An Investigation into Green Roofs

Maan Almarghalani, Voon Qian Chang, Han Chen Wang, Yo-Wei Yang, Ricky

University of British Columbia

APSC261

November 30, 2010

An Investigation into Green Roofs

Maan Almarghalani

Voon Qian Chang

Han Chen Wang

Yo-Wei Yang, Ricky

Date of Submission: November 30th 2010

Course: Technology and Society APSC 261.

Instructor: Dr. Paul Winkelman.

ABSTRACT

Sustainability has been an important factor in the design process of new buildings. One of the major problems in sustainable developments is water management. In response to the AMS's request to manage the water consumption in the new SUB, this project aims to achieve a net zero water consumption. That is, the water produced is equal to the water consumed in a period of one year. In order to accomplish this goal, it is suggested to implement a green roof in the new SUB. A green roof provides vegetation or a plant cover over a waterproof crust on the roof of the building. The main constraint is the cost of implementing the solution. Installing a green roof is an environmentally friendly approach for the new SUB water management. It helps to eliminate rainwater runoff and also to reduce the new SUB's overall energy consumption. Constructing green roofs encompasses environmental, economical and social benefits. From an environmental perspective, it is shown that having a green roof decreases the surface runoff significantly. Also, installing a green roof makes the building more sustainable because it reduces energy consumption. From an economical point of view, although implementing a green roof results in a higher initial cost than a conventional roof, an overall decrease in cost is expected due to energy conservation in the long run. From a social standpoint, constructing a green roof helps in creating new jobs since it requires labourers, landscapers and experts. It improves students' lives given that it increases the interaction between students and nature. Furthermore, the university will gain some benefits. Having a green roof in the new SUB earns the university LEED points. Ultimately, it may promote the university's ranking. Based on the findings, it is recommended to implement a green roof in the new SUB to effectively manage water consumption.

TABLE OF CONTENTS

List of illustrations

Glossary

Runoff Coefficient:	The percentage of precipitation that turns into as runoff.
Urban Heat Island:	The increased air temperatures in metropolitan areas in contrast to surrounding rural areas which are cooler.
Abiotic Depletion:	Consumption or use of non-living resources faster than they are replenished.
Eutrophication:	The intense growth of plant life in ecosystem due to the increase in nutrients concentrations.
EnergyPlus	An energy simulation software.

List of Abbreviations

- LCA: Life Cycle Assessment
- UMTs: Urban Metropolitan Types
- NPV: Net Present Value
- LEED: The Leadership in Energy and Environmental Design

1.0 ENVIRONMENTAL ASPECTS

Green infrastructures currently play a vital role in helping cities adapting for climate change by implementing sustainable developments. The purpose of this section is to outline the environmental impacts of implementing a green roof in the new UBC SUB based on a case study in Greater Manchester and a Life Cycle Assessment (LCA) conducted in Madrid.

1.1 SURFACE RUNOFF MODEL

Green roof is effective in retaining rainwater runoff. With the increasing of precipitation expected by the 2080s, green roof helps to preserve runoff before it is released into the sewer system [2]. Also, it shrinks the probability of flooding and contaminating the rivers [3]. The objective of this section is to analyze the role of soil type acts in this surface runoff model. This section also evaluates the benefits of green roof on reducing surface runoff.

1.1.1 <u>Soil Type Analysis</u>

Selecting the soil type is an important factor to be considered while greening the roof, because it directly affects the runoff coefficient*. According to [2], slower infiltrating soils* have higher runoff coefficients than faster infiltrating soils. Therefore, it is very important while choosing the soil type for the green roof, especially in the cities where the level of precipitation is high, such as Vancouver. Faster infiltrating soils, such as sandy soils, are highly recommended for the construction of the green roof in the new SUB.

