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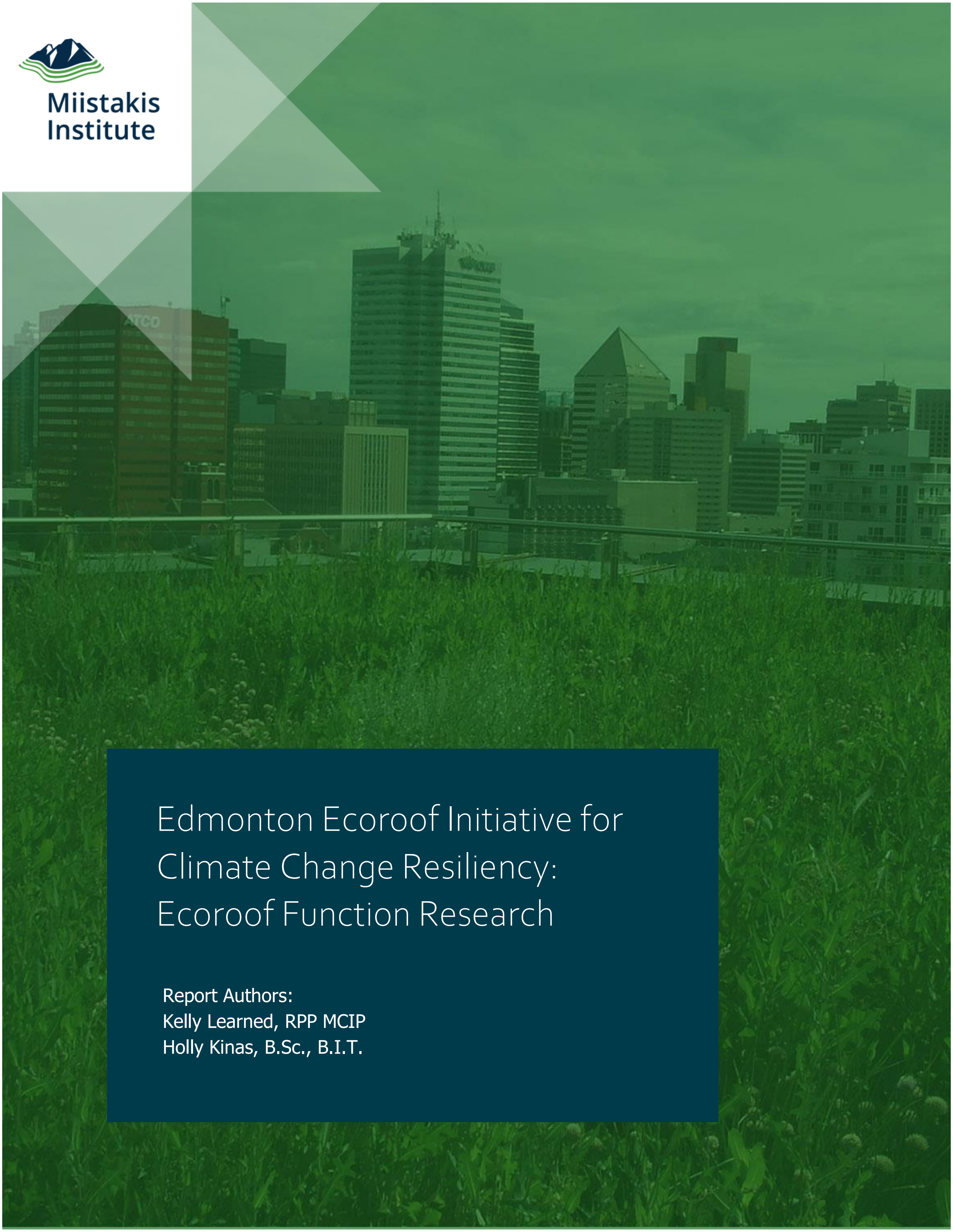

Edmonton Ecoroof Initiative for Climate Change Resiliency: Ecoroof Function Research

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THE ECOROOF INITIATIVE
FOR CLIMATE CHANGE RESILIENCY

Edmonton Ecoroof Initiative for Climate Change Resiliency: Ecoroof Function Research

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About the Edmonton Ecoroof Initiative for Climate Change Resiliency

The Edmonton Ecoroof and Climate Change Resiliency Initiative is a research project being led by the Miistakis Institute in partnership with the City of Edmonton. The purpose of the project is to explore the potential for an ecoroof policy program as a strategy for climate adaptation by gathering research, engaging stakeholders and identifying potential key motivators for a policy program.

This research and stakeholder engagement will inform potential strategies and actions in alignment with the City's climate change adaptation strategy, *Climate Resilient Edmonton: Adaptation Strategy and Action Plan.*

What are Ecoroofs?

An ecoroof, also known as a green roof, vegetated roof, rooftop garden, or living roof is an extension of an existing roof which involves high quality waterproofing membrane, root repellent system, drainage system, filter cloth, lightweight growing medium (soil), irrigation system, and plants. Some designs might also involve a water feature. Ecoroof implementation involves the creation of "contained" green space on top of a structure. This green space could be below, at, or above grade.

Ecoroofs provide ecosystem services in urban areas including improved stormwater management (both quantity and quality), better regulation of building temperatures, reduced urban heat island effects, and increased urban wildlife habitat and biodiversity (Oberndorfer et al., 2007). Some jurisdictions refer to ecoroofs as a 'no-regrets' climate adaptation measure (Mees, Driessen, Runhaar, & Stamatelos, 2013) because they serve multiple societal goals.

Photo Dusty Gedge

Executive Summary

An extensive desktop review was conducted between September 2018 and February 2019 to gather research findings of various studies regarding the environmental impacts ecoroofs provide to urban environments. The research team attempted to find research applicable to the Edmonton context and was able to find a number of studies conducted in cold climates. The purpose of this report is to provide the City of Edmonton and stakeholders with research that reveals the potential ecoroofs may have for climate adaptation and community resiliency.

Urban Heat Island Effect

Heat islands cause increased energy consumption, greater rates of heat-related illness and death and increased air pollution. Ecoroof installation shifts the rooftop from being one that absorbs solar radiation creating higher surface temperatures to one that provides natural cooling with vegetation. A modeling study for Toronto, predicted that adding ecoroofs to 50% of the available surfaces downtown would cool the entire city by 0.1°C to 0.8°C. Irrigating these roofs could further reduce temperatures by about 2°C and extend a 0.5°C to 1°C cooled area over a larger geographic region.

The Toronto, Adelaide, and NYC case studies reviewed, all included the assumption of a large percentage of buildings implementing ecoroofs, showed a 0.1°C to 0.8°C, 0.6°C, and 0.2°C reduction in urban heat island effect respectively.

Building Energy Efficiency

Ecoroofs reduce energy consumption for cooling and heating by reducing the air temperature near air intakes and providing additional insulation during winter months, respectively. A thesis project on "Thermal Performance of Green Roofs in Cold Climates," tested ecoroof thermal performance in Ontario. Ecoroofs required 13-33% less energy to maintain the testing room temperature; energy savings of about 24% and 10% of the total heating energy used may be realized over the winter months, with more savings possible when considering summer cooling needs.

A Walmart study in Chicago found about 6-10% energy cost savings plus 2.5% peak demand reduction when comparing an ecoroof and a white roof. Additionally, the green roof performed better during the hottest temperatures of the summer. This was a very short period each day, but it was consistent. This translates to about $8,000 - $24,000 CAD savings annually for a full ecoroof. Researchers for the Walmart Chicago ecoroof study predict that in other climates a 1-6% in total energy savings could be realized with an ecoroof.

Stormwater Retention

By reducing stormwater runoff, ecoroofs assist in improving overall water quality and reduce the quantity during rain events. The Alberta Ecoroof Initiative research roof in Calgary, AB found total retention capacity for two test roofs were 66% and 59%, respectively. The retention capacities of the ecoroofs for July to September were much higher (81-99%) likely due to less rainfall and increased evapotranspiration with the higher summer temperatures.

A comparative study between a conventional roof and an ecoroof in Toronto demonstrated the following: rain events less than 15mm in summer months and proceeded by six days of dry weather achieved 100% reduction in flow volumes. Comparatively the ecoroof test plots demonstrated significantly reduced flow rates during all seasons compared to the control (non-greened) roof. Lag time for the ecoroofs were measured at between 20 and 40 minutes with a calculated peak flow rate reduction of 25% to 60% adjusted to a per m^2 basis.

A US department of energy study found that an ecoroof with 76mm - 102mm of soil can retain about 25mm of rainfall. This report concluded that a typical ecoroof will absorb, filter, retain and store up to 75% of the annual precipitation that falls on it under conditions prevalent in most areas of the United States.

Biodiversity and Habitat

Ecoroofs can provide habitat opportunities in an urban setting, where ground-level space is limited. They have been shown to provide habitat for various species of plants, animals, and insects.

"Extensive green roofs provide interesting islands of urban ecosystem that are valuable as habitat for carabid and spider species characteristic of prairies, grasslands and naturally disturbed habitats that are threatened by urbanization in the Edmonton region" and across Alberta (p. 86, Bergeron, Pinzon, & Spence, 2018).

Roof species surveys in Switzerland found that 10% of the beetles observed were considered threatened and 40% of the spiders were considered rare.

In a review of key research for species of interest in London, England it was found that in all ecoroof categories combined (sedum and biodiverse) 15% of the spiders and 10% of beetles recorded had either a local or national importance.

Key research gathered from various studies on bees in Switzerland and the UK found that bees prefer biodiverse ecoroofs compared to those dominated by sedum and that there was greater species richness of bees on biodiverse roofs. Researchers also found a variety of different bee species, including species of concern.

Air Quality

Plants have been used in urban environments to remove air pollutants – ecoroofs are a surface area that can provide vegetation to assist with improving air quality. Researchers estimate that a 1,000-square foot (93 m^2) ecoroof can remove about 40 pounds [(18kg)] of Particulate Matter (PM) from the air in a year, while also producing oxygen and removing carbon dioxide (CO_2) from the atmosphere. Forty pounds [(18kg)] of PM is roughly how much 15 passenger cars will emit in a year of typical driving.

In a modelling study for Washington, D.C., researchers analysed the potential air quality benefits of installing ecoroofs on 20 percent of total roof surface for buildings with roofs greater than 10,000 square feet (930 m^2). Under this scenario, ecoroofs would cover about 20 million square feet (almost 2 million m^2) and remove an estimated 6.0 tons of O_3 and almost 6 tons of PM of less than 10 microns (PM10) annually. This is comparable to the amount of pollutants that could be absorbed by about 25,000 to 33,000 street trees (U.S. Environmental Protection Agency, 2008a) and is a significant finding given the limited amount of space available at ground level in urban contexts.

