incentive programs in place. Obtaining reliable local cost data is a key step to determining the nature and magnitude of incentives that should be offered.

2.0 THE ISSUE

While significant progress has been made in the areas of green roof research and policy development in the Greater Toronto Area, developers and building owners remain reluctant to build green roofs in part due to concerns that green roofs require both a higher capital expenditure and higher maintenance costs than conventional roofs, without the demonstration of appropriate offsetting benefits to the proponent. During two green roof technology stakeholder workshops held by the City of Toronto, 79% of workshop participants ranked cost as either the first or second most significant barrier to green roof development (City of Toronto, 2005). While a great deal of research has demonstrated the potential cost savings associated with green roofs - such as lower energy bills and increased roof membrane lifespan – the concept that green roofs may pay for themselves in the long term does not seem to be the prevailing opinion in the development industry. This may be attributed to the following factors;

a) Literature appears to be somewhat divided on the cost issue. While some studies indicate that green roofs cost building owners less in the long term due to energy savings and increased roof longevity, other studies suggest that long term cost savings aren't enough to offset the high capital costs.
b) Capital costs for construction of the green roof are often incurred by the developer while long term cost savings benefit building owners and/or managers. It may be difficult to translate potential long term cost savings into a reasonable increase in the cost at which the development is sold.
c) The magnitude of cost savings may be variable and dependent upon factors other than the quality of the green roof materials and installation process. Facility management and maintenance plays a major role in determining energy costs for heating and cooling. Further, improper maintenance of the garden (*i.e.* over-irrigation, neglect) can lead to accelerated deterioration of the roof garden. The loss of this aesthetic value will ultimately impact revenues that the building owner may obtain from tenants or other building users.
d) Revenues or savings associated with green roofs tend to be less tangible and more difficult to evaluate than capital and maintenance costs. Increased rental or purchase prices of the building or units within the building are examples of green roof related revenues that are less tangible.

There is general agreement that the initial cost to design and install a green roof is greater than that of a conventional roof. What remains uncertain is the magnitude of this cost differential and the key life cycle factors that affect conventional and green roof costs.

3.0 THE INTENT

A clear determination of the cost of a green roof relative to a conventional roof is necessary in order to determine whether financial incentives provided by municipalities are sufficient to make this technology an attractive option for developers and building owners. The goal of this study is to estimate the capital and long term financial costs, as well as potential cost savings to building owners, associated with green roofs in the GTA. Costs related to structural modifications, materials and labour for installation, and long-term maintenance are discussed. Green roof costs and savings are compared to those associated with conventional roof assemblies in order to provide a context for the evaluation of cost differentials.

The present study provides estimates of the direct cost of green roofs to building owners and/or developers specifically, without quantifying value based on the numerous public benefits that green roofs provide to the environment and communities in the GTA. A study evaluating these public benefits has already been completed by Ryerson University (2005), however it did not assess the cost implications of green roofs to building owners. Table 3.1 lists the benefits accruing to the owner and those which have some public value. A summary of the public benefits of green roofs is provided in Appendix A.

Table 3.1: Potential benefits of green roof infrastructure to the private and public sectors

Private Benefits	Public Benefits
Longer roofing membrane lifespan	Decreased stormwater runoff to receiving water
Energy savings	Improved stormwater runoff quality
Satisfaction of a portion of stormwater policy requirements	Reduced combined sewer overflows / fewer beach closures
Building amenity value	Reduced greenhouse gas emissions
Improved public relations	Urban heat island mitigation
Noise insulation	Improved air quality
Food production (agriculture)	Improved urban biodiversity

In evaluating the cost of green roofs, the study focuses on installations which meet the following criteria:

i. The green roof is extensive (6 inches or less substrate depth), rather than intensive. Extensive green roofs are less expensive to build and a more practical option for most buildings.
ii. The green roof has either been planted or naturally seeded. Roofs with growing media but no vegetation are not covered in this study.
iii. The green roof is installed on a commercial, institutional, industrial or multi-unit residential building which is heated to room temperature (approximately 21°C) during cold weather.

Both new and retrofit installations are included in the cost analysis, and the materials and labour requirements of each are compared. Data presented are derived from a variety of sources, including published research, product supplier quotations and completed green roof project budgets.

4.0 THE APPROACH

Data for this study was assembled from a variety of sources. The following sections describe the data sources and approach used to develop cost and savings estimates presented later in this report.

4.1 Review of literature

The literature review served as one of several sources of information for capital, long-term and life-cycle costs of green and conventional roofs, as well as the type and magnitude of savings and/or revenues that have been derived from green roofs. Since there were no local data on the dollar value of savings associated with owning a green roof, estimates of energy savings and roof longevity were derived solely from the literature review.

4.2 Industry survey

Cost data for local green roofs were collected through a survey (see Appendix B) distributed to industry representatives via email. Each completed survey form provided the costs for one green roof installation. Survey distribution was based on discussions with industry contacts and research into local green roof installations. Individuals asked to complete the survey owned or had access to cost data for a specific green roof installation. This group consisted of green roof suppliers and installers, building managers or their representatives, and architects. The option of keeping the identity or location of the building confidential was offered to all survey participants.

Survey questions addressed characteristics that affect both the capital and long term cost of the project, such as the location and green roof type. Participants were also asked to provide the actual costs for design, installation and maintenance. A detailed breakdown of costs was also requested, but most respondents could only divide costs based on the broad categories of design, green roof materials and installation, and maintenance. Few participants were able to assign a cost to long term maintenance because many of the installations were rather new and were still covered under a maintenance plan provided by the supplier or installer as part of the original cost. This data gap was filled by obtaining a cost estimate from a local green roof installer and comparing the cost to estimates provided through other studies.

4.3 Supplier interviews

Telephone interviews were conducted with representatives from several major Canadian companies that supply and/or install green roofs in order to obtain cost estimates. All interviewees were asked to provide a per square foot cost range for their green roof systems. While several suppliers do not offer installation services, they normally have a list of certified installers that they provide to their clients. Most interviewees were also able to provide a reasonable estimate of the total installed cost even for companies that do not install their own products.

Several of the companies surveyed were mainly involved in roofing and waterproofing; green roofing was a relatively small part of their businesses. The representatives interviewed from these companies provided a total installed cost for both the roofing system (including insulation, membrane, etc.) and the overlying garden system. Some of these companies only sold their green roof systems in conjunction with their roofing membrane while others sold the green roof system separately, or even sold individual components of the system (such as growing media or drainage layer) separately. Estimates obtained from green roof suppliers whose cost quotations included the underlying base roof were also used as a basis for verification of conventional roof cost estimates obtained from literature and discussions with industry representatives.

The same interviewees were also asked about the saturated weights of their green roof systems at a specific depth. This information was collected in order to provide a context for comparison of green roof weights to the weights of conventional roof surfacing materials such as gravel. This comparison facilitates a discussion of the structural implications of converting an existing roof to a green roof. All data collected from supplier interviews are presented in section 8.0.

4.4 Data analysis

Data obtained from industry surveying was entered into a spreadsheet database in order to facilitate price comparisons, identify trends, and determine averages. Information obtained for installations that did not match the criteria in the study scope (see section 3.0) were omitted from the main data set used to calculate average costs. Outliers in the cost data were investigated by contacting the survey respondent to verify the information provided and determine whether there were circumstances that caused the numbers to be high or low relative to industry averages. Any unusual circumstances or 'extras' that may have impacted the green roof cost were listed in a comments column or as a footnote in the results tables.

The names of the buildings, survey respondents, and green roof suppliers were omitted from the results tables upon request of the individuals who provided data. Other data that were provided in the completed surveys but which could potentially allow for identification of the buildings or respondents were omitted if they were not relevant to the cost discussion.

4.5 Life Cycle Cost Analysis

Life cycle cost (LCC) is defined by Fuller and Petersen (1996) as "the total discounted dollar cost of owning, operating, maintaining, and disposing of a building or a building system" over a period of time. An LCC analysis is an economic method used to evaluate investment alternatives over a selected period of time, and is particularly useful as a means of determining whether or not a higher capital cost of an investment will ultimately be justified by reductions in future costs (ASMI, 2005). According to the Athena Sustainable Materials Institute (ASMI, 2005), the following steps should be followed in conducting an LCC analysis:

1. Identify the alternative investment scenarios and any operational limitations
2. Establish basic financial assumptions

3. Compile all relevant cost data for each scenario
4. Compare alternatives to determine which has the lowest LCC
5. Make a final decision based on LCC results as well as any risk, uncertainty or unquantifiable effects that may impact the decision

Data collected through the literature review, surveys and key informant interviews were used to conduct a pre-feasibility level LCC analysis of a green and conventional roof on a one-storey office building in Waterloo, Ontario. This analysis was conducted using a Life Cycle Cost Calculator developed by the ASMI[1].

The calculator is a set of linked Excel© based spreadsheets which allows up to three scenarios to be run at the same time. The first worksheet in the calculator allows the user to input all parameters to be used in the calculation including the study period, discount rate, inflation factors, capital costs, annual costs (or savings), replacement interval, replacement cost and salvage value. Once all parameters have been inputted, the first worksheet will display the net present value of the investment at the end of the study period, as well as at one-third and two-thirds of the study period. The other worksheets in the calculator are results calculators which display the annual cash flows by cost element, the resultant total cash flow for individual year on both a nominal (unadjusted) and discounted basis, and the calculated life cycle cost results for the investment over the expected life. One results calculator worksheet is generated for each scenario for which data is inputted in the first worksheet. Input parameters used in the LCC analysis are discussed in section 9.0.

[1] The Athena Sustainable Materials Institute is a not-for-profit organization which undertakes and directs various research and development activities that make it possible to factor environmental considerations into the design process from the conceptual stage onward. The Institute has a developed a strong reputation over the past 10 years in the field of sustainable building and life cycle assessment (LCA). The products and services offered by the Institute include software, LCA databases and customized consulting services.

5.0 ROOFING 101

In order to provide an appropriate context for evaluating green roofing as an alternative to more conventional roofing options, the following subsections describe the main roofing systems utilized in modern construction and how these systems are modified to accommodate the growing media and plants of a green roof. This discussion is focused on low-slope membrane roofs, as these are the types of roofs upon which green roofs may be installed. Component descriptions may not apply to metal roof assemblies (Roofing Technology Network, 2006). Readers with a good understanding of how conventional and green roofs are constructed may skip this chapter without compromising their understanding of results presented in subsequent chapters.

5.1 Basic components

5.1.1 Deck

The main function of the roof deck and its supporting structure is to provide structural support to the roof (Figure 5.1). The strength and rigidity of this component are the key properties that determine its suitability for the desired application (Chown, 1990). The deck used must be capable of supporting all live and dead loads expected on the roof, foot traffic, and wind, rain and snow loads. (Johns Manville Roofing, 2006). It must also act as an appropriate base for any mechanical fastening or adhesives that will be used (Chown, 1990). Common materials used for decks include concrete, steel and wood.

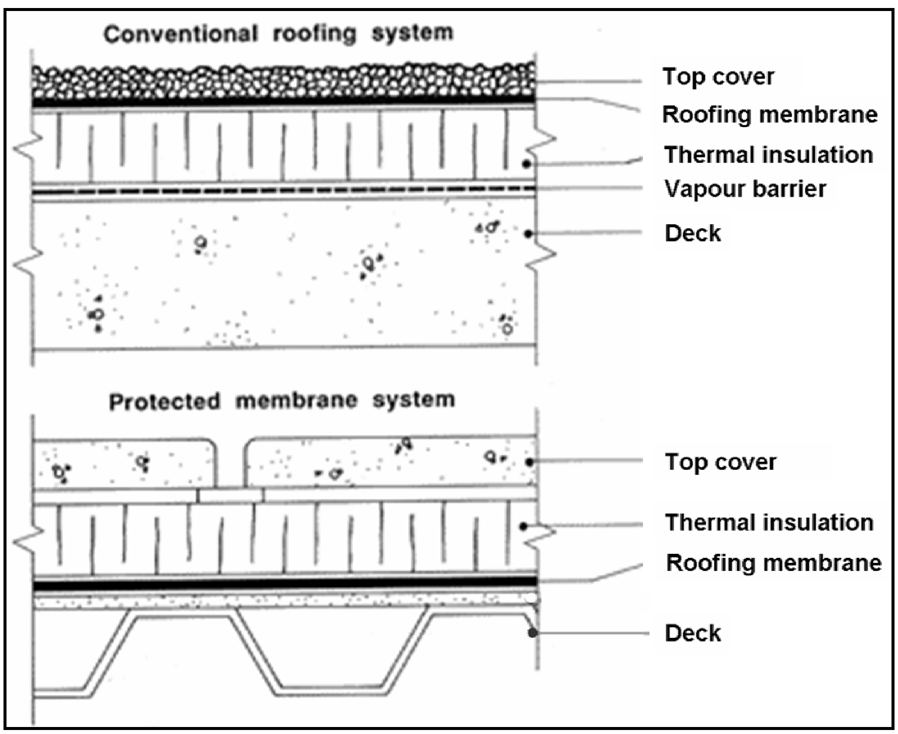

Figure 5.1: General cross-section of a conventional (top) and protected membrane (bottom) roof assembly (Source: Hedlin, 1989)

5.1.2 Vapour Barrier

This component is used in conventional roof assemblies, which use insulation beneath the membrane. Protected membrane (PM) roofs (described in section 5.2) do not include vapour barriers above the deck (Figure 5.1) as the membrane acts as the vapour barrier. The vapour barrier is intended to control the movement of moisture in the form of water vapour. This barrier prevents moist indoor air from travelling from the interior of the building to the roofing components above the deck. Water vapour that reaches the insulation layer (which is exposed to colder outdoor temperatures) may condense in that layer or beneath the roofing membrane, ultimately causing damage and premature roof failure (Handegord, 1960). Vapour barriers are usually plastic or foil sheets such as polyethylene film or aluminum foil.

5.1.3 Thermal Insulation

The insulation layer used on roofs is intended to prevent heat flow into and out of the building (Figure 5.1). In PM assemblies the insulation is installed above the roofing membrane and thus has the additional function of protecting the membrane from weather and/or mechanical damage. Some materials used as roof insulators, listed in order of increasing thermal resistance, include wood fibreboard, cellular glass, rigid glass fibre, expanded polystyrene, extruded polystyrene, and polyisocyanurate (Chown, 1990; Hedlin, 1989; Baskaran, 2005).

5.1.4 Roofing Membrane

The main function of the membrane is perhaps the most important among all components in the roofing system: to keep water from penetrating into the building. To do this, the membrane must be both waterproof and continuous (Chown, 1990). Figure 5.2 provides a detailed breakdown of the various categories and sub-categories of low-slope roofing membranes.

