Uncovering the Potential of the Urban Roofscape:
A Life Cycle Assessment-Based Method for Exploiting Flat Roof Areas in Canadian Cities

Flat Roofs as 'Multifunctional Surfaces'

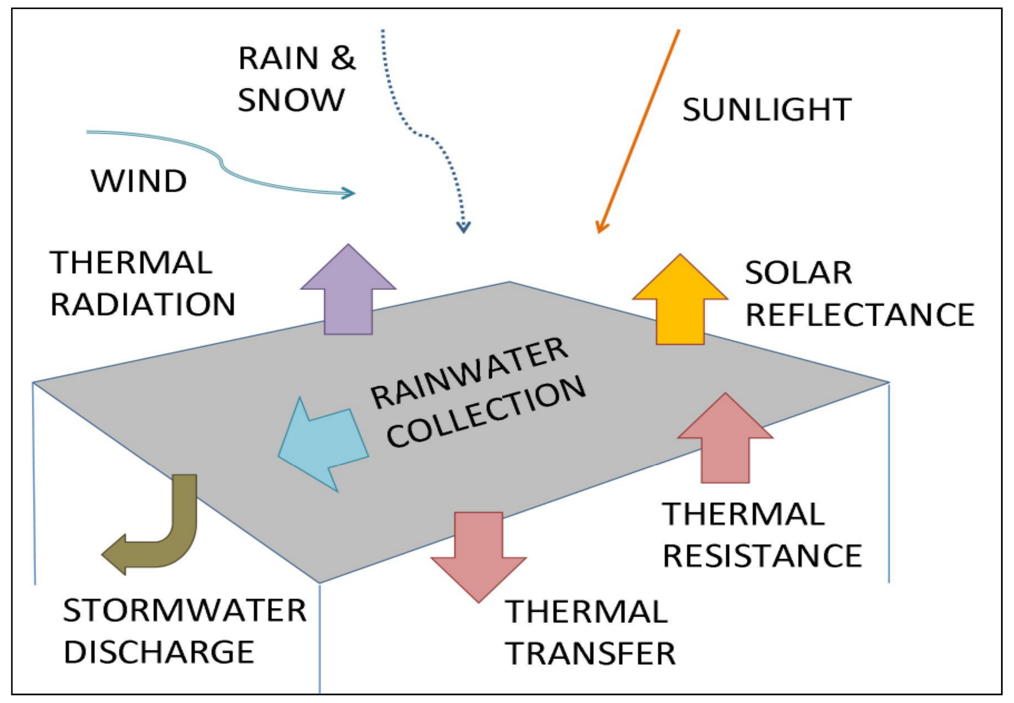

Figure 1 Primary Flat Roof Functions
source: the author

Conventional Functions

Figure 2 Typical Rooftop Equipment
source: flatroofer.net

Figure 3 Roof Terrace, New York
source: trendir.com

Potential 'Green' Functions

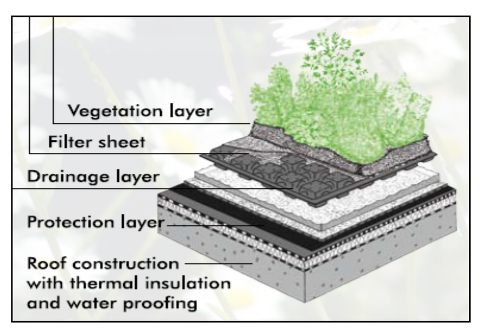

Figure 4 Extensive Vegetated Roof
source: igra.com

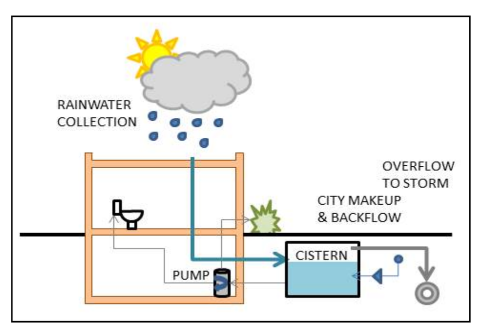

Figure 5 Rainwater Collection
source: the author

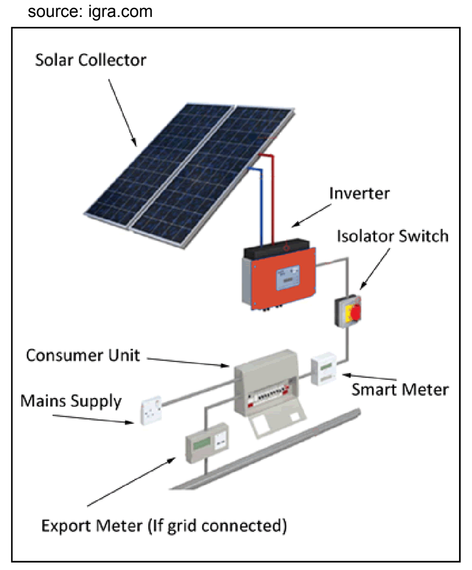

Figure 6 Photovoltaic System
source: ufw.co.uk

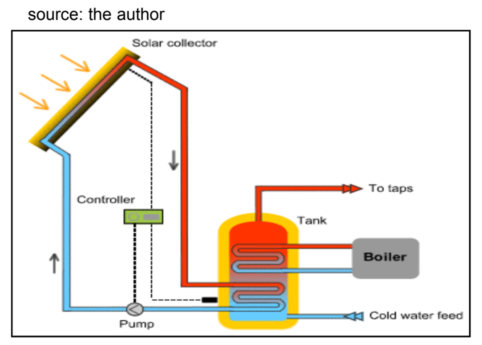

Figure 7 Solar Thermal System
source: stephhicks68.hubpages.com

Flat Roof Functions

Flat roofs perform a variety of functions with a wide range of impacts for both buildings and their urban context. As illustrated in Figure 1, these include primary services of providing protection of the building interior from precipitation, insulation from outside temperature fluctuations, and shading from sunlight. Resulting impacts of these functions include rapid stormwater discharge, thermal transfer of solar energy into the building, a well as radiative heating of the urban environment, known has the 'urban heat island' effect.

Flat roofs can also serve a variety of other functions in addition to provision of basic shelter. Most commonly, they offer an expedient location for mechanical ventilation and exhaust systems. More elegantly, flat roofs can provide accessible terrace areas offering sunlight and views for otherwise congested building sites. Some examples of these functions are illustrated in Figures 2 and 3.

Over the last decade, a number of innovative systems have emerged for utilizing roof surfaces to improve the environmental and energy performance of buildings. As illustrated in Figures 4-7, these 'green' measures include vegetated roofing, roof-mounted photovoltaic power generation systems, roof-mounted solar thermal water heating systems, and rainwater harvesting systems.

