KTH Architecture and
the Built Environment

Green Skyscraper: Integration of Plants into Skyscrapers

Shahrina Afrin

Degree Project SoM EX 2009-35

Stockholm 2009

KTH, Department of Urban Planning and Environment

Division of Urban and Regional Studies

Kungliga Tekniska högskolan

www.infra.kth.se/sb/sp

Green Skyscraper: Integration of Plants into Skyscrapers

Master's Thesis By

Shahrina Afrin

Approved as to style and content by:

____

Peter Brokking
Researcher and Head teacher, Urban Infrastructure
Director of Studies Dept of Urban Planning and Environment
Supervisor of the Thesis Committee

____

Dr. Tigran Haas
Assistant Professor of Urban Planning and Design
Director of Urban Planning & Design Program
Examiner of the Thesis Committee

Major Subject
Environmental Engineering and Sustainable Infrastructure (EESI)

September, 2009

ABSTRACT

This research has been emphasized on integration of plants in skyscraper design which play a vital role for the energy conservation by the building as well as improving the living quality into these vertical cities. Throughout the thesis work it has been studied to establish the necessity of planting to incorporate into skyscrapers, for the well being of our economy, society and the environment. The rules and regulations in various countries have been studied. The provisions of integrate plants into skyscraper includes the four possible options like, Green roof, Green wall, Biofilter and Indoor potting plants which can be incorporate into the design. Benefits and impacts have been studied in terms of energy savings and indoor environmental qualities. For example green roof can reduce 50% of cooling load; green wall can reduce 10 degree centigrade indoor temperature, where as biofilter and indoor plants purifies indoor air by 50% to 60%. Available technologies for green installments, like complete, modular and vegetated blanket system for green roof; modular, free-standing and cable-rope system for green wall; active and passive system for biofilter and different types of indoor plants have been addressed here along with their examples and case studies. At the end the recommendation shows that integration of plants into skyscrapers can change the micro and macro environment, climate, can restore the ecology and benefited to the economy. Results are the noticeable decrease in urban heat island, rapid reduction of energy consumption and cost, refreshing air for a healthy environment.

Key words: Green Skyscraper, integration of plants, green roof, green wall, biofilter, ecological impact, climate, energy savings, indoor air quality, aesthetics, design technology.

DEDICATION

This thesis is dedicated to my family, specially my Mom and Dad. Without their selfless effort and endless support I would not be where I am right now. Special gratefulness to my Husband for his endurance and continuous inspiration which helped me finish my thesis work abroad. I would also like to dedicate this work to Mohua Aunty, Topon Uncle, Anindo, Anonna and Rosie Aunty, who assisted me a great deal throughout my entire master’s program in Sweden. My gratitude also goes towards my Grandma, my Mother and Father-in-law, my sisters and brother-in-laws for their incessant encouragement in completing this Master’s Degree.

ACKNOWLEDGEMENT

My first and foremost gratitude goes to my supervisor Peter Brokking, researcher and head teacher, Urban Infrastructure, Director of Studies, Dept of Urban Planning and Environment, KTH- Royal Institute of Technology, whose help, suggestions and constructive criticism brought me up to this far. I am grateful to him for letting me work on my thesis work overseas and deliver his patience and continuous support throughout the period of this research. I am also grateful to my examiner Dr. Tigran Haas, Assistant Professor of Urban Planning and Design, KTH for his helpful suggestions and criticisms.

I would like to thank Mr. Joakim Stureson for his assistance and technical support in the online presentation. Thanks would also go to Ms. Sofia Norlander, Malin Hansen, and Caisa Naeselius, for their help in the administrative works on campus and online.

Gratitude to my friends in KTH, Tawhid Amanullah, Atiq Uz Zaman, Himanshu Sanghani and Jim Loewenstein, for their support and suggestions in numerous ways and other classmates from EESI who have always been there to make Sweden a wonderful experience.

Table of Contents

ABSTRACT iii

DEDICATION iv

ACKNOWLEDGEMENT v

Table of Contents vi

List of Figures xiv

List of Tables xviii

1 Chapter 1: Introduction 1

1.1 Background 1

1.2 Green Skyscraper and its features 2

1.3 Skyscraper 3

1.4 Differences between a Skyscraper and Green Skyscraper 4

1.5 Problem Identification 4

1.6 Specific Aim 5

1.7 Objectives 5

1.8 Rational of the Thesis 5

1.9 Methodology 8

2 Chapter 2: Green Building Rating System 9

2.1 LEED points available for green roof 11

2.2 LEED points available for green walls ... 12

2.3 LEED points available for BioFilter ... 12

2.4 FLL Guideline for Performance rating systems ... 13

2.5 Karlsruhe Performance Rating System ... 14

2.6 Green building rating system in Asia ... 15

2.7 Fields need to be focused ... 16

3 Chapter 3: Provisions of incorporating plants ... 18

3.1 Introduction ... 18

3.2 Green Roofs: Green outer ... 18

3.2.1 Examples of Green Roofing ... 19

3.3 Green Wall: Green outer ... 20

3.3.1 Green Wall Categories ... 20

3.3.2 Examples of Green Wall ... 21

3.4 Biofilters: Green Inner ... 22

3.4.1 Examples of Biofilter ... 22

3.5 Indoor Plants: Green Inner ... 23

3.5.1 Examples of Indoor Plants ... 24

4 Chapter 4: Benefits of Incorporating Green ... 25

4.1 Introduction ... 25

4.2 Potential green roof benefits ... 25

4.2.1 Energy budgets of individual buildings....26
4.2.1.1 Energy Saving Calculation....30
4.2.1.2 Economic Benefit....31
4.2.1.3 Effect of soil moisture content on Energy Savings....33
4.2.1.4 Temperature variation of thin Green roof system....34
4.2.1.5 Reduce HVAC Cooling loads....35
4.2.2 Urban heat island....35
4.2.3 Stormwater management implications....37
4.2.4 Air quality impacts....39
4.2.5 Green amenity space....40
4.2.6 Habitat preservation....41
4.2.7 Property values....41
4.2.8 Sound Insulator....42
4.2.9 Extend Roof Life....43
4.2.10 Derivation of economic benefit from green roofs....43
4.2.10.1 Time period....43
4.2.10.2 Discount rate....43
4.2.10.3 Installation and maintenance costs....44
4.2.10.4 Energy cost savings....44
4.2.10.5 Urban heat island....45
4.2.10.6 Stormwater flow reduction....45
4.2.10.7 Air pollution and greenhouse gas effects....46
4.2.10.8 Aesthetic benefits....46
4.2.10.9 Job creation....47
4.2.11 Cost-benefit ratios and life-cycle cost assessments....47
4.2.12 Green Roof: Fast Facts....47
4.2.13 Green Roof Barriers and Overcomes....48

4.2.13.1 Cost ... 48
4.2.13.2 Repairs ... 49
4.2.13.3 Aesthetic ... 50
4.2.13.4 Lack of Expertise ... 50
4.2.13.5 Lack of Research and Standards ... 50
4.2.14 Ensuring Proper Long-Term Maintenance ... 51

4.3 Potential Green Walls Benefits ... 51

4.3.1 Reduce energy consumption ... 51
4.3.2 Reduce Heat Island Effect ... 52
4.3.3 Reduce Heat Gain ... 52
4.3.4 Sound Insulator ... 53
4.3.5 Prevent Bird kill ... 53
4.3.6 Ecological Preservation and beautification ... 55
4.3.7 Precaution and maintenance for green wall ... 56

4.4 Potential Biofilter Benefit ... 56

4.4.1 Removes Pollutants from Indoor Air ... 57
4.4.2 Reduces HVAC Energy Consumption ... 58
4.4.3 Retrofit Biofilter system ... 58
4.4.4 Provides Dramatic Aesthetic Amenity ... 58
4.4.5 Provides Equivalent Outdoor Air Exchanges ... 59
4.4.6 Adds Oxygen ... 59
4.4.7 Create economic benefit ... 59
4.4.8 Potted plants vs. Biofilters ... 60
4.4.9 Some shortcomings of Biofilter ... 60
4.4.9.1 Generation of noise ... 60

4.4.9.2 Require direct Sunlight 60
4.4.10 Future possibilities 61

4.5 Benefits of Indoor Planting 61

4.5.1 Noise reduction 61
4.5.2 Increase of productivity 61
4.5.3 Reduce sickness absence 62
4.5.4 Improve indoor environment quality 63
4.5.5 Staff pressures / recruitment / retention 63
4.5.6 Government pressure / incentives 64
4.5.7 Other positive impacts of planting 64
4.5.7.1 Alternatives to manufactured/engineered solutions to building problems 64
4.5.7.2 Reducing demand on the water supply 64
4.5.7.3 Cooling 64
4.5.7.4 Improvements in indoor air quality 65
4.5.7.5 Improvements in well-being 65
4.5.8 Some drawbacks 65

4.6 Summary 65

4.6.1 The environmental benefits of green buildings 66
4.6.2 The optimal use of plants 66
4.6.3 Additional way of energy savings 67
4.6.4 Obstacles for integrating plants 67
4.6.5 Differences for building green in the different parts of the world 67

5 Chapter 5: Technologies to incorporate Green into Skyscraper 69

5.1 Green Roof Design Technology 69

5.1.1 Category of Green Roof Design 69
5.1.1.1 Complete systems 70
5.1.1.2 Modular systems 70
5.1.1.3 Pre-cultivated vegetation blankets 71
5.1.2 Extensive verses Intensive green roof design 72
5.1.2.1 According to Construction Options 73
5.1.2.2 Roof Slope 74
5.1.2.3 Cost effectiveness 74
5.1.2.4 Comparison between Intensive and Extensive Green Roof 75
5.1.3 Typical Plants for Living Roofs 75

5.2 Green wall Design Technology 77

5.2.2 Types of green walls 79
5.2.3 Types of green façade support structures 80
5.2.4 Best plant types to use for green walls 81
5.2.5 Negative aspects of green wall 81

5.3 Biofilter design Technology 82

5.3.1 Types of living wall 82
5.3.1.1 Options for making a Living Wall active 83
5.3.2 Alternative to ventilation 83
5.3.3 How Biofilters work 84
5.3.4 Reason of using green plants into Biofilter 84
5.3.5 Capacity of Air Filtration 85
5.3.6 Maintenance 85
5.3.7 Some Drawbacks 86
5.3.3 Typical Plants for Biofilters 86

5.4 Plants of Green Pockets 88

5.4.1 Type of Indoor Plants 89

5.4.1.1 Night time workers 89

5.4.1.2 Plants which raise humidity levels 89

5.4.1.3 Best air cleaning flowering plants 90

5.5 Reluctance of incorporating plants 90

5.6 Regulations for green design 91

5.6.1 Washington State Law 91

5.6.2 Green roof policies in some other countries 92

6 Chapter 6: Case Studies 101

6.1 Ecological-Skyscrapers 101

6.1.1 The EDITT Tower, Singapore 101

6.1.2 Tokyo Nara Tower, Tokyo 102

6.1.3 Chilean Consortia Building, Santiago, Chile 104

6.2 Some other case studies of designed green structure 107

6.2.1 Tennessee Tower, Tennessee: Green Roof Case Study 107

6.2.2 The Pinnacle at Symphony Center: Green Roof Case Study 108

6.2.3 Cambridge City Hall: Green Wall Case Study 109

6.2.4 The Living Wall at Club Monaco: An Urban Biofiltration Case Study 110

6.2.5 The Genzyme Center: Case Study of Indoor Planting 112

7 Chapter 7: Discussion 115

7.1 Introduction 115

7.2 Discussion about the findings 115

7.3 Recommendations ... 117

7.3.1 Vegetation based on Building's location ... 117

7.3.2 Location of deep soil for extensive roof ... 117

7.3.3 Green wall support for skyscrapers ... 118

7.3.4 Design options for green wall in skyscrapers ... 119

7.3.5 Ecological Nexus: Design to make it environmentally viable ... 120

7.3.6 Planting design in built forms for economic, social and environmental benefit ... 122

7.3.7 Green roofs in a greater scale ... 123

7.4 Some policy guidelines ... 123

7.4.1 Educational Benefit of green roof and green wall: A socially viable issue ... 124

7.4.2 Economic Value for building "Green" ... 124

7.4.3. Reducing Ecological Impact for environmental benefit ... 125

7.4.4. Performance Rating Systems ... 126

7.4.5 Other Policy Initiatives and Tools: Competitions and Media Coverage ... 126

7.4.6 Greening of Public Buildings ... 127

7.5 Conclusion ... 127

8 References ... 129

List of Figures

Figure 1: Environmental Reasons an Increasing Factor in Energy Savings Investments. 10

Figure 2: A typical ugly commercial roof that provides no ecological, economic, aesthetic, or psychological benefits. 19

Figure 3: Aerial view of the roof garden atop Chicago City Hall The building is 11 stories tall, 220 feet above street level, and covers 38,000 square feet. (Photo courtesy of Roofscapes, Inc.). 19

Figure 4: An extensive roof covers the garage providing an aesthetically pleasing view for the building occupants. (Courtesy Behrens Systementwicklung GmbH, Germany)...............................19

Figure 5: The Chicago City Hall green roof helps cool the building and minimize water run-off. (Photo courtesy of DOE/NREL I Photographer: Katrin Scholz-Barth). 20

Figure 6: Green roof practice in the skyscrapers in Chicago. Photo Source: Author Self 20

Figure 7: Vertical and verdant, living wall systems sprout on two buildings, in Paris and Vancouver, (photos courtesy by Joann Gonchar) 21

Figure 8: The air smells sweeter at Toronto's Club Monaco after it installed a 40 square foot "living wall." (Valvasori and et al. 1999). 22

Figure 9: NEDLAW Living Wall is front and centre in Cambridge City Hall which received Gold certification from LEED Canada. (Darlington, Alan, 2001)...23

Figure 10: Biofilter placed at the atrium in the Robertson Building. (Darlington and Dixon, 2002). 23

Figure 11: Plants contribute to interior humidity by adding moisture to the air through transpiration and secondarily through evaporation from growing media and drainage dish surfaces. (Jacobs, H., 2008b)...24

Figure 12: Flowers and plants promote innovation and ideas. (Jacobs, H., 2008b). 24

Figure 13: Living Indoor plants improve business. (Jacobs, H., 2008a). 24

Figure 14: Methodology to analyze the impact of cool roofs and cool pavements on energy use. (After Akbari et al. 2001). Source: Ryerson University, Quantitative Findings Oct. 2005, Report on the Environmental Benefits and Costs of Green Roofing. 27

Figure 15: Initial cost saving related to capital costs or an amount of annually recurring cost saving. (Banting, D. et al., 2005). 32

Figure 16: Conceptual drawing of the adiabatic effect- Summer during fair weather and mid-day. (Yamada, H., 2008)......34

Figure 17: Temperature variation of the green roof system in dry and moist condition. (Yamada, H., 2008)......34

Figure 18: Living roof reduce the cooling load. Truett, Rick. (2003) 35

Figure 19: Generalized cross-section of a typical urban heat island. (www.epa.gov). 36

Figure 20: Relationship between the peak flow and runoff on green roof (After Jennings et al., 2003) 38

Figure 21: Living roof lower the discharge of rainwater (Truett, 2003a) 46

Figure 22: Temperature distribution of West wall with and without Boston Ivy. (Yamada, 2008). ..51

Figure 23: Reduce heat island effect. (Yamada, H., 2008)......52

Figure 24: Temperature variations of Green walls. (Yamada, H., 2008). 53

Figure 25: Living wall worked as a 'Shell', help prevent sound pollution. (Jacobs, 2008a)......53

Figure 26: While the photographer was watching this building an American Crow ran into it at about the 15th story. The flat glass mirrors the moving clouds perfectly......54

Figure 27: The reflection of sky is so strong here that the window washers reported birds flying into the buildings all day long......54

Figure 28: Habitat reflected in untreated reflective glass is an extreme hazard for flying birds. Green wall would make the building bird-friendly. Photo: FLAP 54

Figure 29: The collision zone of migrating birds in urban areas. (Klem, Daniel, and et al., 2007). ...54

Figure 30: Vegetated Green wall will reduce the reflecting glass surface. (Klem, Daniel, 1990)......55

Figure 31: Recorded Health Improvements after the introduction of Interior Plants. (Fjeld et al. 1998). 62

Figure 32: A typical Sopranature green roof assembly on conventional roof. (Banting, D. et al., 2005). 70

Figure 34: Green roof block system. (Adapted from St. Louis Metalworks Company). 71

Figure 33: Green Grid system. (Adapted from Western Solution Inc.). 71

Figure 35: Photograph showing ELT system. (Adapted from Elevated Landscape Technologies) . 71

Figure 36: Xero Flor System installation and cross section. (Adapted from Xero Flor Canada)........ 72

Figure 37: Intensive green roof 72

Figure 38: Extensive green roof 72

Figure 39: Intensive green roof 72

Figure 40: Extensive green roof 72

Figure 42: Modular 73

Figure 41: In-Situ 73

Figure 44: Sloped Roof 74

Figure 43: Flat Roof 74

Figure 45: Proprietary 74

Figure 46: Non-Proprietary 74

Figure 47: Typical Plants for Living Roofs 77

Figure 48: "Standoff" brackets for Green wall 78

Figure 49: Mounting Clips for Green wall 78

Figure 50: Green Wall Structural Panel 79

Figure 51: Biofiltration System. (Darlington, A., 2008) 84

Figure 52: Biofilter Systems can be designed for most any need, from small residential to large commercial applications. Source: Furbish Company, Sustainable Building. 84

Figure 53: Typical Plants for Biofilters 88

Figure 54: EDITT Tower, Singapore, example of an 'Ecological Skyscraper. The Planting concept and rain water collection and recycling process. Source: Yeang, 2006........ 102

Figure 55: Tokyo Nara Tower, Tokyo. Plant integration with the spiral structure of the tower..... 103

Figure 56: Colorful facade at autumn 105

Figure 57: Green facade at summer 105

Figure 58: Concept drawing for the green façade. (Pastorelli, 2009). 105

Figure 59: Detail Vertical Section. (Pastorelli, 2009). 106

Figure 60: Walking isle between the glass facade and green shell. (Pastorelli, 2009)....................106

Figure 61: Tennessee Tower Green roof Design....................................107

Figure 63: The Pinnacle Green Roof Plan 108

Figure 64: Green Wall, Cambridge City Hall¸ Ontario (Source: Fegan, Linda, 2009). 110

Figure 65: The air smells sweeter at Toronto's Club Monaco after it installed a 40 square foot "living wall." (Valvasori and et al. 1999). 112

Figure 66: Indoor Planting in Genzyme Center. (Fjeld, T., et al., 1998)....................................113

Figure 68: Mound for large plants for rooftop planting. Wong, Nyuk Hien and et al., (2002). 118

Figure 67: Deep Soil over Structural columns. 118

Figure 70: Green wall installation details in the skyscraper. 118

Figure 69: Proposal for green wall installation in the skyscraper. 118

Figure 71: Sectional detail for vegetated curtain wall. 119

Figure 72: Variations of green wall design. (Source: Yeang 2006) 120

Figure 73: Landscape bridge connection for fragmented green areas 120

Figure 76: Designing plants and non-human biomass into built system. Source: Yeang, 2006......121

Figure 75: Continuous vertical landscaping. Source: Yeang, 2006....................................121

Figure 74: Continuously integrated planting zone from ground to roof....................................121

Figure 77: Green Skyscraper: Integrated planting design. 122

Figure 78: Green Roof, sky courts and green walls create new urban habitats, and restore the previous one 123

List of Tables

Table 1: Green roof requirements in selected European jurisdictions. (Banting, D. et al., 2005) 15

Table 2: Summary of key findings from literature review related to heat transfer, energy use and green roofs. 28

Table 3: Energy Saving Calculation. (Yamada, H. 2008). 30

Table 4: Average savings in air conditioning usage (Yamada, H. 2008). 31

Table 5: Cost Savings Initially and Annually. (Banting, D. et al., 2005). 32

Table 6: Hydrolic retention for the WCC green roof in Goldsboro, April 2003. (After Jennings et al., 2003). 38

Table 7: Summary of key findings from literature review related to the air quality and green roofs. (After Jennings et al. 2003) 42

Table 8: summarizes the potential savings in energy use in buildings resulting from the implementation of green roofs. 45

Table 9: Comparison of Extensive and Intensive Green Roof System. 75

Table 10: Excerpt from the Wastewater Fee Bylaw of 14.12.2003. Source: Stadt Köln (2003)........96

Table 11: Weighting factors. Source: SenStadtUm (2004b) 99

1 Chapter 1: Introduction

1.1 Background

In the years after the 2nd World War, in many places in Europe there was a shift in public attitude to the construction of skyscrapers. With the Torre Pirelli in Milan and the Thyssenhaus design in Dusseldrof an early form of European skyscraper. The construction of John Hancock Center in Chicago in 1969 marked a new phase in the evaluation of the skyscraper in United States. Although the super tall skyscrapers used revolutionary features in their construction methods and attracted worldwide attention with the record for tallest buildings they set, nevertheless in terms of their aesthetics they provided little that the public could identify with. Moreover their connection with their urban surroundings was generally not carefully conceived (Lepik, Andres, 2004). The cuboid structures, which dominated at 1970s with flat reflective mirrors like glass skin, often provided large internal public spaces in glazed atriums but externally they looked like glass boxes with no real connection to their urban settings. For example, United Nations Plaza in New York (1976), the John Hancock Center in Boston (1976) by Pei Cobb Freed & Partners, IDS Center in Minneapolis by Johnson & Burgee Architects (1973).

Skyscrapers, by definition are not primarily ecological. The construction and running of these tall buildings can only be achieved at the cost of an extraordinary input of primary energies and raw materials (Powell, Robert, 1999). They will ensure highly efficient use of spatial resources if provided with high density of quality workstations and good connections to public transport system. But the oil crisis in late 1970s prompted a reevaluation of ways to improving the use of energy in the running of skyscraper, in our densely cities. Norman Foster, for the design of Hongkong and Shanghai Bank give some important solutions by cooling the building with sea water which is also used to flush the toilets, thus significantly reduces the consumption of pure drinking water. The use of natural light in the interiors has been improved to create better quality workstations (Lepik, Andres, 2004). Thus skyscrapers today deserve more emphasis for its impact on environment. The reestablishment of "green" that was eliminated by its construction can be a possibility to refurbishment the nature as well as improve the quality of living into it.

The theory of 'Green' Skyscraper has been notably shaped by the writing of Ken Yeang. He proposes, in his theories, the interconnecting measures regarding the use of energy, water and light. He further relates these to green plants, local climate, and ecology to the spatial conditions and the functions of the building (Lepik, Andres, 2004). Thus the planning and design of skyscraper influenced by a complex series of demands, where green plants can play a vital role for the energy conservation by the building as well as improving the living quality into these vertical cities. The Minara Mesiniaga in Malaysia (1992) is such practical example of an ecological tall building.