Carbon Sequestration

Ecoroofs have the potential to sequester carbon within their substrate and plant biomass. The net benefit, especially after applying carbon cost of the ecoroof, is small, but some research supports that it is a positive benefit, sequestering more carbon than it produces; whereas other research found the opposite, that ecoroofs cost more carbon then they sequester. The carbon sequestration section outlines a number of research findings.

One benefit that ecoroofs afford with regard to carbon sequestration is that when compared to traditional roofs, they provide the prospect of sequestering carbon and traditional roofs do not (Getter, Rowe, Robertson, Cregg, & Andresen, 2009). Getter et al. (2009) provide an example where, according to their methodology, if all industrial and commercial buildings in Detroit were covered in ecoroofs, the carbon sequestered would be equivalent "to removing more than 10 000 midsized SUV or trucks off the road for a year" (p. 7569, U.S. Environmental Protection Agency, 2005 as cited in Getter et al., 2009).Although the function of carbon sequestration from ecoroofs is still being discovered, several recent studies have found a small net benefit that can be multiplied greatly by increasing the scale and number of ecoroofs in a region.

Additional Benefits

The focus of this research paper was on environmental contributions ecoroofs provide in urban environments however, we would be remiss if we did not mention social and economic benefits. Ecoroofs can support improved health of residents, patients in hospitals, and employees related to the numerous environmental benefits mentioned above. They can also improve the overall quality of life simply by people having access or a view to green space compared to a concrete roof top. Economic benefits at the building and neigbhourhood scale relate to lower energy costs, reduced stormwater costs, job opportunities and a substantially increased life expectancy of the roof (approximately fourty years compared to approximately seventeen years of a conventional roof).

Challenges

Typical challenges for ecoroofs relate to design, installation and maintenance. Up front cost is also a consideration although, as mentioned in the section above, ecoroofs last longer and provide benefits resulting in cost savings over time. Design challenges include ensuring the building can support the added weight of an ecoroof as well as understanding the microclimate on the roof in order to recommend the appropriate plant species. Leak prevention during installation is also a challenge if the contractors are new to ecoroofs. Maintenance can pose challenges as well if personnel are new to ecoroof requirements.

Conclusion

Findings from the *Climate Resilient Edmonton: Adaptation Strategy and Action Plan* outline changes in climate that Edmonton will need to adapt to: an average increase in temperature, precipitation pattern changes, an overall increase in the frequency of extreme weather events, and an overall warmer and drier climate leading to potential ecological changes.

The research outlined in this report highlights how ecoroofs help improve urban environments by reducing the urban heat island effect, increasing building energy efficiency, increasing stormwater retention, increasing biodiversity, providing habitat for a variety of species, improving air quality, and the potential for carbon sequestration. Other ecoroof benefits that were not reviewed as part of this research include improved quality of life for residents or employees with a view of or access to roof top green space, urban agriculture opportunities, and economic opportunities for trades, industry and suppliers. The research gathered is not specific to the Edmonton context, however it does reveal ecoroofs have a positive environmental impact on the urban context. The scope of impact varies depending on the roof type, location and number of other ecoroofs in a given area. As one research report stated, ecoroofs are often seen as a no regrets approach to climate adaptation because there are so many benefits offered by the technology.

Ecoroofs and Climate Resiliency

As cities develop, vegetation is typically replaced with non-permeable, non-vegetated surfaces. This change in surface often results in increased runoff during storm events contributing to combined sewer overflows, reductions in water quality, increased temperatures in urban areas resulting in higher energy demand for cooling, increased GHG emissions, reduced air quality, and loss of habitat and biodiversity.

Climate change is expected to result in more frequent occurrences of extreme temperatures and precipitation events. These changes will exacerbate many ongoing environmental problems in Canadian cities because as mentioned above, urban areas typically replace natural vegetation with non-permeable, non-vegetated surfaces as development occurs (Bass & Baskaran, 2003).

There is international recognition that climate change is an urgent threat and that global efforts are needed to reduce GHG emissions and limit global warming. Ninety-seven percent of actively publishing climate scientists agree that the world is experiencing a change in climate caused by humans (Cook, 2016). Historical climate records also show the world is warming at unprecedented rates. For Edmonton, scientists predict that the city will be exposed to higher temperatures, drier summers, more extreme precipitation events, more variable extreme weather events, and an overall warmer and drier climate. Without action, these impacts can exacerbate existing climate pressures on economic, social, infrastructure, and environmental systems (City of Edmonton, 2017).

Ecoroofs are one of the strategies the City of Edmonton could consider to reduce the impacts of climate change. By increasing the area of vegetated roofs in the city, the potential for improved stormwater retention, reduced UHI and building energy consumption, enhanced biodiversity, habitat and improved air quality will lead to a more resilient community. Ecoroofs also have social and economic benefits related to quality of life, access to secure green space, urban agriculture opportunities, the creation of industry and employment, and increased life expectancy of the roof of up to fourty years compared to a conventional roof span of approximately seventeen years. For these reasons, the City of Edmonton is researching the potential impacts ecoroofs could have on climate resiliency in Edmonton.

This document compiles research on ecoroof function completed in a variety of jurisdictions. The purpose is to demonstrate the benefits in other jurisdictions from a sampling of ecoroof research. This document is not a localized study and is intended to provide a narrative of outcomes related to stormwater retention, urban heat island effect, building energy efficiency, biodiversity and habitat, and air quality to start the conversation in Edmonton on whether ecoroofs are something of interest to decision makers and would potentially benefit climate resilient actions.

Literature Review of Ecoroof Function

The following sections outline a literature review of the various functions studied and monitored for ecoroofs. Studies were conducted in various municipalities and countries and are meant to provide information about ecoroof potential. It is recognized studies in cities with different climate zones may yield different results than if they were performed in Edmonton. However, the research findings do indicate ecoroofs have a positive impact on the environment – the magnitude of the benefits for the Edmonton context would depend on several factors such as: building height, size or roof surface, type of ecoroof installed (extensive or intensive), plant material, exposure, temperature in surrounding area, urban versus suburban context and amount of precipitation. Regardless of the factors that need to be considered, the research shows ecoroofs will positively impact the local environment more positively than a traditional asphalt or gravel roof and in many circumstances more positively than a low reflective roof surface (white roof). What also needs to be considered is the increased costs of implementing ecoroofs. This is something that could be addressed as part of a policy and incentive program should the City of Edmonton decide to pursue this strategy.

Urban Heat Island Effect

What is the Urban Heat Island Effect?

As urban areas develop, changes occur in the landscape when buildings, roads, and other infrastructure replace open land and vegetation. Surfaces that were once permeable and moist generally become impermeable and dry (U.S. Environmental Protection Agency, 2008b).

Non-vegetated and non-porous surfaces such as roofs, walls, roads and pavement absorb the incoming solar energy and convert it to heat thereby increasing their surface temperatures and the surrounding air temperature. In an urban area with high building density or a large amount of impermeable surface, the increase in the surface temperatures artificially elevates the urban temperature – resulting in what is referred to as the urban heat island (K. K. Y. Liu & Bass, 2005). This elevation in temperature can cause several negative impacts including but not limited to a decrease in building energy efficiency, which leads to an increase in air conditioning and as a result, and the consequent increase in greenhouse gas emissions (K. K. Y. Liu & Bass, 2005). Also, high summer temperatures can be associated with many environmental and health problems caused by heat stress and smog, which forms more rapidly at higher temperatures (McCarthy et al., 2001 [as cited in Liu & Bass, 2005]). Reducing high temperatures in urban areas has become a major concern for a number of major metropolitan cities in North America (K. K. Y. Liu & Bass, 2005).

What is the Relationship Between Urban Heat Island and Ecoroofs?

As with trees and vegetation at grade, vegetation on an ecoroof shades surfaces and reduces surface temperatures, through evapotranspiration. The surface of a vegetated rooftop can be cooler than the ambient air, whereas conventional rooftop surfaces can exceed ambient air temperatures by up to 50°C (90°F) (U.S. Environmental Protection Agency, 2008a). Reducing temperatures of the roof surface will reduce the temperatures of the surrounding air, thereby assisting in lowering air temperature in areas of the city where ecoroofs are present, and depending on the local meteorology, in other areas as well. Reduced surface temperatures also reduces the temperature of the air being drawn into the building for the air exchange, reducing the amount of energy required to cool the building (Moseley et al., 2013). See section below for more information on the building energy impacts of ecoroofs.

Cities like Chicago and New York City are focusing on "hot spot" areas, which are often found in dense, built up urban cores. Given the limited space available for parks and green space in many metropolitan cities, placing vegetation on otherwise unused building rooftops becomes an attractive solution to mitigate the urban heat island effects. Ecoroofs may be the only option to provide an effective amount of vegetation in these older city centers that have vast amounts of impervious cover due to high density development, premium land prices and few opportunities to retroactively plant vegetation with sufficient canopy coverage at ground level to effect reductions of the urban heat island (K. K. Y. Liu & Bass, 2005; U.S. Environmental Protection Agency, 2008a).

Methodology for Measuring the Impact of Ecoroofs on Urban Heat Island Effect

Research found regarding the impact ecoroofs have on the urban heat island effect used scenario modelling and comparative analysis methodologies.

Comparative analysis (conducted through observation or modeling):

- Typical roof surface temperature compared with an ecoroof surface temperature. (Neighbouring buildings)
- Average maximum surface temperature of one ecoroof compared to adjacent light coloured roof

Modeling based on scenarios:

- Model air temperature reductions two meters, or 6.5 feet, above the roof surface based on a scenario assuming 100 percent conversion of all available roof area to ecoroofs. Averaged over all times of the day (p. 3, U.S. Environmental Protection Agency, 2008b).
- Model study area (i.e. defined geographical area of a city) scenarios with 50% ecoroof coverage, then with irrigation (p. 5-6, Liu & Bass, 2005)

URBAN HEAT ISLAND AND ECOROOFS RESEARCH

Several municipalities have completed modeling studies to quantify the impact of ecoroof installation on mitigating urban heat island, the results of which are summarized in this section.

Chicago compared summertime surface temperatures on an ecoroof with a neighboring building. On an August day in the early afternoon, with ambient temperatures in the 32°C+ (90°F+) range, the ecoroof surface temperature ranged from 33 to 48°C (91 to 119°F), while the dark, conventional roof of the adjacent building was 76°C (169°F). The near-surface air temperature above the ecoroof was 4°C (7°F) cooler than that over the conventional roof (National Renewable Energy Laboratory, 2004).