These systems introduce a variety of complex interactions with the building and its surroundings. As well, while they can be used in combination, they are not necessarily compatible with one another. For instance, solar collection panels can shade vegetation and affect its viability. Also, vegetated roofs can cause siltation of rainwater harvesting systems, damaging equipment and fixtures.

Measuring Benefits of Alternative Measures

Considerable research attention has been paid to the evaluation of vegetated roofs on buildings, leading to the identification of a number of potential benefits. Most studies concentrate on a specific attribute of vegetated roofs, such as rainwater retention or energy savings, in comparison to conventional built-up asphalt roof surfaces. These have demonstrated an overall net benefit associated with vegetated roofs, in terms of impacts on such indicators as natural resource depletion, primary energy consumption, global warming, air quality, and water quality. Of course, such benefits are meaningful only to those who are concerned with improving these indicators as part of their goals for a particular project. Likewise, it is difficult to equate the relative benefit of impacts from different categories. While primary energy or resource savings may have generally recognized values, the valuation of global warming benefits is a topic of much controversy, as are benefits to air or water quality, because these are incremental improvements to extremely complex global systems.

A limitation common to virtually all recent studies is their failure to compare the benefits from vegetated roofs with other potential 'green' improvements to roof surfaces: including increased insulation performance, membrane coatings, rainwater harvesting, as well as photovoltaic and solar thermal systems. Making such comparisons introduces numerous interdependent variables into the analysis, and therefore what is attempted in this study is the creation of a model in which a variety of scenarios can be entered and evaluated according to measurable outcomes.