1.2 Green Skyscraper and its features

Green Skyscraper refers to both the practice and product of creating tall buildings which are better for our health, environment and economy. It will be environmentally responsible and resource-efficient throughout its life-cycle, as well as a sustainable and high performance building for economy, utility, durability, and comfort (EPA). Definitions of green skyscraper vary but the green movement has three main goals (Rachael, 2005):

- Ensure a healthy, productive indoor environment for occupants to work and live.
- Prevent negative impacts to our environment and improve its health.
- Reducing operating cost and increase profitability for building owners through energy and resource conservation.

Green Features: Through an integrated design approach which considers building location and orientation, site preparation, energy and water efficiency, material selection, and indoor environmental quality, green buildings will be part of building healthy, sustainable communities for our future (Rachael, 2005). Green building features include:

- Location near existing services.
- Natural lighting and solar energy.
- Excellent indoor air quality.
- Reduced or recycled_ content building materials.

- Green or vegetated roofs, walls and indoors.

Beside the 'green movement' another typology of practicing green into skyscraper is introduced by Architect Ken Yeang, where the consideration of site's climate and ecology is the main focus for designing a 'Green Skyscraper' also known as 'Bioclimatic Skyscraper'.

Bioclimatic skyscraper: A bioclimatic skyscraper is a tall building whose built form is configured by design, using passive low-energy techniques to relate to the site's climate and meteorological data, resulting in a tall building that is environmentally interactive, low-energy in embodiment and operations, and high-quality in performance (Yeang, K., 1994).

Some other concepts on "Green"

'Bright Green Building': A bright green building is one that is both intelligent and green. It is a building that uses both technology and process to create a facility that is safe, healthy and comfortable and enables productivity and well being for its occupants. It designed, constructed and operated with minimum impact on the environment with emphasis on conserving resources (Frost & Sullivan, 2008).

By Architect Norman Foster (2001), "A 'green' building will use as little energy as possible and will make the most of the embodied energy required to build it. Ideally a building should create its own energy by burning renewable fuels such as vegetable oil and harvesting solar energy. If possible it should create more energy then it uses so that it can provide energy to other buildings. The building should have a structure that allows for flexibility so that will have a long life". Whereas Architect Ken Yeang (1994), suggest a successful 'green' building will integrates seamlessly with the natural systems in the biosphere, with minimal destructive impact on these systems and maximum positive impacts.

So, A Green Skyscraper is the tall building type which uses low energy for its operation and maintenance, posses a little ecological footprint, designed with considering the ecology and biological climate and provide a comfortable living environment to its users. Thus a skyscraper should be considered as 'green' have little or no negative impact on the environment.

1.3 Skyscraper

The Dutch term for the 'Skyscraper' literally translated refers to a building that 'gently touches the sky'. This is the much more being description of the skyscraper and its physical and visual impact on the skyline (Richards, I., 2001). According to Harris, C. (ED), (2005), 'Skyscraper' means a very tall multistoried building. The term originally applied to buildings of 10 – 20 stories, but now it refers the high-rises of more than 40 – 50 stories. Structurally, skyscrapers consist of a substructure supported by a deep foundation of piles or caissons beneath the ground, an aboveground superstructure of columns and girders, and a curtain wall hung on the structural framework.

1.4 Differences between a Skyscraper and Green Skyscraper

The conventional skyscraper is the pile of floor spaces around or with a core area, staked homogeneously and vertically, one over another, enclosed with glass façade, seeking to optimize net-to-gross area efficiencies (Yeang, 1994). They are generally high energy consuming, polluting, waste producing tall buildings. From their very invention, while made by concrete or steel the design of these tall buildings remains the same, though technology and engineering have become far better and much more sophisticated. On the other hand Green skyscraper is the practice of creating structures and using processes that are environmentally responsible and resource efficient throughout the building's lifecycle from sitting to design, construction, operation, maintenance, renovation and deconstruction. These are the sustainable and high performance buildings.

1.5 Problem Identification

Skyscrapers, though considered as a negative structure over the earth, will remain constructed as the population increased and so their demands. These tall buildings posses a lot of bad affects over our economy, environment and society by their excessive energy consumption, toxic materials using and destroying ecological balance. But as we cannot stop their construction all of a sudden, we need to search for alternative solutions to retrofit these harmful effects. The main problems that these skyscrapers are impacting are as follows:

1. A greater amount of energy consumption for its cooling as the effect of excessive heat gain by its exposed concrete roof, vast glass curtain and concrete wall façade.

2. Poor indoor environment quality for using toxin materials which often emits Volatile Organic Components or VOCs. It also results for air tight situation for the air conditioning purposes.
3. Negative impact on environment as its construction destroys the site’s ecology, flora and fauna. Its highly reflective glass surface often confused the migrating birds with the reflection of sky and trees cause the bird’s death as they try to fly into it.

These are the major problems, need to be addressed and focused to eliminate.

1.6 Specific Aim

To find out the possible ways to integrate plants into skyscrapers and asses how the integration of plants into the skyscraper design can help to reduce the energy use, improve the environment and enhance the living quality.

1.7 Objectives

a. To find out the provisions of integrate plants into the skyscraper design.
b. Analyze their impacts on energy consumption and living environment.
c. Explore the procedures of structuring the different ways of incorporating plants.
d. Suggest some alternative solutions to eliminate the drawbacks and propose some guidelines for good practice to make it viable economically, socially and environmentally.

1.8 Rational of the Thesis

The Green Building movement is gaining strength in many countries. Developers, especially governments and local authorities, often set the trend by commissioning buildings built to recognized ‘green building’ standards. The main motivation in building to such standards is that ‘green buildings’ are much more energy efficient than conventional buildings and consequently, cost less to run. However, there are other factors that motivate developers to adopt ‘green building’ standards, including a desire to enhance their image as responsible corporate citizens or employers, or to increase the lettable income from the buildings (Freeman, Kenneth, 2007). By thinking the economical, environmental and social perspective of tall green buildings or skyscrapers, I think the concept matches with the present time crisis. The twentieth century was a century of skyscrapers. Most likely in the industrialized countries where population has stabilized, the growth will remain limited. On the other hand, in developing countries, they will continue to be built to meet the ever increasing requirements to accommodate larger populations. Many people speculated after the destruction of the World Trade Center in 2001 that it was the end of tall buildings. Such prediction proved to be premature since tall buildings were developed not because of an architect's or owner's whim but by sheer practical necessity with appropriate economic considerations. When the economy of a region is booming, tall buildings will be built as long as the basic conditions are there (Beedle, L. S. et al; 2007). The contemporary lifestyles, limited land and increasing combined pressure of urbanization and population growth of our cities demand a redefinition of our conventional perception of working and living in high-rise structures in the city. Unless these urbanization stops or we find more land to develop, the demand for skyscrapers will increase whether we like it or not. So the importance should be given for the improvement of their quality of living in these skyscrapers, how to convert these glass-concrete pillars into lively, and eco-friendly buildings. High-rises can be considered as a vertical city, where it has its own functionality to live, work and play for its users. If we think of the idea of green skyscraper, we can find this is economically sustainable, as the main concept is to reduce the energy uses. Green concept is necessary for environmental sustainability as it reduces energy consumption, help to prevent the destruction of ecology and energy resources and socially sustainable for providing its users a more comfortable and healthy living and working environment. David Johnston, (2008), president of green building consultancy says, "You're really looking at a tripod of components". For a better human and environmental health, "First, energy efficiency has to be above minimal code requirements for the climate. The second component has to do with improved water and resource efficiency, and the third concerns indoor air quality. If the design doesn't address all three of these issues, then it doesn't be a green building." To incorporate plants into skyscraper design can help to provide partial or total fulfillment of above these conditions, therefore we can tell that plants play a vital role for "Green Architecture".

So, as an environmental Architect, I believe that this sector of Skyscraper need more research. Because a single skyscraper involves a thousand of elements to consider for make it 'green', it is impossible for a single person to cover all of them. But some of them are vital and prominent to consider for a sustainable green skyscraper. The one of them is the energy consumption by its huge vertical surfaces and concrete roof. As most of the modern skyscrapers are covered by transparent or reflective glass surfaces all the four sites, without considering the solar heat catchment direction, they act like a heat trap and produce a massive pressure on air conditioning devices to maintain the indoor air temperature, resulting more electricity consumption and uncomfortable environment. As we know, Plants have the ecological and energy-conservation benefits besides aesthetics; in addition it provides effective response to wind and rain. Planting can shade the internal spaces and the external wall of the built form to minimize external heat reflection and glare into the building, Plant evapo-transpiration process can be effective cooling device on the built form's façade besides creating a healthier microclimate, affecting the façade's microclimate by generation oxygen and the absorption of carbon dioxide. Studies have shown that 150 square meters of plant surface area can produce enough oxygen for one person for 24 hours (Yeang, 2006), which can play role for healthier indoor environment. I, therefore intend to focus this area in my thesis, to analyze the benefits of integrating plants into the skyscraper design, for helping to reduce the energy use, and enhance living quality for the go-green skyscrapers.

1.9 Methodology

This thesis is based on the existing research from literature reviews, documented analysis and information from website, reports, and case studies. The tranquil data for more valid results are taken from various fact sheets. Some of the figures and tables stated and analyzed here are also taken from secondary sources.

The aim was set for asses the contribution of plants to skyscraper design, as described in chapter one. The objectives were decided to breakdown the process of assessment stated in the 'Aim'. Chapter two describes the Green Building Rating system. There are various organizations in different countries to provide the guidelines for "Green Building" System. The information was collected from the respective Governments' and Organization's web sites. Here the LEED points for green roof, green wall and biofilter design are described. A suggestion for more options is made for improving the guidelines as well. In Chapter three, the possible options for integrating plants in skyscraper design is introduced with examples. Whereas Chapter four emphasizes on the information of the benefits of the options found for plant incorporation. Positive outcomes are analyzed for the process and drawbacks are referred for more research. Than the installation technology of the green roof, green wall, biofilter and indoor planting provisions are presented in Chapter five, with appropriate examples, studies and figures. Chapter six includes the case studies of ecological skyscraper practiced by Architect Ken Yeang, and also the buildings recently designed with green roof, green wall, indoor plants and biofilter, along with the analysis about their contribution on energy consumption, environment and society. The discussion and some extended recommendation with sketches are given in Chapter seven, for skyscraper design to eliminate some of the drawbacks, and to make them appropriate for introducing in skyscraper form. A number of guidelines are also proposed for the best practice and at the end the conclusion is given to state the fulfillment of the requirements of the thesis work.

For the analysis the descriptive process are followed with the help of figures, graphs and tables, to find out the optimum possible ways to incorporating plants and the reason behind to take these options. Same process is followed for benefit analysis. Based on the analysis the recommendations are made for integrating those options into skyscraper design in the aim to make these tall buildings fit into the 'Green movement'.

2 Chapter 2: Green Building Rating System

A rating system or certification tool serves to provide a standard against which buildings with different levels of environmental design and efficiency can be compared. The primary objective of these mechanisms has been to stimulate market demand for buildings with improved environmental performance. An underlying premise is that if the market is provided with improved information and mechanisms, discerning clients can and will provide leadership in environmental responsibility and others will follow suit to remain competitive. Rating systems and labeling programs are considered one of the most potent and effective means to both improve the performance of buildings and transform market expectations and demand (World Green Building Council).

The standards, or rating systems as they have become known, have been developed by a range of different organizations. In the UK, the Building Research Establishment developed BREEAM, the BRE's Environmental Assessment Method in the 1990s, and this has become a model for green building rating systems in many other countries. In the UK, it is estimated that as many as 20% of new office buildings are built to BREEAM standards (Advanced Buildings Newsletter 22, 2000). The American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) is a technical society of engineers and other parties. It conducts research and technical programs and develops standards. ASHRAE has several green building-oriented standards. In North America, the United States Green Building Council (USGBC) is a not-for-profit body set up just to promote the ideals of green architecture. Similar organizations exist in other countries, including Australia (e.g. Australian 'Green Star' system), Comprehensive Assessment System for Building Environmental Efficiency or CASBEE (Japan). Spain, Canada and South Korea and they often work together to develop rating systems appropriate to the different locations (Freeman, K., 2007).

Market dynamics are causing unprecedented interest in energy conservation. The Building owners and Managers Association (BOMA) recently announced its 7 Point Challenge, with a goal of 30% reduction in energy use by 2012 as a key component. ASHRAE and the U.S. Department of Energy announced that they will work together to increase building energy efficiency standards for the year 2010 by 30% over 2004 standards (Dunlop, 2007). The desire for companies and government to be green and promote a reputation of sustainability is increasingly a factor in how investments in energy savings are viewed. While cost savings reasons are still the primary driver for making energy savings investments, environmental reasons are now viewed as equal or greater in nearly half of the companies surveyed as in Figure 1, (Energy Efficiency Indicator Report, 2007).

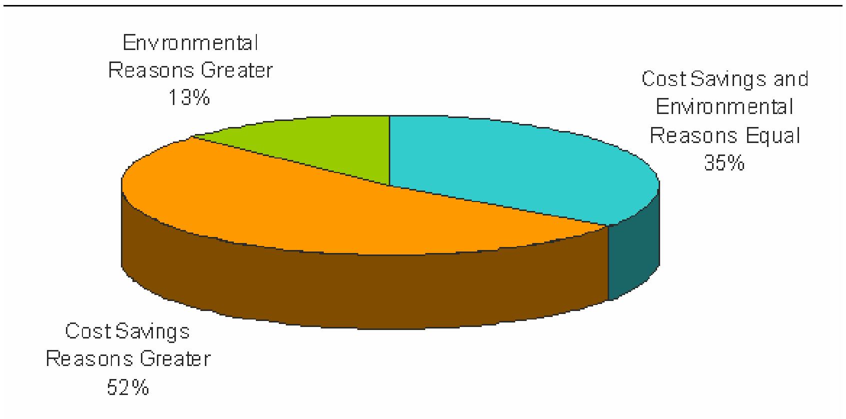


Figure 1: Environmental Reasons an Increasing Factor in Energy Savings Investments.

Environmental Reasons are Increasing Factor in Energy Savings Investments. Nearly half of companies report environmental reasons as equal or greater than cost savings when making investments in energy savings. (Source: Continental Automated Building Association, Energy Efficiency Indicator Report, 2007).

As technology and interest in green buildings has developed, the rating systems have been updated, refined and even expanded to take into account different building types. They have also been expanded to take into account other factors that can only really be considered 'green' in a much broader sense, such as the quality of the work environment that has more to do with good workplace management practice than the conservation of resources and protection of the physical environment. Interior plant displays can contribute to a good green building rating in many ways, not all of which are immediately obvious.

As an example LEED,—an acronym for Leadership in Energy and Environmental Design—is a voluntary, consensus-based national standard for developing high-performance, sustainable ("green") buildings in USA, have points on the Green Establishment in the following way.

2.1 LEED points available for green roof

Living roofs can earn as many as 15 credits under the LEED TM (Leadership in Energy & Environmental Design) system, depending on design and level of integration with other building systems. In some instances, living roofs may not contribute directly to achieving points under the system, but they can earn points when considered as other sustainable building elements such as reduced site disturbance, protected or restored open space, and scape design that reduces urban heat islands and roof space, and/or storm water management (Truett, Rick. 2003a).

2.1.1 Energy and atmosphere:

Energy credit 1 "Optimize energy performance" (2 to 10 pts). Achieve increasing levels of energy performance above the prerequisite standard to reduce environmental impact associated with excessive energy use. Design per ASHRAE/IESNA standard 90.1-1999

2.1.2 Material and Resources:

Material Credit 1 "Building Reuse" (1 to 3 pts). Reuse large portion of existing structures during renovation and redevelopment projects. Because of the long term R-Value and exceptional moisture resistance of T. Clear products, it's often possible to remove the reused Lightguard protected membrane Roof Insulation. The panels are simply set aside while the membrane is repaired or replaced, then the panels are reinstalled to provide the real life-cycle value.

Material Credit 2 "Construction waste management" (2pts). Divert construction debris from landfill disposal by using building products which can be reused in expansion and renovation.

Material Credit 3 "Resource reuse" (2pts). Extend the life cycle of building materials by including material such as lightguard which can be reused when renovating existing buildings instead of having to remove, dispose of and replace components.

2.2 LEED points available for green walls

Green walls can contribute to several LEED credits when used in combination with other sustainable building elements, as explained by Sharp, R., (2007) in Building design and Construction.

Sustainable Sites Credit 7.1: Landscape Design That Reduces Urban Heat Islands, Non-Roof (1 point). Exterior green walls reduce the solar reflectance of a structure, thus reducing the urban heat island effect.

Water Efficiency Credits 1.1, 1.2: Water Efficient Landscaping (1 to 2 points). Buildings can incorporate a stormwater collection system for irrigation of the green walls and other landscape features. Using only captured, recycled, or nonpotable water may enable the project to achieve this credit.

Water Efficiency Credit 2: Innovative Wastewater Technologies (1 point). Green walls can be utilized as wastewater treatment media. Other features, such as the incorporation of compost tea from a composting toilet, is another way for green walls to aid in the reduction of wastewater.

Energy and Atmosphere Credit 1: Optimize Energy Performance (1 to 10 points). Green walls can provide additional insulation and natural cooling, which reduces a building's reliance on mechanical systems.

Innovation in Design Credits 1-4: Innovation in Design (1 to 4 points). Green walls may contribute to innovative wastewater or ventilation systems. (Sharp, R., 2007).

2.3 LEED points available for BioFilter

Biofilters have earned LEED™ innovation credits on a number of projects in which they have been installed. ASHRAE is just beginning to consider the potential benefits of biofilters. As credit is recognized for the air quality improvements delivered by Living Wall biofilters, so additional credit toward LEED points related to air quality and energy reductions will be available (Truett, Rick, 2003b).

2.4 FLL Guideline for Performance rating systems

In Europe performance rating systems have been developed for green roof technology. The rating systems help municipalities stipulate requirements that are tied to various programs related to green roofs on specific projects. They help ensure that the performance goals, which form the basis of municipal support programs, are met and continue to be met. An example of such a system is the one developed by the FLL (FORSCHUNGSGESELLSCHAFT LANDSCHAFTSENTWICKLUNG LANDSCHAFTSBAU E. V. or The Landscaping and Landscape Development Research Society E.V. -FLL, Germany.) in 1998, specifically for the rating of green roofs in land-use planning, building permit approvals, and construction acceptance (Ngan, 2004). Ten base points are assigned for each cm. of depth of green roof available for plant root penetration per sq. m. of green roof coverage. So, a 10 cm design will earn a building 100 (10 points x 10 cm) points per sq. m. coverage of green roof. In order to qualify for these points, the roof construction should meet certain minimum requirements in the following categories:

- water retention capacity of the growing medium;
- water retention capacity of the drainage layer;
- number of plant species for extensive green roofs; and
- Plant biomass or volume for intensive green roofs.

In addition to these above quantitative elements, as Ngan (2004) stated, the FLL system identifies qualitative characteristics according to type of roof construction. These are typically used to judge whether a project is suitable for ecological compensation according to the local conservation requirements. Each natural function parameter is deemed "possible to fulfill completely", "possible to fulfill partially", or "slightly or not possible to fulfill." The qualitative parameters are:

- quality of soil;
- improvement in surface water quality;
- reduction in load of the sewer system;
- improvement in groundwater recharge;
- purification of stormwater;
- filtering of air;
- contribution to oxygen production;
- contribution to urban temperature leveling;

- contribution to establishment of flora and fauna habitat;
- contribution to landscape and urban scenery; and
- contribution to amenity for people / leisure / healing.

2.5 Karlsruhe Performance Rating System

Another example of performance rating is the Karlsruhe Performance Rating System for green roofs (Banting, D. et al., 2005). It rates green roofs according to five natural functions. Each of these functions or categories is assigned a weight based on its importance. The five functions with their weights are as follows:

1. Type and depth of soil used (Soil) – 15%
2. Impact on climate due to evapotranspiration (Climate) – 15%
3. Type and variety of vegetation (Flora) – 30%
4. Impact on zoological biodiversity (Fauna) – 30%
5. Average annual stormwater retention (Water Balance) – 10%

Each type of green roof is assigned a rating in percentage for each of the above five functions. The sum of the weighted rating for each of the five functions is used to compare different green roofing systems and stipulate minimum requirements. In one example an extensive roof with 3-5 cm growing medium is rated at 0.14 on a numerical scale compared to 0.48 for a roof with a 15 cm growing medium. In addition to these examples of specific requirements for green roofs to meet program requirements in specified jurisdictions are provided in Table 1:

Table 1: Green roof requirements in selected European jurisdictions. (Banting, D. et al., 2005)

Name of jurisdiction	Requirements specific to green roofs
North Rhine Westphalia, Germany	Runoff coefficient as tested for specific green roof systems to be less than 0.3 or have a minimum depth penetrable by roots of 15cm.
City of Cologne, Germany	No specific requirements for runoff coefficient or minimum depth. However a stormwater fee discount is applied on a sliding scale, with 90% discount for roofs with a runoff coefficient of 0.1 or less decreasing to a discount of 30% for a runoff coefficient of 0.7. In addition each applicant is required to submit a stormwater infiltration data form providing details of the runoff characteristics of the green roof and the drainage management of the building and the site.
City of Berlin, Germany	Green roofs should meet industry standards such as FLL guidelines
City of Linz, Germany	For underground parking garages, green roofs are to have a root penetrable growing medium of at least 50 cm. with plant coverage of 80% of the designated green roof area. Other parts of new and existing buildings with an area more than 300 sq. m. and slopes of 20° or less are required to have green roofs with a root penetrable growing medium of 12 cm.

2.6 Green building rating system in Asia

GRIHA, in India: The Energy and Resource Institute plays a very important role in developing green building capacities in the country. TERI came up with a rating system called GRIHA which was adopted by the Govt. of India as the National Green Building Rating System for the country. GRIHA aims at ensuring that all kinds of buildings become green buildings. The strengths of GRIHA lie in the fact that it rates even non-air conditioned buildings as green and puts great emphasis on local and traditional construction knowledge. THE CESE building in IIT Kanpur became the first GRIHA rated building in the country and it scored 5 stars, highest in GRIHA under the system. It has become a model for green buildings in the country. It has proved that with little extra investment, tremendous energy and water savings are possible. There are various projects which are the first of their kinds to attempt for green building ratings like apartment residential buildings and non-air conditioned buildings. Measures are being taken to spread awareness about the GRIHA-National Green Building Rating System of India. The Confederation of Indian Industry (CII) plays an active role in promoting sustainability in the Indian construction sector. The CII is the central pillar of the Indian Green Building Council or IGBC. The IGBC has licensed the LEED Green Building Standard from the U.S. Green Building Council and currently is responsible for certifying LEED-New Construction and LEED-Core and Shell buildings in India. All other projects are certified through the U.S. Green Building Council. There are many energy efficient buildings in India, situated in a variety of climatic zones. One of these is RMZ Millenia Park, Chennai, India's largest LEED gold-rated Core & Shell green building. (IGBC, 2007).

