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Quantitative evaluation of greenroof systems for sustainable development

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Abstract

Rooftop gardens or greenroofs provide multiple benefits in support of environmental sustainability such as improved stormwater management, improved air quality, increased energy efficiency, increased roof life cycle and decreased heat loading to the atmosphere contributing to the mitigation of the "Urban Heat Island Effect". The objective of this paper is to design an on-site evaluation for the quantitative benefits of the greenroof system. The study describes the design and data collection of six greenroof systems in the Greater Toronto Area, to specifically quantify the multiple benefits of greenroofs in Canadian climate. The long-term, real-time monitoring program will help to define the ecological and hydraulic benefits of the greenroofs. The findings of this study will be used to support a region-wide database for the evaluation of the potential benefits of installing greenroofs on a broader scale and to support the implementation of new stormwater policies related to rooftop gardens for new installations or retrofitting applications.

1 Introduction

Urban landscape transformation results in the formation of many impervious surfaces such as roads and rooftops, which do not work well within the existing ecosystems and have led to a number of problems that challenge our ability to achieve environmental sustainability. Technologies such as rooftop gardens or greenroofs may prove to provide multiple benefits in support of environmental sustainability such as improved stormwater management, improved air quality, increased energy efficiency, increased roof life cycle and decreased heat loading to the atmosphere contributing to the mitigation of the "Urban Heat Island Effect". Unfortunately, in spite of the wide range of perceivable economic, social and environmental benefits of greenroofs, very limited greenroof installations have been observed in North America (Thompson [1]). A major reason is due to the fact that very few scientific studies and research have been performed to quantify the benefits of greenroof technology for the cool temperate climate in North America. To promote more widespread use of the greenroof concept, such research is a key element to effect policy change, business models, and public perception.

Various research projects are presently underway, or being proposed, to study the benefits of greenroofs in Canada. At present, these sites are provided by different suppliers, employ different soil and plant technologies, and are mostly different in research focus, project scale and monitoring protocol. As a result, data management and meaningful correlation of findings are difficult, and only site-specific conclusions may be drawn. This paper presents a comprehensive design of infrastructure components, site monitoring, instrumentation, and data management to overcome these limitations.

2 Objectives

The objective of this paper is to design an on-site technical study to quantify the various benefits of the greenroof system. The study will describe the major components to be included in a comprehensive data collection and monitoring program for some existing and planned greenroofs in the Greater Toronto Area (GTA) of Ontario, Canada. The long-term continuous, automated monitoring system will help to define the ecological and hydraulic benefits of greenroofs for North American climate.

3 Benefits of greenroofs

A major benefit of greenroofs is the stormwater management (Bass & Peck [2]) through increased water retention, thereby reducing the volume of water conveyed to storm sewers. Rainfall is retained in either the greenroof growing media, intercepted by the vegetation and later evaporated or stored in on-site storage tanks, rain barrels or cisterns. On-site retention of stormwater may eliminate or reduce the size of land-based stormwater ponds and may reduce combined sewer overflows that impair surface water quality. More importantly, greenroofs may also result in significant improvement of the quality of stormwater, through reducing the temperature of the runoff and filtering the water via the soil media. The absorption of pollutants by plants and soil media will reduce the amount of total suspended solids (TSS), metals, plant nutrients such as nitrates and phosphorus, biochemical oxygen demand (BOD) and total organic carbon (TOC) from urban runoff. A study carried out by Graham [3] showed that preliminary results from stormwater modelling have consistently demonstrated the potential of greenroof to enhance stormwater control for urban inner cities. Another study carried out at Portland, Oregon (Frerichs [4]) found that a diversion of stormwater with greenroofs has successfully helped to restore

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and protect the salmonid populations, including Coho, Chinook, and Steelhead, at the local Willamette River.

Greenroofs are also beneficial for energy conservation. Studies have verified that significant additional insulation is provided by greenroofs in the winter, but the trend in global warming has made it attractive to also consider their cooling effects in the summer (U.S. EPA [5]). It has been observed that cities and urban areas generally exhibit a higher temperature than rural and suburban areas, an effect known as the urban "heat island effect". This difference in temperature can vary from 2-5°C, and is especially significant during hot summer months and may result in much higher incidences of smog. This is due mainly to the reflection and heat-trapping characteristics from the expansive hard rooftop surfaces in urban areas. As a result, the additional energy consumption that is attributed to cooling buildings with flat rooftops is considerable. Research (Bass et al. [6]) carried out to simulate the heat island effect has demonstrated the potential of the greenroofs in terms of temperature moderation through vegetation coverage on the rooftop.