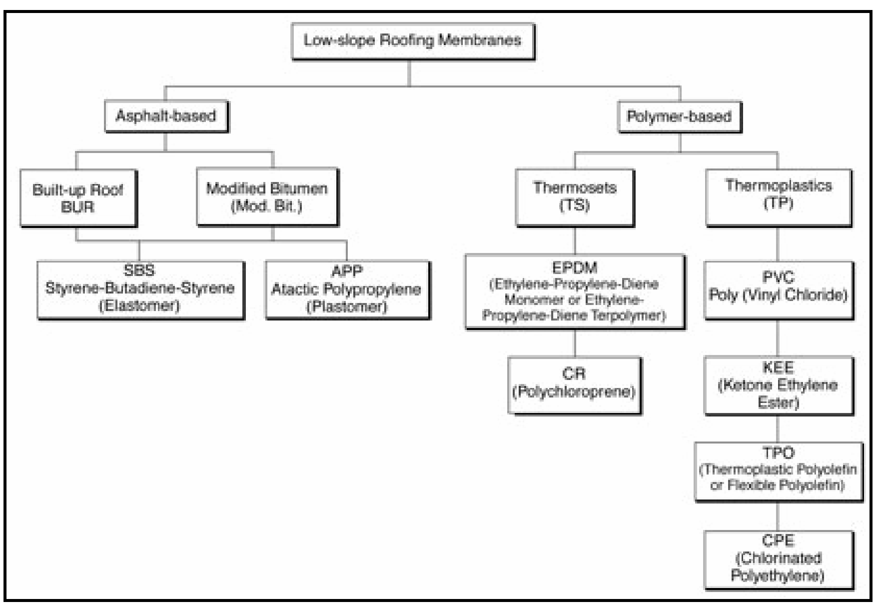

Figure 5.2: Detailed breakdown of low slope roofing membrane types (Source: Paroli et al., 1999)

The percentage of roofing sales in 2000 associated with different membrane types were summarized by the Canadian Roofing Contractor's Association (CRCA) in 2001. Modified Bitumen membranes were the most popular for low slope roofs with approximately 53% of sales for new construction projects. Built-up roofs represented the second highest proportion of the market with 25% of sales, while polymer-based single-ply membranes (including EPDM, PVC, TPO and other varieties) accounted for 15% of sales (CRCA, 2001). A brief description of each of these membrane types is provided below.

<u>Modified Bitumen (MB)</u>

This type of roofing membrane consists of a manufactured sheet of bitumen that has been modified by the addition of a polymer such as atactic propylene (APP) or Styrene Butadiene Styrene (SBS). Sales of SBS MB membranes are much greater than APP MB membranes (CRCA, 2001). The sheets may be reinforced with glass-fiber mats, polyester scrim, or a combination of the two, and may be surfaced with coatings, granules or metal foil. This membrane offers the advantages of high puncture resistance, multiple layers of protection against leaks, and a strong history of reliability.

<u>Built-Up Roofs (BUR)</u>

BUR systems consist of alternating layers of felts and bitumen with a surfacing layer such as aggregate or a liquid applied coating. As the name suggests, this type of membrane must be built up on site. The membrane is not functional until all components are adhered during installation. As a result, the proportion of installation cost attributed to labour may be significantly higher for a BUR than for other systems such as single-ply membranes. Like MB roofs, BURs have a long history of reliability when installed properly. The multiple layers used offer added protection against water penetration and make the membrane more puncture resistant. MB and BUR membranes have common weaknesses such as the potential for blistering and slippage, but BURs require more labour to install.

<u>Polymer based single-ply</u>

This class describes a group of polymer-based factory manufactured membranes that consist of only one ply. These membranes are manufactured to strict quality control requirements in a factory setting. As such, the membrane sheet itself is less likely to contain breaches than a BUR membrane, which is assembled on site and is thus dictated by the level of skill and care used by the roofer. While polymer based single-ply membranes have not been used as extensively in Canada as BUR membranes, they have recently become increasingly popular because of the rising costs of labour and petroleum products, advancements in the polymer technology used, and the demand for flexible roofing materials for use on buildings with more creatively designed roofs (Laaly and Dutt, 1985). One of the main drawbacks of these membranes is that they tend to be more susceptible to mechanical damage on the roof as they are single-ply and thinner than MB and BUR membranes.

As shown in Figure 5.2, single-ply membranes are commonly divided into two categories: thermoplastic and thermoset. Thermoplastic materials consist of long chain molecules held together by weak bonds. The heating or cooling of this material causes it to soften or harden. Conversely, the long chain molecules in thermosets are strongly bonded to smaller molecules in a three dimensional formation. The process of creating this bonding is referred to as vulcanization. The result is a rigid material that does not soften or harden significantly upon heating or cooling. This difference means that thermoplastic roofing membranes may be bonded using heat while thermosets can only be bonded with some sort of adhesive (Paroli et al., 1999).

According to the 2001 CRCA survey, ethylene propylene diene monomer (EPDM) membranes represented by far the largest percentage of low slope roofing sales among polymer based single-ply membranes. Polyvinyl chloride (PVC), thermoplastic polyolefin (TPO) and chlorosulfonated polyethylene (CSPE) membranes also fall into the single ply category, but represented a much smaller portion of the market.

5.1.5 Top cover

A covering or surfacing material may or may not be required above the roofing membrane depending on the membrane type, the expected exposure to the elements or foot traffic, the type of assembly used and other factors (Chown, 1990). Common materials used as a top cover include liquid applied coatings, gravel, pavers, and factory applied mineral and metal surfaces. Reflective or white coloured surfacing materials are commonly used in 'cool roofs' which are intended to absorb less solar radiation and thereby minimize heat flow into the building envelope through the roof. This technique can be an important way of achieving the cooling benefit that a green roof provides (through evapotranspiration) at a significantly lower cost.

5.2 Component assembly

Roofs may be classified in a variety of ways based on characteristics such as slope, membrane type or assembly design. Conventional and protected membrane assemblies are common terms used to classify the way that roofing components are assembled in relation to the membrane. Figure 5.1 shows cross-sections of both assembly types.

The main difference between a conventional and PM assembly is the location of the membrane relative to the thermal insulation (see Figure 5.1). In PM assemblies (also referred to as inverted roofing membrane assemblies) the insulation is installed above the roofing membrane in order to provide added protection from ultraviolet radiation, thermal stress and various forms of mechanical damage caused by weather conditions or pedestrian traffic. The membrane is laid down directly on top of the roof deck in this configuration. The insulation in a PM roof is far more susceptible to damage from moisture than the insulation in a conventional assembly. As a result, fewer options for insulation materials are available on PM roofs. Extruded polystyrene insulation is often used due to its ability to remain at a relatively low moisture level (Hedlin, 1989). There are a few strategies used to keep insulation from moving due to wind uplift or floatation due to submergence. Some of these strategies require ballasting which adds significantly to the load on the roof. The disadvantages associated with this assembly include the potential additional weight, the exposure of the insulation to environmental damage, and difficulty associated with accessing the membrane for repairs. Its main advantage is that it offers better protection of the membrane relative to a conventional assembly. Better protection translates into fewer repairs and a longer life, which is why the system remains a relatively popular choice within the Canadian market (Hedlin, 1989).

5.3 How to make it green

Green roofs may be installed as new roofs or as retrofits to an existing roof as long as the structural load can be accommodated. While most of the roofing components discussed in the previous section are the foundation layers, a green roof also requires various modifications to these conventional assemblies. Specifications for roof greening are focused on ensuring the long term health of the vegetation and structural integrity of the roofing membrane.

In the installation of a green roof, the following must be considered:

i) The components of the existing (for retrofits) or planned (for new buildings) roof assembly must be capable of supporting a green roof. In particular, the deck and membrane must be carefully selected to ensure that additional loads can be accommodated and that the membrane will withstand additional hydrostatic pressure (Kirby, 2006). This means that the membrane used must be waterproof, not just weatherproof. In evaluating the load-capacity of the roof deck, both dead loads (static load including weight of roof materials) and live loads (which are variable and include the weight of maintenance personnel, wind, rain and snow) must be taken into account.

ii) A green roof assembly (of which a generic cross-section is shown in Figure 5.3) consists of the following components above the roofing membrane (in a conventional assembly): a root-resistant layer, a drainage layer, filter fabric, growing medium, and plants. In a PM assembly, the root-resistant layer would still be located directly above the roofing membrane with insulation above it, followed by filter fabric, a drainage layer, another sheet of filter fabric, growing medium and plants (Liu and Baskaran, 2005a). The filter fabric prevents particles of growing media or drainage media (which is sometimes a thin layer of aggregate) from migrating down into the roofing assembly and accumulating in the insulation or at the surface of the roofing membrane. Table 5.1 describes the function of each of these green roof components (Liu and Baskaran, 2005a).

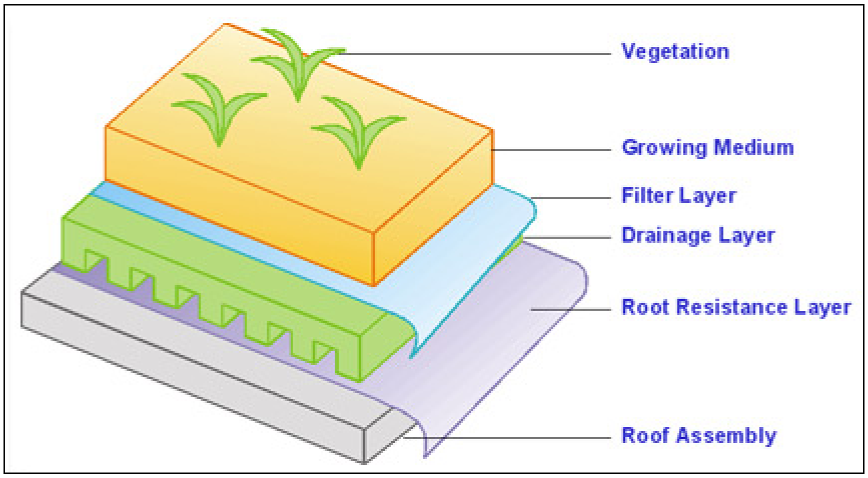

Figure 5.3: General cross-section of a green roof assembly (Source: Liu, 2006).

Note: The drawing is only a schematic and the actual appearance of each component can vary widely between different proprietary green roof systems.

Table 5.1: Green roof system components and their functions

Component	Function
Root-resistant layer	To minimize root damage to the membrane. This could be a chemical agent incorporated into the membrane or a physical root barrier, which can be a layer of PVC, polyester or polyethylene.
Drainage layer	To remove excess water from the growing medium. This can be a layer of gravel, specialized polymer foam panels or a highly porous polymeric mat.
Filter layer	To prevent fine particles in the growing medium from clogging the drainage layer. It is a geotextile material.
Growing medium	To support plant growth. The composition and depth depend on the vegetation selected. Artificial lightweight growing media are typically used to replace regular soil in order to reduce structural loading.
Plants	Plants should be selected for their adaptability to local climate conditions. An irrigation system might be needed, depending on the specific plants and climate.

Source: Liu and Baskaran, 2005a.

5.3.1 Structural considerations

A green roof will generally impose higher loads on a building's structure than most conventional systems, although newer green roof systems are being designed to weigh as little as some of the heavier conventional roofing systems on the market. The additional cost associated with accommodating higher loads due to a green roof will vary widely based on the weight and type of green roof system and the type of building structure. The marginal cost of providing a structure to resist additional loads in a new building is likely to be low compared to the total structural costs for the building. As a result, there is a broader range of green roof systems available for use on new buildings relative to the number of options available in a retrofit situation.

In an existing building, one must consider the overall capacity of the columns, foundation, roof framing and deck to carry additional loads. In the presence of excessive loads, the roof framing may fail due to lack of strength or deflect excessively beneath the extra weight (personal comm., Hitesh Doshi, 2007). In a tall building, it would be reasonable to assume that the addition of weight associated with a green roof would add relatively little stress to the columns which are already capable of supporting a significant amount of weight (all the floors in the building). Industrial buildings present a different scenario than most residential, commercial or institutional buildings. Industrial buildings are generally one story and occupy a larger ground area. Column supports may be more widely spaced and have lower load bearing capacities than high rise buildings. The larger spans between columns mean that supporting additional weight on the roof is a greater challenge unless the structural roof framing is strong and rigid.

One structural modification that can be made to accommodate a green roof and avoid framing failure is adding a structure to the roof which transfers the weight of the garden so that, instead of adding load on the part of the roof deck directly below it, load-bearing walls or columns receive the additional load. Thus, the weight that would be on the roof framing is transferred directly to the columns which may be able to better handle the additional load (personal comm., Hitesh Doshi). The design of the green roof can also assist in dealing with load issues. Placing deeper soil or heavier plants over columns or load-bearing walls can help to circumvent the need for a major retrofit while still providing the flexibility of having a deeper substrate and more planting options (Barr Engineering Company, 2001). While these strategies can help to minimize costs associated with a green roof retrofit, a site-specific assessment by a structural engineer would still be required to determine whether they are viable options for a given building.

5.3.2 Waterproofing membranes

The key difference between a roof membrane and a waterproofing membrane used under a green roof relates to their relative capacity to tolerate hydrostatic pressure (Kirby, 2006). While all roof membranes are designed to withstand some hydrostatic pressure, conventional membranes are designed based on the expectation that water will be drained away quickly. A membrane used beneath a roof garden must be capable of withstanding more hydrostatic pressure and for very long periods of time. The roofing assembly in a green roof must be stable in a wet environment and the membrane should be fully adhered rather than loosely laid or partially adhered to the layer below (Kirby, 2006). The specific types of membranes recommended for use in green roof installations include the following:

- four-ply coal tar BUR
- polymer modified asphalt applied as a hot fluid (at a minimum 5.4 mm thickness)
- two-ply polymer modified bitumen sheet
- Butyl rubber membrane (at minimum 2.3 mm thickness)
- EPDM (at minimum 1.5 mm thickness)
- PVC (at minimum 2.0 mm thickness)
- Elastomeric, fluid applied

Avoiding water damage to membranes beneath green roofs involves ensuring adequate slope for drainage, using a drainage layer, increasing membrane flashing redundancy, and using membranes that can withstand hydrostatic pressure (Honza, 2005).

Once a roofing system (insulation, vapour barrier, membrane, etc.) has been constructed, tests should be conducted to ensure that there are no breaches in the membrane prior to the installation of the garden. There are a few different leak detection methods available, however 24 hour flood tests and electric field vector mapping (EFVM) are the most common types. The flood test involves submerging the roof area with a few inches of water and plugging drains so that the water remains on the roof for 24 hours. In EFVM a wire is placed around the perimeter of the roof surface and an electric potential is introduced. If the membrane is watertight, no electrical connection occurs. However if there is a breach in the membrane, an electrical connection will be detected and the leak can be located with a high level of accuracy (Eichorn, 2006).

6.0 THE LITERATURE

6.1 Capital costs

Peck and Kuhn (2002) estimate a cost range of between $10 to $15 per square foot for removing an existing roof and re-roofing with a root-repelling membrane. The cost of an inaccessible extensive green roof system, its plants, and the labour for installation is estimated to range between $9 and $21 per square foot. An additional cost of between $2 and $4 per square foot is required if an automated irrigation system is installed. These estimates are based on the assumption that the green roof will be installed on an existing building with sufficient loading capacity.