In New York City, researchers modeled air temperature reductions two meters, or 6.5 feet, above the roof surface based on a scenario assuming 100 percent conversion of all available roof area to ecoroofs. The model results estimated a temperature reduction of 0.2°C (0.4°F) for the city as a whole, averaged over all times of the day. The model projected that temperatures at three o'clock in the afternoon would be reduced 0.4°C (0.8°F). The researchers also evaluated, in detail, six areas within the city. The area with the highest 24-hour average reduction in temperature had a change of 0.6°C (1.1°F), and the reductions at three o'clock in the afternoon in those six areas ranged from 0.4°C (0.8°F) to 1.0°C (1.8°F) (Rosenzweig et al., 2006). The New York study researchers inferred that in addition to reduced energy demand from ecoroof implementation, mitigation of New York City's heat island could improve air quality and public health, as well as reduce the city's contribution to greenhouse gas emissions. Reduced energy demand could also reduce the cost of air conditioning for both residential and commercial customers.

In Adelaide Australia, the ability of two types of extensive and intensive ecoroof temperatures were monitored to assess the reductions on the surrounding temperatures. The results showed that ecoroofs have significant cooling effects during the summer and could also function as an insulation layer to keep buildings warmer in the winter (see Building Energy Efficiency section below for more research on this topic). Furthermore, different scenarios of adding ecoroofs to the Adelaide urban environment were investigated using the Envi–MET model. Envi-Met is a dynamic climate model designed to be used at a very high resolution over a very small domain, such as a city block or areas smaller than one-square kilometer. The scenario modelling of adding ecoroofs in a typical urban area in Adelaide, Australia, supported the results of other research, which suggested that ecoroofs can lead to reductions in energy consumption in the urban environment (Razzaghmanesh, Beecham, & Salemi, 2016).

A modeling study for Toronto, Canada, predicted that adding ecoroofs to 50 percent of the available surfaces downtown would cool the entire city by 0.1°C to 0.8°C (0.2°F to 1.4°F). Irrigating these roofs could further reduce temperatures by about 2°C (3.5°F) and extend a 0.5°C to 1°C (1°F to 2°F) cooled area over a larger geographic region. The simulation showed that, especially with sufficient moisture for evaporative cooling, ecoroofs could play a role in reducing the urban heat island (K. K. Y. Liu & Bass, 2005).

In general, the research demonstrated a reduction in roof temperature when an ecoroof was installed (see Table 1 below for a summary of the findings). The temperature reduction depended on the depth of the roof, vegetation, and growing medium. In several of the research studies, a link was made between a reduction in roof surface temperature due to ecoroof installation and a reduction in Urban Heat Island effect – although more research may be required to further detail the correlation.

TABLE 1 RESEARCH ROOF SUMMARIES – ECOROOF TEMPERATURE REDUCTIONS

Chicago, USA	4°C (7.2°F) cooler <u>ambient air</u> than a conventional roof
New York, USA	0.4°C to 1.0°C (0.7°F to 1.8°F) temperature reduction range at ground level

Adelaide, AU	0.6°C (1.1°F) reduction in surface (ground level) temperature (if 30% of roof surfaces in Central business district were ecoroofs)
Toronto, CA	0.1°C to 0.8°C (0.2°F to 1.4°F) reduction in temperature to entire city if 50% of roof surfaces downtown were ecoroofs.

Summary

Research from Toronto, Chicago, New York and Australia demonstrate a roof temperature reduction for ecoroofs in comparison with typical roofs. The surface of a vegetated rooftop can be cooler than the ambient air, whereas conventional rooftop surfaces can exceed ambient air temperatures by up to 50°C (90°F) (U.S. Environmental Protection Agency, 2008a). Reducing temperatures of the roof surface will reduce the temperatures of the surrounding air, thereby assisting in lowering air temperature in areas of the city where ecoroofs are present and have a positive impact on urban heat island effect.

The Toronto, Adelaide, and NYC case studies, all based on a large percentage of roofs implementing ecoroofs, showed a 0.1°C to 0.8°C (0.2°F to 1.4°F), 0.6°C (1.1°F), and 0.2°C (0.4°F) reduction in urban heat island effect respectively. The Chicago case study demonstrated a very large reduction in roof surface temperature when an ecoroof was installed on a building; 27.7°C - 43.4°C (35.5°C average) 49.86°F - 78.12°F (63.9°F average) cooler than the conventional roof. While these results may not directly translate to the Edmonton context, it is evidence there is an impact on the urban heat island effect when ecoroofs are installed. Further research needs to be conducted to determine the potential temperature reduction range for the Edmonton context.

Building Energy Efficiency

What is Building Energy Efficiency?

The amount of energy needed to heat or cool a building is a measurement of the building's energy efficiency; the less energy required, the higher the efficiency.

As urban areas develop, changes occur in the landscape when buildings, roads, and other infrastructure replace open land and vegetation. Non-vegetated and non-porous surfaces such as roofs, walls, roads and pavement absorb the incoming solar energy and convert it to heat thereby increasing their surface temperatures and the surrounding air temperature (K. K. Y. Liu & Bass, 2005). This heat can also be transferred to the interior of buildings, causing a rise in temperature and a need to increase air conditioning, which results in an increase in greenhouse gas emissions (K. K. Y. Liu & Bass, 2005). Likewise, there is an increase in heating needs during the cold winter months due to heat lost through the roof, lack of energy efficiency, which also leads to an increase in greenhouse gas emissions.

What is the Relationship Between Energy Efficiency and Ecoroofs?

One of the many benefits ecoroofs provide is the increase in building energy efficiency, thus a reduction in heating and cooling needs and a reduction in greenhouse gas emissions (GHG) (K. Liu & Baskaran, 2005; K. K. Y. Liu & Bass, 2005). Ecoroofs can increase building efficiency "through direct shading of the roof, evapotranspiration and improved insulation values" (p. 1, Minke and Witter, 1982; Liesecke et al., 1989; Christian and Petrie, 1996; Eumorfopoulou and Aravantinos, 1998; Palomo, 1998; Environmental Building News, 2001 as cited in K. K. Y. Liu & Bass, 2005). Both plants and the ecoroof growing medium contribute to the insulation value of an ecoroof (K. K. Y. Liu & Bass, 2005).

With the growing commitments to reduce GHGs, ecoroofs can play an important role in this reduction as "buildings account for approximately 30% of energy use and 27% of greenhouse gases emission in Canada" (p. 506, Natural Resources Canada 2004 as cited in K. Liu & Baskaran, 2005). There is also a growing trend towards sustainable building certifications, such as LEED (Leadership in Energy and Environmental Design) Green Building Rating System, which includes ecoroofs as a sustainable design feature (K. Liu & Baskaran, 2005).

Methodology for Measuring the Impact of Ecoroofs on Building Energy Efficiency

The research found on the impact ecoroofs have on energy efficiency, similar to the urban heat island research, used comparative analysis and scenario modelling approaches.

Comparative analysis:

- Temperature and heat flow of a reference roof were compared with an ecoroof, at various depths and locations on/in the roof system, including indoors directly below the roof (K. Liu & Baskaran, 2005)
- Thermal performance of ecoroof systems were compared to a conventional flat roofing system, specifically in a cold climate, and conducted in a laboratory setting. A thermal model was used to assess heat savings of a commercial building during winter months (Bass & Baskaran, 2003; Lanham, 2007)
- Thermal performance of an ecoroof system was compared to a 'cool' white roof (Moseley et al., 2013)

Modeling based on scenarios:

- Model data from comparative analysis were used to determine predicted energy efficiency (Lanham, 2007)
- Model thermal performance of ecoroof components were used to predict energy efficiency when those materials are combined as an ecoroof (Del Barrio, 1998)

ENERGY EFFICIENCY AND ECOROOFS RESEARCH

Several urban municipalities have completed comparative analysis to quantify the impact ecoroof installation could have on building energy efficiency. The results of several studies are summarized below.

In 2002, the National Research Council of Canada installed two extensive ecoroof study sites in the City of Toronto to quantify their thermal performance, which was a part of a larger cost-benefit study on the use of ecoroof technology in Toronto. The ecoroofs were installed at two different sites, one in a residential neighbourhood (with some commercial buildings) and one on Toronto City Hall (surrounded by high-rise buildings). At each site there was a reference roof, and one to two ecoroofs, of varied design. The sites were observed for a year and suggested that ecoroofs "are effective in reducing heat flow through the roof, thus lowering the energy demand for space conditioning in the building, for both conventional and protected membrane roofing systems" (p. 513, K. Liu & Baskaran, 2005). Additionally, the results suggested ecoroofs were more thermally effective in the summer than in the winter. The two lightweight extensive ecoroofs (75-100 mm growing medium) installed on a conventional roofing system reduced the heat flow through the roofing system by 70-90% in the summer and 10-30% in the winter (p. 513 (K. Liu & Baskaran, 2005)). Liu and Baskaran (2005) also recommended, not to replace the thermal insulation with extra growing medium, in cold climates, because once the growing medium freezes, it acts as a poor insulator in the winter, even though it provides better insulation than other insulating materials in the summer.

Another study was published in 2003 by the National Research Council of Canada and used data from test roofs and a vertical garden in Toronto, Canada, to model different real-world scenarios to determine the ecoroof's effect on energy efficiency. The research showed that the shading and insulation properties provided by an ecoroof would reduce the total energy usage by 5%, with an energy reduction for heating of 10% and an energy reduction for cooling of 6%. The research also looked at the thermal impacts of green walls, and the results suggested that green walls could contribute more to energy efficiency than ecoroofs (Bass & Baskaran, 2003).

A thesis project was conducted on the "Thermal Performance of Green Roofs in Cold Climates," which tested ecoroof thermal performance in a controlled laboratory setting in Ontario. This research was undertaken to specifically address the need for more research on ecoroofs in cold climates, especially in Eastern Ontario where ecoroofs are gaining popularity. The study found that:

- ecoroofs required 13-33% less energy to maintain the testing room temperature;
- the thermal resistance value of the ecoroof was 11-41% greater than conventional roof;
- the insulating properties of an ecoroof in cold climates are most affected by the insulation layer and the growing medium is secondary in its effect on thermal insulation properties of the ecoroof;
- with the installation of an 82 mm or 127 mm ecoroof over the winter months November to March, energy savings of about 10% and 24% of the total heating energy used by a commercial conventional roofed building may be realized. This corresponds to a $116 - $288 savings over the same period. The annual savings expected to be gained from ecoroof installation are larger than indicated by the winter savings as the thermal benefits of ecoroofs also extend to the summer due to

the shading and evaporative cooling provided by plants during summer (Lanham, 2007).