Greenroofs may provide substantial improvement on urban air quality, comparable to that of naturally vegetated area, through the plant uptake of carbon dioxide and other greenhouse gases, as well as other trace metals from the atmosphere. In addition, a greenroof will also provide filtration of air mass moving through it, and achieve some removal of fine airborne particulate matter that are detrimental to human with respiratory problems. It is estimated (Green Roofs [7]) that a 1-m^2 plot of grass-covered roof can remove 0.2 kg of airborne particulates and generate 70% of the human annual oxygen requirement.

Many of the above benefits also have their corresponding economical implications. For example, there are cost saving opportunities for building owners in terms of energy, insulation, and maintenance. For the community, there are also substantial cost savings from increased stormwater retention and improved water quality, as well as greenhouse gas reductions. In addition, it has been observed that there are many social benefits derived from greenroofs, such as sound insulation, aesthetics improvement, as well as human health and well being (Bock [8]). Psychological studies have shown that the restorative effect of a natural view results in a population much less susceptible to illness. This is due in part to the additional oxygen, air filtration, and humidity control provided by plants, and also from the therapeutic benefits derived from caring for and having access to plants and a natural environment. Finally, greenroof also provides good insulation for sound – with soil blocking lower sound frequencies and plants blocking higher frequencies. For example, a greenroof with a 20 cm soil layer can reduce noise by 46-50 decibels per m^2.

4 Greenroof design concepts

A detailed guideline for the design, selection, maintenance and costing of greenroofs may be found in Peck & Kuhn [9]. Figure 1 shows the proposed design of a fully-monitored greenroof system (Greenroof Systems

Consortium [10]), which is made up of the following major components to quantify the benefits of the concept:

1) A closed greenhouse/indoor air filtration module to circulate and filter indoor air prior to mixing it with outdoor air and re-circulated back into the building.
2) An open green roof garden that provides a function similar to naturally vegetated areas, with soil to contribute to water infiltration, evapo-transpiration and insulation, and plants for outdoor air filtration and carbon storage.
3) A precipitation capture module to capture and store rainwater and snowmelt in a "gray water system", to be recycled for toilet flushing and plant watering.
4) A real-time web-based monitoring and analysis system connected to a comprehensive meteorological station and other instrumentation networks. The parameters to be monitored include precipitation, air temperature, soil temperature, soil moisture, roof flow rate, infiltration, air quality and stormwater quality.
5) A control module made up of the original rooftop but installed with a similar instrumentation network, to provide a baseline comparison of the various performance parameters.

A summary of the performance objectives of individual components is given in Table 1.

Table 1: Performance objectives of greenroof components.

Components	Performance Objectives
Greenhouse/indoor air filtration module	• ↑ indoor air quality • ↓ energy consumption • ↓ carbon loading of indoor air • ↑ health of occupants
Open greenroof system	• ↓ urban heat island effect & heat loss • ↑ outdoor air quality and green space • ↓ stormwater runoff • ↑ stormwater quality • ↓ combined sewer overflow • ↑ sound insulation • ↑ roof life expectancy & property value
Precipitation capture module	1. ↓ municipal water use 2. ↓ stormwater runoff 3. ↓ sewer charges 4. ↓ combined sewer overflows
Monitoring & analysis system	• ↑ capacity to quantify benefits • ↑ information transfers & communication
Control	Establish baseline conditions for performance evaluation