According to Dunnett and Kingsbury (2004), this assumption may be valid on new roofs where relatively lightweight substrates are used, as they estimate that 4 inches (10 cm) of stone chippings weighs approximately the same as an extensive green roof with a 1.6 inch (4.1 cm) substrate. Older roofs may be capable of accommodating heavier loads because changes to the snow load calculations in the Ontario Building Code (OBC) mean that some roofs have been designed to accommodate as much as 18 lbs/ft^2 more than what the current OBC requires (Peck and Kuhn, 2002). On buildings where extra loading capacity is provided both by an older version of the OBC and removal of stone chippings, various green roof systems currently on the market could be installed without structural modifications (see Table 8.1 later in this report for saturated weights of some products).

Newer buildings must conform to the current building code and, depending on the building type, are more likely than older buildings to require additional structural modifications to accommodate a green roof. A green roof cost-benefit analysis conducted by Orlando Corporation and The Municipal Infrastructure Group (2006) reported that a new industrial building with a gross floor area of approximately 290,000 ft^2 would require a 45% increase in building structural costs in order to accommodate a green roof with a design load of 25 lbs/ft^2. While several green roof systems available in Canada are lighter than 25 lbs/ft^2, all of these systems are less than 6 inches (15 cm) deep, and would therefore not qualify for the financial incentive provided through Toronto's pilot green roof incentive program. The thinner green roofs, however, may be worth considering even in the absence of a financial incentive as they can significantly reduce the cost of structural modifications, and provide many of the same private and public benefits noted earlier. A case in point is the famous 454,000 ft^2 green roof on the Ford assembly plant in Dearborn, Michigan, which is 3 inches (8 cm) thick and has a saturated weight of only 11 lbs/ft^2 (Schnepf, 2006).

The Canadian cost estimates of green roofs are comparable to those provided by Green Roofs for Healthy Cities (GRHC) in the United States. They estimate extensive green roof costs of $10 to $15 US per square foot (C$11.50 to C$17.50), stressing that costs may vary widely depending on site specific conditions. The cost of having an engineer evaluate the roof's loading capacity is estimated to range from $0 to $1000 US (C$1150). The minimum of the range applies to new buildings that are designed to accommodate a green roof (GRHC, 2005). The cost of structural modifications was not estimated.

While there are few studies that compare the costs of green roofs to conventional roofs, there is little disagreement that the initial capital cost of a green roof is considerably more than that of a conventional roof. The higher upfront costs relate largely to the need for conventional roofing components below the green roof; hence the green roof cost is over and above that of a conventional roof. A cost study conducted in Singapore estimated that the initial capital cost for an inaccessible extensive green roof system and its installation was approximately 82% greater than for a conventional roof with exposed PVC membrane. No additional structural cost was associated with the inaccessible green roof as the weight was deemed comparable to that of the conventional roof. If the green roof was accessible with a deep substrate (i.e. intensive) the additional structural support required would cost approximately 50% more than that of a conventional roof. The soil depth, the type and weight of vegetation used, and the pedestrian traffic expected on the roof were found to be key factors affecting the initial costs of the green roof (Wong et al., 2003).

6.1.1 Cost factors

The size and complexity of the green roof system has a significant impact on both the labour and materials costs. Elaborate designs and more labour-intensive planting methods will increase installation costs. Both the quantity and type of growing media and plants specified will also influence costs (GRHC, 2005).

The cost of transporting materials can be an especially important cost factor, particularly in relation to obtaining growing media (Philippi, 2006). Several material components of growing media sold in North America are not locally available and must be shipped long distances. Further, the application of growing media to the roof remains a labour intensive process in North America because most green roof installers do not yet use technologies such as blower trucks, which greatly facilitate conveyance of growing media onto the roof (Philippi, 2006). When heavy equipment is used, such as a crane for installations on taller buildings, rental costs may have major implications to the project budget (Peck and Kuhn, 2002).

For projects that are intended to be accessible in some way, the installation of additional features for safety or improved aesthetics will increase material and labour costs. Features commonly installed on accessible green roofs include edging, walking paths and safety fencing. The cost of these features may vary greatly depending on the type of materials used (GRHC, 2005).

One of the most important cost factors of all may relate to the market in which the green roof is being constructed. Prices of materials and labour are significantly lower in European countries than they are in North America. For example, estimates of average green roof costs in Germany range from C\$1.57/ft^2 (Philippi, 2006) to C\$4.79/ft^2 (Beattie and Berghage, 2004), compared to roughly \$10/ft^2 in Canada. These low prices are a result of more than twenty years of market development in Germany (Philippi, 2006). In the newer, less developed North American market there is less competition, labour is more expensive (due to a lack of experienced installers) and there is a greater tendency to use custom-designed systems. The use of all-in-one systems, which are common in Germany, eliminates the need for various sub-contractors and significantly reduces the project cost as there is only one company providing all components and undertaking the installation (Beattie and Berghage, 2004).

Aggressive environmental policies (such as those mandating green roofs) in various European municipalities have acted as important catalysts for green market development. These policies were largely spurred by the environmental problems specific to a European historical and geographic context. It is uncertain whether the North American market can be expected to develop in the same way in the absence of a similar pressing need for change (Beattie and Berghage, 2004).

6.2 Long term costs

The long term costs most commonly associated with managing a green roof include both routine maintenance and occasional non-routine repairs. Routine tasks may involve watering, weeding and occasional replanting (City of Chicago, 2001). Generally these chores are required less frequently than on normal gardens because green roof plants are often chosen based on their hardiness and ability to resist drought. Drains and gutters must be inspected and cleared more frequently than without a garden, because plant debris may build up to a greater extent (City of Chicago, 2001).

Appropriate design and construction of a green roof usually minimizes maintenance needs (Auckland Regional Council, 2003). The use of low-growing plants on a green roof, for instance, would limit the need for pruning or trimming of plants to aesthetic preferences only. Once a green roof has been established for one year, maintenance visits for the weeding of invasive plant species should be undertaken two to three times a year (Thompson, 1998).

Porsche and Kohler (2003) compared long term maintenance costs for green roofs to those incurred for conventional roofs. Bitumen and gravel roofs are described as requiring visual inspection every 5 years, while extensive green roofs are described as requiring 1 to 2 inspection/weeding visits per year. Inspection visits to the green roof should include checks of the integrity of the waterproofing components as well as the roof drains (Porsche and Kohler, 2003).

Estimates in Peck and Kuhn (2002) indicate that maintenance will cost between $1.25 and $2.00 per square foot of green roof during the first two years of operation. The GRHC Design manual (2005) provides a broader range of $0.25 to $4.10 per square foot during the first two years. Sources cited in chapters 7 and 8 report much lower maintenance costs after the first two years. The factors expected to influence the short and long term maintenance costs include the size of the project, the type of irrigation system, and the size and type of plants (Peck and Kuhn, 2002).

6.3 Longevity

Green roofs have the potential to increase the lifespan of the roofing membrane by providing protection from thermal stress caused by high temperatures and diurnal fluctuations (Liu and Baskaran, 2004). The exposure of bitumen or polymeric membranes to heat and solar radiation causes premature breakdown of these materials (Liu and Baskaran, 2004). National Research Council (NRC) studies on green roof thermal performance and membrane durability have demonstrated that membranes under green roofs experience lower temperature maximums and less temperature fluctuation.

One NRC study conducted in 2002 and 2003 at the Eastview Community Centre in Toronto reported maximum conventional roof membrane temperatures above 60°C and a median daily temperature fluctuation of more than 45°C. By contrast, the membrane below the adjacent garden experienced a maximum temperature of only 40°C and temperature fluctuation of less than 15°C (Liu, 2006).

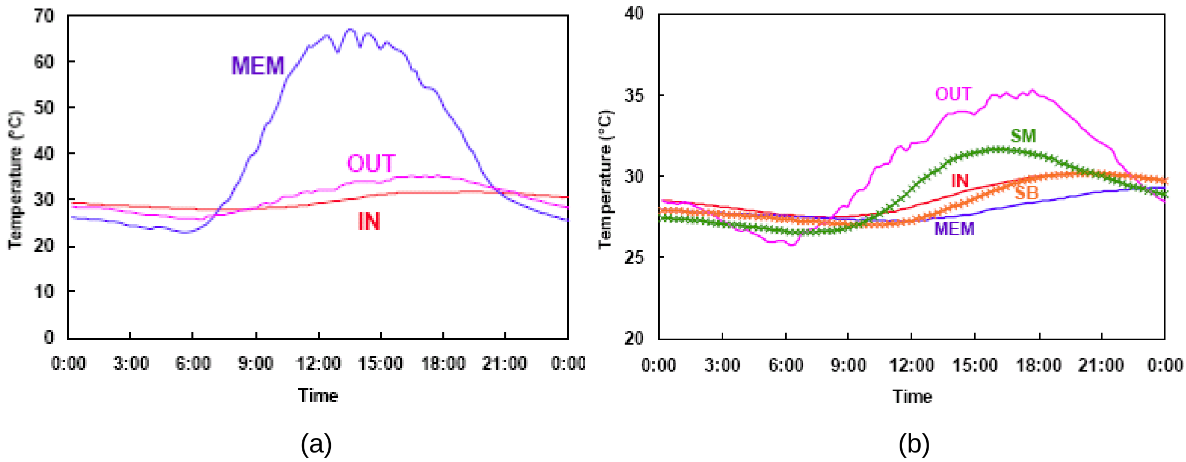

Figure 6.1: Temperatures measured on a sunny summer day during NRC monitoring of (a) a conventional roof and (b) a green roof on their Field Roofing Facility in Ottawa. Curves shown represent the roofing membrane (MEM), the outdoor air (OUT), the indoor air (IN), the middle of the green roof substrate (SM), and the bottom of the green roof substrate (SB). (Source: Liu 2006)

A similar trend was noted during experiments at the NRC Ottawa Field Roofing Facility, as shown in Figure 6.1. In the Ottawa study the green roof substrate was shown to provide substantial thermal protection to the roofing membrane, especially during peak sun hours. The membrane under the green roof also experienced significantly less temperature fluctuation (Liu, 2006). However, NRC research of Toronto City Hall's protected membrane system demonstrated that a green roof does not contribute significantly to protecting the membrane in these types of roofing systems because the membrane is already protected from the elements by the insulation above (Liu and Baskaran, 2004).

While NRC studies have clearly quantified the thermal impact of green roofs on roofing membranes, no field or laboratory experiments that specifically measured the resulting increase in membrane lifespan could be found. German literature indicates that, based on observation of installations in Germany, green roofs will at least double the lifespan of the roofing membrane to 40 or 50 years (Porsche and Kohler, 2003; Krupka, 2001). Porsche and Kohler (2003) also note that membranes beneath some older green roof installation in Berlin have even lasted 90 years without requiring replacement (Porsche and Kohler, 2003).

6.4 Energy savings

Green roofs have the potential to reduce energy used both in the heating and cooling of buildings. In the winter the plants and substrate of a green roof provide insulation (in addition to the insulation layer already installed as part of the underlying roofing system) and prevent heat loss through the roof, while helping to minimize heat gain through the roof during the summer through the cooling effects of evapotranspiration and shading.

Field monitoring in Osaka, Japan demonstrated that the presence of a roof lawn garden reduced summer heat flux into a building by 50% (Onmura et al., 2001). Similarly, Liesecke et al. (1989) reported that indoor temperatures in a building with a green roof were at least 3 to 4°C lower than outside when outdoor temperatures were between 25 and 30°C.

Several research studies have attempted to quantify the potential energy savings that may be realized through the implementation of green roofs. In Canada, the NRC has led most of this research. Energy efficiency monitoring studies have been conducted by the NRC at three green roof sites in Ontario: (i) NRC Ottawa Field Roofing Facility, (ii) Toronto City Hall, and (iii) the Eastview Community Centre in Toronto. Results from two of these sites are summarized in Table 6.1.

Table 6.1: Summary of energy efficiency results from NRC studies at the Ottawa facility and the Toronto Eastview Community Centre

Site	Reduction in Heat Gain (%)	Reduction in Heat Loss (%)	Max. Daily Temperature Fluctuation of roof membrane (°C)		Reduction in heat flow through roof relative to reference (%)	
			Green roof	Reference	Summer	Winter
NRC Ottawa	95	26	6	45	47 (annual)	
Eastview C.C.	95	23	10	50	70-90	10-30

Source (NRC Ottawa results): Liu and Baskaran, 2003
Source (Eastview C.C. results): Liu and Baskaran, 2005b

Results from the Toronto City Hall green roof were similar to the Eastview Community Centre green roof in terms of reducing heat flow through the roof. During the summer, heat flow reduction relative to the reference roof ranged from 50 to 90% while winter values ranged from 10 to 40% (Liu and Baskaran, 2005b). In terms of actual savings in energy use, the NRC Ottawa green roof was found to reduce daily energy demand for space conditioning by more than 75% relative to the reference roof during the spring and summer (Liu, 2002). Winter performance was generally less impressive, due to the fact that the green roofs monitored were more effective at reducing heat gain than preventing heat loss (Liu and Baskaran, 2004).

The results of a recent modelling study conducted by Bass et al. (2006) suggest that green roofs do contribute to energy savings during winter in cold climates. In this study the effect of green roofs on both the NRC Ottawa Field Roofing Facility and a prototype “cold climate house” were modelled to determine whether the presence of the green roof would help to reduce the amount of energy consumed for building heating in the winter. The study found that the green roof reduced energy consumption for both scenarios during the months of January and February, although the amount of energy saved was not specified.

A green roof feasibility study conducted by the City of Waterloo (2004) also modelled the savings in heating and cooling energy attributed to the installation of a 6 inch extensive green roof covering 100% (17,222 ft^2) of the roof on a 1-storey commercial office building in Waterloo. Results showed that annual energy savings from heating would be \$0.023/ft^2 of green roof while energy savings from cooling would be \$0.033/ft^2, assuming that the HVAC system was appropriately sized for the reduced load. If a green roof was installed on an existing building and the HVAC system was not resized, the heating savings would not change significantly but the cooling savings would be only \$0.012/ft^2 annually. Natural gas was assumed to be the form of energy provided for heating while electricity was assumed to provide cooling. Calculations were based on a natural gas cost of \$0.010/ft^3 and electricity cost of \$0.12/kWh.

Building design has also been identified as a key factor affecting the ability of the green roof to bring about a reduction in energy consumption. Martens and Bass (2006) conducted a modelling study investigating the impact of roof-to-envelope ratio on the energy savings provided by a green roof. The potential energy savings associated with roof greening was found to be far greater for single story buildings than for 2 or 3 story buildings. During a July day in Toronto, a green roof with dimensions of 820 ft by 820 ft was found to bring about energy savings of 73%, 29%, and 18%, for 1, 2, and 3 story air conditioned buildings, respectively.