In 2007-09, a study was conducted on the roof of a Walmart in Chicago. The research compared a white 'cool' roof, 58,000 sf, with a vegetated ecoroof, 75,000 sf. Energy was one of the measures of performance analyzed for the roof, along with stormwater management and financial analysis. The research showed the total estimated impact of the green roof vs. the white roof was a 6 - 11% reduction in heating energy and a 7 - 15% reduction in cooling energy, which results in 2 - 6% savings in total modeled store energy use (kWh) or about 6-10% energy cost savings plus 2.5% peak demand reduction in Chicago. This translates to about $6,000 - $18,000 USD ($8,000 - $24,000 CAD) savings annually for a full green roof (Moseley et al., 2013).

The results from the two-year monitoring study of the Wal-Mart roof in Chicago, suggests that ecoroofs are effective throughout the winter with a snow cover, although the ecoroof did not replace the thermal insulation in the conventional roof. Rather it was added on top of the conventional roof. It was also found that the ecoroof side showed lower peak heat gain than the white roof, but it seems that the white roof performed slightly better at releasing heat. This is possibly due to the ecoroof retaining heat at night. However, the ecoroof more than made up for this in its better heat flux performance during the rest of the year. Additionally, the green roof performed better during the hottest temperatures of the summer. This was a very short period each day, but it was consistent.

Additional energy savings can be found by the tempering effect the ecoroof had on the rooftop heating/cooling units' intake, reducing the need to use energy to adjust the intake air temperature. It is also likely that over time, energy savings produced by an ecoroof will be enhanced by vegetation growth resulting in an increase in cover. Researchers for the Walmart Chicago ecoroof study predict that in other climates a 1- 6% in total energy savings could be realized with an ecoroof (Moseley et al., 2013).

Researchers conducted a study to monitor different roofing systems in Toronto and determined that ecoroofs reduce temperature fluctuations within the roofing system, thus mitigating the amount of heat flowing in and out of the structure. Reduction in heat fluctuation and heat flow indicates enhanced insulation in the ecoroof system which leads to a reduction in the need for heating and cooling in the winter and summer, respectively; this is especially seen in the summer (K. K. Y. Liu & Minor, 2005).

Summary

The research paper by Bass and Baskaran (Bass & Baskaran, 2003) articulates various ecoroof benefits such as stormwater management, urban heat island mitigation, and energy savings as well as other social benefits. The energy efficiency research demonstrates that ecoroof installation reduces rooftop temperature fluctuation, reduces heat flow into the building particularly in hot, summer months and acts as a thermal layer in cold months, particularly before it freezes. Energy efficiency of a building due to ecoroof installation also results in financial savings as demonstrated in the Walmart Chicago case study (Moseley et al., 2013). The heat flow between a building and its environment is an important consideration because it creates energy demand for space conditioning (either cooling or heating). Below a certain temperature, the demand for electricity is inelastic however above this threshold, every degree Celsius increase can increase electricity consumption by 5% - an estimate for southern Ontario (Bass & Baskaran, 2003).

Stormwater Retention

What is Stormwater Retention?

As urban areas develop, changes occur in the landscape when buildings, roads, and other infrastructure replace open land and vegetation. Surfaces that were once permeable and moist generally become non-porous and dry (U.S. Environmental Protection Agency, 2008b) affecting how the landscape is able to manage water (flood and drought events) from precipitation events at a site, neighbourhood and regional scale.

A prominent environmental challenge of urbanization is that the urban hydrological system has to cope with a highly fluctuating amount of surface runoff water. In urban areas during precipitation events heavy runoff "can overburden existing storm-water management facilities and cause combined sewage overflow into lakes and rivers. In addition to exacerbating flooding, erosion, and sedimentation, urban runoff is also high in pollutants such as pesticides [nutrients] and petroleum residues, which harm wildlife habitats and contaminate drinking supplies" (p. 827, Moran et al., 2005 as cited in Oberndorfer et al., 2007). Climate change may also further increase these fluctuations between flood risk and drought events (Moudrak, Feltmate, Venema, & Osman, 2018).

The use of natural infrastructure, including ecoroofs, can aid in both flood and drought mitigation and aid society in becoming resilient to climate change.

Conventional stormwater retention techniques include storage reservoirs and ponds, constructed wetlands, and sand filters; however, these technologies may be difficult to implement in dense urban centers due to the requirement for land that is not readily available (Mentens, Raes, & Hermy, 2006).

What is the Relationship Between Stormwater Retention and Ecoroofs?

Estimates for some urban centres report between 30% and 50% of non-permeable surface is rooftops (Stovin et al., 2007 as cited in Green Plants for Green Buildings, 2014; Mentens et al., 2006). Ecoroofs store rainwater and reduce surface water runoff and sewage overflows from increased precipitation rates (Oberndorfer et al., 2007). They form an innovative alternative and complement to more conventional stormwater measures such as sewage networks and drainage canals. Ecoroofs also deliver private benefits to property owners (e.g. energy savings, thermal comfort, aesthetics) (Mees et al., 2013). A critical mass of ecoroofs for stormwater retention purposes can support increased stormwater reduction particularly in areas where densities are high, (green) space is scarce and the capacity of the traditional stormwater systems has reached its limits. Various studies show that rainfall retention of ecoroofs ranges from between 25% to nearly 90%, depending on the depth and material of the substrate, the vegetation used and the slope of the roof (Oberndorfer et al., 2007). Factors that affect stormwater retention in ecoroof systems include water holding capacity, depth of substrate, antecedent (existing) moisture conditions, rainfall intensity and/or precipitation depth, irrigation, and composition and extent of plant coverage (Struck, Ross, & Sagi, 2014).

While it is recognized ecoroofs provide additional capacity for stormwater runoff, irrigation may be recommended to address drought and low precipitation rates and therefore would reduce water retention capacity. This conflict warrants further discussion by policy makers in relation to trade-offs articulated by GRIT Lab researchers: supplemental irrigation reduces water retention capacity but increases thermal cooling, vegetative cover, and biodiversity. As discussions advance and standards for ecoroofs are outlined, there are opportunities to synergistically design irrigation and ecoroofs as a closed-loop system, achieving water conservation, runoff reduction, thermal cooling, and biodiverse planting to support habitat (Margous, 2017). This type of closed-loop system was implemented on the Mountain Equipment Co-op (MEC) building in Winnipeg in 2000. On the MEC building, a cistern is used to collect and store rainwater to water their ecoroof "via a solar powered irrigation system" (p. 2-7, MEC, 2002 as cited in Phare et al., 2003).

Methodology for Measuring the Impact of Ecoroofs on Stormwater Retention

The following approaches were used to assess the impacts ecoroofs have on stormwater retention.

- Typical data include number of rainfall events, rainfall depth, continuous rainfall and runoff are collected for water quantity studies.
- Custom made weir and lysimeter systems frequently used to quantify runoff during ecoroof studies (Culligan et al., 2014).
- Soil Water Apportioning Method (SWAM) is a water balance approach which analytically links precipitation to substrate moisture and enables inference of ecoroof runoff and evapotranspiration from information on substrate moisture changes over time (Culligan et al., 2014).
- Runoff from a conventional roof is compared with one or multiple ecoroofs.
- Outflow (flow rate, volume, pollutant concentrations) from ecoroofs and irrigation on an ecoroof might be collected to assess the water quality of runoff, soil moisture holding capacity and design parameters of the growing medium (Struck et al., 2014)

STORMWATER RETENTION AND ECOROOFS RESEARCH

Several urban municipalities have completed modelling to quantify the impact ecoroof installation could have on managing stormwater. The results of several studies are summarized below.

The Alberta Ecoroof Initiative (AEI) is located at the Alastair Ross Technology Centre in northwest Calgary, Alberta, Canada. The project entails 250m^2 (2700 sq ft) of ecoroof on top of an existing roof of the Alastair Ross Technology Centre located in the University of Calgary Research Park. Two raised platforms for stormwater research were constructed adjacent to the ecoroof. Good runoff volume mitigation was observed with both ecoroofs in the study. Retention capacity was lower in months where rainfall was high, such as May and June (28-55%). Total retention capacity was greater for Sopraflor "L" compared to Sopraflor "X" (66% and 59%, respectively). The retention capacities of the ecoroofs during July, August, and September were much higher (81-99%) likely due to less rainfall and increased evapotranspiration with the higher summer temperatures. The water retention capacity performance of the ecoroofs were dependent upon irrigation frequency, rainfall volume, rainfall intensity, humidity, evapotranspiration, and the length of the interval between rainfall events, making these parameters important in ecoroof water quantity performance (Struck et al., 2014).

A research roof was constructed in Toronto, Ontario with the aim of providing technical data on the performance of ecoroofs in Toronto and to illustrate their benefits in an urban context. Two extensive ecoroof systems were installed (as test plots) on a community centre and were compared to a conventional roofing system. Details of the three different roofing systems are as follows:

- Control/Reference roof: "consisted of steel deck, gypsum board, vapor retarder, thermal insulation, fibreboard and modified bituminous membrane."
- Ecoroof System G: "consists of a composite semi-rigid polymeric drainage and filter mat and a root-anchoring mat. It has 100 mm of lightweight growing medium containing small light-colored granules."
- Ecoroof System S: "consists of expanded polystyrene drainage panels and a geotextile filter fabric. It has 75 mm of lightweight, dark- colored growing medium containing porous ceramic granules." (p. 3, K. K. Y. Liu & Minor, 2005)

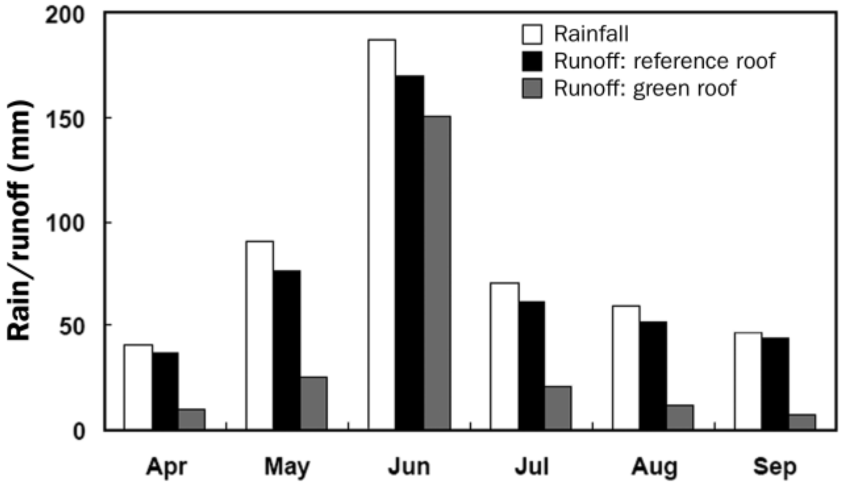
Rain events that were less than 15mm (0.6in) in summer months and were proceeded by six days of dry weather achieved 100% reduction in flow volumes. Comparatively the ecoroof test plots demonstrated significantly reduced flow rates during all seasons compared to the control (non-greened) roof. Lag time for the ecoroofs were measured at between 20 and 40 minutes with a calculated peak flow rate reduction of 25% to 60% adjusted to a per m^2 basis (K. K. Y. Liu & Minor, 2005).