GBI in Malaysia: The Standards and Industrial Research Institute of Malaysia (SIRIM) promotes green building techniques. Malaysian architect Ken Yeang is a prominent voice in the area of ecological design. Driven by environmental needs, Green Building Index (GBI) was jointly founded and developed by Pertubuhan Akitek Malaysia (PAM) and the Association of Consulting Engineers Malaysia (ACEM) in 2009. GBI (M) is a profession driven initiative to lead the property industry towards becoming more environment-friendly. From its inception GBI has received the full support of Malaysia's building and property players. It is intended to promote sustainability in the built environment and raise awareness among Developers, Architects, Engineers, Planners, Designers, Contractors and the Public about environmental issues. Malaysia's Green Building Index or GBI(M) will be the only rating tool for the tropical zones other than Singapore Government's GREENMARK. GBI(M) parameters are within the tropical climatic conditions. Its scoring priorities are very much customized for the current state of Malaysia where a lot of priority is given to energy and water efficiency scores. GBI(M) differs markedly from Singapore's GREENMARK thus understandably GBI(M)rating priorities should be like-wise customized to suit – both to Malaysian climate and also the current state of the country's development and existing resources. (Yeang, 2006).

2.7 Fields need to be focused

All the points and guidelines are cited by these organizations are for new construction or for retrofit designs. There are very few regulations available for monitoring the use stage or Life-cycle assessment (LCA) whether theses green installments of the building is properly maintained and fulfilled their requirements over the time period. A precise guideline and strict regulation of monitoring authority should be developed to get the best result. Some points can be allocated for the successful outcome of the purposes of green design after a time period is necessary. Otherwise the focus of green establishment could be emphasized on the point collection from these organizations and not to the shake of real environmental benefit.

There are debates going on for LEED rating system that indicates, in general, life-cycle assessment is not sufficiently addressed in this system. In addition, the system neither successfully addresses functional relevance with regard to materials selection. Finally, as to the environmental relevance of the system, it incorporates environmental impacts associated with building sectors in the sets of criteria, but, the rationale for the weights given to each criterion is not transparent or necessarily consistent with LCA methods. This disconnection between the weight of each rating criterion and the relative importance of the life-cycle environmental impacts associated with it (as estimated by previous LCA studies) remains a flaw in the system. Furthermore, many of the criteria are independently rated by cut-off values lacking an assessment of the tradeoffs between them. As a result, one may find two very different combinations of scores, both leading to a fulfillment of the same certification requirement, while their overall life-cycle environmental impact differs substantially (Smith, T. M. and et al., 2006).

3 Chapter 3: Provisions of incorporating plants

3.1 Introduction

Incorporating Green plants into the skyscrapers has some design possibilities. There are two options for building to make it green. Plants can be integrate at outside and at inside. For outside, it can be done on roofs, outer vertical walls and for inside, it can be a living wall or biofilter, or potted plants placed in atriums, indoor rooms to act as a pocket of green patch into these vertical cities. This thesis covers both the sectors of this aspect to a building design, i.e. green outer and green inner.

3.2 Green Roofs: Green outer

An aerial view of most urban areas shows swathes of asphalt, black tar and gravel-ballasted rooftops. Heat radiates off of the dark roofs, and water rushes over the hard, impermeable surfaces. Studies shows that most traditional dark colored roof surface absorb 70% or more the solar energy striking them, resulting in peak roof temperature of 65-88 degree Centigrade (Yeang, 2006). These heat absorption and monotony of these common roofs can be break though green roof tops. Green rooftops have begun to appeal to homeowners, businesses and even cities as an attractive way to promote environmentalism while solving the problems of conventional roofs. Green roofs supplement traditional vegetation without disrupting urban infrastructure – to take a neglected space and make it useful. The term "green roof" is generally used to represent an innovative yet established approach to urban design that uses living materials to make the urban environment more livable, efficient, and sustainable. Other common terms used to describe this approach are eco roofs, and vegetated roofs. Green Roof Technology (GRT) is the system that is used to implement green roofs on a building (Banting, D. et al., 2005). Green roofs replace the vegetated footprint that was destroyed when the building was constructed. The concept of rooftop gardens is introduced with the aim of reducing heat gain into a building and modifying the ambient conditions through photosynthesis and evapotranspiration of plants. Results from several studies suggest that rooftop gardens can effectively cool down the immediate ambient environment by 1.5 [degrees] C. (Wong, N. H. and et al., 2002). Generally, the surface temperature readings collected from the rooftop garden were found to be lower than that recorded on a barren concrete rooftop. This shows that the thermal insulation of a building is improved in the presence of plants. High relative humidity (RH) at the rooftop garden was also observed due to the presence of plants. To prevent discomfort due to high humidity, adequate natural ventilation should be ensured (Wong, N. H. and et al., 2002). According to Benting (2005), Green roofs are constructed using components that:

- have the strength to bear the added weight;
- seal the roof against penetration by water, water vapour, and roots;
- retain enough moisture for the plants to survive periods of low precipitation, yet are capable of draining excess moisture when required
- provide soil-like substrate material to support the plants;
- maintain a sustainable plant cover, appropriate for the climatic region;
- offer a number of hydrologic, atmospheric, thermal and social benefits for the building, people and the environment;
- protect the underlying components against ultraviolet and thermal degradation (Banting, D. et al., 2005).

3.2.1 Examples of Green Roofing

Figure 2: A typical ugly commercial roof that provides no ecological, economic, aesthetic, or psychological benefits.

Figure 3: Aerial view of the roof garden atop Chicago City Hall The building is 11 stories tall, 220 feet above street level, and covers 38,000 square feet. (Photo courtesy of Roofscapes, Inc.).

Figure 4: An extensive roof covers the garage providing an aesthetically pleasing view for the building occupants. (Courtesy Behrens Systementwicklung GmbH, Germany).

Figure 5: The Chicago City Hall green roof helps cool the building and minimize water run-off. (Photo courtesy of DOE/NREL I Photographer: Katrin Scholz-Barth).

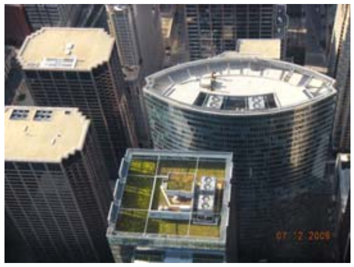


Figure 6: Green roof practice in the skyscrapers in Chicago. Photo Source: Author Self

3.3 Green Wall: Green outer

The green façade is the outer wall which can be free-standing or part of a building, partially or completely covered with vegetation and in some cases, soil or an inorganic growing medium. They are also referred to as living walls, biowalls, or vertical gardens. The vegetation for a green façade is always attached on outside walls, but some cases it can also be used in interiors (Knowles, L., 2005). Green walls are regularly used throughout Europe and Asia, and in Tokyo they are considered more valuable than green roofs for cooling the city. But the vegetated green wall as Sharp R. (2007) said is still new to the U.S. with the exception of ivy-covered buildings whose aggressive, self-clinging plants grow without specially engineered support and are known to damage walls and hinder building maintenance. The green walls being advocated today are designed and engineered with a support structure. Based on current applications and data from the experience of green roofs, green walls can offer considerable cost savings to both the public and private sectors. For example, the reintroduction of vegetation into cities has been correlated with the reduction of the urban heat island effect, and therefore will reduce energy consumption (Sharp R., 2007). Cities are cooler and quieter through shading, evaporative transpiration, and the absorption of sound by green walls.

3.3.1 Green Wall Categories

There are two main categories of green walls: green façades and living walls. Green façades are made up of climbing plants either growing directly on a wall or in specially designed supporting structures. The plant shoot system grows up the side of the building while being rooted to the ground. On the other hand, in a living wall the modular panels are often comprised of polypropylene plastic containers, geotextiles, irrigation systems, a growing medium and vegetation (Sharp R. 2007).

3.3.2 Examples of Green Wall

Patrick Blanc, a French botanist, invented a vertical garden that relies on an innovative way to grow the plant walls without soil. The garden walls are not heavy and can be installed outdoors or indoors and in any climatic environment. For indoors some type of artificial lighting is required, while the watering and fertilization is automated. The walls act as a phonic and thermal isolation system, as well as an air purification device.

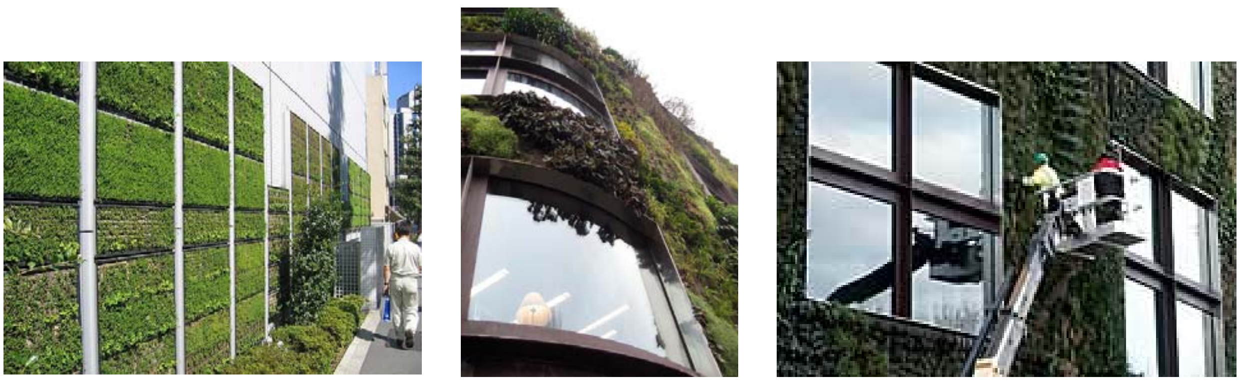


Figure 7: Vertical and verdant, living wall systems sprout on two buildings, in Paris and Vancouver, (photos courtesy by Joann Gonchar)

About 150 plant species are growing at Quai Branly, where the wall is composed of a polyvinyl chloride (PVC) sheet on a metal frame. The sheet serves as a waterproof layer, provides rigidity, and prevents roots from penetrating the drywall-and-stud assembly beyond, says Jean-Luc Gouallec, a botanist and consultant for the wall's designer, of Patrick Blanc. The plants grow in a layer of acrylic felt stapled to the PVC. An automated drip irrigation system supplies water and periodic fertilization. Maintenance, primarily trimming of overgrown plants, is conducted about three times a year, says Gouallec. However, the Aquaquest project uses rainwater collected from the roof and stored in an underground cistern to irrigate the living wall, as well as to flush toilets and refill freshwater fish tanks. Sharp (2007) says he is keen to design a vertical garden as part of a gray-water recycling system that would capitalize on the water's nutrients as fertilizer and cleanse it for further use. The living wall is great for urban areas or dry and arid areas because the garden makes great use of vertical areas, which are abundant in cities, and allows for less evaporation than horizontal gardens (Gonchar,J.,2009).

3.4 Biofilters: Green Inner

There is another type of green wall, known as 'Active living walls' or 'Biofilter', which is used in indoors incorporating with building's HVAC system based upon the sciences of biofiltration and phytoremediation. According to a study done at the University of Waterloo, Knowles, L. et al, (2005) mentioned, "Living walls with biofilters increase the capacity of air filtration". These biofilters replace high-tech, energy consumptive air filtration systems with living walls that harness the natural phytoremediation capabilities by drawing air through the root system of the wall of tropical houseplants to effectively remove common airborne pollutants (Truett, R., 2003b). Beneficial microbes actively degrade the pollutants in the air before returning the new, fresh air back to the building's interior (Knowles, L. et al, 2005). In the breathing wall filtration takes place right in the active Living Wall. Basically, dirty air, drawn in from indoor space, makes close contact with the constantly-flowing water within the wall, pollutants are moved from air to water. Water flows over a lava rock wall covered by moss and other plants, then into a small pond. Contaminants in the air are absorbed by the vegetation and consumed by micro-organisms in the soil, improving air quality. Once dissolved into the water, pollutants are attacked by biological components on the wall itself, and are metabolized into a harmless state. Any excess waste is carried to the pond, where it is eaten by fish, frogs or insects. "Everything acts as a filter," explains Amelung, the Toronto biologist, studies conducted by Guelph University confirm the biofilter's success.

3.4.1 Examples of Biofilter

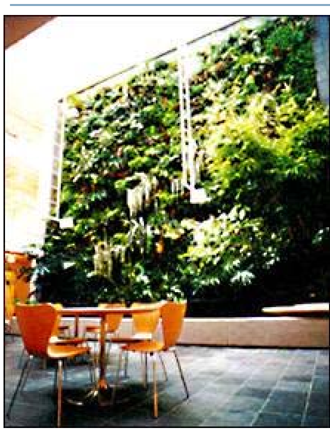


Figure 8: The air smells sweeter at Toronto's Club Monaco after it installed a 40 square foot "living wall." (Valvasori and et al. 1999).

Figure 9: NEDLAW Living Wall is front and centre in Cambridge City Hall which received Gold certification from LEED Canada. (Darlington, Alan, 2001).

Figure 10: Biofilter placed at the atrium in the Robertson Building. (Darlington and Dixon, 2002).

3.5 Indoor Plants: Green Inner

Interior landscaping has become increasingly popular during the last 30 years. Most architects now include plants in their design specification for new shopping centres, office complexes and other public areas, and people expect to see when they walk through the door. Thus plants became such important building accessory. The main reason is, indoor plants look attractive – people get charmed by the graceful arch of palm leaves or the exotic beauty of orchids. However, recent research has shown that the value of plants goes far beyond the purely aesthetic. Plants are actually good for the building and its occupants in a number of subtle ways and are an important element in providing a pleasant, tranquil environment where people can work or relax.

Plants can be used to decrease noise levels in an office. According to Green Plants for Green Buildings, if plants are placed strategically, they can help to quite down the office. A small indoor hedge placed around a workspace will reduce noise by 5 decibels (Jacobs, H., 2008). Along with decreasing noise levels, there is more benefit to adding green plants to workplaces. The presence of plants in the office not only aesthetically pleasing but also helps increase workers productivity, reduce stress and improve air quality. According to a Texas A&M University and Surrey University study, participants also reported feeling more attentive when plants were present. Participants who worked in an environment with plants were 12% more productive and less stressed than those who worked in an environment with no plants (Gilhooley,M., 2002). Plants can also improve the indoor environmental quality. Research from the Environmental Laboratory of John C. Stennis Space Center in Mississippi showed that rooms with plants contain 50% to 60% fewer of airborne molds and bacteria than rooms without plants (Gilhooley,M., 2002). The plans clean the office air by absorbing pollutants into their leaves and transmitting the toxin to their roots, where they are turned into food for the plant. With cleaner office air building occupants are less likely to be sick, thus increasing productivity and decreasing absenteeism. In buildings where sick building syndrome is common, employees should each have a plant within 6 to 8 cubic feet of where they spend most of the day (Jacobs, H., 2008b).

3.5.1 Examples of Indoor Plants

Figure 11: Plants contribute to interior humidity by adding moisture to the air through transpiration and secondarily through evaporation from growing media and drainage dish surfaces. (Jacobs, H., 2008b).

Figure 12: Flowers and plants promote innovation and ideas. (Jacobs, H., 2008b).

Figure 13: Living Indoor plants improve business. (Jacobs, H., 2008a).

4 Chapter 4: Benefits of Incorporating Green

4.1 Introduction

This chapter is based on literature reviews, case studies and reports from various sources and organizations. The tables, figures, numeric information and tranquil data provided here are from second hand sources. This chapter is focused on the positive impact of the green plants provide in economical, social and environmental point of view along with the benefits they deliver to exterior and interior of a building. Most of the data derived here are from the researches and case studies done on various buildings in various parts of the world. Not necessarily all the options of incorporating plants (green roof, green wall, biofilter and indoor plants) are done on single building, nor on the skyscrapers, but they have done separately on various cases. A summary of the findings has been provided on the tables. And at the end some drawbacks or shortcomings are mentioned for these practices.

4.2 Potential green roof benefits

Numerous benefits can result from the adoption of green roof technologies. Besides the obvious aesthetic and psychological benefits of being surrounded by garden-like settings, common ecological and economic benefits include the recovery of green space, moderation of the urban heat island effect, improved stormwater management, water and air purification, and a reduction in energy consumption. Municipalities considering policies for green roofs will need to examine the tangible and intangible benefits and costs associated with green roofs on a community-wide basis. What is needed is an approach that is comprehensive and realistic in determining the costs and benefits across the spectrum of circumstances and potential opportunities that may arise from installing green roofs (Banting,D. et al., 2005). Impacts of green roof that have been commonly cited are as follows:

- effects on energy budgets of individual buildings;
- effects on the urban heat island;
- effects on stormwater management strategies;
- effects on urban air quality;

- repercussions for urban amenities, such as food production, aesthetics, recreation; urban agriculture, noise reduction, real estate, therapeutics, open space;
- effects on waste management from increase in roof material "life cycle";
- promotion of horticulture/landscaping,
- promotion of biodiversity and wild life protection;
- promotion of health and well-being

4.2.1 Energy budgets of individual buildings

Green roofs have been investigated for their effects on building energy costs. The insulating effects of added materials seem likely to reduce the penetration of summer heat and the escape of interior heat in winter and there is some scientific evidence to support these notions. There is possibly an even greater benefit in the summer due to the cooling created by the evapotranspiration effect from plants and the evaporation of retained moisture from the soil. In some of the earliest reported research, measurements in Berlin conducted in 1984 revealed not only reduction in maximum surface temperature but also temperature amplitudes reduced by half due to green roof installation (Kohler et al., 2002). Akbari et al. (1999, 2001) investigated means of reducing building energy in mid-latitude cities as one of several means for reducing the urban heat island (UHI) effect and documented the enhanced air conditioning demands (up to 10%) brought about by the UHI. This elevated load generally occurs in the late afternoon hours, corresponding to the peak summer electric utility load. Akbari also demonstrated that the afternoon electric utility load for southern California increases by more than 2% per degree Celsius increase in air temperature. Also noteworthy, was the determination that ozone concentration in the Los Angeles basin was positively correlated with air temperature, increasing at a rate of 5% per degree Celsius (Akbari et al., 1990; Sailor, 1995). By making roofs cooler, designers can reduce the amount of absorbed solar energy, and consequently reduce the amount of heat conduction into buildings. This reduces daytime net energy inputs (Akbari and Konopacki, 2004); and the demand for air conditioning. England et al.,(2004) also carried out calculations to examine the thermal behavior of a planted roof and concluded that green roofs can contribute to the thermal performance of buildings. This study further showed that of the total solar radiation absorbed by the planted roof, 27% is reflected, while the plants and the soil absorb 60%, and 13% is transmitted into the soils. Evidently, with a green roof the insulation value is in both the plants and the layer of substrates (England et al., 2004).

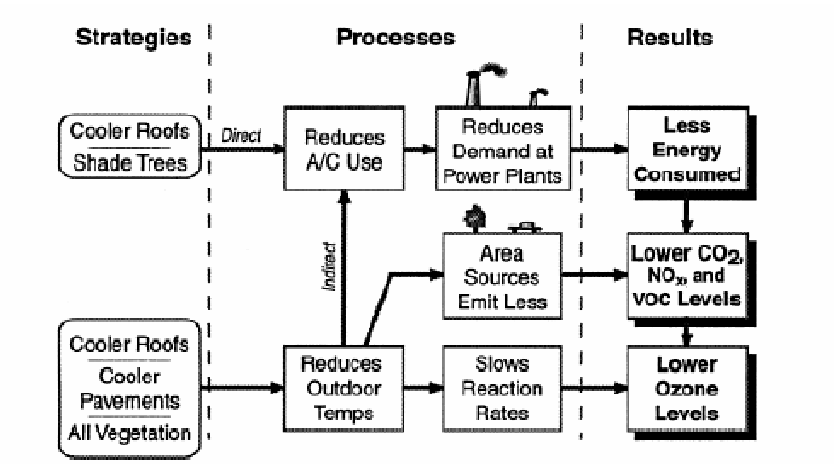


Figure 14: Methodology to analyze the impact of cool roofs and cool pavements on energy use. (After Akbari et al. 2001). Source: Ryerson University, Quantitative Findings Oct. 2005, Report on the Environmental Benefits and Costs of Green Roofing.

Table 2: Summary of key findings from literature review related to heat transfer, energy use and green roofs.

Study	Location	Monitoring	Qualitative/Quantitative Changes due to green roof	Study recommendations	Conversion to costs or benefits
Kohler et al. (2002)	Berlin, Germany	As early as 1984 surface temperatures of a green roof were monitored. The surface temp; shadowed surface temp of gravel; shadowed surface temp of green roof; temp of substrate; ambient air temp. were all measured	Green roof reduced surface temp. but also more importantly reduced the max. temp. amplitude by half.	The complex composition of green roofs represents a decisive additional buffer zone; the lowering roof temp. and added insulation effect are undeniably positive for indoor climate; the durability of flat roof is increased significantly	
Sailor (1995)	Los Angeles	Three-dimensional meteorological simulation of urban surface characteristics i.e. increasing albedo and or vegetative cover.	Increasing the albedo over the downtown L.A. area by 0.14 decreased summer time temperatures by 1.5^{0}C. Increasing the vegetative cover by using green roofs showed similar results.	Preliminary evidence suggests that albedo and vegetation increases would benefit cities by reducing air temp. and energy demand. A thorough cost-benefit analysis for modifying urban surfaces for other geographical locations is needed; feasibility issues for large scale implementation must be resolved	A reduction of 1^{0}C in summer time afternoon air temp for L.A. corresponds to a 2% energy savings
Del Barrio (1998)	Mediterranean region	Mathematical model	Green roofs do not act as cooling devices but as insulation, reducing the heat flux through the roof	Soil density, thickness and moisture content are identified as relevant for green roof design parameters.	
Eumorfopoulu (1998)	Athens, Greece	Mathematical model to determine the thermal behaviour of planted roofs and the thermal protection	Of the total solar radiation absorbed by the planted roof, 27% is reflected, 60% is absorbed by the plants and the soil through evaporation and 13% is transmitted into the soils; Evidently, the insulation value is in both the plants and the layer of substrates.	Green roofs block solar radiation, reduce daily temp. variations and thermal ranges between winter and summer; planted roofs contribute to the thermal protection of a building, but do not replace the insulation layer.	