6.5 Improved public relations

In a recent survey of members of the Building Owners and Managers Association (BOMA) in Indianapolis and Chicago, public relations ranked highest among perceived benefits of green roofs to building owners (Hendricks, 2005). While difficult to quantify, there is evidence that this perceived benefit has actually been realized among owners of buildings with green roofs.

The implementation of a green roof on a controversial or unpopular development can help to appease local residents and decrease opposition to the project (Welsh as cited in Loder and Peck, 2004). In the case of a green roof installed on a new Ryerson University building in downtown Toronto, nearby condominium residents expressed less opposition to this infill development project because a green roof was being used (Quinn, as cited in Loder and Peck, 2004).

Mountain Equipment Co-op has also received a great deal of positive feedback for installing a green roof on one of their stores located in downtown Toronto. The company receives 3000 visitors to their green roof each year and considers the installation a great success (personal comm., David Robinson, 2006).

6.6 Other considerations

While there are various other potential revenues to be derived from installation of a green roof, such as higher condominium selling prices or rental charges for roof usage, there appear to be few if any studies quantifying the dollar value of these. The use of a green roof for agriculture can be a potential method for generating additional revenue. For example, the Fairmount Waterfront Hotel in Vancouver has a green roof on which herbs, flowers and vegetables are grown. They estimate that this saves the hotel approximately $30,000 per year in food expenditures (Roberts, 2003). It is important to note however that the use of a green roof for agriculture would likely require a specialized growing media type and depth (which may be associated with a higher saturated weight) and higher maintenance expenditures.

Clearly, building type plays a role in the potential to capitalize on the amenity values a green roof may provide. An industrial building, for example, may have many users over the building lifespan, each with different equipment and racking layout requirements requiring roof penetrations in various locations. The presence of a green roof may ultimately complicate the process of carrying out the retrofits required by building users with unique roofing requirements.

6.7 Life Cycle Cost

The results of three life cycle cost (LCC) studies comparing extensive green roofs to conventional roofs are summarized in Table 6.2. The very different life cycle cost estimates among studies reflects differences in methodologies and assumptions. For example, the study by Porsche and Köhler (2003) assumed a green roof membrane life span of 90 years, which is more than twice that which was assumed in the other two studies. This increased roofing membrane lifespan had a significant influence on the outcome as the costs of membrane replacement and disposal were significant, and the conventional roof was assumed to last only 15 years. The green and conventional roof life cycle costs were almost the same in the Singapore study. Green roofs likely emerged as a favourable option in the Singapore LCC analysis due to the frequency of conventional roof replacement assumed. The authors assumed a lifespan of 10 years for the new conventional roof, and subsequent replacement at five year intervals thereafter. Conversely, the green roof membrane was assumed to last for 40 years without replacement or significant repairs.

The LCC analysis conducted by the Athena Sustainable Materials Institute (ASMI) for a proposed green roof in the Regent Park neighbourhood in Toronto was the only study in Table 6.2 which yielded a higher life cycle cost for the green roof. In this study, the LCC of extensive and intensive green roofs were compared to that of a traditional inverted (protected membrane) roof. The cost of the traditional inverted roof was the lowest, followed by the extensive installation; the intensive installation was the most expensive (ASMI, 2004). In another scenario, the installed green roof cost and annual maintenance costs were set at the bottom of the range of what was considered feasible ($\$11/ft^2$ and $\$0.25/ft^2/yr$, respectively). This generous assumption resulted in life cycle costs slightly lower than the inverted conventional roof (ASMI, 2004). Compared to the other two studies, this study used a higher private sector discount rate (17%), and the green roof was assumed to need replacement prior to the end of the investment period. Replacement of the green roof likely contributed significantly to the LCC of the green roof in the ASMI analysis.

Table 6.2: Summary of results for LCC studies of green and conventional roofs

Study	Location	Building Type	Investment Period	Discount Rate Applied**	Assumptions		Cost (ratio of conventional to green roof)
					Conventional Roof	Green Roof	
Porsche and Köhler, 2003	Germany	1080 ft^2 roof, building type not specified	90 years	Not specified	Flat gravel roof; 15 year life span	90 yr life span	1.69 and 1.84*
Wong et al., 2003	Singapore	Medium-rise, air conditioned commercial, 21,500 ft^2 roof	40 years	5.2%	Flat exposed PVC roof; 10 yr life span	40 yr life span	1.09
ASMI, 2004	Toronto	Low-rise, air conditioned residential, 4140 ft^2 roof	50 years	17%	Protected membrane (inverted) roof; 22 yr life span	40 yr life span; average capital & maintenance costs	0.55
						40 yr life span; minimum capital & maintenance costs	1.10

* 1.69 for a green roof system that includes PVC products, 1.84 for a green roof that does not include PVC products

** The discount rate is the rate of interest used to adjust the values of the cost distribution to a common reference point in time, which in this case is the present time.

6.8 Incentive programs

Recognizing that cost is a significant barrier to wider adoption of green roofs, several incentive programs have been developed by municipalities in North America and Europe. Examples of measures that have been adopted or are under consideration include fee rebates, grants, subsidies, low-interest loans, density bonuses, and various types of special consideration provided through the development application process. The Canada Mortgage and Housing Corporation recently published a document (authored by Lawlor et al., 2006) entitled *A Resource Manual for Municipal Policy Makers*, which describes the development of green roof policies in municipalities around the world.

Within North America, the City of Portland, Oregon has moved the fastest towards developing policy to support green roofs (Lawlor et al., 2006). Incentives include a floor area bonus based on the percent of green roof coverage as well as a potential 35% discount in stormwater fees for reducing the amount of impervious area on the site. The use of green roofs would qualify for this discount (City of Toronto, 2005).

The City of Chicago has also taken an active role in encouraging green roofs through both regulatory measures and financial incentives. Incentives offered by the City include stormwater retention credits, density bonuses, grants for both new and retrofit projects, an expedited permit process for green developments, and waived fees for projects that implement an extraordinary level of green strategy (Berkshire, 2006; Lawlor et al., 2006). The waiving of these fees can constitute a savings of between $5,000 and $50,000 depending on the size of the project (Berkshire, 2006).

Within Canada, the Quebec gas utility Gaz Métropolitan offers a rebate of $5 per square foot for green roof installations which meet the specified criteria (Lawlor et al., 2006). The City of Toronto also launched a pilot incentive program in March 2006 which offered a grant of $0.93/ft^2 of green roof area up to a maximum of $20,000.

The longstanding history of green roof incentive programs in Europe, and particularly in Germany, serves as the most significant demonstration of the importance of policies and incentives in helping to overcome barriers to the implementation of this technology. Since 1986, Stuttgart, Germany has had a green roof incentive program in place which pays 50% of the construction cost up to a maximum of €1.70 (C$2.50) per square foot. Thus far this program has contributed to 55,000 square metres of green roof (CMHC, 2006). Between 1989 and 1996, green roof coverage in Germany increased from 1 to 10 million square metres (Boivin, 1992). In 2001 alone, 14% of the country's newly constructed flat roofs were green roofs, which translates into an increase in green roof cover of 13.5 million square meters (Hämmerle, 2002). This success is largely attributed to the policies and incentives adopted by state and municipal governments (Boivin, 1992), although corresponding decreases in green roof material and installation costs have also been an important factor (Keeley, 2004).

7.0 SURVEY RESULTS

The industry survey of green roofs within southern Ontario yielded results for a total of 24 installations, all of which had already been constructed at the time of surveying. While building identities are not included based on the confidentiality preferences of the survey respondents, Table 7.1 lists several characteristics of the roofs surveyed. These characteristics were selected due to their potential impact on the capital cost of the installation, however it is not necessarily the case that each one had a significant impact on cost for every installation surveyed.

Table 7.1: Summary of green roof characteristics for installations surveyed

ID #	Type (int/ ext)	Retrofit or New	GR area (ft^2)	Accessible (yes/no)	Location	Slope (%)	Building Type	Height of installation (stories)
G1	ext	new	400	No	Downtown Toronto	20	Residential	1
G2	both	new	2200	Yes	Downtown Toronto	flat	Commercial	12
G3	ext	new	1500	Yes	Downtown Toronto	flat	Residential	2
G4	ext	new	400	No	Downtown Toronto	flat	Residential	1
G5	ext	retrofit	1000	No	Downtown Toronto	flat	Residential	2
G6	ext	new	2200	No	Midtown Toronto	40	Institutional	2
G7	ext	new	1000	No	Midtown Toronto	flat	Institutional	2
G8	ext	new	600	Yes	Downtown Toronto	flat	Residential	2
G9	ext	retrofit	12000	Yes	York Region	flat	Institutional	3
G10	ext	new	1800	Yes	Downtown Toronto	flat	Commercial/ Residential	3
G11	ext	retrofit	4000	Yes	Downtown Toronto	flat	Commercial	5
G12	ext	retrofit	1800	Yes	Downtown Toronto	flat	Institutional	3
G13	ext	new	1600	No	East Toronto	flat	Institutional	2
G14	ext	new	3000	No	East Toronto	flat	Institutional	2
G15	ext	new	20000	No	Waterloo Region	flat	Commercial	3
G16	ext	new	8000	Yes	Downtown Toronto	flat	Institutional	5
G17	ext	new	1800	Yes	Downtown Toronto	flat	Multi-unit residential	8
G18	ext	new	4000	No	Essex County	flat	Institutional	2
G19	both	retrofit	10000	Yes	Downtown Toronto	flat	Multi-unit residential	5
G20	ext	new	10000	Yes	Downtown Toronto	flat	Commercial	2
G21	both	retrofit	3200	yes	Downtown Toronto	flat	Institutional	20 (west) & 27 (east)
G22	ext	retrofit	2250	limited	Downtown Toronto	1 - 3	Institutional	2
G23	int	retrofit	300	yes	East Toronto	flat	Institutional	4
G24	ext	retrofit	5000	no	East Toronto	flat	Institutional	2

7.1 Capital Costs

Tables 7.2 and 7.3 summarize survey results on the capital costs of extensive installations for new roofs and retrofits, respectively. In the tables, capital costs are grouped into installation costs and building structural modification costs. The table also indicates whether a leak detection system (LDS) or irrigation system is included in the cost of each installation, however this information was not available for all green roofs listed.

7.1.1 Structural Load

All but one survey respondent for new roofs (Table 7.2) indicated that there were no extra costs related to structural modifications. It was not clear whether the building would have been built in exactly the same way without the green roof, or whether the extra cost was simply not broken out because it was originally designed with a green roof. In the case of green roof G20, for which structural modification costs were $50,000 (or $5/ft^2), the respondent indicated that it was possible to break out the additional structural cost of accommodating the green roof because the building had already been designed without this additional loading capacity, and costs associated with that design had been determined. The decision to add the green roof was made thereafter, and the design and cost were adjusted accordingly.

Survey respondents for green roof retrofit projects (Table 7.3) also indicated no expenditures associated with structural modifications. This is perhaps less surprising because few owners considering a green roof would choose that option if the building required significant modifications to accommodate the additional weight. Also, many buildings that have already been constructed are capable of accommodating light weight extensive systems (personal comm., Hitesh Doshi). Depending on the version of the Ontario Building Code (OBC) in place at the time of building construction, many buildings may have been constructed with a higher load-bearing capacity than what is required by the current version of the OBC. Changes to the method of calculating snow loads in the OBC could mean that for some buildings an additional 18 lbs/ft^2 are available for accommodating a lightweight green roof (Peck and Kuhn, 2002). The removal of ballast or other surfacing aggregates – which can weigh between 10 and 12 lbs/ft^2 - may also allow for some additional weight to be accommodated (City of Portland, 2000; Metropolitan Area Planning Council, 2005). Structural considerations associated with roof greening are discussed in greater detail in section 5.3.1.

Table 7.2: Survey results for capital costs* of new extensive green roofs (building characteristics are provided in Table 7.1)

ID #	Structural Modification Cost (Cdn $)	Cost of garden system incl. materials and labour (Cdn$)	Total capital cost ($/ft^2)	LDS** included ?	Irrigation system included?	Comments
G1	0	4000	10.00	no	no	
G3	0	12500	8.33	no	yes	
G4	0	3200	8.00	no	no	
G6	0	37000	16.82	no	no	Includes purchase and installation of stainless steel edging.
G7	0	7500	7.50	no	no	
G8	0	6500	10.83	not known	yes	Includes purchase and installation of edging materials.
G10	0	14000	7.78	not known	yes	Includes purchase and installation of edging materials and patio stones intended to improve accessibility.
G13	0	19000	11.88	no	no	
G14	0	18000	6.00	no	yes	
G15	0	162000	8.10	no	yes	Cost does not include garden design. The total cost including roofing membrane and insulation is $20-$23/ft^2.
G16	0	80000	13.33	no	yes	Extra labour charged due to difficulties in staging work relative to other teams working on the roof (such as HVAC).
G17	0	18600	10.33	no	yes	
G18	0	20000	5.00	no	no	Does not include cost of plants or labour for planting. All other garden components were included as were design and consultation costs.
G20	50000	120000	17.00	no	no	
	Average:		**10.45*** **			

* Capital cost includes structural modifications to the building to accommodate additional weight (when necessary) as well as the purchase and installation of the green roof. Costs quoted are over and above the cost of the base roof.

**An electric leak detection system (EFVM) should cost approximately $0.65 /ft^2 (personal comm., Chris Eichorn of International Leak Detection Ltd.)

*** Average excludes G18 because the cost does not include plants and planting labour. The cost of plants would add $1 to $3 to the per square foot cost (Peck and Kuhn, 2002). Labour for planting would be an additional cost. Peck and Kuhn (2002) suggests a minimum cost for all labour associated with green roof installation is $3/ft^2. The labour associated with planting alone would be expected to be no greater than this minimum.

Table 7.3: Survey results for capital costs* of retrofit extensive green roofs (building characteristics are provided in Table 7.1)

ID #	Structural Modification Cost (Cdn $)	Cost of garden system incl. materials and labour (Cdn$)	Total capital cost ($/ft^2)	LDS** included ?	Irrigation system included?	Comments
G5	0	8000	8.00	no	no	
G9	0	98000	8.17	no	yes	Includes purchase and installation of patio stones
G11	0	40000	10.00	no	yes	Not including leak detection system
G12	0	34000	18.89	no	yes	Includes purchase and installation of patio stones.
G22	0	84000	37.33	not known	not known	Includes removal of old roof and installation of the new roof (including membrane, insulation, etc.) over the entire building. The garden covers only a small portion of the roof surface.
G24	0	55000	11.00	not known	not known	Total cost including removal of old roof and installation of the new roof (including membrane, insulation, etc.) and garden was $298,000.
	Average:		**11.21*** **			

* Capital cost includes structural modifications to the building to accommodate additional weight (when necessary) as well as the purchase and installation of the green roof. Costs quoted are over and above the cost of the base roof.

**An electric leak detection system (EFVM) should cost approximately $0.65 /ft^2 (personal comm., Chris Eichorn of International Leak Detection Ltd.)

*** Average excludes cost of G22 because it includes the cost removing the old roof and installation of a roof before the garden was installed.