1.1.2 Surface Runoff Analysis

Green roofs play a fundamental role in reducing surface runoff. As [2] demonstrates, adding green roofs to all the buildings including town centres, retail and high-density residential, actually helps in decreasing the runoff. Figure 1 shows the runoff for selected Urban Morphology Types (UMTs) in Greater Manchester, with and without green roofs added.

The study also shows that increasing green or tree cover helps to deal with surface runoff. However, the outcome of doing so is not as significant as adding green roofs to the buildings. For example, adding 10% tree cover to residential areas in Greater Manchester actually reduces the total runoff by only 1.9%, while greening the roofs in the high-density residential buildings lowers the runoff by 18.9% [2].

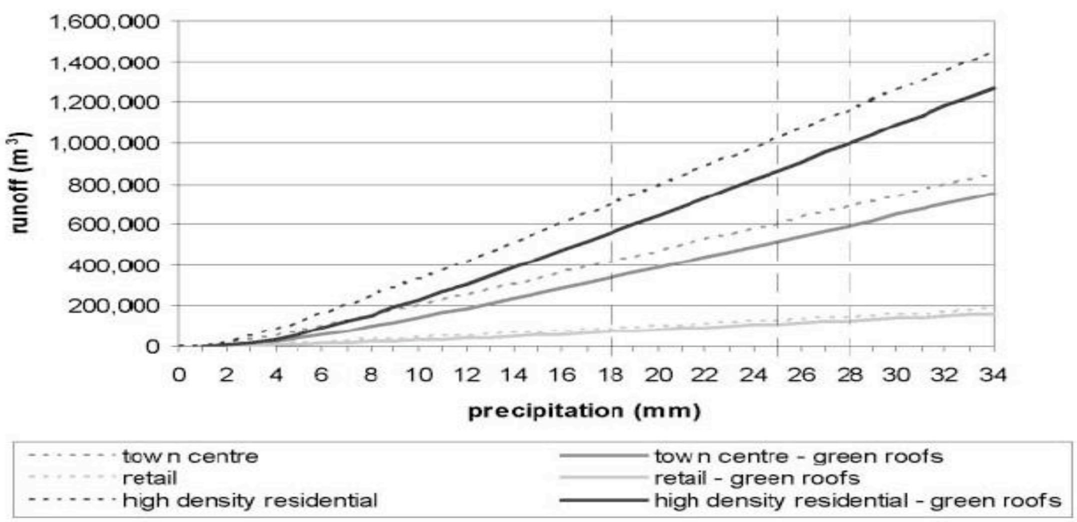

Figure 1: Runoff for selected Urban Morphology Types (UMTs) in Greater Manchester, with and without green roofs added [2].

1.2 COMPARATIVE LIFE CYCLE ASSESSMENT (LCA) OF STANDARD GREEN ROOFS

Life Cycle Assessment (LCA) has been used to evaluate the benefits of green roofs. This assessment was conducted to an eight storey residential building in Madrid. Based on this study, green roofs have reduced energy consumption and environmental impacts.

1.2.1 <u>Reduction in Energy Consumption</u>

The hallmark of a green roof is the low solar absorption. One study [3] examines that this in turn reduces surface temperature of a building since there is less heat flux going through the roof. In addition, green roofs serve as natural shading too. That is, installing green roofs to the buildings in the cities contributes to the reduction of the urban heat island*. "Studies in Toronto suggests that a 1 degree Celsius drop in temperatures would be obtained over one-third of the city if 50% of the buildings had green roofs and at least 3% of the green roofs were fully saturated" [3]. Besides, implementing a green roof in a building minimizes the thermal fluctuation between the outer and inner surfaces of the roof. As a result, it cools the rooms below the roof during the summer and also raises their heat during the winter [1]. In short, green roofs lessen the energy use since they help in heating the building in the winter and cooling it in the summer. Table 1 shows the annual energy consumption for the eight-story building with and without the green roof.

Table 1: Annual Energy Consumption for the Building with Common Flat Roof (BFR) and Reductions for Green Roof (BGR) and White Roof (BWR) [3].