A Proposed Integrated Decision-Making Model

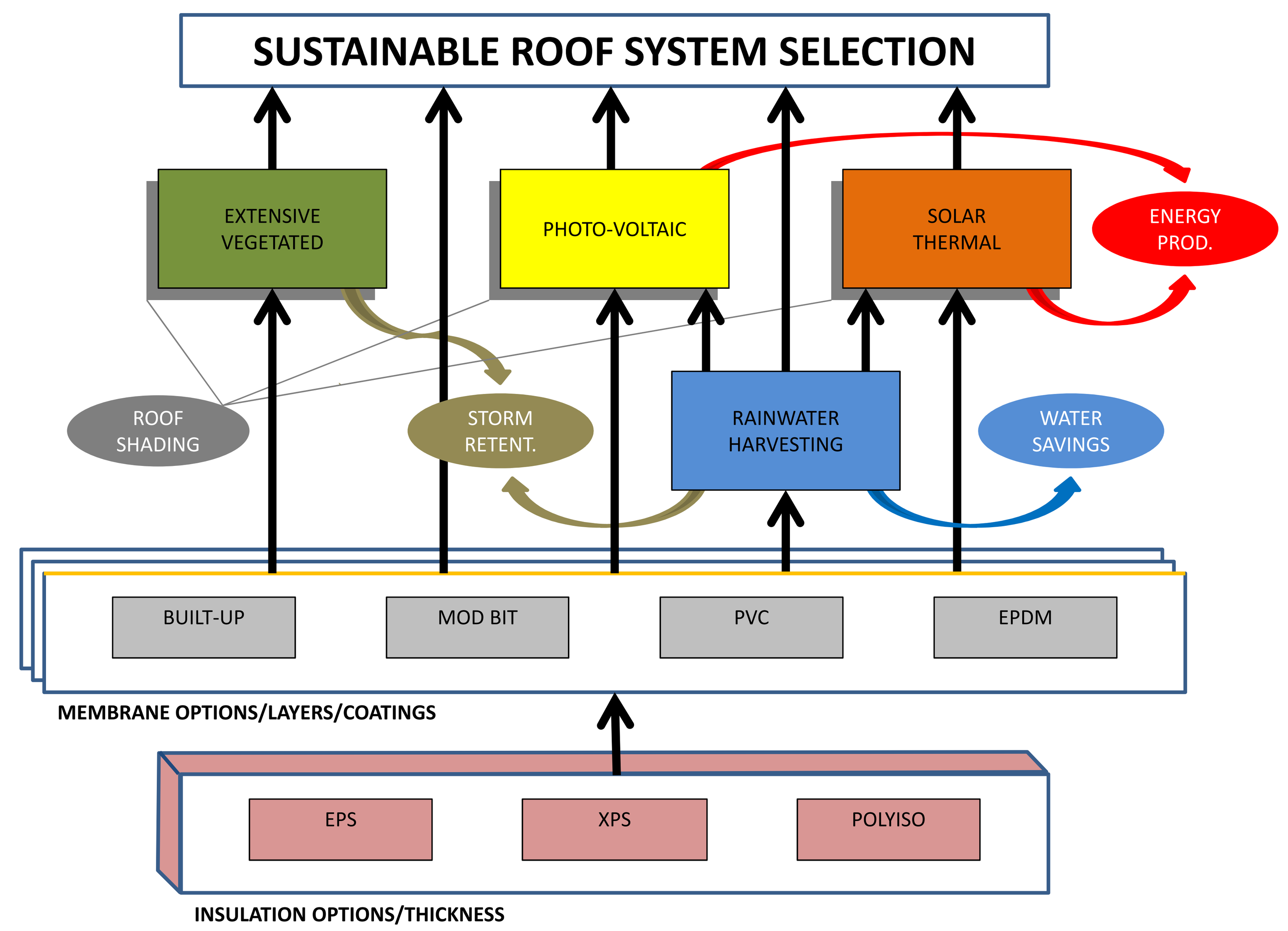

Figure 8 Sustainable Roof System Parameters & Primary Impacts
source: the author

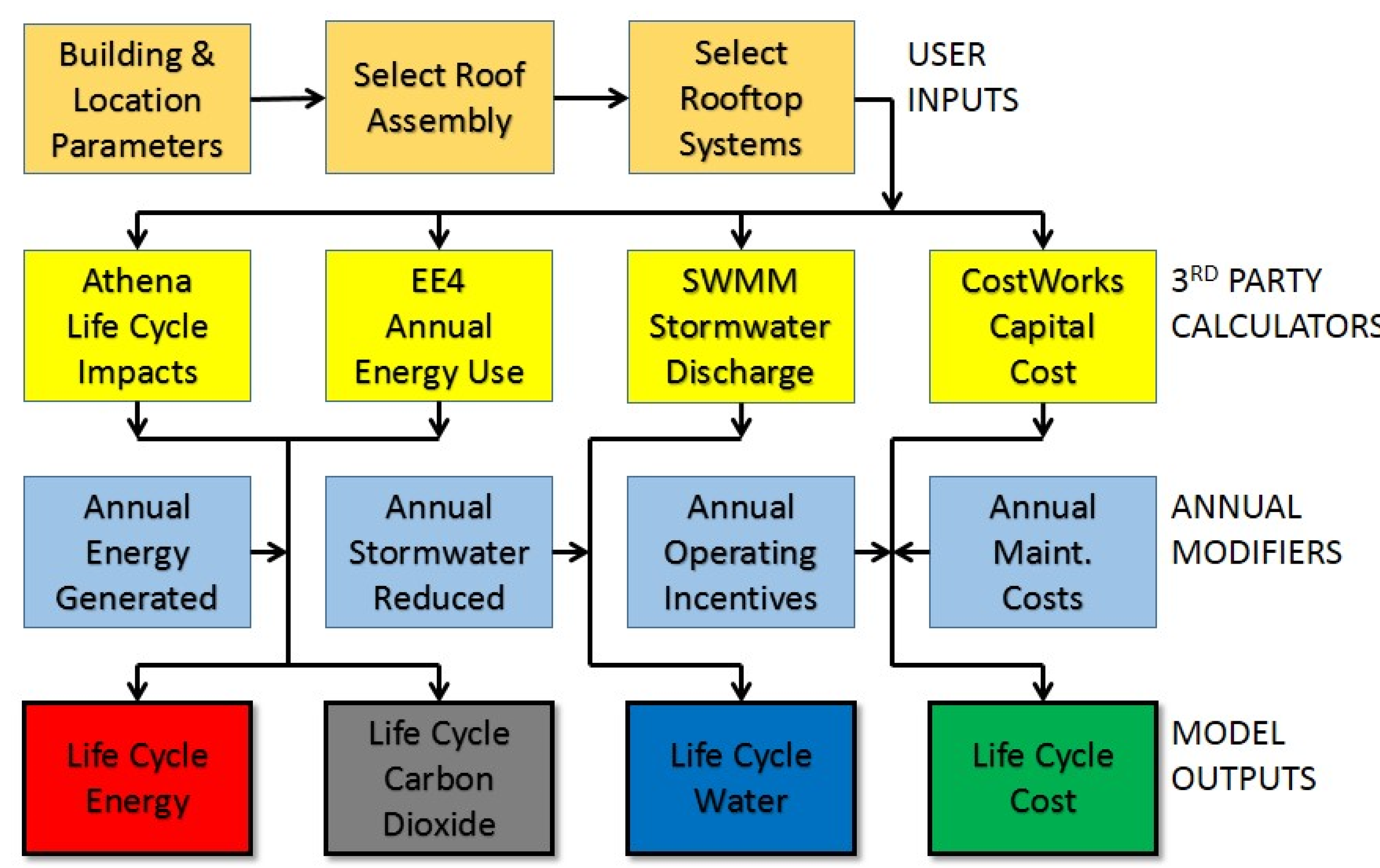

Figure 9 Roof Impact Calculator Flowchart
source: the author

Study Goals and Methodology

Goal of Study

The goal of this study is to develop a decision-making model which building designers and public policy makers can easily use to explore the potential of flat roof areas as a resource in urban settings. The intended outcome is an online tool which will enable a User to select a series of potential flat roof material combinations and 'green' rooftop systems to compare various scenarios based on life cycle energy, CO_2e, and water impacts.

As mentioned, flat roofs perform a variety of primary functions, including thermal insulation, prevention of air and vapour leakage, waterproofing, and protection from solar radiation. There are a number of insulation and membrane choices available to perform these functions, and the model incorporates their respective life cycle impacts. Also as indicated, flat roofs collect and rapidly discharge stormwater, and therefore the impacts and benefits of alternative methods of rainwater collection will also be identified. The impacts and benefits for vegetated roofs are able to be addressed using similar parameters. Finally, because flat roofs offer opportunities for both photovoltaic power generation and solar thermal water heating, these systems also form part of the model.

Figure 8 illustrates the proposed model for integrating these parameters, indicating a variety of possible decision pathways depending on the selection of insulation, membrane, and supplementary rooftop systems.

Assessment Methodology

Life cycle impacts for materials, energy, and water use, drawn from authoritative sources, are input as assumptions for the model, which calculates impacts and benefits for a particular combination of roof system elements using Microsoft Excel. Figure 9 outlines the construction of the Impact Calculator, taking User inputs for the building size and location, roof assembly, and rooftop systems and calculating their life cycle impacts through a series of third party calculators. The outputs are modified by factors reflecting the benefits provided by some systems to produce net impacts in terms of energy, CO_2e, water, and total cost. The calculator uses 60 years as the building life span, although this is also User-selectable.

The simulation calculates impacts and benefits based on a series of objective functions for capital cost, maintenance cost, energy, global warming potential, and water resource conservation. To normalize the results, the simulation also allows the User to input relative dollar values for energy, CO2e, and water.