7.1.2 Green Roof Installation

Tables 7.2 and 7.3 list costs for materials and labour associated with garden installation for new roofs and retrofits, excluding costs for the conventional roofing systems (e.g. membrane, insulation) below the garden. Costs figures listed include only the green roof layers described in section 5.3.

Among green roof installations on new roofs (Table 7.2), the average installed cost for the garden was $10.45/ft^2, and the range was $6/ft^2 to $17/ft^2. The most expensive installation listed (G20) included $5/ft^2 structural modifications to accommodate the green roof, representing 29% of the total green roof cost. If this expenditure is omitted, the per square foot cost of G20 would be $12/ft^2, which is more in line with the costs of the other installations in Table 7.2. The second most expensive installation listed (G6) included stainless steel edging. Depending on the quality of materials and labour required for installation, the use of aesthetic trims such as edging and walking paths can result in substantial cost escalation. The extra cost in this case may also relate to the 40% roof slope (see Table 7.1) – a characteristic that can complicate the installation process. The least expensive installation listed (at $5/ft^2) was not included in the average because the cost of plants and planting labour were not incorporated. Surveys from other lower than average cost installations in Table 7.2 did not explain why these installations were less expensive.

Green roof retrofit installations (Table 7.3) averaged $11.21/ft^2, with a range between $8 and $19 per square foot. The retrofit sample size was too small (n = 5) to attach statistical significance to cost differences between new and retrofit green roofs. The median cost for both new and retrofit roofs was $10/ft^2. It is not clear why G12 cost more than other retrofit roofs, but complexity of design and the additional labour requirements for patio stone installation may explain part of the additional expense. The amount of roof area greened can also be an important factor which is not easily discerned in Tables 7.2 and 7.3. Per square foot costs should decrease as the roof area to be greened increases, due to the fact that consultants and installers charge a base amount for travelling to the site, and the incremental cost increases associated with greening a larger area is less significant than this base cost. Factors influencing costs were discussed previously in section 6.1.1.

7.2 Long-term costs

There were few estimates of long term costs because most green roofs in the survey were less than 2 years old. All installations listed in Table 7.1 were installed between 1998 and 2006. The current maintenance cost for the oldest green roof listed is $5000 per year (or $0.50/ft^2), which covers the cost of a minimum of 4 visits annually. In this case, the fee is paid out to a green roof maintenance company, and the garden is kept healthy and aesthetically appealing as part of this contract. Services provided include weeding, removal of invasive or undesirable plants, seasonal operation of the irrigation system, and re-planting as needed.

Survey respondents did not indicate the need for unexpected maintenance expenditures such as repairs to the roofing membrane or extensive re-planting. These expenditures may not have been required, or perhaps the survey respondents were not aware of ongoing maintenance activities as most were green roof installers, not building maintenance staff. The average fees charged for maintenance of a green roof are discussed further in section 8.2.

8.0 INDUSTRY INTERVIEWS

This section presents the results of interviews with various representatives within the commercial green roof industry, such as structural engineers, roofing consultants, product manufacturers, installers and horticulturalists. Individuals interviewed were selected according to their ability to provide estimates of various capital and long-term costs of green roofs.

8.1 Capital costs

8.1.1 Structural Load

The first step in the process of planning a green roof for an existing building is to consult a structural engineer to determine whether the building can accommodate the additional weight. The cost of consultation with a structural engineer will vary based upon the time commitment required to determine the existing load-bearing capacity of the building. In circumstances where the original engineering drawings for the building are available, the time commitment is minimal because load calculations and associated assumptions made by the original engineer (engineer of record) are normally included on the drawings. The consulting engineer would then likely provide a letter which would verify the true load-bearing capacity. The cost for this service would likely be close to $1,000 (personal comm., Mike Buckley of Halsall and Associates).

Costs escalate in situations where drawings are not available and a site visit is required. The cost in this case will be based on the amount of time required to determine load-bearing capacity. A site visit would be conducted to take measurements of structural supports, and following the visit, information would be consolidated and then analyzed. In buildings where beams are easily accessible, the measurement process may be relatively straightforward. The total cost associated with these services will vary greatly depending upon building size, design, and the ease with which measurement of structural supports can be undertaken (personal comm., Mike Buckley of Halsall and Associates). The current hourly rate charged by a junior structural engineer ranges from $75 to $90 per hour, a senior engineer between $140 and $160 per hour and a principal engineer, approximately $200 per hour (personal comm., Mike Buckley of Halsall and Associates). A junior engineer may be sent out to take measurements at the site, while a principal engineer may only be involved in the review.

Structural requirements depend largely on the saturated weights of the green roof. Table 8.1 shows this saturated weight data and associated system depths obtained from nine green roof product manufacturers and suppliers. In absolute weight, the lightest product listed is the 1.5 inch pre-cultivated system sold by manufacturer S6, which weighs only 8 lbs/ft^2. Overall, the thin pre-cultivated systems were the most lightweight both in absolute and unit depth weights. Specially designed absorptive blankets may be included in these systems to increase stormwater retention. This additional retention capacity increases the saturated weight accordingly, as demonstrated with the three options available from manufacturer S8. As mentioned earlier, the roof ballast on retrofit roofs can weigh 10 - 12 lbs/ft^2. Removal of this ballast as part of re-roofing could allow the weight of several systems listed in Table 8.1 to be accommodated.

Table 8.1: Depths and saturated weights of extensive green roof systems available in Canada

Supplier	System Depth (in)	Saturated Weight (lbs/ft^2)	Saturated Weight per unit depth (lbs/ft^2/in)	Comments
S1	6	30 – 43	5.0 – 7.2	Using engineered growing medium
S3	2.5 - 3.0	20 – 25	8.0 – 8.3	For the lightest system sold by this manufacturer
S6	1.5	8	5.3	Thin pre-cultivated system
S6	6	30	5.0	Using engineered growing medium planted or seeded on site
S7	4	18	4.5	Using engineered growing medium planted or seeded on site
S7	6	30	5.0	Using engineered growing medium planted or seeded on site
S8	2	8.2	4.1	Thin pre-cultivated system with no absorptive blanket
S8	2.5	10.4	4.2	Thin pre-cultivated system with one layer of absorptive blanket
S8	3	12.6	4.2	Thin pre-cultivated system with two layers of absorptive blanket
S9	1 - 6	12 – 50	8.3 – 12.0	Using engineered growing medium

The data in Table 8.1 demonstrate a correlation between system depth and saturated weight (R^2 = 0.79 based on maximum depths and weights), as would be expected. However, factors other than system depth also influence the weight, and it may not be best to select the lightest medium, especially if weight is not an issue for the site. The heavier substrates may, for instance, be capable of supporting a wider diversity of plants (both tall and small) with more complex nutrient requirements. This may explain why products sold by S1 and S9 can weigh 43 and 50 lbs/ft^2 respectively at a depth of 6 inches, while the same depth of S6 and S7 substrates both weigh only 30 lbs/ft^2.

While thin green roofs may be adequately supported on industrial buildings without structural modifications, thicker substrates will likely require extra support. As there were no industrial green roofs surveyed, the cost of these roofs is still an open question. However, if structural support is not required, it would be reasonable to expect that the per square foot cost of a large thin green roof on a one story industrial building would be closer to the minimum supplier quotes listed in Table 8.2, because it would be easy to get the material onto the roof, and there would be economies of scale associated with the large area of roof covered. Per square foot maintenance costs would also be lower for a larger roof area given that the incremental cost increase for maintaining a larger roof area is not as significant as the base cost of having the maintenance personnel travel to the site.

8.1.2 Green Roof Installation

Tables 8.2 and 8.3 present manufacturer cost estimates for green roof systems. Estimates in Table 8.3 include the cost of the underlying roofing system as well as the garden, as these were readily available from a few companies for which conventional roofing represents the bulk of their business.

Table 8.2: Supplier cost estimates for extensive green roof systems excluding underlying base roof

Supplier	Garden System Installed ($Cdn\$/ft^2$)		Comments
	Minimum	Maximum	
S1	10.50	11.00	Cost range for system with engineered growing medium and plants
S2	12.00	13.00	Cost range for system with engineered growing medium and plants
S3	10.00	15.00	Cost range for a system which uses a pre-cultivated vegetation blanket
S4	8.00	25.00	Cost approaches maximum for a system with a complex design
S5	8.75	10.00	Cost for system using engineered growing medium and seeds. Cost approaches maximum with deeper growing medium and the use of plugs instead of seeds.
S6	6.50	20.00	Pre-cultivated or planted on-site options available. Cost approaches maximum for use of more elaborate plants such as ornamentals.
S7	15.00	20.00	Cost for system using engineered growing medium and seeds. Cost approaches maximum with deeper growing medium and the use of plugs instead of seeds.
S8	9.00	12.00	Cost range for a system which uses a pre-cultivated vegetation blanket
Average:	**9.97**	**15.75**	

Table 8.3: Supplier cost estimates for extensive green roof systems including underlying base roof*

Supplier	Garden system installed including roofing (excluding the deck) ($Cdn\$/ft^2$)		Comments
	Minimum	Maximum	
S2	20.00	25.00	Cost range for system with engineered growing medium and plants
S5	20.00	30.00	Cost for system using engineered growing medium and seeds. Cost approaches maximum with deeper growing medium and the use of plugs instead of seeds.
S7	20.00	30.00	Cost for system using engineered growing medium and seeds. Cost approaches maximum with deeper growing medium and the use of plugs instead of seeds.
S9	35.00	50.00	Cost range for system with engineered growing medium and plants
Average:	**23.75**	**33.75**	

*Suppliers listed in this table are providers of both conventional roofing components and the green roof components above.

While there is a fairly large price range quoted by certain manufacturers listed in Table 8.2, the minimum costs are relatively consistent and are generally in line with the average determined from the survey of existing installations as well as literature values (Table 8.4).

Table 8.4: Summary of extensive green roof costs from various sources

Source	Garden installation (Cdn$/ft^2)	
	MIN	MAX
Peck and Kuhn (2002)	9.00	21.00
Green Roofs for Healthy Cities (2005)	11.85	17.77
Surveys	6.00	18.89
Supplier interviews	9.97	15.75

Overall the cost estimates from the four sources fell within the same general range. Supplier quotations tended to be higher on average than the survey cost results. The average survey result (for new roofs, excluding base roof cost) was closer to supplier minimums (approximately $10/ft^2). The average maximum quoted by suppliers is $15.75/ft^2, with significant variation among quotes. Per square foot maximum costs quoted by S4, S6 and S7 were the highest at $25, $20 and $20. These manufacturers indicated that these maximums would be charged for complex designs and for gardens requiring plugs rather than seeds and/or more expensive plants.

The estimates in Table 8.3 are also in line with expected costs for the total system including conventional roof layers and the garden. The per square foot cost of conventional roofing is highly variable, due in large measure to the different systems available, but also because total roof area influences cost. Discussions with individuals involved in industrial development projects indicated that the cost of installing built-up roofs on two industrial buildings (both constructed during the past 3 years) was $2.62 and $4.50 per square foot. The respective roof areas were 368,489 and 139,700 square feet. These industrial buildings have a much larger roof area than the green roofs included in Table 8.3, which may partly explain the substantial cost differential between the industrial building quotes and those for the residential and commercial sector. City of Toronto research (2005) indicated that conventional roofs cost between $8 and $12/ft^2. This range is in line with what one would expect based on the cost ranges listed in Table 8.3. While some of the maximums in Table 8.3 seem unusually high, it is important to note that many factors can cause roofing costs to escalate, such as the type of assembly (protected membrane is more costly) and the quality of the materials used (such as insulation with a higher thermal resistance).

8.2 Long-term costs

The cost per maintenance visit and number of visits required can vary substantially based on the size of the green roof, the distance the horticulturalist must travel to the site, and the expected level of service. The individual preference of the building manager or maintenance supervisor will dictate how much maintenance is needed. Activities may be limited to the simple removal of the odd tree, or it may include occasional re-planting, weeding, pruning and application of organic fertilizer. The green roof installation company *Gardens in the Sky* commonly bills $40/hr/person for a maintenance visit. There is a 2 hour minimum billed for a site visit and for most green roofs at least 2 staff would be sent out to carry out maintenance tasks. On average, 4 to 5 visits per year would be considered reasonable for adequate green roof maintenance (personal comm., Gardens in the Sky). In instances where the building manager already has a landscape maintenance contract in place, or employs an in-house landscaper, the maintenance work could possibly be carried out by these staff for a lower added cost.

9.0 THE BOTTOM LINE: LIFE CYCLE COSTS

The life cycle cost of a roof represents its cost over the entire life span of the product. The calculation of these costs can become very complex if the costs borne by society associated with the products are also considered. These ‘external’ social costs may include the costs associated with greenhouse gases emitted in the manufacture of a product, or the public benefit of reduced runoff from a green roof. There are several such costs and benefits, and they should not be ignored in considering the installation of a green roof, even if the costs and benefits are difficult to quantify. The objective of the current study, however, was to determine the financial costs and benefits of green roofs to the owner or developer; hence the foregoing LCC analysis does not consider public costs or benefits.

Life cycle costs of a green roof and conventional roof alternative were calculated using a costing tool developed by the Athena Sustainable Materials Institute in order to determine which roof is the more economical option. The tool requires input of various data including capital and long term costs, long term savings, investment period, lifespan, predicted inflation rates, and discount rates. Capital and long term cost (and savings) data inputted into the tool were based on the best information obtained from surveying, interviewing and review of other green roof studies. Once completed the tool returns the life cycle cost of the investment (the roof in this case) in present value dollars, over the specified time period. The term “net present value” describes the value of the future stream of costs and benefits of the roof discounted to the present by means of a discount rate (or hurdle rate) which reflects the investor’s time value of money.

Discount rates will vary based on the nature of the investor. For example, a home buyer’s discount rate could be the cost of capital (*e.g.* mortgage rate), or what he or she might receive from another investment with the same level of risk. A building developer, on the other hand, would typically use the company’s average weighted cost of capital (debt and equity) adjusted for the perceived risk of the investment. Alternatively, a building developer may use a set rate of return specified by company policies used to assess prospective investments (ASMI, 2005).

9.1 General Assumptions

The general assumptions used in the life cycle cost calculation are listed in Table 9.1. These assumptions are common to both the conventional and green roof scenarios.

Specifications of the building used in the life cycle analysis were the same as the reference building used in the City of Waterloo’s Green Roof Feasibility study (2004). The City conducted simulations using the EE4/DOE-2 building energy simulation software and empirical results from the National Research Council. The City of Waterloo’s study was the only one reviewed that included a full energy savings calculation, including both cooling and heating scenarios, and translated the energy savings into a dollar amount. The energy costs obtained from the modelling in the Waterloo study were used as inputs in the current life cycle cost calculations.