	BFR energy consumption	% change	
		BGR	BWR
heating (kWh) from natural gas	240,800	−0.12	+ 0.7
cooling (kWh) from electricity	90,200	−6.2	−4.0
lighting (kWh) from electricity	31,800	0	0
outlets (kWh) from electricity	66,100	0	0
hot water (kWh) from natural gas	71,000	0	0
total (kWh)	500,000	−1.2	−0.4

1.2.2 <u>Reduction in Environmental Impacts</u>

Green roofs play a crucial role in decreasing environmental impacts. One study [3] shows that adding green roofs to buildings reduces environmental impacts by 1.0 to 5.3%. Table 2 shows the changes in environmental impacts over a 50-year building life span upon adding a green roof. Abiotic* depletion and eutrophication* are the categories that have the largest reductions as shown in Table 2.

Table 2: Changes in Environmental Impacts over a 50-year Building Life Span upon the Addition of a Green Roof (BGR) [3].

impact category	impact indicator	Δ materials	Δ use	Δ maintenance	Δ total	% change total
abiotic depletion	ton Sb equiv.	0.02	−4.72	−0.50	−5.20	−5.0
global warming (GWP100)	ton CO_2 equiv.	2.0	−101	−40.0	−139	−1.0
ozone layer depletion (ODP)	kg CFC-11 equiv.	0.00	−0.02	−0.01	−0.03	−2.4
human toxicity	ton 1,4-DB equiv.	1.00	−81.0	−15.0	−95.0	−2.6
photochemical oxidation	ton C_2H_2	0.00	−0.06	−0.02	−0.08	−2.7
acidification	ton SO_2 equiv.	0.00	−0.96	−0.29	−1.25	−2.1
eutrophication	ton PO_4 equiv.	0.00	−0.13	−0.01	−0.14	−5.3
freshwater aquatic ecotoxicity	ton 1,4-DB equiv.	0.06	−6.00	−0.40	−6.34	−2.7
marine aquatic ecotoxicity	10^3 ton 1,4-DB equiv.	0.00	−211	−4.00	−215	−2.4
terrestrial ecotoxicity	ton 1,4-DB equiv.	0.00	−0.35	−0.10	−0.45	−1.5

1.3 ENVIRONMENTAL DRAWBACKS OF GREEN ROOFS

By implementing green roofs, total phosphorus concentrations found in the runoff from a green roof do not yield the same amount as the one found in precipitation. According to [4], total phosphorus concentrations in normal flat roof runoff were reported to be lower than the runoff from the green roof. Michael hypothesizes that phosphorus has been leaching from the soil media [4]. Hence, plants must be carefully selected to ensure that they do not require fertilizer, since phosphorus is one of the main nutrients in fertilizer.

2.0 ECONOMICAL ASPECTS

Green roof is a new technology that has gained global acceptance and has the potential to mitigate the complex environmental problems. While it is encouraged to implement green roofs at the local and regional level, installation costs are still unaffordable. The objective of this section of the report is to evaluate installation costs, stormwater fees and energy savings from an economical perspective. A comparison of the conventional roof and the green roof based on the case studies in the University of Michigan in Ann Arbor, Michigan and Washington, DC follows.

2.1 COST-BENEFIT ANALYSIS

Green roof is evaluated by the cost-benefit analysis. This analysis provides information to developers, owners, and designers regarding the cost and the environmental benefits of the green roof technology [5]. The following sections summarize the steps for the cost-benefit analysis at a building scale and at a city scale.

2.1.1 <u>Installation Costs</u>

Environmental benefits will reduce the cost gap between conventional roofs and green roofs. In order to determine the cost gap, we have to obtain the cost, size and the estimated lifetime of the roof. In the case of the University of Michigan, the mean cost of a conventional flat roof was $167 per square meter [5]. As the price of the green roof can vary according to the depth of the roof, the case study in Michigan uses a depth between 5 to 15cm. The mean cost difference is summed to be the cost gap. On the other hand, in Washington, DC, the mean cost of conventional flat roofs is $242 per square meter. Green roofs, after the cost data research, were estimated to have a mean cost of $306 per square meter [6].