During late fall conditions flow rates from the test plots showed a shorter lag time compared to summer. As the ecoroof media became saturated, the response rates behaved similar to the control roof. The peak flow rate reductions were not as dramatic, compared to summer conditions, but still exhibited a calculated peak flow rate reduction of 10% to 30% (when adjusted on a per m^2) (K. K. Y. Liu & Minor, 2005).

The reduction in runoff volume and rates of flow demonstrated in the results of this study achieved an annual average reduction in volume of 57% for the ecoroof test plots compared to the control (conventional roof). This is significant when viewed as lot-level control and from an overall stormwater retention infrastructure perspective (K. K. Y. Liu & Minor, 2005).

Oberndorfer et al. (2007) conducted a review of evidence that exemplifies the benefits ecoroofs can have, including their contribution to ecosystem services. Below is a summary of key research findings related to stormwater retention:

- Stormwater runoff retention in an ecoroof test plot in Ottawa in 2002. Values in the figure below are sums of total runoff avoided with an ecoroof. The ecoroof had 15 centimeters (5.9 inches) of growing medium and was planted with lawn grasses. It was compared with an adjacent conventional roof of the same size (Liu and Baskaran, 2003)



(Liu and Baskaran, 2003)

- A study conducted in Portland, Oregon and East Lansing, Michigan found that rainfall retention from specific ecoroofs was 66% to 69% for roofs with more than 10 cm (3.9 in) of substrate (Moran et al., 2005)
- Various studies summarized by Beattie and Berghage, 2004 found that rainfall retention varied from 25% to 100% for shallower substrates in other studies.

In one study out of New York, researchers recorded 520 rainfall events with 0.25mm to 180mm (0.01in to 7.40in) rainfall depth. The rainfall retention of the ecoroofs was 42%-62% and the percent of rainfall retained by the ecoroofs decreased as rainfall depth increased (Culligan et al., 2014).

Johnson (2008), for the Chesapeake Bay Foundation – Anacostia River Initiative, conducted a review of stormwater management data, research, and evaluation process for best management practices and found the following key studies and conclusions:

- The US Department of Energy study found that an ecoroof with 76.2mm - 101.6mm (3-4 in) of soil can retain about 25.4mm (one inch) of rainfall. 25.4mm (one inch) of rain is equivalent to about 2.3L (0.6 gallons) of water per square foot of ecoroof area. This report concludes that a typical ecoroof will absorb, filter, retain and store up to 75% of the annual precipitation that falls on it under conditions prevalent in most areas of the United States (US Department of Energy, Energy Efficiency and Renewable Energy, Federal Energy Management Program).
- City of Portland Bureau of Environmental Services determined that a typical ecoroof captures and evaporates between 10 and 100 percent of the rainfall depending on both the roof design and the characteristics of the rain event (BES, 2004).
- Roofscapes, Inc. states that about three inches of growing media will reduce average annual rainfall by more than 50 percent (Roofscapes Inc., 2002).

- An ecoroof in Washington, DC, monitored by the American Society of Landscape Architects (ASLA), retained approximately 75% of the total rainfall volume that fell on it over the ten-month period that data were collected.
- Extensive ecoroofs reduce storm-water runoff by 50-100% during most rains resulting in an average of about 50% - 75% total water retention from rainfall over a typical year.

Summary

The effects ecoroofs have on stormwater retention are arguably one of the greatest benefits of ecoroofs, especially in a predominantly impermeable, urban setting. Ecoroofs allow for enhanced retention of water from both large and small precipitation events, along with delaying peak flow rate time. This lag time allows stormwater infrastructure time to recover from a precipitation event, which is important where infrastructure is nearly at capacity and could result in localized flooding.

Ecoroofs are not only used to retain stormwater, but they have been shown to be effective at removing pollutants from stormwater and other sources. Common pollutants that might be found in stormwater include nutrients such as nitrogen and phosphorus as well as heavy metals. The pathway of pollutants through an ecoroof is by deposition from the atmosphere and through fertilization. Although many of these pollutants also enter stormwater from sources on the ground, atmospheric deposition may be something that occurs in Edmonton and could be mitigated with ecoroof implementation. Some concern has been raised about nutrients in the first year of ecoroof establishment, and where nutrient levels are high in the runoff, it seems to be in this first year.

As mentioned, irrigation will impact the stormwater capacity of an ecoroof and must be considered in the design of the roof.

Overall, urban stormwater retention is enhanced with the installation of ecoroofs, permeable structures in an overwhelmingly impermeable urban environment.

Biodiversity and Habitat

What is Urban Biodiversity and Habitat?

'Biodiversity' can be simply defined as the variety of living organisms occurring within an area. In richly biodiverse areas, there is a large range of species which make up the ecosystem, including plants, insects, and animals. 'Habitat' is the living and non-living environment in which an organism lives. Biodiversity and habitat go hand-in-hand; a healthy habitat supports biodiversity and biodiversity creates a healthy habitat, both are needed to create a stable and functional ecosystem. As urbanization occurs, land use changes "are predicted to negatively impact already impoverished biodiversity worldwide" (p. 52, McDonald et al. 2013, Millennium Ecosystem Assessment 2005, Sala et al. 2000, Seto et al. 2011 as cited in Ksiazek-mikenas, Herrmann, Menke, & Köhler, 2018). Biodiversity is important as it creates ecosystems that are more resilient to changing climate conditions (Rolfe, 2018).

In the urban environment, biodiversity and habitat can take on different characteristics, often creating a novel ecosystem (Hobbs et al. 2006 as cited in Ksiazek-mikenas et al., 2018), "which are human influenced habitats containing previously undocumented species combinations" (p. 53, Ksiazek-Mikenas et al., 2018). Traditional biodiversity conservation focuses on preservation of unaltered ecosystems "but increasingly include restoration and conservation in urban areas, particularly as cities continue to expand" (p. 52, Ellis et al. 2010 as cited in Ksiazek-mikenas et al., 2018). Biodiversity "supported by novel ecosystems contributes to resilient ecological communities and supports global conservation goals" (Kowarik 2011, Pickett and Zhou 2015 as cited in Ksiazek-mikenas et al., 2018).

The novel, urban environment can cause unpredictable changes in biodiversity (Ksiazek-Mikenas et al., 2018) as urban plant and animal species "undergo dramatic changes after establishment as the species responds to repeated disturbance and stress" (p. 53, Odum 1969, Palmer et al. 1997, Sterling et al. 1984 as cited in Ksiazek-mikenas et al., 2018). "Patterns of species richness, diversity, and composition" (p. 53, Ksiazek-Mikenas et al., 2018) can all be unpredictable in the urban environment and thus each site, and the way it supports biodiversity conservation, is unique (Ksiazek-Mikenas et al., 2018).

What is the Relationship Between Biodiversity and Ecoroofs?

There is no better example of a novel ecosystem than an ecoroof; it is human-altered, human-designed, contains a unique composition of species, and has widely variable site characteristics. Researchers have only recently begun to study the ability of ecoroofs to contribute to conservation of biodiversity and habitat within the urban environment, where green space is scarce. Evidence suggests that ecoroofs can provide habitat for plants and highly mobile animal (i.e. bird) and insect species. Further research seeks to conclude if these microhabitats can function as "corridors, linking fragmented habitats and facilitating wildlife movement and dispersal" (Marinelli, 2006).

The very essence of ecoroofs, being human-altered/controlled environments, can facilitate conservation in ways not often possible, by providing the opportunity to design an ideal habitat for specific species such as an endangered species. Providing a microhabitat tailored to an endangered species' needs gives that species a competitive advantage and thus ecoroofs become an important tool for species conservation. Additionally, research is beginning to suggest that "if suitable niches are provided on ecoroofs, plants and animals will move in rapidly and establish communities," which in turn contributes to overall biodiversity and habitat enhancement in an otherwise nature-starved urban environment (Marinelli, 2006).

Methodology for Measuring the Impact of Ecoroofs on Urban Biodiversity

Different types of data are used to assess ecoroof impact on increasing biodiversity in urban areas.

- Studying of bird behaviour with regard to breeding success and food foraging will support habitat studies (Baumann, 2006)
- Ecoroof media characteristics (substrate) depth, and substrate composition (natural/local vs. non-natural/non-local), irrigation (Bergeron et al., 2018) can provide an indication as to what plant and animal habitats can be created on an ecoroof (Brenneisen, 2006)

- Establishment or use of ecoroofs by rare or endangered species supports habitat studies (Brenneisen, 2006)
- Research has shown that the area of habitat is an important parameter in promoting biodiversity on ecoroofs (Brenneisen, 2006)
- Species inventory on the ecoroof (plant, animal, insect, etc.), both use and colonization rate are typical of biodiversity research (Brenneisen, 2006)
- Insect species assemblage (inventory) and richness (number of different species) on ecoroof (Bergeron et al., 2018)
- Surveys of ecoroofs for species abundance, richness, and diversity (ex. plants, arthropods, etc.) and species of conservation concern are also typical of biodiversity studies (Gedge, Grant, Kadas, & Dinham, n.d.; Kadas, 2006; Ksiazek-mikenas et al., 2018)
- Research on life cycles of insect that are observed on ecoroofs (Bergeron et al., 2018)

BIODIVERSITY, HABITAT AND ECOROOFS RESEARCH

A variety of studies have been completed to measure the impact ecoroof installation could have on biodiversity.