Significance of Results

Flat roots have significant energy, atmospheric carbon, and water impacts for buildings and the cities in which they are located. As well, flat roots have a variety of potentially beneficial uses to generate energy, to contribute to climate change mitigation, as well as to reduce both stormwater flows and potable water use.

In light of the importance of flat roofs in Canadian cities, the potential benefits of alternative strategies, including enhanced insulation, advanced membrane coatings, rainwater harvesting, photovoltaic power generation, and solar thermal water heating, as well as vegetative coverings, deserve comprehensive assessment prior to selecting the optimal combination of systems for a particular building project and its urban context.

Impact Indicators and Sources

Impact Category (units)	Operating Energy				Total Effects			
	BUR	MODBIT	PVC	EPDM	BUR	MODBIT	PVC	EPDM
Fossil Fuel Consumption (MJ)	1.98E+06	1.98E+06	1.98E+06	1.98E+06	3.18E+06	4.04E+06	8.23E+06	3.85E+06
Weighted Resource Use (kg)	6.36E+04	6.36E+04	6.36E+04	6.36E+04	1.31E+05	1.20E+05	2.45E+05	1.14E+05
Global Warming Potential (kg CO2 eq)	1.26E+05	1.26E+05	1.26E+05	1.26E+05	1.59E+05	1.53E+05	3.39E+05	1.72E+05
Acidification Potential (moles of H+ eq)	5.20E+04	5.20E+04	5.20E+04	5.20E+04	6.46E+04	6.88E+04	2.25E+05	7.33E+04
HH Respiratory Eff (kg PM2.5 eq)	2.61E+02	2.61E+02	2.61E+02	2.61E+02	3.17E+02	3.33E+02	6.53E+02	3.57E+02
Eutrophication Potential (kg N eq)	4.24E+00	4.24E+00	4.24E+00	4.24E+00	6.61E+00	8.38E+00	3.18E+01	2.05E+01
Ozone Depletion (kg CFC-11 eq)	4.74E-08	4.74E-08	4.74E-08	4.74E-08	3.92E-07	3.69E-07	9.61E-07	2.46E-04
Smog Potential (kg NOx eq)	5.10E+01	5.10E+01	5.10E+01	5.10E+01	1.69E+02	3.14E+02	8.62E+02	1.44E+02

Table 1 Comparative Membrane LCA Impacts
source: Athena Institute/the author

MONTH	BILLING ENERGY (m^3)	BILLING DEMAND (m^3)	ENERGY CHARGE ($)	FIXED CHARGE ($)	TOTAL CHARGE ($)	VIRTUAL CHARGE ($ / UNIT)	NATURAL GAS CONSUMPTION (MJ)	Electrical Consumption (MJ)
JAN	61,790	144	$15,447	$150	$15,597	$0.252	2,300,952	1298214
FEB	54,339	142	$13,585	$150	$13,735	$0.253	2,023,484	1176282
MAR	48,202	137	$12,050	$150	$12,200	$0.253	1,794,950	1229011.2
APR	30,110	108	$7,528	$150	$7,678	$0.255	1,121,263	1050883.2
MAY	21,750	99	$5,438	$150	$5,588	$0.257	809,942	973983.6
JUN	12,243	68	$3,061	$150	$3,211	$0.262	455,909	918522
JUL	11,391	33	$2,848	$150	$2,998	$0.263	424,165	1020492
AUG	12,076	53	$3,019	$150	$3,169	$0.262	449,687	990651.6
SEP	14,565	88	$3,641	$150	$3,791	$0.260	542,387	889585.2
OCT	26,582	103	$6,645	$150	$6,795	$0.256	989,859	996109.2
NOV	39,278	124	$9,819	$150	$9,969	$0.254	1,462,641	1120284
DEC	55,123	141	$13,781	$150	$13,931	$0.253	2,052,697	1271624.4
TOTAL	387,451	144	$96,863	$1,800	$98,663	$0.255	14,427,936	12935642.4

Table 2 Annual Building Energy Use
source: MNECB / the author

Fixtures	Quantity	Uses/occ/day	Flow rate	Total (l)
Toilets	7f	3	4.2	1348
	2m	1	4.2	449
Urinals	3m	2	1.9	407
Total water requirement per day				2204
Total collectable roof area				3000
Average annual rainfall (cm)				82
Collectable rainwater (less 20% for losses)				1,968,000
Total water requirement per year				573,040
Days of drought protection				7
Capacity required including drought protection				15,428

Table 3 Rainwater Cistern Calculator
source: rainwaterharvesting.ca.uk / the author

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WATERLOO
ENVIRONMENT

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