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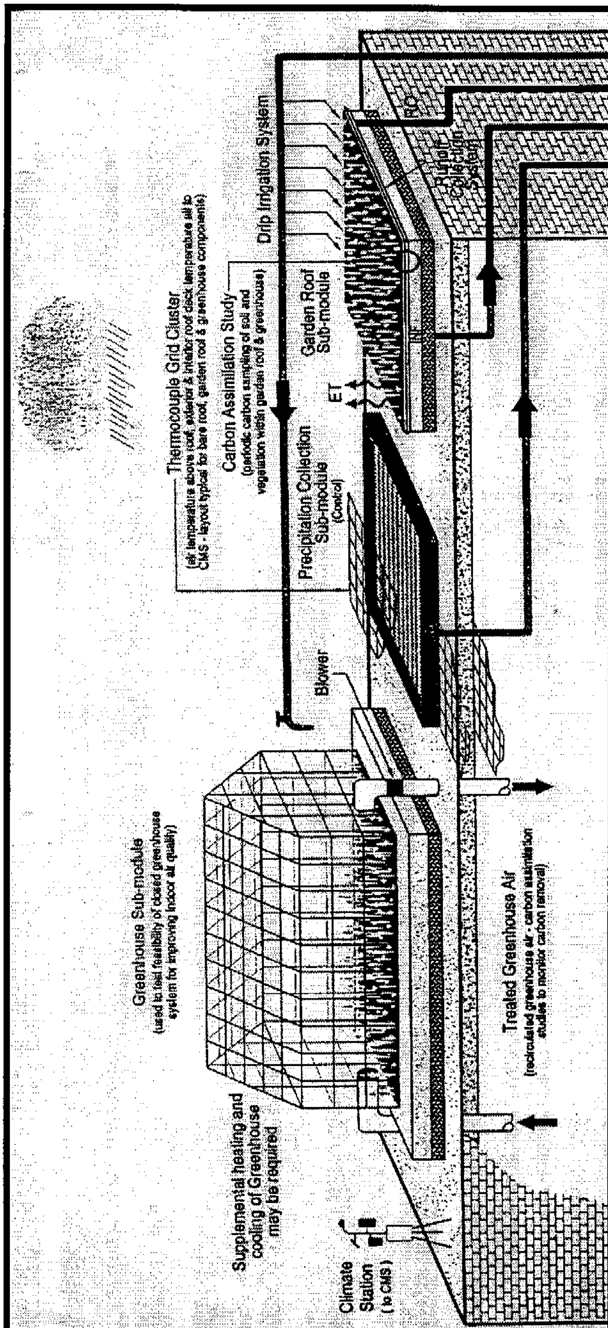

Figure 1: Design of a monitored greenroof (after Greenroof Systems Consortium [10]).

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5 Data requirements and instrumentation

A total of six greenroof sites, as shown in Figure 2, has been retrofitted or being constructed in the Greater Toronto Area for this study. A detail description of all the sites is summarized in Table 2.

Table 2: Summary of GTA greenroof sites of the study.

Location	Description	Greenroof Area (m^2)	Construction Type	Cost (Can $)
Eastview Community Centre	Old 1930's box-structured building with flat roof	448	Retrofitted in 2002	$285,000
Ryerson University	New engineering building at Gould and Church Streets	850	Planned occupancy in Sept. 2004	Budgeted $250,000
York University	New computer science building, with 10% sloped roof	241	New building and roof constructed in 2001	
Toronto City Hall	Old office building	300	Retrofitted in Nov. 2000	$260,000
Merchandise Loft Building	Old 800 person condominium complex	360	Retrofitted in 2000	
Mountain Equipment Co-Op Store	New two-storey building built in 1998	903	New greenroof wrapped around central skylight	$170,000

To achieve a consistent sampling protocol and data set for long-term comparisons, each of the sites should be equipped with the following instrumentation:

Weather information: A comprehensive weather station should be installed at each site, to monitor the precipitation (rainfall and snow), air temperature, wind speed and direction, relative humidity and evapo-transpiration. All the instrumentation should be housed within a heated installation on the rooftop with automated sampling capabilities.

Flow monitoring: Electromagnetic flow meters will be used to measure the rate and volume of flow from the tested and control areas. The meters should be installed in-line with the PVC pipe beneath the grating on the storm runoff storage tanks. Onsite power supply, as well as data communication cables, is to be installed along the edge of the walls and housed in weather-protected channels.