The specifications of the reference building described in the Waterloo study are listed in Table 9.2. The reference building is a one-story 17,222 ft^2 office building, using electricity for cooling (at a rate of

\$0.12/kWh) and natural gas for heating (at a rate of \$0.010/ft^3). The total annual heating and cooling energy costs for this building (without a green roof) were found to be \$8,675 and \$3,310 respectively.

Table 9.1: General assumptions used in LCC calculations

Parameter	Assumption	Basis or Justification
Installation type	new	Assume additional load could be accommodated without altering the building design.
Investment period	30 yrs	
Applicable discount rate	6.5%	Approximated based on current lending rates
General price inflation factor	2.5%	ASMI tool default - average observed since 1990
Thermal fuel energy price inflation factor	9%	ASMI tool default - average observed since 1992
Electricity price inflation factor	3%	ASMI tool default - average observed since 1992
Cost of natural gas	\$0.010/ft^3	City of Waterloo, 2004
Cost of electricity	\$0.12/kWh	City of Waterloo, 2004

Table 9.2: Parameters of a reference building used in City of Waterloo energy performance modelling

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 (17,222 ft^2)
Building height	3.5 m
Model zones	North, East, South, West, Core
Floor description	Un-insulated 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 software)
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

Source: City of Waterloo, 2004.

* Note that metric units are used in this table (while imperial are used in all other sections of the report) given that metric units are more commonly used for several of the energy efficiency related variables.

9.2 Base Scenario descriptions

The ASMI life cycle costing tool was run for four base scenarios, as defined in Tables 9.3 and 9.4. Since most cost data obtained were ranges rather than averages, the LCC was determined for both ends of the range – that is, the minimum and maximum costs for both the conventional and green roof. The minimum and maximum conventional roof scenarios are described in Table 9.3.

Table 9.3: Input values for conventional roof minimum and maximum cost scenarios

Parameter	MIN	MAX	Basis / source
Conventional roof lifespan	15 yrs	15 yrs	TMIG, 2006; Peck and Kuhn, 2002; Johnston and Newton, 2004; Porsche and Köhler, 2003.
Installation	$137,778	$206,666	Calculated from City of Toronto (2005) low ($8/ft^2) and high ($12/ft^2) end cost estimates.
Re-roofing after 15 years	$137,778	$258,333	Minimum assumes no removal of existing roof prior to re-roofing, therefore cost is the same as the initial roofing cost of $8/ft^2. Maximum assumes removal of existing roof prior to re-roofing and is calculated from Peck and Kuhn (2002, p. 15) maximum cost of $15/ft^2 for removal and re-roofing.
Leak Detection System	$0	$11,194	For minimum assume no LDS installed. Maximum calculated from Chris Eichorn, International Leak Detection Ltd. estimate of $0.65/ ft^2 for EFVM system.
Annual maintenance	$1,378	$2,067	Calculated based on ASMI (2004) assumption of 1% of capital cost.
Annual heating (natural gas)	$8,675	$8,675	City of Waterloo (2004) energy modelling result
Annual cooling (electricity)	$3,310	$3,310	City of Waterloo (2004) energy modelling result

The minimum cost scenario assumes that during re-roofing at 15 years, the new roof will be installed over the existing roof and thus the additional labour associated with removal of the existing roof is avoided. This practice may be employed as long as the additional weight of the replacement roof can be supported. Not all roofing practitioners agree with this approach, but it is nevertheless commonly done. In the maximum cost scenario, the cost of removing the existing roof is incorporated and thus the re-roofing cost is higher than the initial roofing cost.

The minimum and maximum extensive green roof scenarios are described in Table 9.4. Based on the specifications of the Waterloo study, the green roof in these scenarios is a 6 inch extensive installation covering 100% of the roof area (17,222 ft^2). The scenarios assume that the green roof does not require additional structural support. Values associated with tenant or public access to the roof (i.e. amenity values) and improved public relations are also not included (see section 6.5 and 6.6). Omitting these factors from the analysis is a simplification and should not be interpreted to mean that there are not real costs and savings associated with these factors.

Table 9.4: Input values for extensive green roof minimum and maximum cost scenarios

Parameter	MIN	MAX	Basis / source
Green Roof lifespan	30 yrs [2]	30 yrs [2]	TMIG, 2006; Dinsdale et al., 2006
Structural consulting services	$0	$1,200	Minimum assuming green roof was planned during building design and no outside consulting services were needed. For maximum, Green Roofs for Healthy Cities, 2005, p. 36.
Green roof installation	$409,027	$581,249	Calculated based on the average of the minimum ($23.75/ft^2) and maximum ($33.75/ ft^2) cost estimates from suppliers, listed in Table 8.3.
Leak Detection System	$0	$11,194	For minimum assume no LDS installed. Maximum calculated from Chris Eichorn, International Leak Detection Ltd. estimate of $0.65/ ft^2 for EFVM system.
Annual maintenance (first 2 yrs)	$43,055	$68,889	Calculated from Peck and Kuhn (2002, p. 15) low ($1.25/ft^2) and high ($2.00/ft^2) end estimates.
Annual maintenance (after first 2 yrs)	$1,000	$8,608	Minimum calculated based on minimum cost per visit estimates from Gardens in the Sky (pers. comm., 2007) - 2 staff @ $40/hr each, 2 to 3 hrs/visit, 5 visits annually. Maximum based on survey response of $0.50/ ft^2 for G20.
Annual heating (natural gas)	$8,275	$8,275	City of Waterloo (2004) energy modelling result
Annual cooling (electricity)	$2,756	$2,756	City of Waterloo (2004) energy modelling result

[2] While a green roof membrane lifespan of 30 years is somewhat conservative given that several European (and particularly German) sources indicate that membranes beneath green roofs can last for over 50 years (Porsche and Köhler, 2003), local data supporting a lifespan beyond 30 years are scarce.

In terms of maintenance, it was assumed that annual expenditures would be incurred for the life of the green roof, but that costs would be elevated during the first two years. In the minimum cost scenario, maintenance costs after the first two years are based on the bare minimum recommended by the green roof installer *Gardens In the Sky*. While the maximum cost scenario uses survey data from installation G20, this is not necessarily the maximum cost one might expect to pay for green roof maintenance. Nevertheless the level of service provided to G20 for this cost is rather substantial and can be expected to ensure that the green roof remains both functional and aesthetically pleasing over the course of its expected life.

The City of Waterloo energy performance modelling indicated that the green roof would result in a 4.6% reduction in heating energy consumed and a 16.7% reduction in cooling energy consumed, assuming that HVAC systems would be sized according to decreased loads associated with this lower cooling demand. This reduced energy consumption translates into an annual dollar value savings of $400 for heating and $554 for cooling in comparison to the conventional roof.

9.3 Life cycle cost results

9.3.1 Base scenarios

The net present value for the four base scenarios run using the ASMI Life Cycle Cost (LCC) tool are presented in Table 9.5. All values are listed as negative balances (represented by brackets) because this calculation yields the present value of the amount spent on the roof over the investment period.

Table 9.5: NPV of green and conventional roofs for minimum and maximum cost scenarios

	Extensive Green Roof		Conventional Roof	
	MIN	**MAX**	**MIN**	**MAX**
Net Present Value at 30 yrs	($441,725)	($785,305)	($283,170)	($481,430)
Net Present Value at 20 yrs	($447,551)	($762,295)	($234,255)	($391,672)
Net Present Value at 10 yrs	($451,051)	($723,508)	($149,008)	($234,707)

Over the 30 year investment period, the minimum and maximum conventional roof LCCs were 36 and 39% lower than those of the extensive green roof, respectively. The range between the minimum and maximum green roof LCCs was considerably greater than that of the conventional roof. Hence, while the minimum cost green roof scenario was about 9% lower than the maximum cost conventional roof scenario, the maximum cost green roof scenario was close to 3 times higher than the minimum cost conventional roof scenario.

9.3.2 Alternative scenarios

Life cycle costs of six alternative scenarios were calculated to illustrate the cost impact associated with changes in LCC assumptions. A description and rationale for each scenario is provided in Table 9.6. In each case, one model parameter was varied to determine the impact on cost relative to the base scenario.

Figure 9.1 shows the results of the scenario analysis. The results for the base case and alternative scenarios are presented as the ratio of green to conventional roof LCCs and as the percentage change from the base case. To simplify, results were calculated based on the green and conventional roof cost minimums only. Detailed scenario descriptions and results for minimums and maximums are provided in Appendix C. The main findings of the scenario analyses were as follows:

<u>Extended Green Roof Membrane Scenario</u>: Increasing the life of the green roof membrane from 30 to 45 years, as suggested by German literature sources (Porsche and Köhler, 2003), reduced the green-to-conventional roof LCC ratio from 1.56 in the base case to 1.37 (a 12% decrease). The impact was less significant than anticipated because the costs for conventional roof replacements that occur at 15 and 30 years are much lower than the initial installation cost when converted to present value dollars.

Table 9.6: Summary of Alternative Scenarios

Scenario	Description	Rationale
Extended green roof membrane lifespan	Increase longevity of green roof from 30 to 45 years	German literature sources suggest that green roofs last longer than 30 years.
Non-air conditioned building	Eliminate green roof energy savings associated with air conditioning in the summer	Some industrial buildings are not cooled in the summer and high rise buildings may experience minimal energy benefits from a green roof
Government Incentive Program	Green roof capital cost is reduced by $2/ft^2 reflecting what was considered to be a relatively generous government subsidy.	The City of Toronto currently offers an incentive and some other GTA municipalities are considering the possibility of doing so. Several jurisdictions in the U.S. have developed green roof incentive programs.
Green Roof Market Development	Green roof capital cost is reduced by $7.75 due to growth of the green roof industry in Canada.	Costs in Germany declined considerably as the market for green roofs expanded
Green Roof Salvage Value	A salvage value is assigned to green roof materials after 30 years.	When the green roof membrane is replaced after 30 years, many of the materials can be re-used.
Public vs. Private Discount rate	LCC discount rate is varied from 6.5% in the base case to 3.25 and 13%, representing the public and private rates, respectively.	Discount rates applied to investment decisions vary widely depending on the perceived risk associated with the investment.

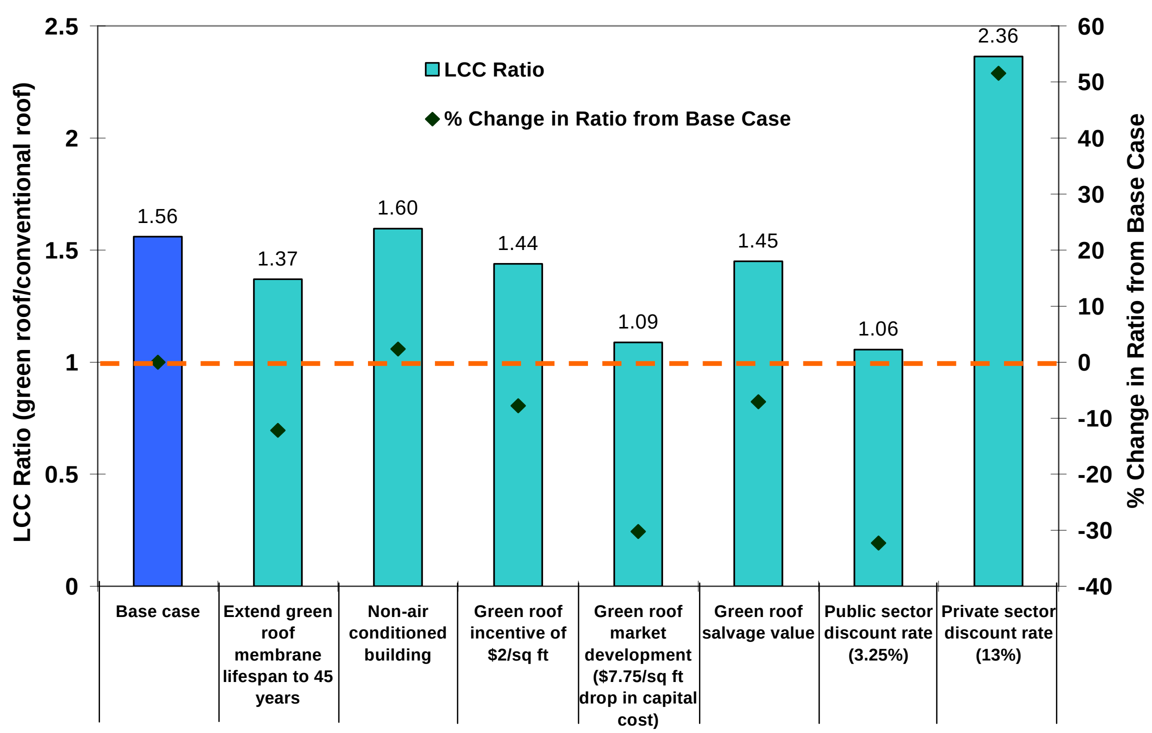

Figure 9.1: Ratio of green roof to conventional roof LCC for all scenarios (based on minimums only)

Non-air Conditioned Building Scenario: Eliminating the summer cooling energy savings from green roofs increased the LCC ratio by a mere 2% relative to the base case. This scenario does not include capital cost savings associated with a downsized building HVAC system due to lower cooling demand in a green roofed building. The cost impact of this scenario would have been greater had this consideration been incorporated. Unfortunately, there were no data upon which to estimate the potential savings associated with this change.

Municipal Incentive Program Scenario: The installed cost of the green roof was subsidized by an amount similar to what would be considered the value of a generous government green roof incentive program in Canada, estimated at $2/ft^2. The subsidy reduced the LCC ratio from 1.56 in the base case to 1.44 (a decrease of 8%), making the investment a more attractive option to building owners.

Green Roof Market Development Scenario: Reducing the installed cost of the green roof (including the cost of the underlying base roof) from a minimum of $23.75/ft^2 to 16.00/ft^2 substantially narrowed the cost gap between the green and conventional roof LCC, bringing the ratio down to 1.09. Relative to the other scenarios shown in Figure 9.1, market development yielded the second lowest cost differential between the green and conventional roofs.

Green Roof Salvage Value Scenario: This scenario involved assigning a salvage value to green roof materials once the roof membrane needed replacing (30 years). Literature suggests that 70% of the installed green roof system cost (which was approximately $10/ft^2) should be attributed to materials, while 30% should be assigned to labour. Thus, only materials costs were used to determine salvage value, which was estimated at 80% of the original value. The potential for re-use of materials is highest for cases in which a roofing membrane beneath a green roof requires replacement and the green roof is intended to be re-installed thereafter. There is likely less demand for salvaged green roof materials that are not for re-use on the same building. Accounting for salvage value of the green roof caused the LCC ratio to fall to 1.45 from 1.56 in the base case, a decrease similar to that of the government subsidy scenario.

Public vs Private Discount Rate Scenario: LCCs were calculated based on discount rates of 3.25% and 13%, representing public and private sector rates respectively. The LCC ratio fell to 1.05 when the public sector rate was applied, and increased to 2.36 with use of the private sector rate. Varying the discount rate changed the conventional roof LCC more significantly than the green roof LCC because of the need to replace the conventional roof after 15 years. A higher discount rate decreases the present value of future investments and vice versa. Thus, replacement of the conventional roof costs much less in present value terms when a high discount rate was applied, and much more when the discount rate was reduced. Since the green roof did not require replacement over the 30 investment period, the present value cost of the green roof was less affected by discount rate changes. These results indicate that green roofs will tend to be more affordable for investors such as those in the public sector, who tend to look for lower risk investments with more modest rates of return.