2.1.2 Stormwater Fees and Reductions

In the past, the budget for stormwater management is provided through property tax. In the recent years, municipalities have decided to make property owners pay their own stormwater fees (commercial stormwater fee is $279 per acre per quarter). However, if green roofs are installed for stormwater reduction, it is believed that the stormwater fee will be reduced up to 55% [5]. Washington, DC updated its stormwater fee structure on May 1, 2009 to accurately charge according to stormwater generation [6]. The money goes toward maintaining the drains and pipes that channel rainwater away. In the meantime, an incentive program is being developed to reduce the stormwater fee. Stormwater fee can then be reduced to up to 50% after installing the green roof [6].

2.1.3 Energy Savings Valuation

Energy savings are based on reducing the use of electricity and gas consumptions. Different methods are used to simulate the energy flow in buildings. In 2003, the total expenditures for electricity and gas consumption cost at the University of Michigan are estimated to cost $22500 [5]. EnergyPlus v2.0.0 * and a simplified 1-dimensional heat flux equation are both used to account the heat flux through green roofs. The simplified 1-dimensional heat flux equation is shown below:

$$\dot{Q} = h \times A \times \Delta T = \frac{A \times \Delta T}{R}$$

Q = Heat Flux through the roof

A = Area of the roof

Delta T = Temperature Difference

h = Heat Transfer Coefficient

R = inverse of h

However, soil moisture is not considered in the simulation.

Washington, DC used EnergyPlus v3.1.0 as building energy simulator to determine the heat flux through the roof. Four types of buildings with average roof areas ranged from 55, 125, 270 and 1795 meter squared are used as scaling tool to the whole city [6]. Furthermore, savings on direct cooling ventilation losses due to the change in roof surface temperature is calculated by the equation below:

$$Q_{cooling\_saving} = V_{dot\_air} \times Cp_{air} \times (T_{surfaceconv} - T_{surfacegreen})$$

V_{dot_air} = air tightness

Cp_{air} = heat capacity of air

T = temperature

The surfaces on the conventional roofs are assumed to be 10K based on the green roof thermal performance in nine cities. Accordingly, these cooling savings are then translated into electricity savings.

2.2 RESULTS

The cost-benefit analysis weighing the total expected costs against benefits in installation cost stormwater fees and energy savings. The following summarizes the result using net present value (NPV) analysis.

2.2.1 <u>Stormwater Benefits</u>

The assessment in the University of Michigan shows that stormwater fee would cost $340 per year for a 2000 meter squared conventional roof, whereas the installation of the green roof would reduce the stormwater fee to $160 per year [5]. Stormwater fee for commercial buildings in Washington, DC costs $596 per year reduced to $209-298 per year after installing green roofs [6]. The saving is different from the assessment in University of Michigan because of the higher stormwater fee in Washington, DC. Since the stormwater fees are being raised, the benefits may grow accordingly.

2.2.2 <u>Energy Assessment</u>

For the Ann Arbor assessment, the EnergyPlus analysis shows that the green roof would save $710 over the conventional roof. In addition, for the R-value analysis, it shows that the green roof would save $1670 over the conventional roof [5]. In Washington, DC, Washington National Airport is used as the model. Natural gas and electricity consumption of facilities with green roofs are analyzed using EnergyPlus. The consumptions of the green roof compared to the conventional roof in each of the four categorizes are 4.7MWh vs. 1.6MWh for commercial buildings with 1795 meter squared roof area; 0.2MWh vs. 0.3MWh for a residential building with 55 meter squared roof area 0.4MWh vs. 0.6MWh for residential building with 125 meter squared roof area; 0.7MWh vs. 1.2MWh. The above data showed that 2% electricity and 8% gas is saved [6].