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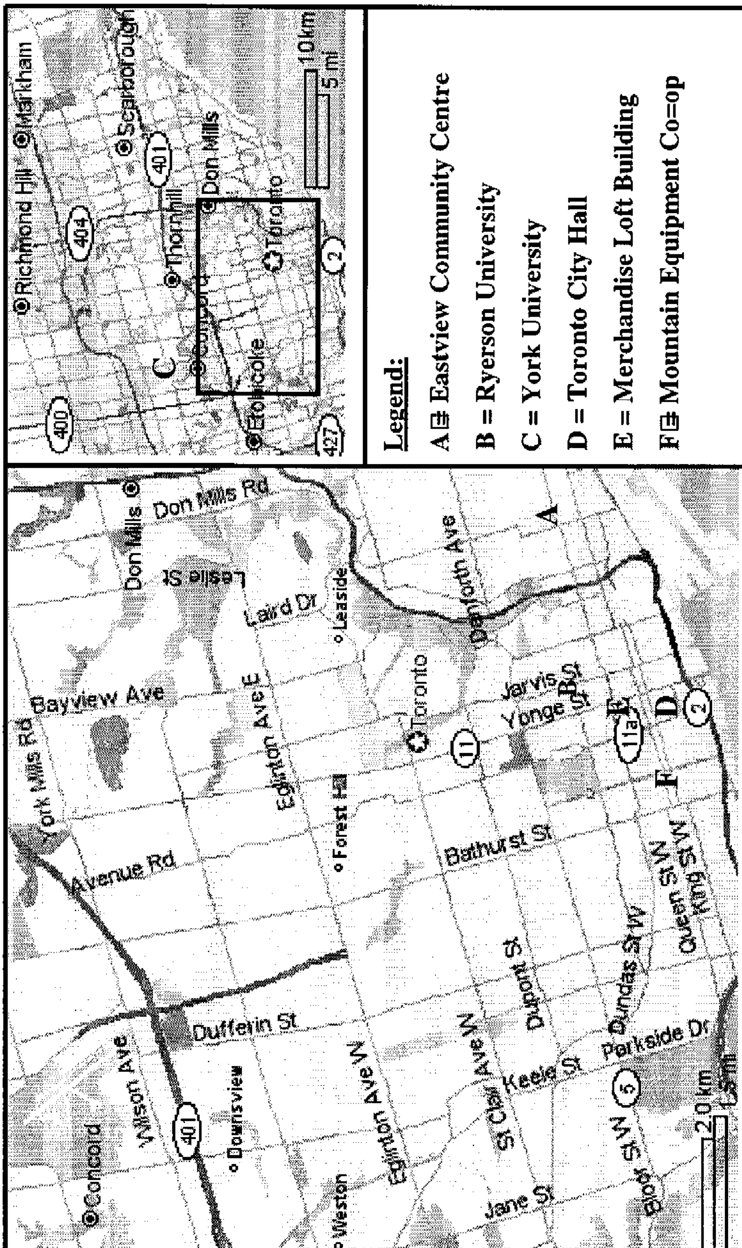

Figure 2: Location of the six GTA greenroof sites.

Infiltration and soil moisture: Electronic infiltrometers and soil neutron moisture sensors are required at various depths under each group of plants. The moisture sensors will allow for the assessment of the moisture retention capacity and root absorption for a diversity of plants, including grass, wildflowers, succulents, perennials, sedums and herbaceous plants. As a result, detailed volumetric profiling may be performed to assess infiltration, soil abstraction, retention, and storage of stormwater for hydrologic simulations. In addition, signals from the moisture sensors may be relayed to activate an automatic sprinkler system to provide better maintenance of the plants.
Temperature gradient: A thermocouple grid of multiple temperature sensors are required to monitor the complete temperature distribution of the greenroof area. The installation should have the capability to monitor the vertical temperature gradient at different depths of soil cover, with each horizontal grid layer consisted of 2 to 5 m individual cells.
Quality data: Water quality samples of the stormwater runoff may be analyzed for various parameters such as TSS, TOC, BOD, metals, nitrates and phosphates with an automated comprehensive aqua-analyzer. Air samples are analyzed with a continuous-flow gas chromatograph for concentrations of CO_2, CH_4, NO_x, VOC and particulates.

6 Web-enabled database network

To provide a consistent monitoring and data analysis protocol, an overall database management strategy is required to ensure reliable collection, storage, and interpretation of this extensive database. Utilizing high-speed internet connectivity in conjunction with real-time monitoring and control technology will enable common analysis protocols to be coupled with extensive data logging and analysis capabilities. Figure 3 shows the web-based monitoring and analysis system (WEBS) by Tridium Inc. proposed for the system, which allows for the real-time gathering of various instrumentation and weather data and provides a tool for in-depth analysis of the data. With this, an automated high frequency continuous sampling program based on a common protocol can be supported at multiple sites with remote management carried out at a central web server station.