A local study conducted in Edmonton, Alberta by researchers at the University of Alberta and Natural Resources Canada, evaluated carabid and spider assemblage and diversity on six extensive ecoroofs and four ground sites; then compared the two types of sites. The research showed that extensive ecoroofs provide islands of urban ecosystems characteristic of prairies, grasslands and naturally disturbed habitats that are threatened by urbanization in the Edmonton region and across Alberta. These ecosystems are valuable as habitat for carabid and spider species so much so that complete life cycles for some species, including reproduction, were observed on ecoroofs. Despite the unique conditions of ecoroofs such as substrate composition, depth and vertical isolation, arthropod communities on the ecoroofs studied do not seem to be impoverished compared to ground habitats. Even though there was a lower abundance of spiders and carabids on roofs, the number of different species did not differ between the roof and nearby ground sites. The researchers also point out that irrigation is an important variable to consider when designing ecoroofs as this, and proximity to on-ground habitats such as wetlands, can change the type of species that are present on the eco roof. In conclusion, the Edmonton study suggests that a diverse set of native arthropods readily colonize and use ecoroofs, thus these low impact urban infrastructures may be strategically used in conservation planning related to species of threatened native prairie and grasslands habitats (Bergeron et al., 2018).

Cavity-nesting bees and wasps that provision brood in human-made trap nests were monitored over three years on 29 vegetated and non- vegetated roofs in Toronto, Canada. The study identified 27 species nesting on rooftops but found that building height was negatively correlated with the abundance of brood cells provisioned in trap nests, and positively correlated with the number of unfinished nests. A decline in green space area within a 600 m radius around each rooftop resulted in decreasing species richness and abundance. Although the introduced bee, Megachile rotundata (Fabricius) occupied more sites than any other bee or wasp (27.6%) and was the most abundant species, amounting to half (48.9%) of all brood reared, native bees were 73% of all bee species reared. The most abundant wasp was the native spider-collecting Trypoxylon collinum Smith (11.4%), but the introduced aphid-collecting Psenulus pallipes (Panzer) occurred at more sites (24.1%). For the pollination and pest controlling services they provide, bees and wasps should be considered in the design of vegetated roofs. Evidence here suggests that building height and surrounding green space at ground level impact bee and wasp diversity on vegetated roofs. Efforts supporting their populations using trap nests should target low- and mid-rise buildings (5 stories or less) (MacIvor, 2015).

In a study on ground nesting birds on ecoroofs in Switzerland, a preliminary two-year study examined the breeding success of the little ringed plover (Charadrius dubius) and northern lapwing (Vanellus vanellus) on ecoroofs in five sites surrounded by varied levels of development. Early results show that northern lapwings have begun to breed consistently, though as of yet unsuccessfully, on some ecoroofs. Because the observation time was short, the available data are incomplete however certain tendencies with regard to the habitat selection and behavior of young and adult birds were revealed which can be applied to future research and ecoroof design (Baumann, 2006).

Design of an ecoroof can play a key role in the habitat created. Brenneisen (p. 27, 2006) explains that "research focusing on the biodiversity potential of green roofs [(ecoroofs)] has led to an amendment in building and construction law in Basel, Switzerland." Brenneisen (2006) conducted a literature review of how ecoroof design can influence biodiversity and habitat creation in urban Switzerland. Ecoroofs are now mandatory on new buildings with flat roofs in Basel, Switzerland as part of the city's biodiversity strategy and guidance is provided for the creation of different plant and animal habitats on ecoroofs. Design criteria for the creation of these habitats include varying the substrate thickness and using natural soils from nearby areas (Brenneisen, 2006). Additionally, varying the depth on an ecoroof provides habitat variety and increases biodiversity. The use of local and natural materials for the substrate is ideal when conserving biodiversity. A variety of microhabitats can be produced, such as riverbanks, mountain, grassland, wet/dry meadow habitats, and the use of local natural substrate aids in the creation of these microhabitats. The microhabitats can be designed with a specific species in mind, creating additional opportunity for endangered species conservation.

In summary, Brenneisen (p. 31, 2006) states that with the correct design considerations, "Extensive ecoroofs can provide suitable habitat for animal and plant species that are able to adapt to and develop survival strategies for extreme local conditions and are also mobile enough to reach habitats on roofs." There are limitations to habitat creation for species that are not able to reach the ecoroof, don't attempt to visit the roof, or cannot survive in the harsh conditions (Brenneisen & Hänggi, 2006 as cited in Brenneisen, 2006).

Research conducted in London, England of invertebrates existing on ecoroofs, brown/biodiverse roofs, and brownfields showed that at least 10% of species collect were designated national rare or scarce. This shows that these habitats can be important tools for invertebrate conservation (Kadas, 2006).

‘Creating ecoroofs for invertebrates: A best practice guide’ by Gedge et al. (n.d.), seeks to encourage the design of ecoroofs specifically with invertebrates in mind in an effort to increase the overall ecological value of a roof by supporting invertebrates. In this guide, authors provide a review of key research, some of which is highlighted below:

- Switzerland: “The study concluded that there were a number of factors that influenced the composition of invertebrate assemblages on ecoroofs, the most important of which was variation in substrate depth” (p. 20). Gedge et al. also recommend using locally sourced substrates. Additionally, on the survey roofs, 10% of the beetles observed were considered threatened and 40% of the spiders were considered rare.
- London: spiders were studied as an indicator for overall complexity of invertebrate assemblages; rare and scarce species were found. In another study “spider species diversity was higher on biodiverse roofs compared to sedum roofs” and 205 of the species on biodiverse roofs were locally or nationally important (p. 23). This study also confirmed that ecoroofs are valuable as invertebrate habitat and that invertebrates readily colonized these artificial habitats. The varying design of ecoroofs and the vegetation that colonizes them determines the species of spiders that populate the roof, which can change over time as conditions and vegetation changes.
- Gedge et al. (n.d.) also provided a review of key research for species of interest and found that in all ecoroof categories combined (sedum and biodiverse) 15% of the spiders and 10% of beetles recorded had either a local or national importance. Also, the combined roof categories accounted for almost 10% of all UK spider fauna and nearly 20% of the Greater London spider fauna. Biodiverse roofs were shown to have greater species richness over sedum roofs.
- Key research pulled from various studies regarding bees conducted in Switzerland and the UK, found that bees prefer biodiverse ecoroofs compared to those dominated by sedum and there was greater species richness of bees on biodiverse roofs. Researchers also found a variety of different bee species, including species of concern (Gedge et al., n.d.).

Summary

The studies outlined above demonstrate the variety of research occurring to understand how ecoroofs influence biodiversity and habitat on rooftops. Considerations for creating biodiverse roofs include substrate type, depth, plant species, irrigation, roof height, exposure and ground level green space (to name a few). If an urban ecoroof policy program wants to encourage biodiversity, habitats, and potentially address fragmentations for certain species, the roof must be designed with these objectives in mind.

As noted in a recent Urban Naturalist issue… [we] “urge ecologists to “look up” to ecoroofs for future research and partnerships that can shape the health and sustainability of future cities” (p. vi, MacIvor et al., 2018).

Air Quality

What is Air Quality?

Air quality plays a major role in human and ecosystem health, especially in the urban environment where pollutants can be heavily concentrated and the urban heat island effect can occur. A study done in the City of Toronto in 2000 estimated that exposure to five common smog-related air pollutants contributes to over 1,000 premature deaths and about 5,500 hospitalizations each year. One of the major components of smog is ground level ozone, a gas that is created when oxides of nitrogen (NOx) and volatile organic compounds (VOCs) mix with the atmosphere in sunlight. The Ontario Medical Association estimated that air pollution costs Ontario more than one billion dollars per year from hospital admissions, emergency room visits and absenteeism. Common health-related consequences include breathing difficulties, cardiac exacerbations and asthma. The effects are most noticeable immediately after air pollution levels peak, especially in hot summer temperatures (Currie & Bass, 2008).

The urban heat island effect can also have a negative impact on air quality as warmer temperatures typically increase energy demand for cooling which can cause higher levels of air pollution and greenhouse gas emissions. Pollutants from most power plants include sulfur dioxide (SO2), nitrogen oxides (NOx), particulate matter (PM), carbon monoxide (CO), and mercury (Hg). (U.S. Environmental Protection Agency, 2008b)

What is the Relationship Between Air Quality and Ecoroofs?

There are several ways that ecoroofs can improve air quality, especially within an urban setting. As explained in earlier sections, ecoroofs help reduce ambient air temperatures and insulate buildings, increasing energy efficiency and reducing the needed for cooling systems, thus reducing emissions. With the reduction in ambient air temperatures and the mitigation of the urban heat island effect, the production of ozone decreases and ultimately creates better air quality.

Another way ecoroofs enhance air quality is in the physiology of the plants that make up the roofing system. Trees, shrubs and other natural vegetation in urban areas positively affect air contaminant levels, and by extension, air quality and the overall experience of health and well-being of residents in urban areas.

There are also additional key factors that influence the ecoroof's ability to reduce air pollution such as ecoroof area and vegetation type, because some plants are more efficient at capturing pollutants than others (Tomalty & Komorowski, 2010 as cited in van Beukering et al., 2015).

Methodology for Measuring the Impact of Ecoroofs on Air Quality

A literature review revealed the following approaches/metrics used to understand the impact ecoroofs have on enhancing air quality in urban areas:

- Ecoroof area
- Vegetation type

- Cost savings to society (emissions credits, health care costs) (van Beukering et al., 2015)
- Modelling approaches to test various scenarios
- Quantify levels of air pollution for contaminants such as: NO_2, SO_2, CO, CO_2, $PM_{2.5}$, PM_{10}, and Ozone (O_3)
- Pollution removal rates
- Ambient air temperature reduction

AIR QUALITY AND ECOROOFS RESEARCH

A variety of studies have been completed to measure the impact ecoroof installation could have on air quality. The results of several studies are summarized below.

Currie and Bass (2008) modelled different scenarios of ecoroof and green wall applications to determine their effects on air pollution in urban Toronto. They found that ecoroofs improve air quality and by extension public health and safety. They also found that trees had the largest impact on pollutant removal, but shrubs and grass made important contributions to air quality as well, depending on which pollutant was being studied. For example, in the case of PM_{10}, shrubs were shown to be almost equivalent to trees in the baseline in terms of air pollutant removal. The study findings show that when installed in sufficient quantities, ecoroofs coupled with existing vegetation at ground level can improve air quality (Currie & Bass, 2008).