2.3 NET PRESENT VALUE ANALYSIS

The net present value (NPV) analysis is used to determine the length of time that is needed for a return on the investment of a building. The NPV in both University of Michigan and Washington, DC are both based on 40 years of lifetime of green roofs with one replacement of the conventional roof. In Clark's article, it is found that the mean green roof upfront cost is 39% higher than the conventional roof ($464000 versus $335000). The NPV is then calculated using estimated energy savings and stormwater fees. The NPV of green roof is found to have average of 20.3% and 25.2% less than the conventional roof over 40 years [5]. Please refer to the table for more information.

Table 3: Net Present Values of Roof Systems under Various Benefit Scenarios after 40 Years Assuming Conventional Roof Replacement at 20 Years [5]

benefit scenario	roof type: conventional	roof type: green	percent change in NPV
R-value; mean stormwater	$613 969	$468 366	23.72
EnergyPlus; mean stormwater	$587 465	$468 366	20.27
R-value; high stormwater	$619 828	$463 944	25.15
EnergyPlus; high stormwater	$593 324	$463 944	21.81
low air valuation; R-value; mean stormwater	$613 969	$443 644	27.74
low air valuation; EnergyPlus; mean stormwater	$587 465	$443 644	24.48
low air valuation; R-value; high stormwater	$619 828	$439 222	29.14
low air valuation; EnergyPlus; high stormwater	$593 324	$439 222	25.97
high air valuation; R-value; mean stormwater	$613 969	$374 611	38.99
high air valuation; EnergyPlus; mean stormwater	$587 645	$374 611	36.25
high air valuation; R-value; high stormwater	$619 828	$370 190	40.28
high air valuation; EnergyPlus; high stormwater	$593 324	$370 190	37.61

Figure 2 shows the NPV from the beginning when the green roof is built to t year over the lifetime of the green roof system

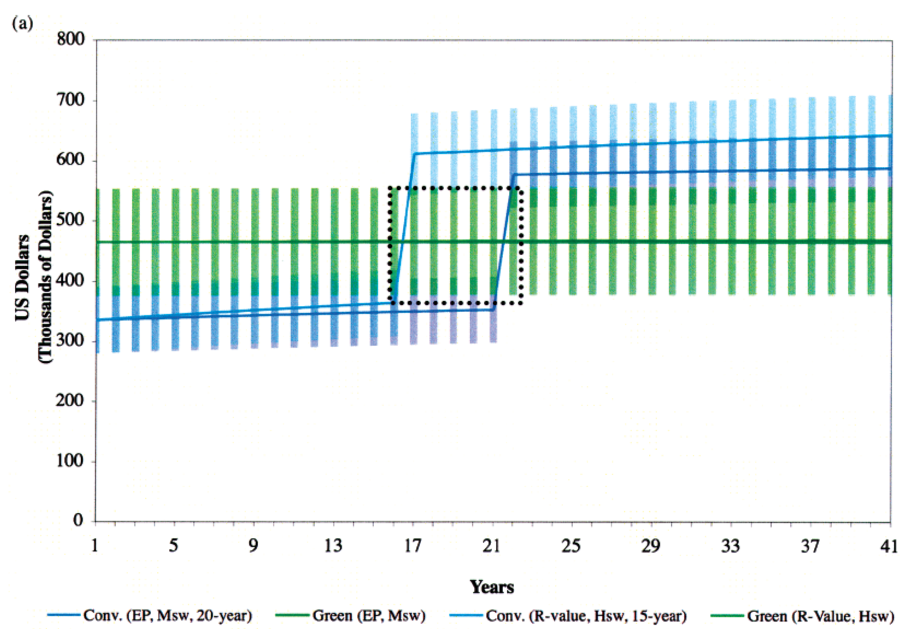

Figure 2: Net Present Value from 0 to year t over 40 years of lifetime consider green roof valuation stormwater fee and energy savings [5]

3.0 SOCIAL ASPECTS

The social impact of green roofs is an important aspect to consider because it is closely tied with students and universities. The social aspect of the triple bottom analysis is divided into three parts: impacts on the production, impacts on the users and impacts on the university. While research can be done on production and university impacts, limited information was available for the impact on student life. Therefore, a survey was conducted to students at UBC to obtain primary information.