With remote programming and system-wide event alarming capabilities, the need for constant data logging can be eliminated. In addition, conventional storage limitations can also be overcome as real-time log files from remote sites are automatically stored on hard drive media at the central web server. Once stored at the central web server, the data can be analyzed and correlated to aid in hydrologic modeling. Web browsers are employed to display data archived by the web server, enabling speedy access to concurrent users with authorized passwords. If any monitored parameters, such as sampling frequency, diagnostics and scaling, need to be adjusted, this can be carried out remotely over the internet for all the connected sites. With this method, a region-based database may be established to satisfy a multitude of greenroof research objectives.

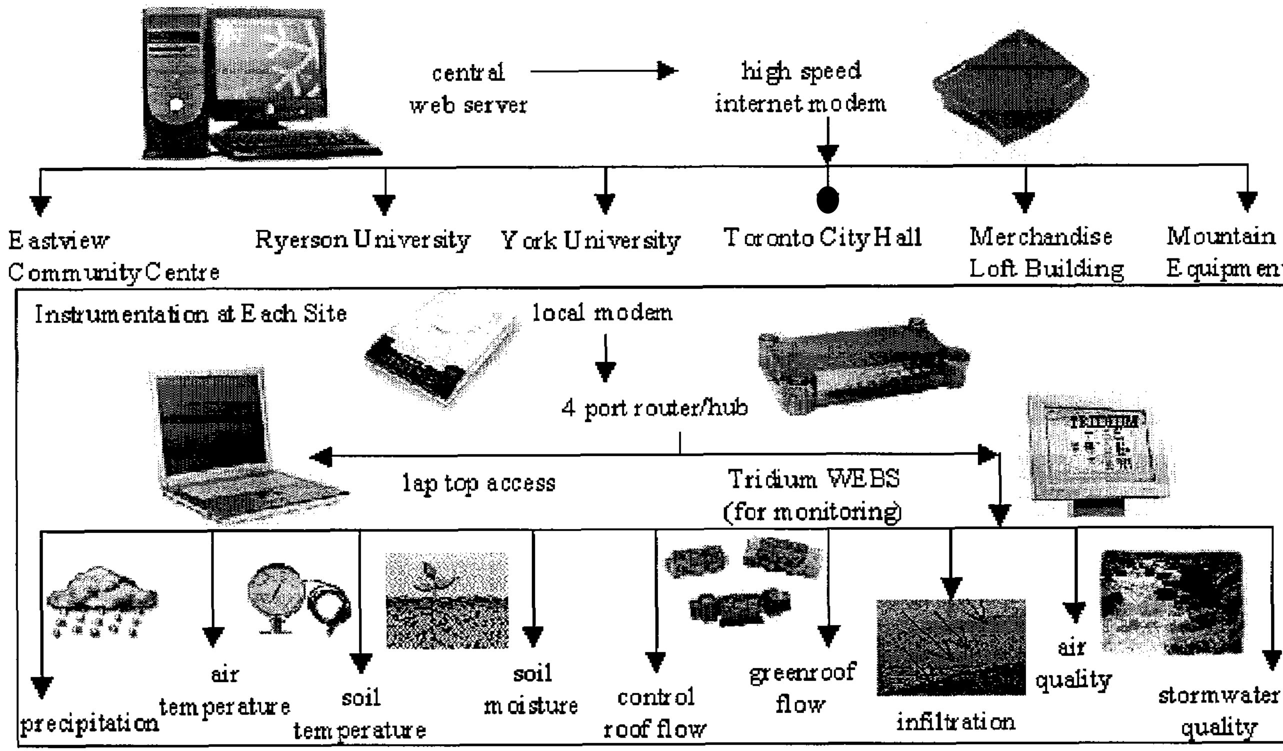

Figure 3: Instrumentation and web-based data management system.

7 Discussion and conclusions

To promote the greenroof as a cost-effective alternative with environmental, hydrological, energy and socio-economic benefits, a system-wide scientific research with common monitoring protocol is necessary. There are other important considerations, such as minimizing disturbance to existing roof area and integrating all monitoring equipment and appurtenances into roof setting, which should be incorporated into the design. It would also be preferable to minimize the amount of site maintenance. In addition to demonstrating quantitatively the manifold benefits of the greenroof system, the data collected from the proposed monitoring network will provide very good information for future numerical modelling and cost-benefits analyses.

Acknowledgements

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