Study	Location	Monitoring	Qualitative/Quantitative Changes due to green roof	Study recommendations	Conversion to costs or benefits
Onmura et al..(2001)	Japan	Field measurements; wind tunnel experiment; numerical calculations.	The evaporative cooling effect of a roof lawn garden showed a 50% reduction in heat flux in the rooms below the garden. A reduction in surface temperature from 60 to 30°C during day time led to the conclusion that evaporative component is an important role in reducing the heat flux.	Evaporation was dependent on the moisture content in the lawn	
Liu and Baskaran (2003); Bass and Baskaran (2003)	Ottawa, Canada	A green roof and a reference bituminous roof were instrumented to allow direct comparison of thermal performance	The green roof was more effective at reducing heat gain than heat loss. The green roof reduced temperature fluctuations and also modified heat flow through the roofing system by more than 75%	During the observation period, the green roof reduced 95% of the heat gain and 26% of the heat loss as compared to the reference roof. Then it is expected that its effectiveness will be more significant in warmer regions	A reduction from 6.0-7.5 kWh/day to less than 1.5kWh/day which corresponds to a 75% reduction and the potential for savings.
Alcazar and Bass, (2005)	Madrid, Spain	The energy performance of three roofing systems is compared. Thermal and optical characteristics are monitored ESP-r energy simulation software is used to compare annual energy consumption	The study show that the installation of a green roof in the building provides savings in annual and peak energy consumption; The green roof resulted in a total annual energy consumption reduction of 1% with a 0.5 % reduction in the heating season and a 6 % reduction in the cooling season.	This reduction was not homogeneous throughout the building. Below the third storey, under the roof, no savings were achieved. .	A total annual energy reduction of 1%
Bass et al. (2002)	Toronto, Canada	A mathematical model (MC2) was used to quantify the mitigation of the urban heat Island	Low level air temperatures were simulated for 48 hours in June 2001. With a 50% green roof coverage a 1°C reduction in low level air temperatures was observed. Irrigation of the green roofs produced a cooling of 2°C	Further research is needed in this area. The model operated well, however, unexpectedly low reductions in air temperature may have been caused by unknown underlying assumptions.	

Source: Ryerson University, Quantitative Findings Oct. 2005, Report on the Environmental Benefits and

Onmura et al. (2001) conducted a field measurement on a planted roof in Japan. The evaporative cooling effect of a rooftop lawn garden showed a 50% reduction in heat flux in the rooms below the garden. This research also revealed a reduction in surface temperature from 60^o to 30^{o}C during the day. The importance of evaporation in reducing the heat flux was quantitatively simulated in a series of wind tunnel experiments. Reviews by Wong et al. (2003) and Kohler et al. (2002), have shown that under a green roof, indoor temperatures were found to be at least 3 to 4^{o}C lower than outside temperatures of 25 to 30^{o}C. In a Canadian study, Liu and Baskaran (2003) report that field research in Ottawa has revealed that the energy required for space conditioning due to the heat flow through the green roof was reduced by more than 75%. The study focused on controlled conditions featuring a reference roof and a green roof of equal dimensions; the experimental roof surface area was 72 m2 (800 ft2) with the green roof on one half and the reference roof on the other half. An energy reduction from 6.0 to 7.5 kWh/day for cooling was demonstrated (Liu and Baskaran, 2003; Bass and Baskaran, 2003). Alcazar and Bass, (2005) have very recently reported that the installation of a green roof in Madrid reduced total energy consumption by 1% with 0.5% reduction in the heating season and a 6% reduction in the cooling season.

4.2.1.1 Energy Saving Calculation

Energy savings provided by a Green Roof is significantly affected by the moisture content of the soil at a given time. When the Extensive Green Roof System's soil is moist and it has a healthy plant base, it is expected at least a 2.0°C decrease in thermal load. This works out a reduction of 0.052kWh/ft^2 (0.56kWh/m^2) in a single day. Thus the below example can be use as a basis to calculate energy savings (Yamada, H. 2008).

Reduced Energy	0.052kWh/ft^2 (0.56kWh/m^2)
Air Conditioner Efficiency	400W/1000W
Electricity Rates (based on California residential average)	~12¢/kWh
Total Savings	0.25¢/ft^2

Table 3: Energy Saving Calculation. (Yamada, H. 2008).

After calculating this number using the local energy providers electricity rate, the air conditioning usage schedule need to be figured out to calculate the yearly energy savings, as shown below.

In a single year, the average usage of the Air Conditioner can be break down into three states, Quasi-usage, Full-usage and Quasi-usage (in most areas, this translates to Spring, Summer, Fall). The average air conditioning usage days and usage percentage can be figured out by calling the local electricity provider.

Table 4: Average savings in air conditioning usage (Yamada, H. 2008).

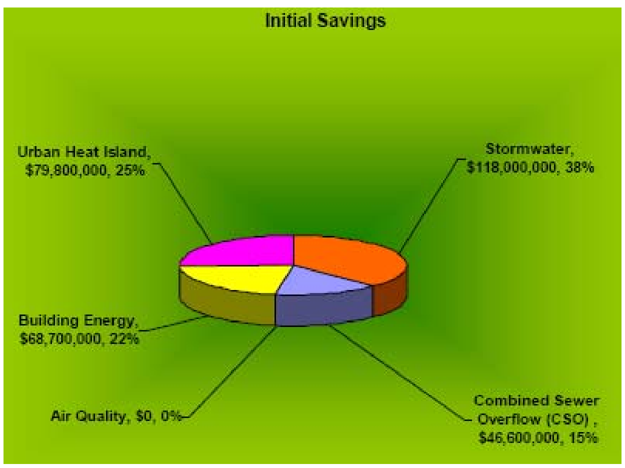
Period	Days	Savings	Usage	Calculation		
1	85	0.25¢/ft^2	60%	85 x 0.25 x 0.6	=	12.75¢/ft^2
2	85	0.25¢/ft^2	100%	85 x 0.25	=	21.25¢/ft^2
3	85	0.25¢/ft^2	60%	85 x 0.25 x 0.6	=	12.75¢/ft^2
		Yearly Savings per Square Foot			=	46.75¢/ft^2

Therefore a 1000 ft^2 G-SKY Extensive Green Roof will produce:
1000ft^2 x 46.75¢/ft^2 = $467.50 / year in energy savings, in California (Yamada, H. 2008).

4.2.1.2 Economic Benefit

Long-term economic benefits of green roof system already outweigh the start-up costs. The initial expense of green rooftops often turns away prospective clients. Because green roofs require professional design, careful structural analysis and multiple layers and systems, even extensive green roofs usually start at $8 per square foot, significantly more expensive than the $1.25 per square foot for built-up roofs (BURs) [Source: EPA]. But benefits and incentives, like those laid down by the City, are prompting new green-rooftop projects. And, as the green-roof industry grows, prices will drop (Yamada, H. 2008).

The City of Toronto has been an active participant in studying wider use of green roofs as a sustainable alternative to meet many of the urban environmental challenges. The study report presented the findings on the municipal level benefits of implementing green roof technology in the City of Toronto. The benefits on a city-wide basis were calculated based on the assumption that 100% of available green roof area be used. The available green roof area included flat roofs on buildings with more than 350 sq. m. of roof area, and assuming at least 75% of the roof area would be greened. The total available green roof area city-wide was determined to be 5,000 hectares (50 million sq. m.) (Banting, D. et al., 2005). The benefits were determined as initial cost saving related to capital costs or an amount of annually recurring cost saving. These are shown in the following charts and table.



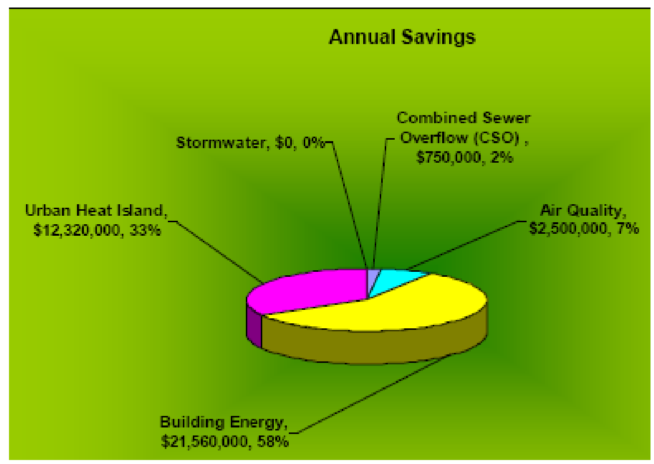


Figure 15: Initial cost saving related to capital costs or an amount of annually recurring cost saving. (Banting, D. et al., 2005).

Table 5: Cost Savings Initially and Annually. (Banting, D. et al., 2005).

Category of benefit	Initial cost saving	Annual cost saving
Stormwater	$118,000,000	
Combined Sewer Overflow (CSO)	$46,600,000	$750,000
Air Quality		$2,500,000
Building Energy	$68,700,000	$21,560,000
Urban Heat Island	$79,800,000	$12,320,000
Total	$313,100,000	$37,130,000

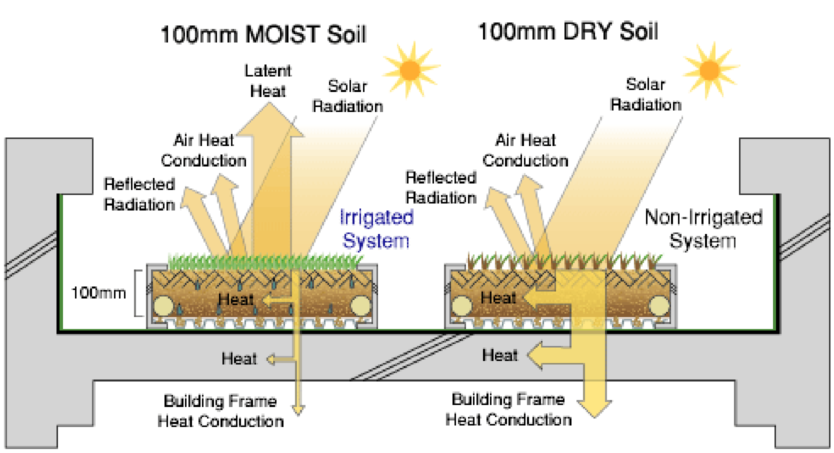
Source: Ryerson University, Quantitative Findings Oct. 2005, Report on the Environmental Benefits and Costs of Green Roofing.

These benefits are encouraging eco-minded homeowners, businesses and cities to build green rooftops.

4.2.1.3 Effect of soil moisture content on Energy Savings

A Green Roof can be thought of as an external "heat" insulation material. The adiabatic efficiency of typical insulation is measured by the materials heat resistance value and its thickness. But these measures do not apply to a Green Roof. The insulating efficiency of "dry" soil is ~1/3 to that of commonly used insulation materials. However, soil is different in that as its moisture content increases its insulating efficiency also increases. Because of this inconsistency, soil is not considered an effective insulation (Yamada, H., 2008).

In the diagram below, refer to the "100mm DRY Soil" illustration; the heat conducted through dry soil is surprisingly high. Thus showing that soil with a poor vegetation cover and low water content does not provide effective heat resistance. In the "100mm MOIST Soil" diagram, the surface of the moist soil is well-covered with vegetation. A great deal of "Latent Heat" is reflected off of the surface of the vegetation, and thereby provides superior heat resistance. The thickness of the arrows representing "Latent Heat" in each diagram is an accurate representation of the ratio of heat transferred away from the roof. With moist soil, heat that reaches the soil is reduced to a point where measurable cooling energy savings are realized. The amount of "Buildng Frame Heat Conduction" in the "25mm DRY Soil" and "Exposed Roof Surface" diagrams is virtually identical. This is due to the low water content in the soil which does not provide adequate evaporation to consume heat (Yamada, H., 2008).



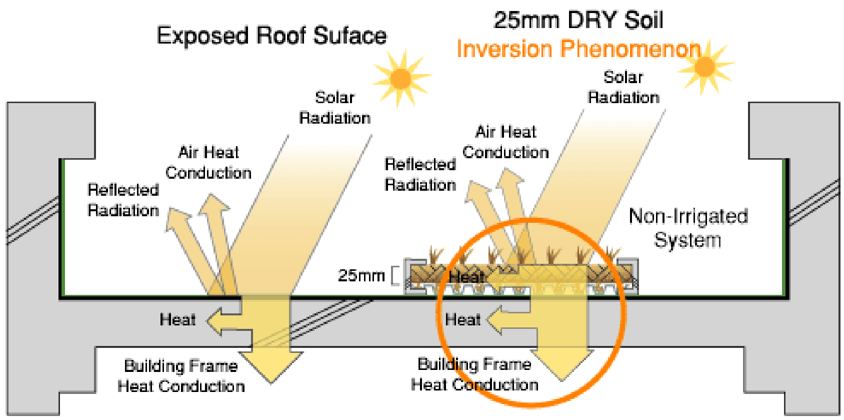


Figure 16: Conceptual drawing of the adiabatic effect- Summer during fair weather and mid-day. (Yamada, H., 2008).

4.2.1.4 Temperature variation of thin Green roof system

Ultra-thin 'non-irrigated' soil bases (≤25mm) provide no adiabatic effect, poor plant health, poor plant surface coverage and could promote heat conduction into the building. This is called the "Inversion Phenomenon" (Yamada, H., 2008). This is caused by the lack of plant coverage due to "dry" thin soil's inability to support healthy plants. Dark exposed soil has a higher heat conduction value than light colored concrete, thereby promoting heat into the building. However, when an ultra-thin system is irrigated, its insular value is increased significantly (see the graph below).

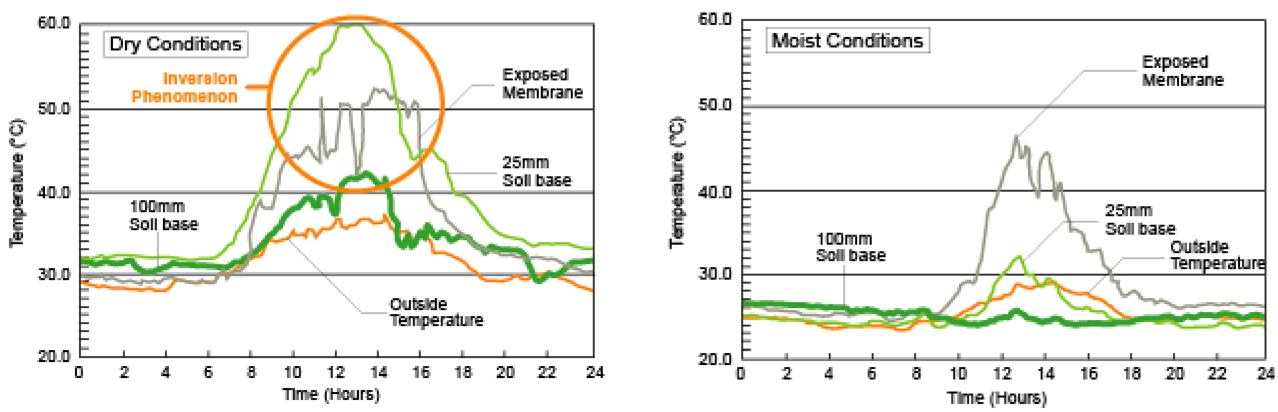


Figure 17: Temperature variation of the green roof system in dry and moist condition. (Yamada, H., 2008).

A healthy plant base shades the soil and water evaporation cools the surface. The effectiveness of moisture's cooling effect gradually increases as soil depth increases from 25mm to 200mm. Depths above 200mm provide no further significant increase in the adiabatic effect. The thickness of a building's roof deck and insulation are also important. On a thick roof deck or with thick insulation (>30cm), adding a Green Roof will provides almost no added heat resistance. In the certain climate, the adiabatic effect of a Green Roof is significant, and can eliminate the need for air conditioning. However, accurate estimates of energy savings must be made based on the water content of the soil at any given time (Yamada, H., 2008).

4.2.1.5 Reduce HVAC Cooling loads

The surface of a traditional rooftop can be up to 90°F warmer than the ambient air temperature on hot summer days as per Truett R. (2003). Some roofs can approach as 200 degrees. The heat from these roofs both conducts downward into the building and radiates upward towards roof-mounted HVAC systems causing them to run inefficiently.

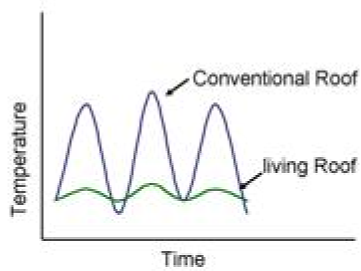


Figure 18: Living roof reduce the cooling load. Truett, Rick. (2003)

The surface temperature of green roof can actually be cooler than ambient air. Shading from plant foliage and the returning of water to the atmosphere (called evapo- transpiration) causes the cooling on living roofs. The growing media serves as additional thermal benefit by absorbing the worst of the heat during the day.

4.2.2 Urban heat island

The most frequently observed and documented climatic effect of urbanization is the increase in surface and air temperatures over the urban area, as compared to the rural surroundings. Oke (1995) simply defines an urban heat island (UHI) as the 'characteristic warmth' of a town or city. The following figure shows a schematic representation of near surface temperature for a large city, traversing from countryside to the city centre. A typical 'cliff' rises steeply near the rural/suburban boundary, followed by a 'plateau' over much of the suburban area, and then a 'peak' over the city centre (Oke, 1987, 1995).

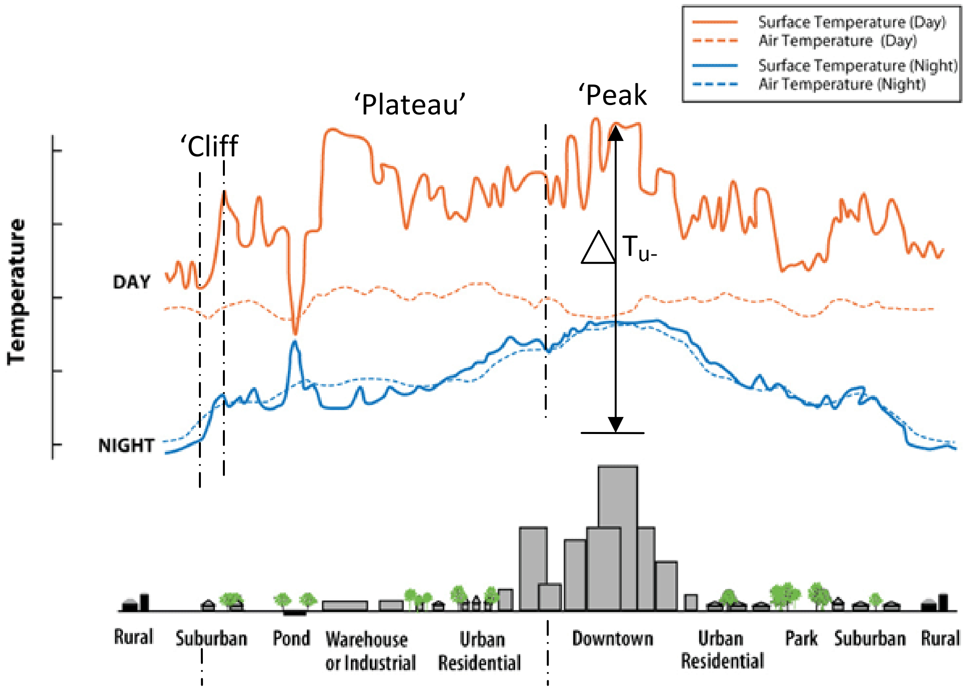


Figure 19: Generalized cross-section of a typical urban heat island. (www.epa.gov).

Green roofs present the opportunity to expand the presence of vegetated surfaces by replacing impermeable surfaces in urban areas, providing for a reduction in peak summer urban heat island temperatures. Richey, Warren (1998) addressed strategies to cool urban areas by reducing the heat island effect and smog in Los Angeles. By focusing on the energy demand of buildings, they developed a model that showed Los Angeles could be cooled up to 3°C by reroofing and repaving using "cool" (high reflectance) materials, and by planting shade trees around buildings. However, Sailor (1995) had argued that in the urban environment, the lack of vegetation, which controls evapotranspiration, is the most significant factor contributing to the urban heat island. Therefore green roof technology offers the possibility of much greater impact on the urban heat island effect than reflective roofs alone. Bass *et al*. (2002) attempted to mathematically model the effect of green roofs on the UHI in Toronto. Using a mesoscale model and the natural and urban surface parameters, low level air temperatures were simulated for a 48 hour period in June, 2001. The simulation assumed 50% green roof coverage and showed a reduction of 1°C in low level urban temperatures. The simulation was repeated with the addition of irrigated green roofs. Irrigated green roofs produced a cooling of 2°C and extended the 1°C over a larger geographic area. However, as successfully as the model operated, model assumptions, case study choices and input data of unknown quality created unexpectedly low reductions (Bass et al. 2002). Thus Green Roofs and Walls reduce A/C requirements in buildings reducing energy consumption and heat production.

4.2.3 Stormwater management implications

Peak stormwater runoff from impervious surfaces is a leading cause of water pollution in urban areas, where over 75% of a rain event can become surface runoff depositing pollutants into waterways (Truett, Rick. 2003). Numerous studies have demonstrated quantitatively that a properly installed and maintained green roof will absorb water and release it slowly over a period of time, as opposed to a conventional roof where stormwater is immediately discharged. Typical extensive green roofs, depending on the substrate depth, can retain 60 to 100% of the stormwater they receive (Thompson, 1998). In addition, according to the ZinCo planning guide (1997), living roofs are normally able to retain 70 to 90% of the stormwater that falls on them during the summer months, depending on the frequency of rain and drying rates. In winter months, green roofs are predicted to retain 40 - 50% of the stormwater. These data are subject to variation based on variations in climatic conditions. The amount retained also depends on numerous factors such as the volume and intensity of rainfall, the amount of time since the previous rainfall event, and the depth and saturation level of the existing substrate (Monterusso, 2003). Several studies conducted in Germany have shown that a green roof with a substrate depth of 2 to 4 cm with a vegetation mix of mosses and sedum can retain 40 to 45% of the annual rainfall that falls on it (Liesecke, 1998). By increasing the depth of the substrate to 10 to 15 cm and changing the vegetation to a mixture of sedum, grasses, and herbs, green roofs can retain up to 60% of stormwater on an annual basis (Liesecke, 1993). Research conducted by Jennings et al. (2003) in North Carolina showed that a green roof can retain up to 100% of the precipitation that falls on it in warm weather. However, the percentage retained for each storm decreased when there had not been an adequate amount of time between each storm event. As shown in Table 5, the percentage retained for each storm decreased with each respective rain event. The percentage of the stormwater retained dropped from 75% to

32%. According to the experimental results, Jennings et al. concluded that the capability of green roof retention is highly dependent on the volume and intensity of rainfall (Banting, D. et al., 2005).

Table 6: Hydrolic retention for the WCC green roof in Goldsboro, April 2003. (After Jennings et al., 2003).