9.3.3 Summary

Results obtained for the base and alternative scenarios demonstrate that the gap between conventional and green roof LCC is most affected by factors that impact capital or replacement costs. These factors include: (i) roof membrane longevity, which decreases periodic replacement costs; (ii) market transformation, which causes a drastic decline in capital costs over time, and (iii) lower discount rates, which cause the more frequent periodic replacement cost of a conventional roof to be more expensive by comparison. Variations in annual costs and savings associated with maintenance and energy use reduction did not have a strong impact on the LCC.

Of course, these LCC calculations only apply to buildings with the same specifications as the reference building described earlier. Changes in these specifications could have a significant impact on the LCC. For example, if the building were a high rise residential unit, the extra cost of the green roof would comprise only a small proportion of the total building cost, and tenant access to the green roof, if provided, may make the extra cost worthwhile. Conversely, a green roof installed on a large flat roof industrial building requiring additional load bearing beams for support may be cost prohibitive (Orlando Corporation and The Municipal Infrastructure Group, 2006), although there are various strategies that may help reduce costs (see section 5.3.1).

The cost estimates provided in this study do not replace the need for a site specific cost assessment, as circumstances vary widely. Those considering a green roof must carefully consider the various conditions that apply in their particular case. It is hoped that this study provides information and data that help facilitate this process.

10.0 RECOMMENDATIONS

The following recommendations are based on results obtained from surveys, interviews and review of literature, as well as the results from the life cycle cost analyses. They are intended to provide insight into the policy instruments and industry transformation that is needed in order to spur the GTA green roof market. Recommendations for further research are targeted towards filling outstanding knowledge gaps so as to enhance understanding of life cycle costs for different building designs and uses.

10.1 Market Development

- Green roofs costs in Europe, and particularly in Germany, are 54 to 85% lower (based on German literature) than they are here in North America. While there are several factors that have contributed to the downward trend in European costs, policy instruments developed both to mandate and incentivize green roofs in various European municipalities have played a key role. GTA municipalities wishing to aggressively support green roof infrastructure should provide an incentive to decrease the capital cost of green roof projects, as green roofs are currently cost-prohibitive for many building designs and uses.
- A direct financial incentive should have a value greater than $2/ft^2, given that this amount had only a minor impact on the life cycle cost (see section 9.3). Decreasing the green roof capital cost by $7.75 (see Appendix C "Market Development Scenario") brought the green roof life cycle cost down to within 8% of the conventional roof life cycle cost. Based on these figures, an incentive of $4 - $7 per square foot would be needed to decrease green roof capital costs enough to make this technology an attractive option, and thus spur market growth.
- While an incentive of more than $8/ft^2 would likely result in even more green roofs constructed, there is also the potential to stunt market growth with such a substantial incentive, as it may lead suppliers to keep costs high rather than striving to develop solutions that reduce prices charged to potential clients.
- The use of other creative policies and incentives may help to stimulate market growth without some of the pitfalls of a direct financial incentive. Allowing a reduction in the size of end-of-pipe facilities to fulfill water management objectives, or expediting the approvals process for owners proposing a green roof are examples of such incentives.

10.2 Further Research

- While this study has provided some comments on the need for structural modifications associated with green roofs, the discussion was based on limited data, especially for green roofs on large flat roofed industrial buildings for which structural considerations may have a particularly significant impact on the bottom line. Further research is needed to investigate the effectiveness of innovative strategies (*e.g.* weight transferring structures, creative green roof design) aimed at minimizing the need for large investments in structural modifications on new and retrofit industrial roofs. Case studies of commercial and industrial buildings with green roofs would help to shed light on the circumstances under which including a green roof makes good business sense.

- Due to the relative newness of the green roof installations in the GTA, local data on green roof membrane longevity were scarce. Estimates were based exclusively on data from green roofs in Europe, which have been in place longer. While it will be several years before data on the longevity of local green roofs will be available, laboratory simulations of the conditions experienced by a membrane beneath a green roof could be an effective way of quantifying expected life spans in the GTA.
- There is some evidence that less quantifiable benefits of green roofs associated with the amenity and public relations value of green roofs can translate into substantial cost savings to building owners. These benefits should be further investigated and their value estimated in economic terms to provide a more comprehensive life cycle cost for green roofs to building owners than was provided in this study.
- Public values associated with green roofs (e.g. fewer combined sewer overflows, heat island mitigation, improved biodiversity) were not assessed in this study because the scope was limited to evaluating costs and savings incurred by, or accruing to the building owner or developer. Results from this study and other research specifically addressing the public values of green roofs (e.g. Ryerson University, 2005) should be combined and re-examined to determine the extent to which the cost of green roofs borne by owners is offset by their overall societal value.

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APPENDIX A

An overview of the public benefits of green roofs

Appendix A:
An overview of the public benefits of green roofs

The public benefits of green roof infrastructure are numerous and have been the subject of much local and international research. This research (particularly in Germany) has fostered a better understanding of the multiple benefits of rooftop gardens and has been an important factor behind their rising popularity in North America. This wave of popularity parallels a growing awareness of the environmental and health impacts associated with intensified urban development and the potential that greenroof technologies offer in mitigating these impacts.

In 2005, the City of Toronto funded a Ryerson University study which calculated the actual savings/revenues that would accrue to the City based on various levels of roof greening. Other southern Ontario municipalities have conducted similar studies, albeit on a smaller scale. These studies are being undertaken in an effort to better understand the value of green roofs to municipalities so that appropriate strategies and incentive programs can be developed to encourage broader implementation of this promising technology. While the public value of green roofs has not been addressed in the present study, these benefits are very real and substantial, and should be considered by anyone considering a green roof. The following sections provide a brief description of the key public benefits of green roofs.

Stormwater Management

Water quantity control

The use of green roofs to improve urban stormwater management is one of the most important benefits this technology offers. Green roofs attenuate peak flows and reduce the total volume of stormwater runoff by retaining rain water in the growing media and returning a portion of it back to the atmosphere through evapotranspiration. The runoff flows leaving the green rooftop, and ultimately draining to receiving waters, are significantly decreased and delayed relative to peak flows in the receiving water system. This helps to minimize downstream channel erosion, flooding risk, and negative impacts on aquatic ecosystems.

Table 2.1 summarizes green roof rainfall retention from several field monitoring studies undertaken in North America and Europe. The average percent retention rate reported in these studies was 60%, ranging from a low of 39% to a high of 72%. Most of the studies did not include winter monitoring, when evapotranspiration and water retention rates would be much lower than the summer (TRCA, 2006; Moran et al., 2004). Substrate thickness had a positive influence on rainfall retention in studies where more than one substrate thickness was monitored. However, the benefit of thicker substrates tended to decrease as thickness increased above approximately 5 cm (Liesecke, 1998; Dürr, 1995; Rowe et al., 2003).

Table A1: Summary of greenroof performance for water quantity control in field monitoring studies

Author(s)	Name of Periodical, Conference or Publishing Agency	Location	Monitoring Period	Slope (%)	Substrate Thickness (cm)	Vegetation Types	% Stormwater Retention
Moran et al., 2004	North Carolina State University	Kinston, NC	July-Aug & Nov-Dec '03	3	10.2	8 species of sedum and 2 of delosperma	63%
		Goldsboro, NC	April - December '03	minimal	10.2 & 5.1[1]		62%
TRCA, 2006	TRCA	Toronto, ON	Apr. '03 – Aug. '05 excluding winters	10	14	non-native grasses and forbs	63% [4]
Carter and Rasmussen, 2006	Journal of the American Water Resources Assoc.	Athens, Georgia	Nov. 2003 – Nov. 2004	2	7.6	4 species of sedums and 2 of delosperma	62%[7]
Liu and Minor, 2005	NRC	Toronto, ON	March 2003 - November 2004 excluding winters	minimal	7.5 and 10 [2]	Mixture of sedums[3]	57%
Liu, 2003	NRC	Ottawa, ON	Nov '00 – Nov' 01	2	15	wildflowers	54% [4]
Liesecke, 1998	Stadt und Grun (City and Green)	Hannover-Herrenhausen, Germany	1985 - 1994	2	2 - 4	unknown	40-45%
					6 - 8		50-55%
					10 - 12		55-60%
Dürr, 1995	Bauverlag, G mbH	Germany	Exact dates not available but numbers represent annual average	minimal	2.5 (with 5cm gravel bed)	moss and sedum	58%
				minimal	6.3	sedum and grass	67%
				minimal	10.1	grass & herbaceous plants	71%
Hutchinson et al., 2003	Greening Rooftops for Sustainable Communities Conf.: Chicago 2003	Portland, OR	May - Oct. '02	minimal	11	succulents, grasses & other herbaceous species	69%
Rowe et al., 2003	Michigan State University	East Lansing, MI	Sept 10-Oct 27, 2002 & Mar 20-28, 2003	6.5	4	7 species and cultivars of sedum	69%
					6		72%
Russell & Schickedantz, 2003	Greening Rooftops for Sustainable Communities Conf.: Chicago 2003	Dearborn, MI	Spring - Summer 2001	2	2	sedums plugs, sedum seeds & native plugs	39% [5]
					10		58% [6]

Notes: 1. The two different substrate depths were arranged in a checkerboard pattern. 2. The study monitored stormwater runoff from two garden plots containing two different substrates. The plot known as "greenroof S" had a substrate thickness of 7.5 cm and plot known as "greenroof G" had a substrate thickness of 10 cm. 3. Vegetation was not well-established during stormwater monitoring. 4. Value represents the reduction in runoff from green roof relative to reference roof runoff, not relative to precipitation. 5. This result represents the retention value obtained from the use of XeroFlor ™ drainage system. 6. This result represents the retention value obtained from the use of Siplast ™ drainage system. 7. Percentage is based on precipitation and flow volumes in Table 1 of the article. Average retention was just under 78%.

The ability of greenroofs to attenuate runoff peak flows has also been demonstrated in several monitoring studies. A monitoring study of a flat extensive greenroof undertaken between 2002 and 2003 in Portland, Oregon (Hutchinson et al., 2003) found that peak precipitation run-on rates ranged from 0.041 to 0.193 ft^3/sec while flow rates running off the greenroof were only 0.008 to 0.012 ft^3/sec. TRCA (2006) reported peak flow reduction rates of 50% for runoff events greater than 40 mm and 87% for events between 10 and 29 mm. Rain from smaller events was often completely retained by the green roof.

Green roofs also delay runoff peaks, which helps to ensure that peak discharges to receiving waters do not occur when the stream is being heavily impacted by stormwater flows from other impervious surfaces. A study of an extensive green roof in Toronto by the National Research Council of Canada (NRC) reported runoff delays relative to a conventional roof of between 20 and 40 minutes on average (Liu and Minor, 2005). TRCA (2006) found average runoff delays of 30 minutes on a green roof with a thicker growing medium.

In older municipalities, such as Toronto, in which combined sewer systems are used, green roofs can be an important stormwater management technology as they do not take up valuable space at ground level. The implementation of green roofs in built up areas of Toronto helps to reduce overall flows to storm sewers and minimizes combined sewer overflows to Lake Ontario. This translates into fewer beach closures and the overall improved health and aesthetic value of the Toronto waterfront.

Improved runoff quality

Green roofs help to decrease the total load of contaminants conveyed to receiving water systems in two key ways: (i) reducing contaminant concentrations and (ii) reducing total runoff volumes from the roof.

Research has shown that runoff from a green roof tends to have lower concentrations of contaminants such as polycyclic aromatic hydrocarbons, heavy metals, and suspended solids (Forster and Knoche, 1998; TRCA, 2006). This occurs because the green roof material does not leach these contaminants into runoff the way a conventional roofing surface does, and also because the green roof soil and plants remove atmospherically deposited contaminants though various chemical, physical and biological processes.

When rain falls on a green roof, the impact is absorbed by the surface soil or substrate, before it percolates slowly through the media, past a geotextile filter and into the drainage cell. On a conventional roof, the impact of rain and flow of rainwater on the hard surface leaches pollutants from the roofing material that were not deposited atmospherically. Several studies have shown that leaching of pollutants from conventional roofing materials can result in very high runoff concentrations of metals, PAHs and other pollutants (*e.g.* Clark et al., 2001).

Atmospheric deposition is another major source of contaminants in rooftop runoff. Analysis of precipitation in a North Carolina study of highway runoff quality revealed that as much as 10-30% of total phosphorus and nitrate, 30-50% of ortho-phosphorus, and 70-90% of total Kjeldahl nitrogen and ammonia in stormwater runoff may be contributed through atmospheric deposition (Wu et al., 1998). In a roof garden, soil adsorption, plant uptake, microbial activity, and filtration are all processes which either remove contaminants from the runoff or prevent atmospherically deposited contaminants from entering runoff.

The retention of runoff by greenroofs discussed earlier translates into a significant decrease in the volume of water discharged to receiving water systems. These lower flow volumes in turn result in reduced contaminant loads in runoff from the roof. Studies by Moran et al. (2004) and TRCA (2006) both found that while concentrations of some contaminants (such as nitrogen and *E.coli*) were higher in green roof runoff, loads were either the same or lower from the green roof due to the substantially lower flow volumes. The one exception was phosphorus, for which both concentrations and loads were higher than conventional roof runoff due to high concentrations in the growing media (TRCA, 2006).

Urban Heat Island

The urban heat island (UHI) effect refers to the elevated air temperatures of urban areas relative to surrounding natural or rural areas. The UHI is caused by the low reflectivity of urban surfaces, decreased urban vegetative cover, the trapping of long wave radiation by contaminants in the air, and intensified heat releases from building heating and automobile use in urban areas. Elevated temperatures associated with the UHI can accelerate the chemical reactions which form smog, while also increase energy demand for the use of air conditioning, which in turn leads to further pollutant emissions. Green roof technology helps to address the negative impacts of the UHI in the following ways.

- Roof greening increases the amount of vegetated surfaces which, due to the effects of evapotranspiration and shading, emit less heat and remain cooler than most impervious surfaces. A study conducted in Oregon showed that while a non-vegetated surface reached temperatures greater than 50°C in the month of July, a vegetated area remained significantly cooler at 25°C. (Luvall and Holbo, 1989).
- The cooling effect of vegetation in urban areas means less smog formation, as the chemical reactions which form smog are accelerated by higher temperatures. A modeling study conducted at Lawrence Berkeley National Laboratory in California predicted that for the Los Angeles basin, a 3.3°C reduction in summer temperatures would lead to an average smog reduction of about 12 % (Rosenfeld et al., 1998).
- During hot and sunny summer days, green roofs remain cooler than most conventional roofs, which results in reduced heat flow into green roofed buildings, and decreased energy demand for air conditioning. Bass and Mizra (2002) found that, in southwestern Ontario, the demand for electricity increases by 3% for every 1°C above a threshold value of 18°C, which is when people turn on their air conditioners. Reducing energy consumption in turn minimizes energy related greenhouse gas emissions and associated trapping of long-wave radiation. Through field monitoring of a green roof in Ottawa, the National Research Council found that a green roof reduced the energy demand for space conditioning during spring and summer by 75% relative to a conventional reference roof (Liu and Baskaran, 2002). A great deal of additional research has been focused on

quantifying the reduced energy consumption associated with green roofs. These are discussed in section 6.4 of the main report.