It is important to note that Currie and Bass recommend that if an ecoroof policy were being developed to improve air quality, it would need to target a large number of roofs in order to bring about a significant air quality impact. Air quality improvements such as reduced amounts of particulate matter, ozone, nitrogen dioxide, and sulphur dioxide take place during daylight hours and during the in-leaf season. Therefore to improve air pollution levels year round in a city like Toronto, coniferous or evergreen species should be installed (Currie & Bass, 2008).

In a white paper produced by Green Plants for Green Buildings (2014), whose mandate is "communicating the aesthetic, environmental, productivity and health benefits of plants in the built environment," the authors provide a summary of current research, design best practices, and community, environment and economic benefits that ecoroofs can provide. When discussing air quality, the authors determined that an ecoroof has the potential to absorb heat thereby decreasing the tendency toward thermal air movement. As well, an ecoroof will also filter any air moving across it.

Researchers estimate that a 1,000-square foot (93 m^2) ecoroof can remove about 40 pounds (18kg) of Particulate Matter (PM) from the air in a year, while also producing oxygen and removing carbon dioxide (CO_2) from the atmosphere. Fourty pounds (18kg) of PM is roughly how much 15 passenger cars will emit in a year of typical driving (Green Plants for Green Buildings, 2014).

In a modelling study for Washington, D.C., researchers analysed the potential air quality benefits of installing ecoroofs on 20 percent of total roof surface for buildings with roofs greater than 10,000 square feet (930 m^2). Under this scenario, ecoroofs would cover about 20 million square feet (almost 2 million m^2) and remove an estimated 6.0 tons of O_3 and almost 6 tons of PM of less than 10 microns (PM10) annually. This is comparable to the amount of pollutants that could be absorbed by about 25,000 to 33,000 street trees (U.S. Environmental Protection Agency, 2008a) and is a significant finding given the limited amount of space available at ground level in urban contexts.

Sicard et al. (2018) asked the question 'Are Urban Trees and Ecoroofs Effective Solutions to Reducing Ozone in Cities?' A comprehensive data and literature review was conducted by the researchers in order to answer this question. They found that trees showed higher O_3 removal capacity (3.4 g m^2 year on average) than ecoroofs (2.9 g m^2 year as average removal rate), with approximately 10 times lower installation and maintenance costs. They do however go on to state that ecoroofs can be used to supplement urban trees in improving air quality in cities (Sicard et al., 2018).

Three studies (Köhler, 2010; Wesseling et al., 2008; CROW, 2012) found the maximum effect of ecoroofs on reducing APM's (atmospheric particulate matter) to be in the lower single digit percentiles. The effect of ecoroofs on APMs seems to differ between studies, but the overall trend seems to be that the benefits are small. Similar to air pollutants, trees are more effective in reducing APM's than the plants usually associated with ecoroofs, and again, extensive ecoroofs are less effective than intensive ecoroofs because of the plant species and density of plantings installed (Tonneijck et al., 2008).

Several studies looked at quantifying the dollar value of air pollution removal. Bianchini and Hewage (2012) calculated the value of air pollution removal based on the market value of NOx emission credits in the United States in 2005. According to Bianchini and Hewage, the annual benefits range between (USD) \$0.025/m^2 and \$0.03/m^2.

As mentioned above, key factors that influence the ecoroof's ability to reduce air pollution include ecoroof area and vegetation type, because some plants are more efficient at capturing pollutants than others (Tomalty & Komorowski, 2010). Tomalty and Komorowski (2010) assess the economic value by calculating avoided costs of health care. They determined the annual value to be \$0.0394/m^2 (USD).

Summary

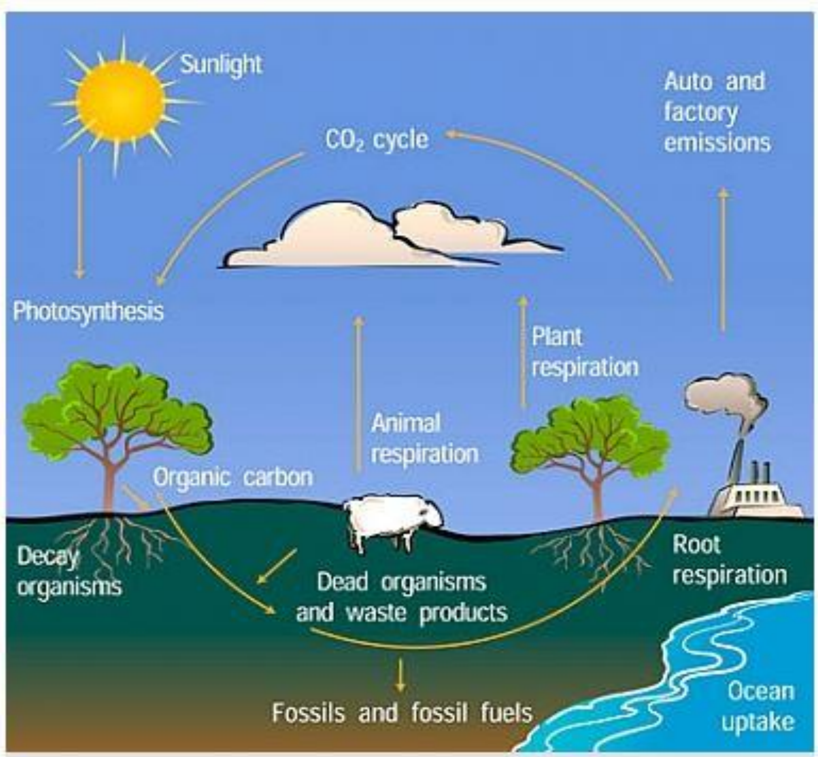
The studies above determined that from an air quality perspective, street trees had a greater impact on reducing air pollutants than ecoroofs. However, what was also discovered was the need for a critical mass of greening to have an impact on air quality – a combination of street trees and ecoroofs.

Carbon Sequestration

What is Carbon Sequestration?

Carbon dioxide (CO_2) is a greenhouse gas, of which we have seen an increase of 32% in the atmosphere since 1750. This increase is caused primarily by the burning of fossil fuels, of which CO_2 is a product. Like the other greenhouse gases, CO_2 traps energy in earth's atmosphere, resulting in an increase in temperature, much like a literal greenhouse that traps heat from the sun within its walls (Michigan State University, n.d.).

Photosyntehsis, the natural process used by plants to create their own energy, "removes carbon dioxide [(CO_2)] from the atmosphere and stores carbon in plant biomass, a process commonly referred to as terrestial carbon sequestration" (p. 7564, Getter, Rowe, Robertson, Cregg, & Andresen, 2009). Photosyntehsis by plants is an important part of a complex cycle, called the carbon cycle (Michigan State University, n.d.). Carbon stored in plant biomass is then transferred to the soil or substrate when the plant foliage dies (ex. leave falling off woody plants in fall, pernial grass above ground biomass die off in fall) (Getter et al., 2009), which eventually leads to decomposition (respiration), where carbon is released back to the atmosphere, completing the cycle. The diagram below illustrates the carbon cycle:



A simple diagram of parts of the carbon cycle, emphasizing the terrestrial (land-based) parts of the cycle.
Credit: UCAR

(University Corporation for Atmospheric Research, 2007)

What is the Relationship Between Carbon Sequestration and Ecoroofs?

Terrestrial carbon sequestration is another factor to consider related to ecoroof function. An ecoroof provides the plant life required as part of the carbon cycle, whereas a traditional or white roof does not. Researchers are still unsure how long carbon remains in the soil or substrate of green roofs before decomposition occurs, however Getter et al. (2009) explain that if the production exceeds decomposition of plant material, then an ecoroof can act as a carbon sink in the short term (Getter et al., 2009). That being said, Getter et al. (2009) also state that ecoroofs cannot be expected to sequester a great amount of carbon because of the species typically used for ecoroofs and the shallow substrate used, which is a concept supported by other studies on carbon sequestration and ecoroofs as well (Kavehei, Jenkins, Adame, & Lemckert, 2018; Whittinghill, Rowe, Schutzki, & Cregg, 2014).

Methodology for Measuring the Impact of Ecoroofs on Carbon Sequestration

A literature review revealed the following approaches/metrics used to understand the impact ecoroofs have on carbon sequestration in urban areas:

- Measurement of carbon content within the following elements, over time:
    - Above ground biomass (ex. leaves, stems, etc.)
    - Below ground biomass (ie. roots)
    - Soil or substrate
    - Atmosphere (and the exchange between surface-atmosphere) (Heusinger & Weber, 2017)
- Carbon content of ecoroof system compared to amount of carbon emitted to produce materials used to build the ecoroof. Usually measured with a payback period in years (Getter et al., 2009; Whittinghill et al., 2014)

There are several factors of ecoroofs that influence the amount of carbon that is sequestered, thusly, these are often measured as part of the carbon sequestration calculation for the ecoroof (Getter et al., 2009; Heusinger & Weber, 2017; Kavehei et al., 2018; MacDonald et al., 2016; Whittinghill et al., 2014):

- Climate
- Season (Heusinger & Weber, 2017)
- Time of day (Heusinger & Weber, 2017)
- Plant species used
- Plant species diversity
- Plant density
- Plant morphology
- Ecosystem age
- Maintenance regime
- Substrate depth and material

- Ecoroof area

CARBON SEQUESTRATION AND ECOROOFS RESEARCH

A variety of studies have been completed to measure the impact ecoroof installation could have on carbon sequestration. The results of several studies are summarized below.

Much of the literature on carbon sequestration potential of ecoroofs points directly back to the pioneer research of Getter et al. (p. 7564, 2009) and their paper "Carbon sequestration potential of extensive green roofs." Their research focused on two different studies. The first study consisted of 12 ecoroofs, varying in age, located in Michigan (eight ecoroofs) and Maryland (four ecoroofs). The ecoroofs were composed primarily of Sedum species, and substrate depths ranged from 2.5 to 12.7cm. The average amount of carbon stored by these ecoroofs was 162 g C·m-2 in above ground biomass (Getter et al., 2009).

Getter et al.'s (2009) second study consisted of twenty test plots on a roof in East Lansing, Michigan. All roofs had a substrate depth of 6 cm and each was planted with a single species of sedum, which were typical of ecoroofs in the United States. Their findings after the two year study were as followed:

- Above-ground plant material (sedum plant species in brackets):
  - ranged from 64 g C·m^{-2} (*S. acre*) to 239 g C·m^{-2} (*S. album*)
  - average of 168 g C·m^{-2}
- below-ground biomass (sedum plant species in brackets):
  - ranged from 37 g C·m^{-2} (*S. acre*) to185 g C·m^{-2} (*S. kamtschaticum*)
  - averaged 107 g C·m^{-2}
- Substrate carbon content averaged 913 g C·m^{-2}, with no species effect, which represents a sequestration rate of 100 g C·m^{-2} over the 2 years of this study.