Storm Event	Rainfall (in)	Green roof Runoff (in)	Retained (in)	% Retained
7 April 2003	0.89	0.22	0.67	75
8-9 April 2003	1.02	0.57	0.45	44
9-11 April 2003	1.63	1.11	0.52	32

As Jennings et al. (2003) concluded, the water holding capacity of the substrate was found to depend on the volume and intensity of the rainfall. Further, both Jennings et al. (2003) and Rowe et al. (2003) found that their green roof was able to reduce the peak flow and the time to peak (by 2 to 4.5 hours) when compared to a standard conventional roof (Figure 20). Liu (2003) also found

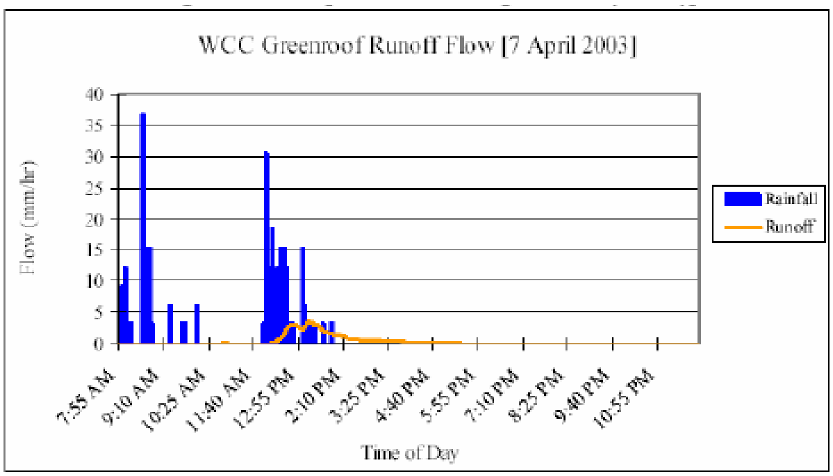


Figure 20: Relationship between the peak flow and runoff on green roof (After Jennings et al., 2003)

a stormwater runoff delay on green roofs. During a light rain (19mm in 6.5 hours), the green roof delayed the discharge of stormwater for 95 minutes.

Green roofs not only reduce the quantity of runoff from roofs but can also filter contaminants from rainwater. The substrate on green roofs has the ability to retain particulate matter in the stormwater and to reduce the quantity of runoff and, as a result the total mass of pollutants that flow off the roof. Thus, the stormwater runoff quality as well as the receiving surface water quality can be improved. Large numbers of studies have been conducted in Germany and Switzerland regarding green roof runoff quality. Dramstad et al. (1996) demonstrated that the physical and chemical properties of the growing substrate, as well as the green vegetative cover help to control the nitrogen, phosphorus, and contaminants generated by industrial activities, which exit the roof surface. In some cases these substances can be taken up and broken down by the plants themselves (Johnston and Newton, 1993), but most of the time heavy metals and nutrients that exist in stormwater are bound in the green roof growing substrate instead of being discharged in the runoff. Johnston and Newton (1993) also concluded that over 95% of cadmium, copper and lead and 16% of zinc can be removed from the stormwater runoff through binding and uptake in the growing substrate. In 2004, the Toronto and Regions Conservation Authority (TRCA) commissioned Marshall Macklin and Monaghan Ltd. and Aquafor Beech Ltd. to analyze runoff reduction due to green roofs in the Highland Creek watershed (Banting, D. et al., 2005). Three types of the stormwater benefits are estimated,

- stormwater best management practice savings due to the application of green roofs;
- pollutant reduction;
- reduction of receiving stream erosion.

After reviewing the best management practice bundles used in the Toronto Wet Weather Study, the findings are the three types of best management practices, which have high cost, may be replaced by green roofs in a generic manner. Based on a 4,984 ha of potential green roof implementation, the following stormwater benefits are estimated:

- A BMP infrastructure saving from $2.8 to $79 million.
- A pollutant reduction benefit of $14 million
- Savings from erosion control measures of $25 million

The total stormwater benefit is estimated to range from $41.8 to $118 million.

4.2.4 Air quality impacts

Declining air quality is an ongoing problem in cities globally, and solutions are being proposed. Akbari et al. (2001) and Kats (2003) discuss cool roofs and green roofs in terms of their potential indirect effect of reducing CO2 emissions from power plants due to a reduction in the demand for summertime peak-period cooling. Yok and Sia (2005), in their report on a pilot green roof project in Singapore, noted air quality improvements due to reduction of sulphur dioxide by 37% and nitrous acid by 21%. However, nitric acid increased by 48% and particulates (PM 2.5 and 10) also increased, possibly from re-suspended chips related to gravel ballast and bare spots on the green roof, though the particle number concentration decreased by 6% on the green roof. Johnson and Newton (1993) estimate in urban forestry studies that 2,000 m^2 of unmowed grass on a roof could remove as much as 4,000 kg of particulates from the surrounding air by trapping it on its foliage. Several researchers report that vegetation benefits air quality by trapping particulates and dissolving or sequestering gaseous pollutants, particularly carbon dioxide, through the stomata of their leaves (Nowak and Crane, 1998). Their research has predicted rates of entrapment and mitigation, given seasonality, daylight hours, and species, etc., and their model is currently being studied in Toronto (Currie, 2005a).

4.2.5 Green amenity space

Some researchers believe that the need for meaningful contact with nature may be as important as people's need for interpersonal relationships (Kaplan, 1993). Moreover, impediments to meaningful contact with nature can be seen "as a contributing factor to rising levels of stress and general dissatisfaction within our modern society" (Zubevich, 2004). Green roofs provide a measurable psychological benefit to urbanites by adding tangible, accessible natural viewing space for social interaction, recreation, and relaxation. A green roof offers building occupants proximity to common spaces where they can relax, dine, meditate, do yoga, interact with friends or business colleagues, and enjoy proximity to green plants. A study of tenants at 401 Richmond Ltd, Toronto, revealed that building occupants greatly value access to their green roof and refer to it as "an oasis in the city" (Cohnstaedt, Shields, & MacDonald, 2003). Similarly, research on graduate students at 30 Charles Street, Toronto, suggested that a view of their green roof "provides sanity and relief" from the pressures associated with dense urban living (Bass et al. 2004). Research on human behavior suggests that a view of gardens and green plants serves to restore calm and reduce stress in humans - particularly those that drive a vehicle (Cackowski & Nasar, 2003). Other studies suggest that humans generally prefer a view of natural settings rather than congested or cluttered built environments and that accessibility to nature, specifically by way of a window or a walk, improves worker concentration and job satisfaction, and buffers negative job stress [Hertzog, Maguire & Nebel, (2003), Laumann, Garling & Morten Stormark, (2003) and Leather, Pygras, Beale, & Lawrence (1998)]. A study by Tayor et al. (2001) determined that children with Attention Deficit Disorder (ADD) were noticeably more relaxed and better behaved after playtime in green settings compared with children who did not have access to green space. There is significant evidence springing from multiple research projects to support the theory that people's exposure to natural elements increases their ability to focus, cope with stress, generate creative ideas, reduce volatility and promote the perception of self as part of a meaningful greater whole. In short, exposure to natural elements enhances an individual's mental well being (Banting, D. et al., 2005).

4.2.6 Habitat preservation

Green space in many urban environments is limited to centralized parks and narrow medians along roadways. Green roofs can provide significant tracts of non-disturbed habitat for birds and other wildlife to forage and nest (Truett, R., 2003a). Many authors report that adding green space in the form of green roofs to densely populated urban environments provides eco-restorative habitats for displaced creatures. Green roofs provide food, habitat, shelter, nesting opportunities and a safe resting place for spiders, beetles, butterflies, birds and other invertebrates (Brenneisen, 2003; Gedge, 2003). In Europe and Chicago, green roofs are being studied for their unique ability to provide undisturbed, viable sanctuaries for rare and nearly extinct species. Studies report that this elevated urban ecosystem affords unique protection from grade level predators, traffic noise and human intervention (Federal Technology Alert, 2004). Studies reveal that butterflies can access green space on the 20th floor of a building (Johnston & Newton, 1993).

4.2.7 Property values

It has been proven that quality landscaping and landscape amenities adds 15% to 20% to a buildings value as per Truett R. (2003). Interviews with social and environmental coordinators at Toronto's Mountain Equipment Co-op (MEC) and Uurbanspace Property Group's 401 Richmond Ltd. report that green roofs have improved their building's aesthetic value (Robinson, 2005; Currie, 2005b). Visitors to Toronto's annual Doors Open event - a public celebration of built form and historic building stock - flock to both MEC and 401 Richmond Ltd to experience a green roof. Attendance at MEC's Doors Open rose from 500 in 2003 to 880 in 2004, and the first requests were to see the green roof. Tenants at Urbanspace Property Group, located at both 401 Richmond Street West and 215 Spadina Avenue, report that interior and exterior green elements add to an overall perception of health and well-being in the urban work space. Toronto property owners like Margaret Zeidler of Urbanspace Property Group suggest that green roofs are the "right thing to do" and that more building owners should "just do it." Zeidler (2005) reports that word of mouth is all she requires to keep the Urbanspace Property Group buildings fully tenanted; there have been no expenditures on marketing to date for either building.

Table 7: Summary of key findings from literature review related to the air quality and green roofs. (After Jennings et al. 2003)

Study	Location	Monitoring	Qualitative / Quantitative changes	Costs / Benefits	Recommendations
Kats. 2003	California				
Yok and Sia, 2005	Singapore	Temperature of surface, substrate, air; HOBO data loggers, infrared radiometer (Thermo tracer TH7102WX, NEC Japan); HOBO Weather Station for humidity, solar radiation, wind speed and rainfall; air quality measured with annular denuder system (URG, Chapel Hill, NC, USA), particle counter (TSI, St. Paul, MN, USA) and air quality with an aerosol sampler (Airmetrics, Eugene, OR) and to measure black cargon mass Aethalometer (Magee Scientific	Reduction of surface temperatures by 15-20 degrees C; visible light (glare) from green roofs lowered by 12-56%; air quality improvements noted in sulphur dioxide by 37%; nitrous acid by 21%; but nitric acid increased by 48%; PM 2.5 and PM 10 increased (possibly from re-suspended chips related to gravel ballast and bare spots on green roof) and particle number concentration decreased by 6% on green roofs.	Benefits to building owner, building occupants, building neighbours, community and country regarding energy savings, improved air quality and subsequent health improvements	Application of green roofs in urban areas for reasons such as: reduced ambient air temperature, improved air quality and reduced glare from buildings
Currie, 2005	Toronto	UFORE – Urban Forest Effects Model from Northeaster Forest Service, Research Station, Syracuse, New York–quantified vegetation effects on air contaminants based on one year of data from Environment Canada's 3 local weather stations in Toronto	Air contaminant reductions between varying levels of vegetation in one neighbourhood in Toronto over a one year period	Externality values ($) by UFORE model $43,106.00 worth of contaminants removed when grass was added on typical flat roofs; in addition to $46,740.00 from shrubs at grade and $103, 176.00 from tress at grade (within the same neighbourhood).	Recommends the application of urban vegetation at grade and/or elevated surfaces to mitigate air pollution with resulting population health benefits.

4.2.8 Sound Insulator

Plants, soil, and air trapped in the soil are great acoustic insulators. In Truett R. (2003a) tests indicate that green roofs can reduce indoor sound by as much as 40 decibels by absorbing, reflecting, or deflecting sound waves produced by machinery, traffic, or airplanes. A green roof's substrate tends to block lower sound frequencies and the plants block higher frequencies.

4.2.9 Extend Roof Life

Ultraviolet (UV) radiation and extreme daily temperature fluctuations are the two leading factors that act to deteriorate and ultimately destroy the waterproofing elements on traditional roofs cited by Truett R. (2003). A green roof buffers the underlying waterproofing from these damaging natural elements, which can in turn more than double the roof's life expectancy. Green roofs also add extra buffering protection from hail damage.

4.2.10 Derivation of economic benefit from green roofs

The economic benefit can be derived by the cost benefit analysis (CBA) method though it has limited comprehensive application to green roof projects. Several life-cycle analyses have been completed on green roof focused on the private costs of green roofs relative to standard roofing materials. These studies also considered the costs of construction, maintenance, and the energy savings that would be part of both the private and social costs and benefits in CBA. A summary of these individual costs and benefits follows (Banting, D. et al., 2005).

4.2.10.1 Time period

In most consensuses appears that green roofs do last longer than standards roofs. A common assumption, such as that made for New York City in Acks (2003), is that a green roof will have a service life of 40 years, while a standard roof will last for 20 years. However, variations in the green roof service life are often found, including 20 years (identical service life) and 60 years in the Acks study.

4.2.10.2 Discount rate

As important as the service life, the discount rate applied to future costs and benefits has significant effects on net benefit calculation for both private and social cases. A higher discount rate implies lower present values of future costs and benefits. Private discount rates vary by industry, depending on factors such as industry-specific rates of return. Acks (2003) used a private real discount rate of 8% for New York City buildings, while the Treasury Board of Canada (1998) suggested a general rate of 10%. Most environmental studies tend to use lower discount rates due to the irreversibility of many environmental activities. For example, both Cline and Arrow et al. used a range of 0-2% for climate change, while Bateman et al. (2004) used values of 1.5% and 3% for conversion of agricultural land to woodland.

4.2.10.3 Installation and maintenance costs

Installation and maintenance cost varies between intensive and extensive roofs, between different materials and plants used, and between new buildings and retrofit installations. In three scenarios, reflecting low, medium and high green roof performance, Acks (2003) used costs of $12, $18 and $24 per square foot for a green roof, and $9 per square foot for a standard roof. Wong et al. (2004) used $4.57 per square foot for a standard roof, $8.35 per square foot for an extensive roof, and $8.97 per square foot for an intensive roof. In that study, accessible rooftops would cost considerably more up to $18.31 per square foot. The approximate doubling of standard roof costs is also consistent with the life cycle analysis in England et al. (2004). Structural costs in most studies are ignored, in effect limiting the analysis to extensive green roofs. Acks (2003) assumed structural costs for all green roofs to be 0.2% of initial costs. The type of green roof under consideration is crucial in the comparison of annual maintenance costs. For extensive roofs, previous studies indicate little difference between green roof and standard roof maintenance costs. For example, Acks (2003) assumed $0.60 per square foot for green roofs and $0.10 per square foot for standard roofs. Intensive roofs presumably require more maintenance, depending on the type of plants chosen (Wong et al., 2004).

4.2.10.4 Energy cost savings

Green roofs potentially reduce urban air temperatures, which would yield the benefit of lower cooling costs in summer months. Although cooling effects are clearly site specific, there have been attempts to generalize the energy cost savings from a green roof. The private cooling cost in Acks (2003) for a standard roof was estimated at $0.16 per square foot through five independent calculations, and a green roof was assumed to reduce cooling costs by approximately 15%. In Wong et al. (2004) energy costs were estimated using the energy model based on the Power DOE program, yielding annual energy savings of between 5,000 and 29,000 kWh. An extensive green roof under these conditions would result in cost savings of $4,773.40 each year, and these energy cost savings could significantly decreased costs of installing both extensive and intensive green roofs. For example, an inaccessible extensive roof was 2.4% more expensive without energy considerations, yet 8.5% less expensive after energy costs were taken into account. England et al. (2004) estimated green roof annual energy savings at a value between $2,500 and $12,500.

The Enermodal study simulated the energy savings in a one storey building from the use of green roofs. It integrated data from work done by the National Research Council of Canada on green roofs in Ottawa. The results from this study related to cooling load were about 4 times lower than the LBL study.

Table 8: summarizes the potential savings in energy use in buildings resulting from the implementation of green roofs.

Savings category	Amount of saving per sq. m. of green roof area
Direct energy savings	4.15 kWh/ sq. m./year
Demand Load reduction from direct energy reduction	0.0023kW/ sq. m. peak

Before the economic benefits from building energy savings can be determined it is necessary to establish the cost of energy. The cost of electricity was calculated, which is predominantly used to run equipment that cools buildings, to be $0.1017 per kWh. Based on annual energy savings of 4.15 kWh per sq. m., the city-wide implementation of green roofs would result in savings of $21 million per year.(Banting, 2005)

4.2.10.5 Urban heat island

Public benefits from a reduction in the urban heat island effect have previously been estimated by Acks (2003) as well, assuming air temperature is lowered by between 0.1 to 1.5 degrees Fahrenheit with the addition of 50% green roof infrastructure. Cooling was assumed to be necessary for temperatures above 65 degrees, and green roofs play a role in lowering temperatures by 0.1, 0.8 or 1.5 degrees thus reducing energy demand in summer by 0.7%, 5%, and 10%, respectively.

4.2.10.6 Stormwater flow reduction

Capital expenditures and operating costs for wastewater treatment in combined sewer areas and stormwater treatment in separated sewer areas are typically assumed to be lessened by the rainfall captured by green roofs. Acks (2003) assumed that a green roof would capture 20%, 50% or 80% of the rainwater that fell on it, which was multiplied by the land area of New York City greened in his scenario (4%) and a scale factor (90%) to generate a percentage reduction in water entering the sewer system. In this way, capital expenditures were reduced by between 0.6% and 3.4% in stormwater treatment.

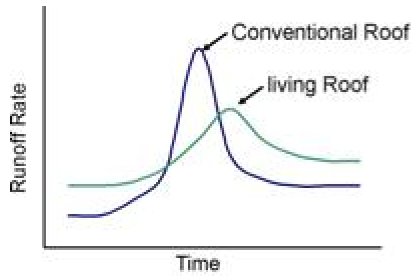


Figure 21: Living roof lower the discharge of rainwater (Truett, 2003a)

4.2.10.7 Air pollution and greenhouse gas effects

Green roofs are expected to have positive benefits for air quality and from greenhouse gas reductions. Airborne particulate, nitrogen oxide, ozone, sulfur dioxide, and carbon monoxide levels have been assumed to decrease in the presence of green roofs. Based on a Toronto study (GRHC, 2003), Acks (2003) assumed that greenhouse gas reductions would be proportional to population and used a value of $20 per ton, or $0.18 per square foot. Airborne particulate matter was assumed to be reduced by 0.04 pounds per square foot of green roof, with a value of $2.20 per pound or $1.43 per square foot, and reductions of other air pollutants were valued at 10% to 30% of particulate matter reductions.

4.2.10.8 Aesthetic benefits

The presence of a green roof can confer an amenity value to both the private owner (through potentially higher property values) and society as a whole (through public enjoyment of the green space). Aesthetics, however, are a public good, such that values of this type are not easily captured through market transactions. For example, an owner may be able to charge higher property rents on the building itself, but cannot limit outside individuals (possibly in neighboring buildings) from enjoying the benefits as well. No study to date has specifically examined the impacts of green roofs on property values, although related values have been estimated. The latter have not been used in past green roof cost-benefit analyses, although *ad hoc* benefits have been included by Acks (2003). In that study, a green roof benefits 6 people, who collectively pay the private building owner $170. For public benefits, it was assumed that between 0.85 million and 3.4 million residents of New York City would enjoy the benefits of having half of that city's viable roofs greened, with each resident willing to pay $10, $25 or $50 towards the cost.

4.2.10.9 Job creation

Several authors have suggested that there are job-creation benefits from green roof expansion. For example, Peck et al. (1999) allude to job creation and enhancement in several different markets related to green roof production, installation and maintenance. However, to date there is no indication that green roof projects will lead to reduction in unemployment. In another way, it is likely that job creation in green roof sectors will be offset by job losses in other markets, most notably standard roof material production, installation and maintenance. The Treasury Board of Canada Guidelines (1998); citing an earlier version, recommend CBA adopt the assumption that resources used would otherwise be fully employed.

4.2.11 Cost-benefit ratios and life-cycle cost assessments

Overall, there is considerable variation in the estimated benefit cost ratios and life-cycle costs between green roofs and standard roofs. Wong et al. (2004) provide three estimates, with only the inaccessible extensive green roof being less costly over the study period than a standard roof. Intensive green roofs are estimated to cost 22.4% (accessible intensive with shrubs) or 42.6% (accessible intensive with trees) more than a standard roof. Despite significantly higher initial costs, England et al. (2004) suggest a green roof has a life cycle cost of 17% to 50% of a standard roof. The private benefit-cost ratio found by Acks (2003) for the moderate case is 0.54 (low 0.38 and high 1.85), while the social benefit-cost ratio for a 50% green roof infrastructure scenario is 1.02 (low 0.66 and high 3.87). Further study is required to determine whether private benefits of green roofs do exceed private costs, and whether social benefits exceed social costs (Banting, D. et al., 2005).

4.2.12 Green Roof: Fast Facts

A $4 investment (per square foot) in building green nets a $58 benefit (per sq. ft.) over 20 years:

- Estimated health & productivity benefits: $46
- Operations & maintenance: $8.50
- Energy savings: $5.80
- Emissions savings: $1.20

- Water savings: $0.50

Tenants can save about 50 cents per square foot each year through strategies that cut energy use by 30%. This can represent a savings of $50,000 or more in a five-year lease on 20,000 square feet (U.S. Environmental Protection Agency, 2007).

4.2.13 Green Roof Barriers and Overcomes

Green roofs have more demanding structural standards. Some existing buildings cannot be retrofitted with a green roof because of the weight load of the soil and vegetation. Depending on what kind of roof it is, the maintenance costs could be higher. Green roofs also place higher demands on the waterproofing system of the structure both because water is retained on the roof and due to the possibility of roots penetrating the waterproof membrane. "However a sedum covering doesn't need water to be retained on the roof as these plants can tolerate long periods without rainfall, so a drainage layer will combat this particular problem" (Alcazar and Bass, 2005). Installing adequate waterproofing systems and root barriers can increase the cost of the roof.

However, there are some other barriers which should be addressed.

4.2.13.1 Cost

As with any other building activity, there are costs associated with green roofs. Depending on the roof type, the structure of the building and including material and labor, green roofs cost between 5 to 35 dollars per square foot (Ngan,G., 2004). The question is whether the benefits outweigh the costs. It is important to separate intensive green roofs from extensive green roofs. Intensive roofs will have many requirements and extra costs associated with them but they are usually selected when the benefits are expected to be great. Similar to a garden or park project, the benefits are often difficult to quantify. A cost-benefit analysis for an intensive roof must be done on a project-by-project basis. Extensive green roofs are less expensive to build and maintain and those with very thin profiles sometimes do not require extra structural support. A cost analysis should take into account the full life-cycle costs, such as the extended lifespan of the membrane resulting from green roof protection. A green roof membrane will not require repairs for 40-50 years whereas a gravel-covered roof needs replacement after 25 years (Krupka, 2001). In Germany, annual stormwater fees also help to offset the green roof investment. When these fees are taken into account, extensive green roofs are often cheaper to build than gravel ballast roofs are. Many of the environmental benefits such as biodiversity and improved air quality for extensive green roofs are also not easily quantified. A tool (*Bewertung von Maßnahmen der Regenwasserbewirtschaftung*) is being developed and tested in Berlin to help developers with cost-benefit analyses which will factor in non-monetary aspects of sustainable design as well as the usual cost-analysis components (Reichmann, 2003). Cost-benefit analyses will convince some owners and developers to build green roofs. Others will need more encouragement or even legislation and this report attempts to assist in developing incentives and policies for this to take place. Another factor for high costs is the limited number of green roof contractors in an area particular. But as the popularity of green roofs increases the price will undoubtedly decrease. Vegetation can extend the life of a roof, because less solar energy reaches the roof substrat, limiting the damage from UV radiation. Daily temperature differences are decreased and money is saved by using less energy in heating and cooling the building (Ngan,G., 2004).