3.1 THE PRODUCTION OF THE GREEN ROOFS

Green roofs use a lot of material and vegetation that are acquired locally, and human labor is needed for the construction of the roofs. Sweatshop labor is unheard of in Canada due to strict rules and regulations. In fact, installing green roofs pays well for a job that does not require a college education; according to [7], the median pay rate for roofers in 2010 is $17.98 CAD per hour. When constructing green roofs, most of the soil and clay are acquired locally. In terms of maintenance, the amount of care needed varies depending on the category of the green roof. Intensive green roofs such as roof gardens are labor intensive as opposed to extensive roofs, which only need annual checkups [8].

The popularity of green roofs has been steadily increasing over the years. For example, 10% of the roofs in Germany have been “greened” [9]. Also, the city of Toronto has implemented a new rule to add green roofs for new property developments. As the demand for green roofs increases, the market will not only need more green roof components, installers, and landscapers, but also experts in the field of structural engineering and architecture. The City of Toronto anticipates that the wide adoption of green roofs will positively impact economic activity and investment, and create new jobs [10].

3.2 THE USERS OF GREEN ROOFS

3.2.1 <u>Student Benefits</u>

It has been proven that the well-being of individuals can be enhanced by interactions with nature as well as spending time in green spaces. Especially in university settings where students are often stressed, psychological studies have shown that the restorative effect of a natural view holds the viewers' attention, diverts their awareness away from themselves and their anxiety thereby improving health [11]. In order to obtain more information, a survey was randomly given to thirty UBC students. Results show that 87.5% of the students support the addition of green roofs for the new SUB and the remaining students did not know what green roofs were. To find out the reasoning behind the popular support of adding a green roof, the survey followed up with more questions regarding student benefits. Many students requested that benches and tables should be added to promote social interactions and some went further and suggested a café or a lounge. Clearly, the interest in creating space for recreational purposes is a major reason behind the support of green roofs. The majority of the students (70%) supported implementing the green roof in order to make the new SUB sustainable. In addition, 90% felt a sense of school pride because the university takes initiative by implementing a greener solution that leaves a smaller footprint on the environment. Also, implementing green roofs may help to improve UBC's standing in university rankings. As a result, companies may be more interested in hiring UBC students.

3.2.2 <u>University Benefits</u>

Constructing green roofs according to LEED standards can add the LEED certification, showing the amount of effort the university puts into sustainable buildings. UBC can retain the reputation of "the most sustainable student union building", getting a lot of media exposure to the world. Also it can help raise awareness and promote sustainability. Ultimately, it will promote the ranking of the university. As the demand for green roofs increases, more structural engineers will be needed. UBC can utilize the green roof as part of a case study – currently being done at McMaster University. Students will also feel that sustainability is actually being put in practice instead of simply being learned in class, which helps stir an interest in related subjects.

The university can use the additional space for school fairs, conferences and social gatherings. Rooftops should be seen as an under-utilized asset. From the survey conducted, 90% of students would like to participate in social events hosted on the rooftop. Living roofs can provide a recreational resource. For example, the Michael Hill Golf Course green roof provides significant visual aesthetics. Recreational green spaces have been provided on living roofs all over the world, such as the Jubilee Gardens in Canary Wharf Station in London, UK.