In summary, for their second study, Getter et al. (p. 7564, 2009) conclude that "the entire extensive green roof system sequestered 375 g C·m-2 in above- and belowground biomass and substrate organic matter." The researchers further their study by applying the carbon cost (embodied carbon) of ecoroof materials and comparing this to the carbon sequestration value, factoring in the emissions reduction created by the ecoroof. Getter et al. estimate that the carbon payback period for their ecoroof would be approximately 7 years (Getter et al., 2009).

Another well-known study on this topic is Whittinghill et al.'s (p. 41, 2014) paper "Quantifying carbon sequestration of various green roof and ornamental landscape systems." This study compared the carbon content of nine in ground and three ecoroof landscape systems of varying complexity in East Lansing, Michigan. Carbon content was measured in the substrate prior to planting and then measured in the following two years, after planting, including the added measurements of below- and above-ground biomass carbon content. A variety of different vegetation was used in this study, ranging from woody plants to herbaceous perennials and grasses to vegetables to native prairie mix to sedums, etc. After adjusting for initial substrate carbon content, the carbon contained in Whittinghill et al. study ecoroofs was as follows:

- Sedum: 4.67 kg C m^{-2}
- Prairie: 5.64 kg C m^{-2}
- Ornamental: 65.25 kg C m^{-2}

Whittinghill et al. (2014) then applied the same approach as Getter et al. (2009) to find the carbon payback period for their four ecoroof systems:

- Sedum: 2.2 years
- Prairie: 1.9 years
- Ornamental: 0.2 years
- Vegetable: 1.2 years

The researchers also suggest that there are two more factors when it comes to assessing carbon sequestration. First is the greater carbon sequestration potential in ecoroofs with deeper substrate. Second is the management regime of the roof system (ex. powered machinery, leaving the foliage once it has seasonally died), which can influence the carbon sequestration and storage capacity of the ecoroof (Whittinghill et al., 2014).

In summary, Whittinghill et al. (2014) found that in many cases the ecoroofs contained less carbon than their corresponding at grade landscapes however, all of the ecoroofs sequestered carbon, and also exhibited greater carbon sequestration than that previously reported by Getter et al. (2009). Whittinghill et al. (p. 48, 2014) state that "greater carbon sequestration can still be achieved on the ground and carbon sequestration will likely only be a secondary benefit of green roofs."

Kavehei at al. (2018) conducted a meta-analysis literature review of international studies that evaluated the net carbon footprint of several types of green infrastructure. They did this by reviewing the life-cycle carbon footprint and subtracting the carbon sequestration value of the green infrastructure. For ecoroofs the researchers created the following table that summarizes carbon sequestration value from various studies that measured those values directly (see table on page 34).

The actual carbon sequestration measurment of the vegetated WSUD technologies. Positive values represent the carbon emissions, and negative values are carbon sequestration rates.

WSUD	Carbon sequestration (kg CO_2 eq. m^{-2} yr^{-1})	Basins media	Climate	Vegetation	Reference
Green Roof	-0.69	Typical GR substrate (6 cm)	Temperate climate, USA	*Sedum* species	Getter et al. [77]
	-25.2	Mixed-sewage-sludge soil (20, 25, 30 cm)	Humid subtropical climate, China	*L. vicaryi, N. auriculata, L. spicata*	Luo et al. [81]
	-22.3	Local natural soil (20, 25, 30 cm)			
	-4.4	Compost-soil-bricks (5, 10 cm)	Mediterranean climate, Spain	*S. vulgaris, L. ovatu*	Ondoño et al. [83]
	-1.9	Compost and bricks (5, 10 cm)			
	-0.91	Compost-silica-sand, -crushed bricks (10 cm)	Mediterranean climate, Spain	*Lotus creticus, Asteriscus maritimus*	Ondoño et al. [87]
	+4.6	Compost- crushed bricks (10 cm)			
	-1.4	Compost-clay loam soil-crushed bricks (10 cm)			
	-3.9	Compost-silica sand-clay loam soil (10 cm)			
	-1.9	Typical GR substrate (10.5 cm)	Temperate climate, USA	*Sedum*	Whittinghill et al. [80]
	-3.1			Native *prairie*	
	-75.9			Ornamental green roofs	
	-2.5	Seedling propagation substrate (5 cm)	Humid-subtropical climate, Japan	*Z. matrella*	Kuronuma and Watanabe [82]
	-1			*O. japonicus*	
	-1.2			*S. mexicanum*	
	-9.4[1]		Humid-subtropical climate, China		Peng and Jim [78]
	-0.77[1]		Northern Greece		Karteris et al. [79]
Vegetated Swale	-0.36	Felsic and crystalline soils and lower coastal plain	Sub-Humid, sub-tropical climate, USA	Mostly grass	Bouchard et al. [73]
	-0.62[1]		USA	Grasses, Woody vegetation and Shrubs	FHWA [88]
Stormwater Pond	-0.30 (vegetated zones)	Three hydrological zones (deep, shallow and temporary inundation)	Sub-humid, sub-tropical climate, USA	Grasses, sedges, and emergent macrophytes	Moore and Hunt [89]
	-0.29	Three hydrological zones (deep, shallow and temporary inundation)	Sub-humid, sub-tropical climate, USA	Littoral shelf and emergent macrophytes	Merriman et al. [90]
	-0.28		Subarctic climates, Sweden		
	-0.50		Humid tropical climate, Singapore		

1—The estimated values of the carbon sequestration.

(p. 1187, Kavehei et al., 2018)

In the above table (page 34), it is clear there is a wide variation in carbon sequestration values; this is partly due to differences in location/climate, plant species, and a variety of other variables. From their meta-analysis, Kavehei et al. (p. 1187, 2018) conclude that "the mean carbon sequestration of green roofs is −58.4 ± 24.7 kg CO2 eq. m−2, which corresponds to 68% of its carbon footprint." The researchers go on to explain that "this results in a net carbon footprint of 27.2 kg CO2 eq. m−2 over a 40-year life time" (p. 1187, Kavehei et al., 2018). The net carbon footprint of 27.2 kg CO2 eq. m−2 is significant because it provides evidence that the ecoroof does not sequester enough carbon to offset the carbon cost of the roof, thus leading to a positive carbon footprint (carbon source) over the 40 year life time. As the literature is lacking with regard to the carbon footprint during the end-of-life and operation and maintenance phases, the researchers recommend that further research is needed to accurately measure an ecoroofs net carbon footprint, including carbon sequestration potential, over the entire life of the ecoroof(Kavehei et al., 2018).

Heusinger and Weber (2017) took a unique approach to evaluating carbon sequestration of an extensive ecoroof. They used a method called the Eddy Covariance Method, which is currently used globally in a variety of different ecosystems, to assess the net ecosystem exchange of CO_2 of the ecoroof. They conducted their study on a newly established, unirrigated ecoroof located in Berlin, Germany over the course of a year (July 2014- August 2015). They found the ecoroof acted as a carbon sink with an annual cumulative NEE of -313 g CO_2 m^{-2} $year^{-1}$, equivalent to -85 g C m^{-2} $year^{-1}$. Researchers believe that as the plants become more established and cover more of the roof surface, the carbon capture would increase. While the roof acted as a carbon sink over the year, during dry conditions, during the daytime the roof acted as a carbon source. The researchers recommended maintaining the substrate moisture level of their research ecoroof over 0.05 m^3 m^{-3} in order to optimize CO_2 uptake (Heusinger & Weber, 2017).

Summary

In summary, there is potential for ecoroofs to sequester and store carbon within their substrate and plant biomass. There are many variables related to the carbon sequestration potential of an ecoroof but overall the value is thought to be relatively small. One group of researchers believe it to only be a secondary benefit when it comes to the value ecoroofs bring publicly and privately (Whittinghill et al., 2014). The net benefit, especially after applying carbon cost of the ecoroof, is small, but some research supports a positive benefit, sequestering more carbon than it produces; whereas other research found the opposite, that ecoroofs cost more carbon then they sequester but also point out that more research is needed into the full life-cycle costing of ecoroofs to determine a more accurate carbon cost calculation.

One benefit that ecoroofs afford with regard to carbon sequestration is that when compared to traditional roofs, they provide the propect of sequestering carbon and traditional roofs do not (Getter et al., 2009). Getter et al. (2009) provide an example where, according to their methodology, if all industrial and commercial buildings in Detroit were covered in ecoroofs, the carbon sequestered would be equivalent "to removing more than 10 000 midsized SUV or trucks off the road for a year" (p. 7569, U.S. Environmental Protection Agency, 2005 as cited in Getter et al., 2009). Therefore, the function of carbon sequestration that ecoroofs provide is still being discovered but most of the research points to a small net benefit that can be multiplied greatly by increasing the scale and number of ecoroofs in a region.

Conclusion

The range of research completed across the globe on the benefits of ecoroofs is extensive and provides evidence that ecoroofs could be effective in urban areas to: reduce the urban heat island effect; assist with building energy efficiency; increase stormwater retention capacity; improve biodiversity and habitat; contribute to air quality improvements; as well as provide carbon sequestration potential. It is recognized that ecoroofs are not the only solution that should be considered to improve a city's resiliency however, ecoroofs are one tool that have a number of environmental benefits – in addition to social and economic benefits.

Findings from the *Climate Resilient Edmonton: Adaptation Strategy and Action Plan* outline changes in climate that Edmonton will need to adapt to: an average increase in temperature, precipitation pattern changes, an overall increase in the frequency of extreme weather events, and an overall warmer and drier climate leading to potential ecological changes.

The research outlined in this report highlights how ecoroofs help improve urban environments by reducing the urban heat island effect, increase building energy efficiency, increase stormwater retention, increase biodiversity, provide habitat for a variety of species, provide carbon sequestration potential, and improve air quality. Other ecoroof benefits that were not reviewed as part of this research include improved quality of life for residents or employees with a view of or access to roof top green space, urban agriculture opportunities, and economic opportunities for trades, industry and suppliers. While the research gathered is not specific to the Edmonton context, it does reveal ecoroofs have a positive environmental impact on the urban context. The scope of public impact varies depending on the roof type, plantings, location and number of other ecoroofs in a given area. As one research report stated, ecoroofs are often seen as a no regrets approach to climate adaptation because there are so many benefits offered by the technology.

Edmonton Valley Zoo
Source: City of Edmonton

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