4.2.13.2 Repairs

The argument that repairs are more difficult on a green roof is partially justified. While it is costly to remove and replace green roof components, deficiencies can be avoided. They generally arise from faulty workmanship, faulty design, lack of or incorrect maintenance and occasionally from material failure. Extra vigilance is required at all stages. Green roof membranes have high technical requirements similar to accessible roof surfaces such as terraces (Krupka, 2001). They cannot be compared directly to conventional roof membranes. Finding leaks is difficult for both green and conventional roofs because the place where water appears rarely corresponds to where it enters. The cause of the leak is first sought at edges and roof penetrations before looking under the main surface. There are search instruments that can precisely pinpoint the location of a leak using electro-impulse, such as electric field vector mapping (EFVM), which can rapidly and accurately pinpoint even minute holes. This system is more reliable than the older flood testing method; need not be installed in advance, and can even be used on steeply-sloped surfaces. Repairs to the waterproofing are typically quick, and disturbance of the green roof is minimal. It is important to note that, leaks in living roofs are less common than conventional roofs because of the physical and UV protection of the plants and soil media (Truett, 2003). Buildings with sensitive uses, such as archives or computer rooms, can be outfitted with leak sensors. In the case of single-course construction, the substrate can be re-used and normally additional planting is not necessary.

4.2.13.3 Aesthetic

Beauty is in the eye of the beholder and some may argue that extensive green roofs look messy and are not even green. The appearance of extensive green roofs should not be compared to lawn and traditional gardens. Extensive green roofs have a natural appearance that changes with the seasons. They are more similar to dry wildflower meadows and develop much in the same way as natural ecosystems (Ngan,G., 2004). The City of Portland prefers the term "ecoroof" because it emphasizes the ecological function over the color green (Hauth and Liptan, 2003).

4.2.13.4 Lack of Expertise

Public opinion, whether based on fact or not, is a key factor in the support that green roof technology will have in the future. An inventory of green roofs in the Greater Vancouver Regional District found that people were mistakenly associating green roofs with the leaky condo crisis (Davis, 2002). It is interesting to look at the development of the green roof industry in Germany. Robert Herman (2003) explains that "in hindsight, the major factor contributing to the public's impression that green roofs can be problematic was the failure of many green roofs installed during the initial green roof construction boom. New, inexperienced companies simply made mistakes or installed poor quality, cheaper materials and "cut corners" in order to keep costs down. This form of negative advertising adversely affected the entire industry. The FLL guidelines are mainly responsible for reversing the downward spiralling reputation of green roofs."

This observation is similar to that of Rudolf Gix (2003) who reported that during reunification in the early 1990's, many commercial companies built outlets in the new states (former East Germany). Because this building surge tended to occur on previously undeveloped sites, the companies wanted to make a good environmental impression by building voluntary green roofs. Tengelmann and Aldi were among the supermarkets that tried green roofs on their 40-80,000 m² per project roof surfaces. Unfortunately, a lack of technical expertise and insufficient budgets resulted in deficient green roofs. The news of the poorly constructed green roofs became public and many companies stopped building them.

4.2.13.5 Lack of Research and Standards

A significant barrier now is that green roof has neither detailed design guidelines, standards that are integrated into local building codes, nor procedures for testing materials and new products. However, this shortfall is being addressed in several places throughout North America. The results of scientific research will soon be able to provide a basis for the development of standards. The

German FLL guidelines provide a source of information for the interim but they should be evaluated for their application to local building practices and climates in Building codes for specific climate and location, and may need to be updated (Ngan,G., 2004).

4.2.14 Ensuring Proper Long-Term Maintenance

The function or the performance of a green roof needs to continue over time in order for the benefits to be realized. Therefore, the green roof must be properly maintained. Municipalities can ensure maintenance with spot checks (e.g. every two years) or they can require maintenance invoices to be submitted. (Ngan,G.,2004).

4.3 Potential Green Walls Benefits

4.3.1 Reduce energy consumption

During summer, hot walls cause temperature to rise inside buildings increasing demand on cooling systems and consuming more energy. A Green Wall surface temperature is reduced by up to 10°C when covered with plants and moist soil. In 1979, Green Wall research by Akira Hoyano (Professor, Tokyo Institute of Technology), a pioneer in passive and low-energy architecture, revealed that the heat energy that passed through a Green Wall was significantly lower than a concrete wall (see below graph).

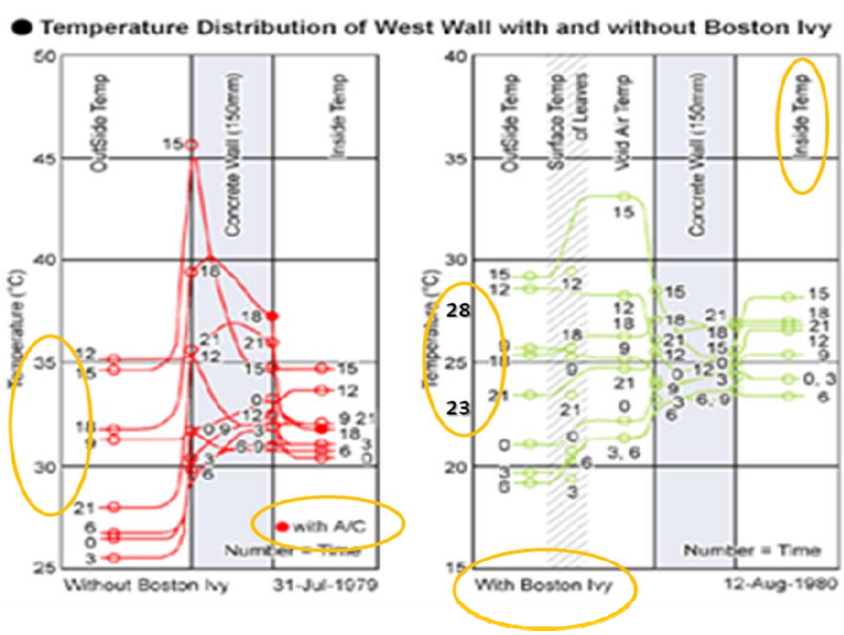


Figure 22: Temperature distribution of West wall with and without Boston Ivy. (Yamada,

4.3.2 Reduce Heat Island Effect

The Tokyo City Government recently undertook a study to measure the effects of Green Walls on the Heat Island effect, and in essence, to confirm Professor Hoyano's earlier findings. They not

Figure 23: Reduce heat island effect. (Yamada, H., 2008).

only confirmed the findings, but they were able to derive the significance of Green Walls in cooling buildings and combating the Heat Island Effect (Yamada, H., 2008).

4.3.3 Reduce Heat Gain

With the Green Wall tests shown here, it was discovered that Green Wall panels reduce the wall temperature by 10°C as seen in the graph below. It was also concluded that Green Wall panel reduce energy transfer into a building by ~0.24kWh/m^2. This is approximately 60% less than that of a Green Roof. The above calculations can be used in the same manner; however, Green Wall energy savings calculations depend greatly on the direction the wall is facing, the sun's angle in the local region, and many other factors that make calculating Green Wall energy savings complex (Yamada, H.,2008).

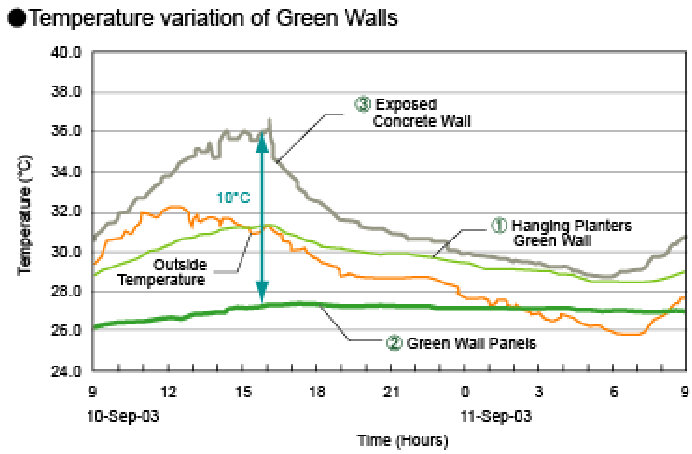


Figure 24: Temperature variations of Green walls. (Yamada, H., 2008).

4.3.4 Sound Insulator

Green wall will act as a sound insulator for the building. It worked as a barrier for noise, dust and protect the wall as a shell.

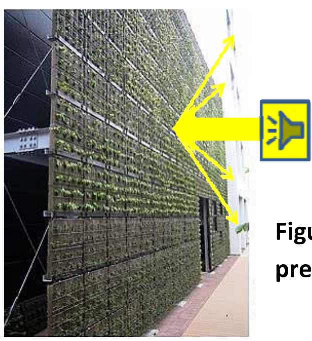


Figure 25: Living wall worked as a 'Shell', help prevent sound pollution. (Jacobs, 2008a).

4.3.5 Prevent Bird kill

Green façade or green exterior wall can prevent a noticeable number of bird kill every day. During the two annual migration periods, the resident bird population experiences a significant influx of migratory birds. Most migratory bird species are unable to adapt to living in cities. During their biannual flyovers they become confused by the combination of light pollution and the effects of glass in the urban environment. This often results in significant numbers of birds colliding with buildings. From 100 million to 1 billion birds are annually estimated to be killed striking clear and reflective windows in the U.S. The yearly death toll is in the billions worldwide (Klem, 2004). Observations and experiments over more than 30 years have revealed that birds act as if clear and reflective panes are invisible. In daytime strikes occur because birds cannot perceive images reflected in glass as reflections, and thus will fly into windows that they think are trees or sky. Clear glass also poses a danger as birds have no natural sense designed to perceive clear glass as a solid object. Birds will strike clear glass while attempting to reach habitat and sky seen through glass façade. The impact of striking a reflective or clear window in full flight often results in death (Klem, D. and et al., 2007).

Figure 26: While the photographer was watching this building an American Crow ran into it at about the 15th story. The flat glass mirrors the moving clouds perfectly.

Figure 27: The reflection of sky is so strong here that the window washers reported birds flying into the buildings all day long.

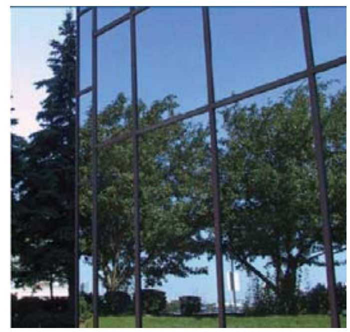


Figure 28: Habitat reflected in untreated reflective glass is an extreme hazard for flying birds. Green wall would make the building bird-friendly. Photo: FLAP

Source: Klem, Daniel Jr., 2004

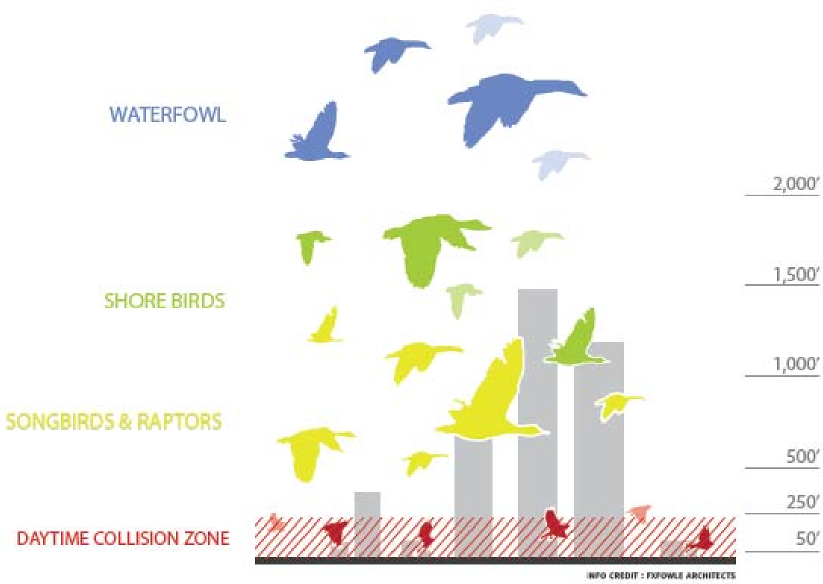


Figure 29: The collision zone of migrating birds in urban areas. (Klem, Daniel, and et al., 2007).

The most hazardous areas of all buildings, especially during the day and regardless of overall height, are the ground level and bottom few stories. Here, birds are most likely to fly into glazed facades that reflect surrounding vegetation, sky and other features attractive to birds. Radar tracking has determined that approximately 98% of flying vertebrates (birds and bats) migrate at heights below 500 meters (1640 feet) during the spring, with 75% flying below that level in the fall. Today, many of the tallest buildings in the world reach or come close to the upper limits of bird (and bat) migration (Klem, Daniel, 1990). Any building over 500 feet tall then approximately 40-50 stories is an obstacle in the path of avian migration and must be thoughtfully designed and operated to minimize its impact.

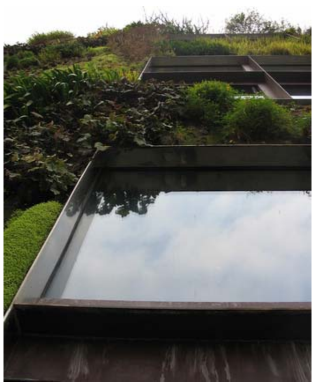


Figure 30: Vegetated Green wall will reduce the reflecting glass surface. (Klem, Daniel, 1990).

The vegetated green wall should be the better solution for theses bird's kill. The vegetation will cover the reflecting glass considerably protect the birds from death. On the top of that these walls will provide them a place to rest whiles their migration.

4.3.6 Ecological Preservation and beautification

Keeping in step with practical and ecologically sound planning, native plants and drought tolerant plants are considered great vegetation choices for green walls, native plants providing habitat restoration and a food source for local birds and butterflies, and drought tolerant plants conserving valuable water. Green walls can even sustain vegetable growth, including the growing of lettuce, herbs, beets, tomatoes, strawberries, radishes & carrots. Green walls utilize soil, or a special inorganic growing medium which works with fertilizer, holds adequate water, and allows the roots to receive plenty of air. The growing medium is perfectly capable of sustaining hydroponics systems (www.eltlivingwalls.com). Living wall also have the Possibilities for habitat preservation and protection of flora and fauna, as it replaces land taken by buildings and thereby contributes to preserving biological diversity. It thus increased urban habitat for song birds and butterflies. Its movement, color, sound and texture of plants add to the overall health and well being of citizens, beautifies barren eyesores of our cityscape and provide unique opportunities for design and creativity as well health and horticultural therapy applications (Jamison, Rachael, 2005). Thus the community overall have benefited from the environmental improvements by these green walls.

4.3.7 Precaution and maintenance for green wall

In the living walls, the plants are rooted in between two sheets of fibrous material, allowing water to trickle through and feed the moss, vines, etc. There are different levels of these living walls, according to Yamada, (2008): "Second-order walls contain only plants and some insects, while third-order walls house fish and salamanders in a pool at the bottom of the wall, where the trickling water is captured before being filtered and re-circulated to the top again." For both green façades and living walls, climbing plants can be selected that do not bear fruit or provide a food source. Also, property managers prefer closely cropped vegetation to discourage shelter or nesting sites for birds. Any excessive growth or dead wood should be removed, and standing water should be avoided. A continuous gravel strip at the base of the building is recommended (Sharp,R., 2007).

4.4 Potential Biofilter Benefit

US Environmental Protection Agency (EPA) places poor indoor air quality fourth on a list of 31 largest environmental threats in the US, affecting nearly 25% of US residents, either at the workplace or the home. These pollutants can be as diverse as toxic chemicals emitted from building materials and furnishings, combustion pollutants like carbon monoxide and toxic particles, and biological contaminants such as moulds and bacteria (Darlington, A., 2008). During all seasons, occupants inside offices and homes alike are suffering from dry air - from cracking skin to coughing and congestion from people with whom they share the space. Actually, these are some common symptoms described by the U.S. Environmental Protection Agency which are indicators of Sick Building Syndrome (SBS). Other more severe indicators include: dizziness and nausea; difficulty in concentrating; fatigue; and sensitivity to odors (http://epa.gov). Multiple sources contribute SBS to having a direct relationship with indoor air quality (IAQ). Buildings, especially newer construction, are built to be air tight to provide a comforting environment with heat and air conditioning. The adverse result is the lack of air circulation and proper filtration. Inadequate ventilation is also a result of HVAC equipment that is either outdated or lacks sufficient means to distribute air (Jacobs, H., 2008b). The following are deemed by the EPA as the leading causes of SBS: inadequate ventilation; chemical contaminants from indoor sources; chemical contaminants from outdoor sources; and biological contaminants (Ibid). The active Living Walls systems use the natural strength of nature's purification processes. They address indoor-air quality problems and significantly improve the performance of HVAC systems (Darlington, A., 2008).

4.4.1 Removes Pollutants from Indoor Air

With over eight years of research at the University of Guelph, there is significant data on the effectiveness of Living Wall biofilters in improving indoor air quality (Darlington, A., 2008). The indoor environment is a complex soup of over two hundred different chemicals. These compounds arise from the off-gassing from the furniture, building materials (fabrics, plywood, paints and rugs), and the activities within the space. Many of these chemicals (commonly referred to as volatile organic compounds or 'VOCs') are known to cause cancer. All will greatly reduce the well-being of the occupants if allowed to accumulate unchecked. The quality of the indoor environment has been identified by the EPA as one of the five top health issues currently being faced (Truett, Rick. 2003b). During studies at the University of Guelph, the researchers released into the wall very low concentrations of some common indoor pollutants to measure the system's potential as a filter. The chemicals were formaldehyde, toluene and trichloroethylene (TCE). These were selected to represent the wide range of chemicals with which the system would need to deal. Formaldehyde is very soluble in water and readily metabolized by bacteria and higher plants. Toluene is slightly soluble and degraded by a select microbial population. TCE is relatively insoluble and resistant to biological degradation. A single pass through the Living Wall removed up to 80% of the formaldehyde, 50% of the toluene and 10% of TCE, which is incredibly impressive for a 5 cm thick filter. Concentrations of toluene and formaldehyde in the aquatic system did not increase during the four-week experiment, suggesting that these materials were readily metabolized. TCE levels in the aquatic system initially did increase slightly, but then plateaued, suggesting a possible capability to degrade this compound because two to three percent of the bacteria present had the ability to break down VOCs (Darlington, A., 2008).

4.4.2 Reduces HVAC Energy Consumption

The traditional supply of good quality outside air to the indoors frequently requires heating or cooling of this air to meet the needs of the occupants. The conditioning of this airflow represents 10-20% of the total building's energy usage under normal operating conditions. Supplying an adequate indoor temperature is the single most energy intensive process in the building. As a consequence, many buildings may not be delivering enough outside air to the occupants. This can lead to a decrease in the air quality and the well-being of the occupants (Darlington, A., 2008). Biofiltration of the air circulating within the building is an alternative means of refreshing the indoor air without having to bring new expensive outside air into the building, leading to substantial energy savings without sacrificing air quality.

4.4.3 Retrofit Biofilter system

Biofilter can be retrofitted into an existing HVAC system; in that case coordination with mechanical engineers is required to maintain appropriate balancing of air flows within the existing infrastructure. The biofilter can also be installed as retrofit with its own ductwork to distribute filtered air throughout a building without direct integration to existing systems. And the simplest retrofit system will discharge filtered air out the top of the biofilter to diffuse naturally in the room without any ductwork at all.

4.4.4 Provides Dramatic Aesthetic Amenity

The biofilter will have the general impact of greening the indoor space. Greening the indoor space has a substantial impact on the psychological well-being of the building occupants. In a two year study at an Oslo office building, Professor Fjeld found that a 20% reduction in fatigue levels and a 30% reduction of headaches occur after the greening of the indoor space (Darlington, A., 2008).

4.4.5 Provides Equivalent Outdoor Air Exchanges

Traditionally, the build-up of VOCs is avoided through ventilation. This is achieved with energy recovery ventilation systems (ERVs) that introduce new 'fresh' outside air into the building to dilute the accumulating indoor contaminants. The conditioning of this additional flow of air can be very expense. It must be heated or cooled (depending on the season) prior to distribution in the building. The cost of operating the biofilter is more than offset by the energy savings of reduced air exchanges to the outdoors. Further, according to Darlington (2008), ventilation does not solve the problem of the pollutants; instead it simply releases the pollutants to the outdoor where they become "someone else's problem". Biofilters provide a natural purification of indoor air within the system.

4.4.6 Adds Oxygen

As commonly understood, plants take up carbon dioxide and give off oxygen providing a wonderful symbiotic relationship with humans. However, the volume of plants required to significantly benefit human occupancy far exceeds practical limits. In other words, a forest of plants would be needed to provide the oxygen consumed by occupants in an average sized building. The objective of the living wall is to remove the toxins from the air; it effectively removes VOCs from the indoor air at a great leverage ratio. Approximately 1 square foot of vegetated wall area will filter the air for approximately 100 square feet of office area (Truett, R., 2003b).

4.4.7 Create economic benefit

Estimates have placed the annual impact of poor indoor air quality on worker productivity in the USA to be between 20 and 200 billion dollars. Twenty percent of all absenteeism is directly related to poor indoor air quality. Sick building syndrome alone has been quoted as costing the American economy between $15 and $40 billion dollars per year (Truett, Rick. 2003b). The biofilter will reduce indoor VOCs and other compounds that are linked to poor air quality and sick building syndrome. Although difficult to quantify, several studies indicate that plants reduce the stress levels of occupants. Professor Lohr at Washington State University demonstrated that the inclusion of plants in computer classrooms reduced the stress levels and led to a 12% increase in the productivity of the students. Professor Fjeld demonstrated that the inclusion of green plants in a Radiology Unit in Oslo, Norway led to a measurable improvement in the work environment which manifested itself as a 5 to 15% reduction in absenteeism (Darlington, A., 2008).

4.4.8 Potted plants vs. Biofilters

While potted plants do provide numerous benefits, they do not remove indoor air pollutants as like Biofilters because it is not the plants themselves, but rather the microbes inhabiting the rhizosphere surrounding the roots of the plants that do the work (Truett, Rick. 2003b). The method of planting plants in a biofilter system increases microbial populations over that found in bare soil, and the mechanical design of the system brings indoor air in contact with these microbes in order to achieve biofiltration and phyto-remediation. Also, the plants species affects the composition of its associated microbial population, and therefore careful selection of plants species promotes desirable VOC-degraders. Many plants produce antibiotic compounds that may actually inhibit biological activity (Darlington, A., 2008).