In addition, students were very interested in the idea of an organic vegetable garden. It would be beneficial to the UBC FARM to take part in the program because it would be a lot closer to where students are. Given that at-grade land in urban centers is considered far too scarce for community gardens and food production, roofs are a logical location for urban agriculture. Urban food production reduces the uncertainty associated with long-distance food supply, including supply interruptions [12]. However, concerns were raised that it would not be productive because the roof would not be big enough. Instead of being a productive vegetable garden, it can be a symbol for sustainability and can be used for educational purposes. Interpretive signs should be placed at each separate ecosystem plot, to educate green roof visitors. For many students who grew up in urban settings and cities, being able to learn about organic vegetable gardens first hand is very remarkable.

4.0 CONCLUSION

As sustainable development has been an important phenomenon in contemporary designs, more research is required to effectively implement green technology. Water management is a significant factor of building developments. Green roofs can provide a sustainable solution to deal with this problem. This green technology has been proven to have positive environmental, economical and social impacts. Based on the findings, green roofs can reduce surface runoff and energy consumption making the building more sustainable. Economically, having green roofs increases the initial cost of the roof; however, the long run cost is less due to the energy conservation. This decrease overcomes the financial constraint of implementing green roofs. Socially, green roofs create a green recreational space for students. As the AMS is aiming to be LEED certified in the design of the new SUB, implementing green roofs in can add LEED points. Clearly, green roofs can provide an improvement to a more sustainable, environmentally friendly and green building. Therefore, it is highly recommended that the AMS implements green roofs in the design of the new SUB.

References

[1] A. Niachou, A. Tsangrassoulis, G. Mihalakakou, K. Papakonstantinou, and M. Santamouris, “Analysis of the green roof thermal properties and investigation of its energy performance,” Science Direct, vol.33, no. 7, Sept. 2001, pp. 719-729.

[2] A.R. Ennos, J.F. Handley, S. Pauleit, and S.E. Gill, “Adapting Cities for Climate Change: The Role of the Green Infrastructure,” Alexandrine Press, vol. 33, no. 1, Mar. 2007, pp. 115-133.

[3] B. Bass, C. Kennedy, K. Pressnail, and S. Saiz, “Comparative Life Cycle Assessment of Standard and Green Roofs,” Environmental Science and Technology, vol. 40, no.13, May 2006, pp. 4312-4316.

[4] M.E. Dietz, “Low Impact Development Practices: A Review of Current Research and Recommendations for Future Directions,” Springerlink, vol. 186, no. 1-4, pp.351-363.

[5] Corrie Clark (2008). Green Roof Valuation: A Probabilistic Economic Analysis of Environmental Benefits. Environmental Science and Technology, v 42, n 6, p.2155-2161 http://pubs.acs.org/doi/abs/10.1021/es0706652

[6] Hao Niu (2010). Scaling of Economic Benefits from Green Roof Implementation in Washington, DC. Environmental Science and Technology, v 44, n 11, p.4302-4308. http://pubs.acs.org/doi/abs/10.1021/es902456x

[7] U.S. Bureau of Labor Statistics, “OCCUPATIONAL EMPLOYMENT AND WAGES”, (May 2009), Available at: http://www.bls.gov/news.release/pdf/ocwage.pdf

[8] Liu, K.K.Y., B. Baskaran, “Thermal performance of green roofs through field evaluation”, NRC CNRC, (May 2003), Available at: www.nrc-cnrc.gc.ca/obj/irc/doc/pubs/nrcc46412/nrcc46412.pdf

[9] Getter, K.L. and D.B.Rowe Greening Rooftops for Sustainable Communities, Atlanta, GA. 3-5 June 2009. The Cardinal Group, Toronto.

[10] Gutteridge, 2003; Green Roofs for Healthy Cities, 2004; The City of Toronto, 2004

[11] "Green Roofs Benefits," [Online document], 2009 Aug 12, [cited 2010 Oct 19], Available HTTP: http://www.greenroofs.org/index.ph/about-green-roofs/green-roof-benefits#social

[12] "Green Roofs Tree of Knowledge," [online article], [cited 2010 Oct.25], Available at: http://www.greenroofs.org/grtok/sbp_inter.php