The extent to which the impacts mentioned above can significantly reduce the UHI will greatly depend on the extent of green roof cover. Modelling of the UHI has been an important tool to allow prediction of the impact of various levels of green roofing on urban temperatures. A simulation of the UHI for Toronto was conducted by Bass et al. (2003) using a mesoscale model (MC2) to predict the urban heat island for a base scenario and for a scenario in which 5% of the total area of the city was covered by greenroofs. The model predicted that the urban heat island of Toronto for the base case would be 2 to 3°C, while the greenroof coverage was predicted to cause a city-wide cooling of 0.1 to 0.8°C (Bass et al., 2003).

Air Quality

Aside from reducing smog formation by cooling the urban environment, green roofs may also be beneficial to urban air quality by helping to reduce concentrations of various atmospheric pollutants. Plants are capable of removing certain greenhouse gases and smog precursors (such as carbon dioxide and nitrogen oxides) from the atmosphere through leaf uptake and contact removal. According to the U.S. Environmental Protection Agency (2006), atmospheric pollutants are removed by vegetation through absorption of gases or attenuation of airborne particulate matter to leaf surfaces. Pollutants absorbed may be transformed through reaction with plant materials or they may simply be stored in the plant. Particulate matter attached to leaf surfaces are eventually dislodged or washed away by rain. Trees and vegetation have the potential to remove atmospheric contaminants such as nitrogen oxides, sulphur oxides, particulates, and ground-level ozone (EPA, 2006).

A greenroof study conducted in Washington, DC used the U.S. Department of Agriculture's Urban Forest Effects (UFORE) model to predict the benefits of green roof implementation in DC. The study found that installing green roofs on 20% of existing green roof-ready buildings and on 80% of new buildings (which is equivalent to 21.7 million square feet of coverage) would result in the removal of an additional 16.8 metric tonnes of air pollutants per year (Casey Trees Endowment Fund & Limno-Tech Inc., 2005). This removal rate was found to be equivalent to that which would be provided by 28,000 street trees.

Urban Biodiversity

The process of urbanization is normally associated with a dramatic decrease in the connectivity, quality and quantity of natural areas which provide habitat for plants and wildlife. A greenroof has the potential to act as either a 'stepping stone habitat' which connects isolated fragments of natural habitat, or as an 'island habitat' for less mobile species, which are isolated from natural areas found at the ground level (Wieditz, 2003). Although greenroofs may not be as valuable as plant and wildlife habitat in comparison to the natural area that the building has replaced, various species of invertebrates and birds may find that greenroofs can provide food, shelter, and breeding grounds (Wieditz, 2003).

A study conducted in Basel, Switzerland compared spider species on a greenroof with those in a similar habitat located on the ground. The study reported no significant difference in the diversity of spider species at the two sites (Brenneisen, 2003a). In the same study, 254 different beetle species and 78 spider species were found on the 16 greenroofs surveyed (Brenneisen, 2003b). The survey results revealed that there are several elements of green roof design that have a significant impact on species biodiversity. Some factors which were found to promote biodiversity include the presence of native plants which provide seeds, varying topography, the use of natural soils and the presence of large stones or pieces of wood (Brenneisen, 2003b).

Other Benefits

Green roofs may provide several other public benefits that are subtle or indirect and therefore difficult to quantify. Many studies have investigated the positive psychological impact of proximity to, or views of, green spaces on students, employees and residents. A behavioural study by Kuo (2001) found that green surroundings improved the ability of inner city residents to manage stress in their day-to-day lives. In a survey of employees who worked at desks, Kaplan (2001) also found that individuals with green views were less frustrated, more patient, and reported higher job satisfaction and overall health in comparison to individuals without green views.

The improved lifespan of a membrane beneath a green roof (which is described in section 6.3) is beneficial not only as a cost savings to the building owner, but also as a reduction in the amount of construction waste sent to landfills. If the presence of a green roof can double or triple the life of a roofing membrane, materials disposal associated with roof replacement will occur that much less frequently.

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APPENDIX B

Green roof cost survey

Greenroof Information Form

One copy of this form should be submitted for each greenroof installation. Please fill in the information requested to the best of your knowledge. You may type "Don't know" in any sections for which you don't have an answer.

Section A: Contact Information

Name:

Address:

Number and Street | City | Province | Postal Code

Telephone Number/Extension: | E-mail address:

Section B: Building Information

This section contains questions associated with the building on which the greenroof is constructed. You may type "Don't know" in any sections where you don't have an answer.

Building location:
(Please give the address or major intersection at which the building with the green roof is located)

Building name or main function:

Building type: ◯ Commercial ◯ Institutional ◯ Industrial | Lot Area (sq ft): | Roof Area (sq ft):

Building Height (ft): | Does the building have an elevator to the top floor? ◯ Yes ◯ No

Date of building construction: | Building Size (sq ft): | Roof Slope (%):

Type of roof deck on the building: ______ If other, please specify ______

Water drains off the roof to: ______ If other, please specify ______

Is the building heated during cold weather? ◯ Yes ◯ No | Type of heating system: ______

Is the building cooled by air conditioning? ◯ Yes ◯ No

Section C: Greenroof Information

Greenroof type: ◯ extensive *< 15 cm media depth* ◯ intensive *> 15 cm media depth* | Greenroof system provider:

Greenroof area (sq ft): | Installation date (dd/mm/yy):

Is the greenroof planted? ◯ Yes ◯ No | Does the greenroof have an irrigation system? ◯ Yes ◯ No

Is the greenrooof used for recreation? ◯ Yes ◯ No
(i.e. as a field for playing sports or patio for barbeques) | Is the greenroof accessible to building users? ◯ Yes ◯ No

If the answer is yes, please specify the type of activity: ______

Are there any other special features (*e.g.* a wetland) that have been installed on the roof? ◯ Yes ◯ No

If the answer is yes, please elaborate: ______

Was the greenroof a retrofit or was it constructed with the building? ◯ Retrofit ◯ New

Is the greenroof irrigated? ◯ Yes ◯ No | During which months is the greenroof irrigated? ☐ Mar ☐ Apr ☐ May ☐ Jun ☐ Jul ☐ Aug ☐ Sep ☐ Oct

If answer above is yes, please select the statement below which best describes the irrigation regime on the greenroof? ◯ daily and not weather dependent ◯ weather dependent ◯ occurs at a regular interval other than daily

Please elaborate if necessary: ______

What is the pump rate or type of sprinkler head? ______

What is the duration of irrigation? ______

Section D: Cost Information

Please fill in as many sections as possible. If the exact dollar amount of a specific component is unknown, please provide the total cost for all components in a given category (i.e. Structural, Building Needs, Greenroof System, etc.) and explain which components are included in this total in the description column.

Category		Cost *(Cdn$)*	Description
Design and Planning			
Architectural Services			
Landscape Designers			
Horticulturalists			
Other design and planning costs			
Total design and planning costs *(fill in only if the specific cost of any of the items above is not known)*			
Building Modifications			
Structural load increases *(please specify what modifications were made in the 'Description' column)*			
Roof Drainage system modifications			
Other building modification costs			
Total building modifications cost *(fill in only if the specific cost of any of the items above is not known)*			
Greenroof System			
Waterproof membrane			
Root Barrier			
Drainage Layer			
Filter Cloth			
Growing Medium (soil)			
Plants (or seeds)			
Labour for installation of the above items			
Leak Detection System *(including installation)*			
Irrigation system *(including installation)*			
Other greenroof system costs			
Total greenroof system cost *(fill in only if the specific cost of any of the items above is not known)*			
Maintenance			
Plant care	Year 1		
	Year 2		
	Year 3		
Roof / membrane repair			
Clean-up or debris removal			
Other maintenance costs			
Total maintenance cost *(fill in only if the specific cost of any of the items above is not known)*			
Please describe and provide the dollar value of any unexpected greenroof-related maintenance or repair costs (if there have been any) which you have incurred since construction of the roof was completed.			
Miscellaneous			
Please list any other costs associated with the greenroof which are not addressed in the categories above.			
Total greenroof cost:			

Comments:

Information obtained from all surveys will be used to calculate the range of costs associated with greenroof installation. Do you give consent to the TRCA to identify the building associated with these costs in a published document?

○ Yes ◉ No

Thank you for completing this information form. Please print a copy for your records and click on the the 'Submit by Email' button below to submit your responses. If you would prefer to submit this form via fax, please print a copy and fax it to 416-661-6898, to the attention of Lisa Rocha. If you have any questions or require assistance in completing this form, please contact Lisa Rocha at 416-661-6600 ext. 5220 or via email at lrocha@trca.on.ca.

Print Form | Submit by Email

APPENDIX C

Alternate life cycle cost scenarios

APPENDIX C:
Alternate life cycle cost scenarios run with ASMI costing tool

Base scenario

Assumptions are defined in sections 9.1 and 9.2 of the main report. All scenarios described below are based on the same assumptions unless otherwise specified.

	Extensive Green Roof		Conventional Roof	
	MIN	**MAX**	**MIN**	**MAX**
Net Present Value at 30 yrs	($441,725)	($785,305)	($283,170)	($481,430)
Net Present Value at 20 yrs	($447,551)	($762,295)	($234,255)	($391,672)
Net Present Value at 10 yrs	($451,051)	($723,508)	($149,008)	($234,707)

Long green roof membrane lifespan scenario

This scenario is based on the assumption that a green roof allows the roofing membrane to last for 45 years without replacement. The tool was run with a green roof lifespan of 45 years and for an investment period of 45 years.

	Extensive Green Roof		Conventional Roof	
	MIN	**MAX**	**MIN**	**MAX**
Net Present Value at 45 yrs	($428,356)	($798,944)	($312,666)	($534,902)
Net Present Value at 30 yrs	($441,725)	($785,305)	($283,170)	($481,430)
Net Present Value at 15 yrs	($449,594)	($745,212)	($230,790)	($386,476)

Non-air conditioned building scenario

As many industrial buildings are not air conditioned, this scenario simulates this situation by removing the cost savings associated with the decreased electricity use for air conditioning in the summer. This scenario also attempts to simulate the energy impact of a green roof on a high rise building, for which the roof-to-envelope ratio was small, and therefore the cooling effect of the green roof is minimal. The tool was run with no green roof energy savings assumed for space cooling.

	Extensive Green Roof		Conventional Roof	
	MIN	**MAX**	**MIN**	**MAX**
Net Present Value at 30 yrs	($452,039)	($795,618)	($283,170)	($481,430)
Net Present Value at 20 yrs	($455,492)	($770,136)	($234,255)	($391,672)
Net Present Value at 10 yrs	($455,678)	($728,136)	($149,008)	($234,707)

Incentive program scenario

This scenario simulates the impact of a direct financial incentive provided by some level of government for green roof installation. The tool was run with the installation cost of the green roof deducted by the value of a relatively generous incentive of $2/ft^2 of green roof. This deduction meant that green roof installation costs inputted into the tool were $21.75 for the minimum and $31.75 for the maximum.

	Extensive Green Roof		Conventional Roof	
	MIN	**MAX**	**MIN**	**MAX**
Net Present Value at 30 yrs	($407,281)	($749,661)	($283,170)	($481,430)
Net Present Value at 20 yrs	($413,107)	($726,651)	($234,255)	($391,672)
Net Present Value at 10 yrs	($416,606)	($687,864)	($149,008)	($234,707)

Green roof market development scenario

This scenario is based on the assumption that the growth of the local green roof market (such as that which was experienced in Germany) would lead to decreased costs as product availability and competition between suppliers increases. To simulate this market growth, the minimum capital cost of green roof installation (including underlying base roof was assumed to be only $16.00/ft^2 rather than $23.75/ft^2. The $16 per square foot cost was estimated based on some of the lower survey results for similar sized roofs (shown in Table 7.2 of the main report) and the minimum conventional roof cost of $8/ft^2. The tool was run with this lower green roof capital cost, and only minimum costs of green and conventional roofs were compared.

	Extensive Green Roof	Conventional Roof
Net Present Value at 30 yrs	($308,253)	($283,170)
Net Present Value at 20 yrs	($314,079)	($234,255)
Net Present Value at 10 yrs	($317,579)	($149,008)

Salvage value scenario

While a green roof's overburden must be removed in order to allow to periodic roof replacement (after 30 years for the base scenario), these materials can have a reuse value, particularly when the green roof materials are to be used to re-install a green roof on the same building. For this scenario, green roof system costs were estimated as 70% materials and 30% labour, meaning that only 70% of the capital cost was used to calculate salvage value. The salvage value for the 70% portion that constitutes materials was estimated as 80% of the original value. The total salvage value was then inputted into its appropriate field in the LCC calculator, where it was accounted for as a positive cash flow at the end of the membrane life.

	Extensive Green Roof		Conventional Roof	
	MIN	**MAX**	**MIN**	**MAX**
Net Present Value at 30 yrs	($411,133)	($737,236)	($283,170)	($481,430)
Net Present Value at 20 yrs	($447,545)	($723,505)	($234,255)	($391,672)
Net Present Value at 10 yrs	($451,047)	($762,289)	($149,008)	($234,707)

Sensitivity analysis of discount rate

Private sector discount rate scenario

The standard discount (or hurdle) rate of 6.5% was doubled to 13% to reflect a rate that would be more appropriate for a private sector investor such as a developer. The higher discount rate reflects the higher risk investments and greater expected returns in the private sector.

	Extensive Green Roof		Conventional Roof	
	MIN	**MAX**	**MIN**	**MAX**
Net Present Value at 30 yrs	($448,770)	($729,505)	($189,801)	($301,631)
Net Present Value at 20 yrs	($450,049)	($724,206)	($181,221)	($294,991)
Net Present Value at 10 yrs	($451,420)	($708,132)	($146,156)	($230,429)

Public sector discount rate scenario

The standard discount (or hurdle) rate of 6.5% was halved to 3.25% to reflect a rate that would be more appropriate for a public sector investor. This lower discount rate reflects the public sector's tendency to lower risk investments and lower expected returns.

	Extensive Green Roof		Conventional Roof	
	MIN	**MAX**	**MIN**	**MAX**
Net Present Value at 30 yrs	($431,974)	($846,682)	($408,989)	($712,511)
Net Present Value at 20 yrs	($444,997)	($796,518)	($286,833)	($487,760)
Net Present Value at 10 yrs	($450,774)	($734,329)	($151,018)	($237,722)