4.4.9 Some shortcomings of Biofilter

4.4.9.1 Generation of noise

The system generates Noise for a little to none, depending on how it is configured. The airflow through the system is very quiet. The water circulation pump may emit some audible sounds depending on how it is configured, whether it is submerged or in-line (Truett, Rick. 2003b).

4.4.9.2 Require direct Sunlight

Though direct sunlight is not required but preferred for Biofilter. The plants are growing hydroponically with air being drawn across their root mass. The plants compensate for this stressful environment by seeking plentiful light. At a minimum, the wall requires 12 hours of light. Natural light is preferred, but if not provided through skylights and windows, supplemental light can be provided with appropriate fixtures and scheduled routines for flooding the plants regularly (Truett, Rick. 2003b).

4.4.10 Future possibilities

The system does not provide for cooling or humidification currently, but this appears potentially feasible. The plants are very tolerant of wide fluctuations in water temperature. Thus, if the water is chilled below the dew point in summer use, humidity in the air will condense when passing through the wall enabling the wall to provide dehumidification when in cooling mode. The reverse is possible in the heating mode. It is conceivable that the biofilter could provide either humidification or dehumidification as needed (Truett, Rick. 2003b).

4.5 Benefits of Indoor Planting

Interior landscaping has become increasingly popular during the last 30 years. Most architects now include plants in their design specification for new shopping centers, office complexes and other public areas, and people expect to see when they walk through the door. Thus plants became such important building accessory. The main reason of indoor planting is, they look attractive, and they charmed people by their graceful arch like palm leaves or the exotic beauty of orchids. However, recent research has shown that the value of plants goes far beyond the purely aesthetic. Plants are actually good for the building and its occupants in a number of subtle ways and are an important element in providing a pleasant, tranquil environment where people can work or relax.

4.5.1 Noise reduction

Plants can be used to decrease noise levels in an office. According to Green Plants for Green Buildings, if plants are placed strategically, they can help to quite down the office. A small indoor hedge placed around a workspace will reduce noise by 5 decibels (Jacobs, 2008b). Along with decreasing noise levels, there is more benefit to adding green plants to workplaces.

4.5.2 Increase of productivity

The presence of plants in the office not only aesthetically pleasing but also helps increase workers productivity, reduce stress and improve air quality. According to a Texas A&M University and Surrey University study, participants also reported feeling more attentive when plants were present.

As per Jacobs, (2008b), participants who worked in an environment with plants were 12% more productive and less stressed than those who worked in an environment with no plants.

4.5.3 Reduce sickness absence

Sick Building Syndrome is a term used to describe buildings where there are high levels of complaints about the indoor environment. Absence from work cost British business £11.8 billion in 2002. Job dissatisfaction and low morale can be prominent factors in short-term absence and could account for as much as 15% of all reported sickness absence. Employers can tackle this most easily by re-examining people management policies and the working environment, to see what can be done to improve staff productivity and well being. If companies with the worst absence rates could meet average levels, the UK economy would be £1.9 billion better off (King, 2009). The humble plant may be part of the solution. There is now a wealth of evidence to show that putting plants in buildings can significantly reduce absence from work. Professor Tove Fjeld of the Agricultural University in Oslo, Norway carried out several conclusive studies regarding health claims relating to Sick Building Syndrome among workers. It was found that the score sum, as a mean of 12 symptoms, was 23% lower during the period when the participants had plants in their offices (mean score sum was 7.1 during the period without plants, vs. 5.6 during the period with plants (P=0.002)). If the symptoms were clustered, a significant reduction was obtained in neuro-psychological symptoms and in mucous membrane symptoms, while skin symptoms seemed to be unaffected by the plant intervention (Fjeld et al. 1998). Data from the study can be found in the table below.

AILMENT	% REDUCTION
Fatigue	20%
Headache	30%
Sore/dry throats	30%
Coughs	40%
Dry facial skin	25%

Figure 31: Recorded Health Improvements after the introduction of Interior Plants. (Fjeld et al. 1998).

It isn't necessary to fill every available space with a plant to achieve this; just a few good-quality specimens located near to where people work and take their rest breaks seem to suffice. The reasons why this has a beneficial effect are probably a subtle but complex mixture of the physiological (improved humidity, reduced noise etc.) and psychological. Being around plants certainly seems to reduce stress and engender a feeling of well-being in most people, a benefit that is even more acute if correct lighting is in place. The fact that the employer has been prepared to spend money on something that has no obvious function other than to make the workplace more attractive may also be a contributing factor, by sending a signal to staff that management cares (Wolf, 2002).

4.5.4 Improve indoor environment quality

Plants can also improve the indoor environmental quality. Research from the Environmental Laboratory of John C. Stennis Space Center in Mississippi showed that rooms with plants contain 50% to 60% fewer of airborne molds and bacteria than rooms without plants (Wolf, 2002). The plans clean the office air by absorbing pollutants into their leaves and transmitting the toxin to their roots, where they are turned into food for the plant. With cleaner office air building occupants are less likely to be sick, thus increasing productivity and decreasing absenteeism. In buildings where sick building syndrome is common, employees should each have a plant within 6 to 8 cubic feet of where they spend most of the day (Jacobs, 2008b).

4.5.5 Staff pressures / recruitment / retention

In an economic climate, such as that which exists in the UK (and the South East of England in particular) where there is real difficulty in recruiting and retaining well-qualified staff for knowledge-based businesses, Wolf, (2002) mentioned the quality of the working environment becomes much more important than it did a decade or more ago. Office workers now expect high quality workspaces and are beginning to 'interview the building' when considering where to work. If companies wish to attract high quality employees, then they have to provide a good working environment for them.

4.5.6 Government pressure / incentives

In most locations, the development of green buildings is driven by the factor which is actively encouraged by government. Canada is perhaps the best example so far. The Canadian Government's Commercial Buildings Incentive Scheme awards up to Cdn$60,000 to developers that satisfy certain green building standards (mainly relating to heat, light and water management). In Australia, the government of South Australia is attempting to lead by example and have stated that all new office buildings that they occupy will have a 'Green Star' rating of at least 5 stars. Australia also has a number of funding opportunities to encourage developers to reach 'Green Star' standards (Jacobs, 2008a).

4.5.7 Other positive impacts of planting

Here are some of the ways that interior plants can help.

4.5.7.1 Alternatives to manufactured/engineered solutions to building problems

Plant displays are usually significantly cheaper than manufactured items, employ fewer resources in their establishment and can fulfill more than one function. Plant displays can be especially useful space management aids in commercial buildings as they form natural screens and partitions, ideal in open plan settings. They help guide people around a space, whilst at the same time reducing noise, collecting dust, humidifying the air and removing some pollutants (Freeman, K., 2007).

4.5.7.2 Reducing demand on the water supply

Rain water is a free resource, which can be collected from the roofs of commercial buildings and used to water interior and exterior plant displays. Grey water (water that's already been used once, for instance to wash hands or dishes), once treated and recycled for re-use where drinking quality is not required, can also be used to water plants (Freeman, K., 2007). Additionally, interior and exterior plant displays can be fitted with water-efficient subterranean irrigation systems and planted with species with a low water requirement.

4.5.7.3 Cooling

One of the benefits of interior plants is that they help cool the air around them through the process of evapotranspiration (the movement of water from the soil, through the plant and into the atmosphere). Large interior plants are also very good reducing temperature through shading. Both of these benefits are especially effective in tall buildings where atrium planting is often employed to help with temperature regulation (Freeman, K., 2007).

4.5.7.4 Improvements in indoor air quality

Research carried out in the USA has demonstrated that plants attract more than their fair share of dust. Particulate levels (including airborne spores) can be reduced by as much as 20% in some situations (Freeman, K., 2007). This could lead to a reduction in the use of air cleaners (although not their replacement) and an improvement in indoor air quality. There is also a body of recent research from Australia and the USA that shows that interior plants are effective at removing a range of pollutants at relatively low planting densities in real office situations (Jacobs, 2008a).

4.5.7.5 Improvements in well-being

Studies in Europe have shown that health complaints at work and symptoms associated with Sick Building Syndrome (SBS) can be dramatically reduced by the addition of good plant displays. Office buildings with large floor areas and deep plans (e.g. low and wide buildings) are seldom 'green' buildings as they can be difficult to ventilate naturally and there is limited access to natural light and views. Good interior landscaping can give people access to an indoor garden or views of vegetation, especially if there is an atrium or other large space, and the combination of plants and artificial daylight can help overcome the problems of lack of access to natural daylight (Freeman, K., 2007).

4.5.8 Some drawbacks

One problem is the care of the plants; this must be carried out regularly. Plants must be monitored for pests, and if any are found, beneficial organisms introduced. This requires a certain knowledge which is often not available. Plants must be cut back, watering devices regularly checked, and the fertilization necessary must be expertly carried out. Instruction must be provided on the care of plants so that they remain attractive and able to function in the long-term.

4.6 Summary

Here are some of the outcomes are highlighted from the literature reviews which needs to be considered for the benefit of planting in the buildings.

4.6.1 The environmental benefits of green buildings

Buildings have been shown to produce more than 40% of global carbon dioxide emissions, an important green house gas (GHG) that contributes to global climate change. Green buildings can reduce carbon dioxide emissions by 35%, compared to traditional buildings. Furthermore, green buildings can reduce energy use by 30-50%, reduce waste output by 70%, and reduce water usage by 40%. (World Green Building Council).

4.6.2 The optimal use of plants

So the optimal use of plants from an energy point of view can be summarized as follows. Two studies in 2001, and 2003 shows that living roof can reduced cooling loads by 50% to 75 % [Onmura et al. (2001),Liu and Baskaran (2003)]. Another study in California shows that average savings in air conditioning usage per Square Foot is = 46.75 ¢ . Thus, a 1000 ft^2 Extensive Green Roof can save = $467.50 / year (Yamada, H. 2008). A Canadian study, by Liu and Baskaran (2003) shows that, from the total solar radiation absorbed by the planted roof, 27% is reflected, 60% is absorbed by the plants and the soil and 13% is transmitted through the soils. Green roof reduce surface water runoff by 70 to 90% in summer and 40 - 50% in winter. Irrigated green roofs produce a cooling of 2°C and extend the 1°C over a larger geographic area. Green roofs can also reduce indoor sound penetration about 40 decibels by absorbing, reflecting, or deflecting sound waves. (Truett R., 2003a). Another study shows that green amenities add 15% to 20% to a buildings value. (Truett R., 2003a). An estimation by EPA shows a $4 investment (per square foot) in building green can give a $58 benefit (per sq. ft.) over 20 years. For the green wall, a study by Professor Hoyano (1979) shows that Green Wall panels can reduce the outer wall temperature by 10°C and the indoor temperature by 7°C, from 30-35 degree centigrade to 23-28 degree centigrade. The Retrofit Biofilter system cleans the air, can reduce HVAC Energy Consumption by 10%-20% for an average room area and thus trim down cost. It also creates economic benefit by reduced absenteeism by 10 per cent and increased productivity by 12 per cent. 1 sqm of active living wall purifies 100 sqm of floor space, for a typical room pollution loads. For indoor plants, a study shows that after introducing indoor plants in an office area, headache reduced by 30% and productivity increased by 12% (Fjeld et al. 1998). Rooms with plants contain 50% to 60% less of airborne molds and bacteria than rooms without plants. (Wolf, 2002). A small indoor hedge placed around a workspace will reduce noise by 5 decibels. (Jacobs, 2008b). So, in buildings where the sick building syndrome is common, each employee should have a plant within 6 to 8 cubic feet of their sitting area. . (Jacobs, H., 2008b).

4.6.3 Additional way of energy savings

In addition of plants, energy saving aspects can be improved by cautiousness of the people for using energy. The lights and air-conditions should be turned off while leaving the room. Motion-sensor lights can be used in the rooms and restrooms especially for public buildings. Solar panels can be mounted on the roofs and outer walls where plants are not incorporated. For example, a greenhouse made with solar panel sheets can be placed at a rooftop garden and the window glasses can be made of such panels which in addition will produce energy. Building orientation with the respect of solar angle and wind flow direction can utilize the natural ventilation, lighting and heating thus can reduce a significant amount of energy use and cost.

4.6.4 Obstacles for integrating plants

As per the literature reviews, the summary of obstacles and barriers for planting are pointed here. A Green Roof is initially costly for its more demanding structural standards, water proofing system and long-term maintenance, but it is cost effective over a time period. Green Walls often require maintenance. The excessive growth or dead wood may cause some problems of overloading so needs to trim down regularly. Standing water should be avoided, so a continuous gravel strip at the base of the building is recommended. Biofilters may generate some noise by the water circulation pump. For the plants of biofilter, 12 hours of natural or artificial light is preferred, it also requires regular maintenance and pest control. The system does not provide for cooling or humidification currently, but this appears potentially feasible. So, more research is needed on this aspect. Indoor Planting needs regular care for watering, pests and fertilization.

4.6.5 Differences for building green in the different parts of the world

Building green for different parts of the world should vary a little extent. First of all the available plant species, recommended plants for green roof, wall or indoor will vary for different climatic and geographical regions. Therefore native plants should be retrieved for using in green design. It will reduce cost, maintenance and increase longevity. In terms of energy savings, the amount of saved energy could also vary for different area. For example in a hot desert region the green building could save comparatively more energy than from a cold region and thus the cost. For the cold countries, deciduous plants should be selected which drop leaves in winter so that the building gets enough sunlight for its natural heating. Thus will reduce load on building's heating system.

5 Chapter 5: Technologies to incorporate Green into Skyscraper

This section will provide the types of green roof, green wall, and biofilter according with their installation technology. The name of typical plants used for green roof, green wall, biofilter and in indoor will be cited as the examples.

5.1 Green Roof Design Technology

In describing Green Roof Technology of the last 10 to 15 years, Dunnett and Kingsbury (2004) find two approaches: extensive and intensive systems depending on the plant material and planned usage for the roof area. Intensive green roofs use a wide variety of plant species that may include trees and shrubs, require deeper substrate layers, are generally limited to flat roofs, require 'intense' maintenance, and are often park-like areas accessible to the general public. In contrast, extensive roofs are limited to herbs, grasses, mosses, and drought tolerant succulents such as Sedum, can be sustained in a substrate layer as shallow as 2.0 cm (1.5 in), require minimal maintenance, and are generally not accessible to the public. The highest density of green roofs occurs in Germany, widely considered a leader in green roof research, technology and usage, where it is estimated that 10% of all flat roofs are green (Rowe, 2002).

5.1.1 Category of Green Roof Design

Green roof systems can be categorized as follows:

- Complete systems where all different components including roof membrane are an integral part of the whole system;
- Modular systems that are positioned above the existing roofing system;
- Pre-cultivated vegetation blankets that consist of a growing medium and plants that are rolled onto the existing roofing system with drainage mats and root barriers as required.

Variations between systems are generally found in the manner in which growing medium and drainage layers are treated (Banting, D. et al., 2005).

The following are the common green roofing systems used in recent years in North America:

1. Sopranature by Soprema.
2. Garden Roof by Hydrotech developed in conjunction with ZinCo GmbH.

3. Easy Green by Elevated Landscape Technologies.
4. Pre-cultivated vegetation blankets by Xero Flor Canada.
5. Roofmeadow assembly by Roofscapes Inc. adapted from Optigreen of Germany.
6. GreenGrid System by Weston Solutions Inc. and ABC Supply Co. Inc.
7. Green Roof Blocks by St. Louis Metalworks Company.

In addition there are several green roof technologies available in Europe. Suppliers of these green roof technologies include: GDT Systems International in Germany, APP's Roof Garden Sets in Germany, Bauder's Green Roof System in the UK, and Kalzip's Nature Roof in UK (Banting, D. et al., 2005).

5.1.1.1 Complete systems

Complete systems provide the most flexibility in terms of the type and nature of growing medium and drainage, and protection layers that can be used. These have direct impact in terms of the type of vegetation that the green roof can support. They also generally contribute the greatest amount the structural design load. Sopranature by Soprema, Garden Roof by Hydrotech, and Roofmeadow by Roofscapes fall into this category. Following Figure shows a Sopranature system on a conventional roof assembly (Banting, D. et al., 2005).

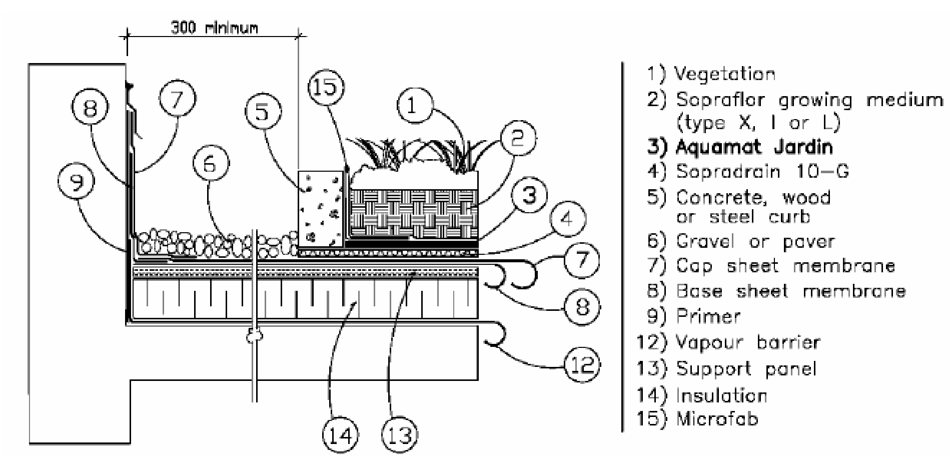


Figure 32: A typical Sopranature green roof assembly on conventional roof. (Banting, D. et al., 2005).

5.1.1.2 Modular systems

Modular systems are essentially trays of vegetation in a growing medium that are grown off site and simply placed on the roof to achieve complete coverage. They are available in different depths of growing medium typically ranging from 75mm to 300mm (3 to 12 inches). GreenGrid and Green

Roof Block systems are examples of modular systems shown in the following Figures (Banting, D. et al., 2005).

Figure 34: Green Grid system. (Adapted from Western Solution Inc.).

Figure 33: Green roof block system. (Adapted from St. Louis Metalworks Company).

5.1.1.3 Pre-cultivated vegetation blankets

Xero Flor Canada and Elevated Landscape Technologies (ELT) offer precultivated vegetation blankets. The following Figure shows photographs of the system offered by ELT. It is a pregrown interlocking green roof tile and in that respect it could be viewed as similar to the modular system. But its thickness categorizes it as a blanket system. It is available in one thickness of about 45mm (1.75 inches), (Banting, D. et al., 2005).

Figure 35: Photograph showing ELT system. (Adapted from Elevated Landscape Technologies)

Xero Flor primarily offers extensive green roof systems. A variety of system designs are available, but perhaps the most versatile system contains 25 mm (1 inch) of planting substrate. The result is a lightweight system ranging in weight from 40 to 60 kg per sq. meter. The majority of the vegetation is made up of several varieties of sedum – a succulent plant (8.0 to 13.0lbs per sq. ft.) that is tolerant of extremes in temperature and that survives with little or no irrigation while requiring very little maintenance. Most Xero Flor systems are cultivated at ground level, then rolled-up and transported as a complete system on pallets or by crane (Banting, D. et al., 2005).

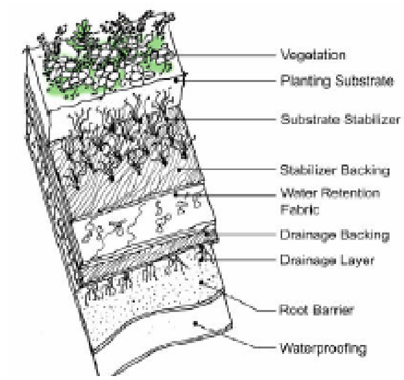


Figure 36: Xero Flor System installation and cross section. (Adapted from Xero Flor Canada).

5.1.2 Extensive verses Intensive green roof design

As cited before the main two types of green roof commonly used is extensive and intensive green roof. The details about these two types are described here.

Figure 37: Intensive green roof

Figure 38: Extensive green roof

Figure 39: Intensive green roof

Figure 40: Extensive green roof

Extensive green roofs are shallow (less than 6"), unirrigated, light-weight at 15-50 pounds (7-23 kilograms) per square foot , roof covers offer low cost and low maintenance with high performance value. Extensive living roofs are typically planted with sedums, low drought tolerant ground covers that thrive in a shallow, rapidly draining growth media and are resistant to harsh rooftop conditions. Sedums come in numerous varieties and can provide beautiful contrast of color and texture. Extensive green roofs usually exist solely for their environmental benefits and don't function as accessible rooftop gardens (Truett, 2003a).

Intensive living roofs are made with deep soil (greater than 6") and greater organic content to support broad variety of plant varieties. Design variations are practically limitless. Most any garden that can be created on the ground can be created on a rooftop, including such elements as trees, shrubs, walkways, patios, ponds, etc. The foot or more of growing medium needed for an intensive green roof creates a load of 80-150 pounds (36-68 kilograms) per square foot. Possibilities are only limited by overall weight of the system and its effect on the cost of the supporting construction (Truett, 2003a).

5.1.2.1 According to Construction Options

Figure 42: In-Situ

Figure 41: Modular

Extensive living roofs of any significant scale are typically built in place. This approach provides the most economical pricing and delivers the most reliable long-term performance. Plantings can be installed from cuttings, plugs, or pre-grown mat depending upon climate conditions and urgency to achieve full plant coverage.

Modular systems offer the ability to achieve full grow-out prior to site installation. Placement of the pregrown trays on the roof requires low skill level and is executed quickly (Truett, 2003a). The reduction in installation cost is often offset by increased cost of the trays and grow-in duration at the nursery. But when access to the roof for grow-in maintenance is limited, this approach can be a viable solution.

5.1.2.2 Roof Slope

Figure 44: Flat Roof

Figure 43: Sloped Roof

Depending on the roof slope, various measures are required to hold the growing media in place and prevent slippage over time. As the roof pitch increases, says Truett (2003a), so does the cost of the components required to keep the system in place. But with the appropriate budget these systems can be grown on any pitch even vertical walls. Flat roofs allow for the construction of the simplest and therefore least costly systems. But if the flat roofs are not perfectly flat then enough pitch will require facilitating positive drainage.

5.1.2.3 Cost effectiveness

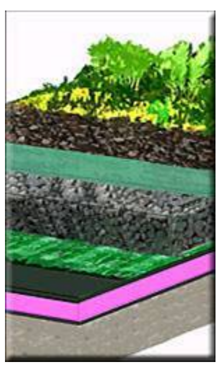


Figure 46: Non-Proprietary

Figure 45: Proprietary

Proprietary is the complete extensive living roof systems that used currently on the market. It is precasting and a little expensive.

Non-proprietary systems comply with FLL standards and can often result in simpler, higher performing green roofs. Sometimes this approach results in highest value combining superior long-term performance with low cost (Truett, 2003a).

5.1.2.4 Comparison between Intensive and Extensive Green Roof

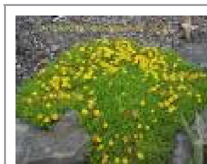
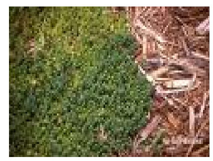
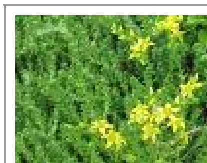
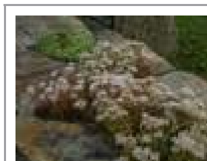
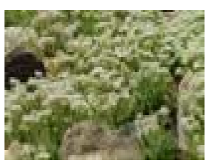
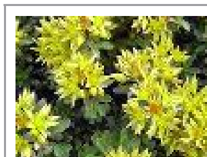
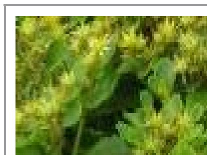
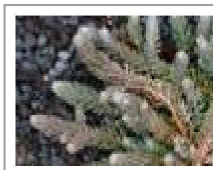
Table 9: Comparison of Extensive and Intensive Green Roof System.

EXTENSIVE GREEN ROOF	INTENSIVE GREEN ROOF
• Thin growing medium; little or no irrigation; stressful conditions for plants; low plant diversity.	• Deep soil; irrigation system; more favorable conditions for plants; high plant diversity; often accessible.
Advantages: • Lightweight; roof generally does not require reinforcement. • Suitable for large areas. • Duitable for roofs with 0 - 30° (slope). • Low maintenance and long life. • Often no need for irrigation and specialized drainage systems. • Less technical expertise needed. • Often suitable for retrofit projects. • Can leave vegetation to grow spontaneously. • Relatively inexpensive. • Looks more natural. • Easier for planning authority to demand as a condition of planning approvals.	**Advantages:** • Greater diversity of plants and habitats. • Good insulation properties. • Can simulate a wildlife garden on the ground. • Can be made very attractive visually. • Often accessible, with more diverse utilization of the roof. i.e. for recreation, growing food, as open space. • More energy efficiency and storm water retention capability. • Longer membrane life.
Disadvantages: • Less energy efficiency and storm water retention benefits. • More limited choice of plants. • Usually no access for recreation or other uses. • Unattractive to some, especially in winter.	**Disadvantages:** • Greater weight loading on roof. • Need for irrigation and drainage systems requiring energy, water, materials. • Higher capital & maintenance costs. • More complex systems and expertise.

Source: adapted from: "Greenbacks from Green Roofs: Forging a New Industry in Canada," CMHC. 1998.

5.1.3 Typical Plants for Living Roofs

Following chart shows the commonly used plants for living roof. These plants are recommend appropriate plantings for the project's micro-climate i.e. exposure to wind, light, shade, drainage, etc. While satisfying the client's objectives such as manicured garden vs. functional with low maintenance (Truett, 2003a).

Allium schoenoprasum				
Delosperma nubigenum				
Sedum acre				
Sedum album				
Sedum album 'Murale'				
Sedum floriferum				
Sedum kamtschaticum				
Sedum reflexum				

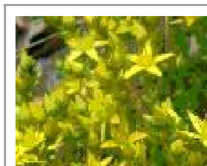
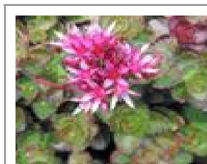
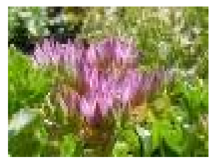
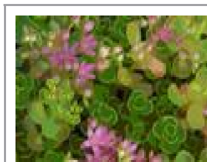
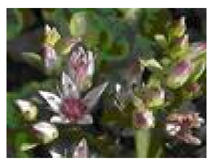
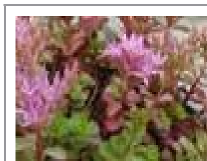
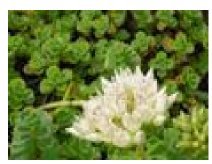
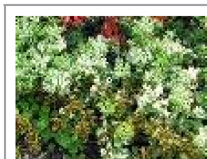
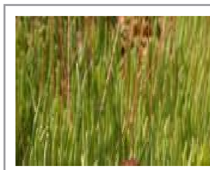
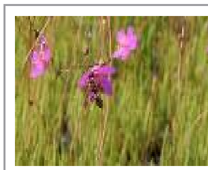
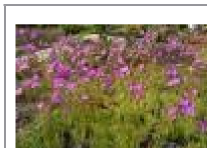
Sedum sexangulare				
Sedum spurium 'Fulduglut"				
Sedum spurium 'John Creech'				
Sedum spurium 'Roseum'				
Sedum spuirum 'White Form'				
Talinum calycinum				

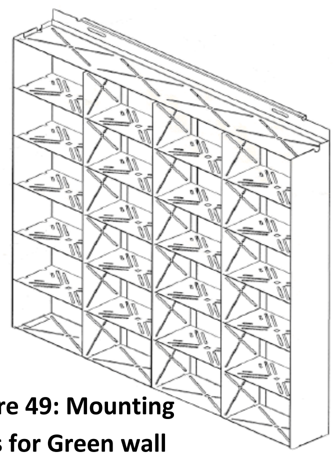
Figure 47: Typical Plants for Living Roofs

Source: http://www.furbishco.com/products/roofs/vegetation.html

5.2 Green wall Design Technology

Wall-mounted green façades can be flush with walls or set 3-18 inches from the wall surface using mounting clips or "standoff" brackets. A waterproof membrane is not required. The depth of the trellis modules protects building surfaces by keeping plants from attaching directly to walls to prevent problems that could otherwise compromise a building's integrity (Gonchar, J., 2009). The structures also help distribute the weight of climbing plants across the screen structure and wall. In cable and rope wire systems, anchors and turnbuckles are installed at one end of each cable for tightening and adjustments as required by plant development.

Figure 48: "Standoff" brackets for Green wall



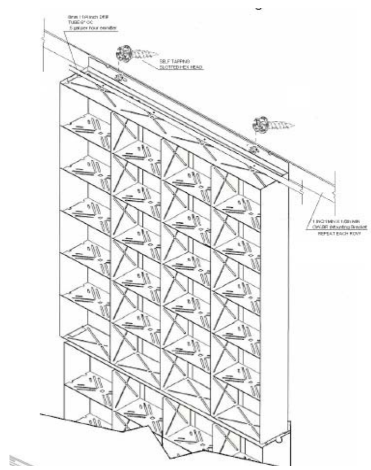


Figure 49: Mounting Clips for Green wall

Climbing plants require a good supply of moisture and occasional pruning, depending on species, appearance, and wildlife control. Supporting structures require minimal maintenance, with only occasional monitoring of the tension and structural connections. Installation of pre-grown panels for living walls requires a lead time of 6-12 months prior to delivery for plants to propagate and grow first as plugs and to fill in the panels (Gonchar, J., 2009). The panels can be grown horizontally until the date of shipment to the site, when they are then mounted vertically. High-density concrete walls may be watertight; however, a waterproof membrane may be required for installation on metal or wood frame structures.

Green Wall Structural Panel:

- Multiple finishes include but not limited to: Aluminum, Stainless, Fine Metal Wraps and Custom Colors
- Simple easy to install mounting system with additional safety mounting slots.
- Can be mounted directly to an existing surface, indoors / outdoors or as a free standing custom rack system.
- Standard panels are 2'x2'x3" Growing Depth.
- Deeper (4" – 6") depths are available as a custom project or for sloped green roof application.
- Minimum 15 year warranty
- Stainless Steel (Exterior) or Aluminum

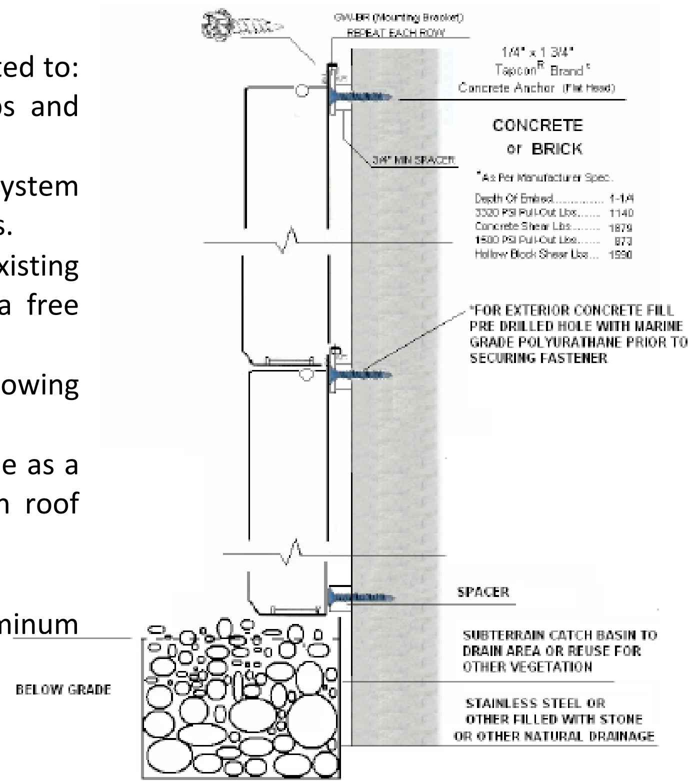


Figure 50: Green Wall Structural Panel

Source: Green Living Technologies, LLC.

Approximately 500 sqf of living wall panels with frame can be installed in one day. At least one month prior to the installation of the wall, water supply and power supply for an automatic drip irrigation system should be connected (at the top of the wall or for individual panels, depending on the system). A standard fertilizer loop is recommended for the injection of liquid nutrients for the plants (Knowles,L.,2005). The growing medium within the panels should be fully saturated once a day during the first week after installation; thereafter, water is provided to maintain moisture without oversaturation. The modular system allows panels to be taken out and replaced if required.

5.2.2 Types of green walls

There are two major categories: green façades and living walls.

Green façades are wall systems where climbing plants or cascading groundcovers are trained to cover specially designed supporting structures. Plant materials can be rooted at the base of the structures, in intermediate planters, or on rooftops. Green façades can be attached to existing walls or built as freestanding structures (Gonchar, J., 2009).

Living walls (also called biowalls or vertical gardens) are composed of pre-vegetated panels or integrated fabric systems that are affixed to a structural wall or frame. Modular panels can be comprised of polypropylene plastic containers, geotextiles, irrigation, and growing medium and vegetation. This system supports a great diversity of plant species, including a mixture of groundcovers, ferns, low shrubs, perennial flowers, and edible plants. Living walls perform well in full sun, shade, and interior applications also, and can be used in both tropical and temperate locations (Sharp,R., 2007). Due to the diversity and density of plant life, living walls require more intensive maintenance like, regular water, nutrients, fertilizer than green façades.

5.2.3 Types of green façade support structures

According to Sharp,R., (2007), stated in Building Design and Construction, there are two primary types are modular trellis systems and cable and rope wire systems.

In **Modular trellis systems** rigid lightweight panels are installed vertically as either wall-mounted or freestanding systems. They can be used on tall buildings in conjunction with intermediate planters or on rooftops. These planters may be required where the growth of climbing plants is physically restricted.

Freestanding structures, such as green columns or canopy tree forms made of rigid panels, can be placed on either urban streets or rooftops where space is limited or weight is restricted. The panels can also be used in horizontal applications such as arbors or as shading devices over the upper level of a parking deck.

Cable and rope wire systems consist of a kit of parts that includes high-tensile steel cables, wire trellises, anchors, spacers, and supplementary equipment. Vertical and horizontal wires can be connected through cross clamps to form a flexible trellis system in various sizes and patterns. To cover large areas, stainless steel wire-rope nets can be supported on flexible or rigid frames.

5.2.4 Best plant types to use for green walls

Green façades use climbing plants, which are divided into 'self-supporting plants' (root climbers and adhesive-suckers) and 'plants that need supporting structure' (twining vines, leaf-stem climbers, leaf climbers, and scrambling plants). Climbers vary by hardiness, orientation, and climate (Sharp,R., 2007). Plants used in vertical exterior applications are exposed to harsher climactic conditions than those at grade or indoors, and as a result, hardy species should be selected for projects that intend to reach great heights. Similarly, climbers with a tolerance for wind, frost, and heat should be selected for projects in less hospitable climates. Rooted at the base of a green facade, climbing plants may take 3-5 years to achieve full coverage (Knowles,L.,2005).

Plant selection will also impact the design of the supporting system. For example, a denser, faster growing plant will require a greater space between supports than less aggressive species, which allow for smaller intervals between supports. The density of plant life will have further implications for the underlying structure, given that the greater the leaf surface area, the more impact snow and rain will have on the weight of the system (Gonchar, J., 2009). Green walls are comprised of a variety of plants in pre-vegetated panels grown in greenhouses and assembled four to six months later on a frame attached to a structural wall (Sharp,R., 2007). Species are usually selected based upon their tolerance of growing system, site-specific environmental conditions, color, texture, rates of propagation, and root systems. The panels support groundcovers, ferns, low shrubs, perennial flowers, and edible plants. Pre-vegetated living walls offer an instant green wall for immediate impact.

5.2.5 Negative aspects of green wall

For both green façades and living walls, climbing plants can be selected that do not bear fruit or provide a food source. Also, property managers prefer closely cropped vegetation to discourage shelter or nesting sites for birds. Any excessive growth or dead wood should be removed, and standing water should be avoided (Sharp,R., 2007). A continuous gravel strip at the base of the building is recommended.

5.3 Biofilter design Technology

Nature has the built-in capacity to adjust to environmental changes. It can repair itself after damage or adapt to exposure from a wide range of compounds. Although the time scale may vary from minutes to centuries, in time a natural ecosystem can repair almost any damage it may sustain. For example, given enough time nature can restore a site contaminated with organic compounds such as VOCs. One reason for this is that, frequently, materials such as VOCs that are toxic to some life are food for others. Most of the biological breakdown of VOCs is done by microbes (bacteria), although higher plants may also be involved. Some pollutant-degrading species are usually present and active in most environments, and the act of introducing the pollutant only increases their relative numbers and/or activity levels (Yeang, 2006). Active Living Walls are a biofilter containing such organisms to remove contaminants present in the air at very low concentrations. In essence, it mimic indoors what happens outdoors every day. Biofilteration is a well established means of removing pollutants from waste air streams. Air is passed through a 'biologically active zone' where highly specialized beneficial microbes consume the pollutants in the airstream as a food source (Truett, 2003b). Thus, unlike conventional filters that remove gaseous contaminants, the biofilter does not accumulate the contaminants that it removes. The beneficial microbes degrade pollutants into their benign constituents of mostly water and CO2. Although the inclusion of green plants greatly improves the aesthetics of the biofilter, their inclusion is much more for practical reasons. This approach relies heavily on the science of phytoremediation, where green plants speed the recovery of contaminated soil and water (Darlington and Dixon, 2002). The presence of plants in the biofilter is vital because plants increase the efficiency of the biofilter through both the direct uptake of pollutants such as carbon dioxide and through improving and sustaining microbial activity.

5.3.1 Types of living wall

Living walls can be further broken down into passive and active systems. Passive living walls are simply exterior, or sometimes interior, walls of green plants. They do not have any means of moving the air into the root system where most of the degradation of pollutants occurs. Thus the impact of passive systems on air quality is scientifically questionable and need further study (Knowles L. et al, 2005). On the other hand, as stated earlier, active Living Walls actively draw air through the root zone of the plants where the real breakdown of pollutants occurs. (Darlington, Alan, 2001). Some active walls are kept behind glass to ensure more predictable airflow than can be achieved with inactive walls, which have no mechanized air circulation. Instead, they are kept open to promote as much free air circulation as possible.

5.3.1.1 Options for making a Living Wall active

There are three ways, according to Darlington and Dixon, (2002), that air can be drawn through the Living Wall to make it active. The most effective way is for the wall to be designed as an alternative return-air path back to the HVAC. The air, which is normally drawn from the space, is first cleansed as it passes through the wall and then is disseminated through the space by the HVAC. Ideally a bypass is integrated into the design so that air can be drawn from the space without passing through the wall (for periods of free cooling, wall establishment or wall maintenance).

The second approach is to build fans right into the wall so it functions as a stand-alone unit; separate from the building’s HVAC. Although this works well, it is not as effective as the first method since it has a much more localized effect.

The third method is a hybrid of the first two. The Living Wall has its own fan system but it also has a duct system to better diffuse air through the space. The mode is selected for best performance based on the space quality and quantity.

5.3.2 Alternative to ventilation

Biofilters proposes a natural solution. Rather than introducing large amounts of fresh air from outside, the building itself has incorporated into the features, responsible for making outdoor air fresh in the first place. That is, to integrate a complex ecosystem as a biological filter into the building's air-handling system. This removes pollutants from the air, and removes them through normal biological processes. The air quality of a space relying almost entirely on active Living Walls is as good as, or better than, similar indoor spaces relying on sophisticated ventilation systems that replace the building air up to six times per hour (Darlington, A., 2001).

5.3.3 How Biofilters work

Biofilter act as a vegetated return air register. It is a vertical hydroponic green wall containing a range of specifically selected plants. The plants include ferns, mosses and a range of other flowering and foliage plants. Air is actively drawn through the green wall of plants and highly specialized beneficial microbes actively degrade pollutants in the air into their benign constituents of water and carbon dioxide. The clean air is then distributed throughout the space by a mechanical ventilation system.

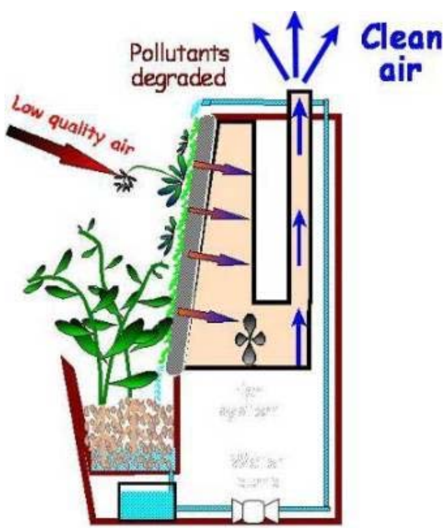


Figure 51: Biofiltration System. (Darlington, A., 2008)

Figure 52: Biofilter Systems can be designed for most any need, from small residential to large commercial applications. Source: Furbish Company, Sustainable Building.

Through the natural processes of biofiltration and phyto-remedaition the system removes and breaks down common indoor air pollutants. The System is an ecological approach to maintain the indoor environment with the whole life cycle of the system taken into account. Although the systems are typically designed up to over 20 years of operation, the biological aspects have the ability to continue with their functions forever (Truett, 2003b). The biology component is a self-repairing, self-rejuvenating air cleanser.

5.3.4 Reason of using green plants into Biofilter

Though microbes are metabolizing most of the pollutants, green plants are included for a number of reasons: they offer ecological stability to the system as a whole by providing species diversity. They also may be active at removing some VOCs to some degree. Furthermore, the inclusion of plants adds important aesthetic value to the space. Of course, since CO_2 is considered an indoor pollutant, green plant, through the process of photosynthesis, offer a means to control it. At the same time species diversity gives the system ecological stability (Darlington and Dixon, 2002). This is very important in order to give the ecosystem the power to deal with a broad range of potential challenges in the indoor setting.

5.3.5 Capacity of Air Filtration

Although there are many factors to be considered, the quickest and easiest estimate for sizing a Living Wall is one square meter of active Living Wall to meet the needs of 100 square meters of floor space, given typical pollution loads generated in most residential and office conditions. This will generate an appropriate ventilation rate and give the desired improvement to the indoor environment. Considering that standard ventilation rates range from 2 to 15 air changes per hour, an indoor air biofilter has to handle large air volumes (Truett, 2003b). So, the wall can be sized on the basis of the amount that needs to be drawn through the space's return air system.

5.3.6 Maintenance

Required Maintenance

A scheduled maintenance on Living Walls every month is recommended. More frequent visits based upon their unique conditions may necessary.

Pest Control

The method is considered as organic procedure to control pests in living walls; the emphasize is on management practices and biological controls such as predators. So-called pests such as white flies, fungus gnats, spider mites and their respective predator species are necessary, even desirable. They contribute to the ecosystem's species diversity and ecological stability (Darlington and Dixon, 2002).

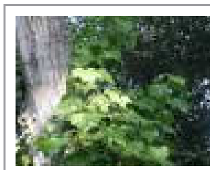
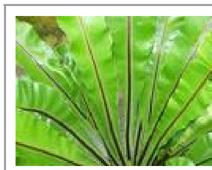
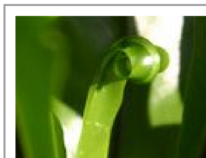
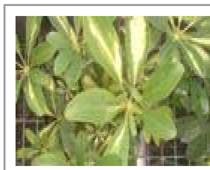
5.3.7 Some Drawbacks

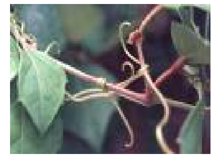
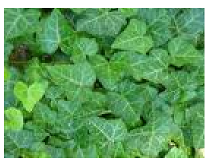
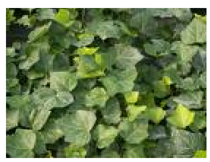
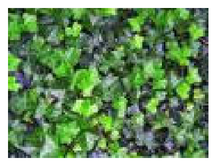
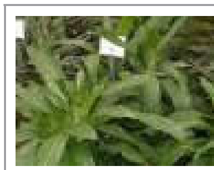
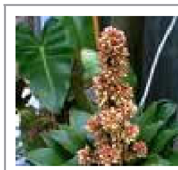
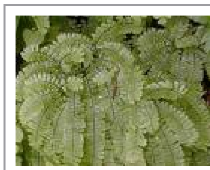
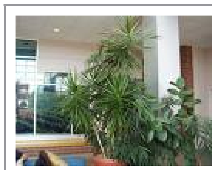
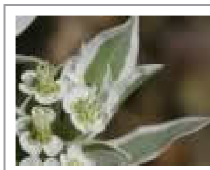
Use of native plants

Some native plants may be present. However, most native plants would not survive well indoors. Plants adapt to their local climate and, as such, plants from northern climates generally require the different seasons to grow properly. For most native plants to survive indoors, the climate in the wall would have to mimic these seasons, making routine use of the space difficult and its performance irregular (Darlington, A., 2001).

5.3.3 Typical Plants for Biofilters

Appropriate plantings for the project's specific growing environment such as, exposure to light, cold, etc., is recommended while satisfying the client's aesthetic and maintenance objectives like, highly manicured vs. functional with low maintenance. The typical varieties of plants that are commonly used in biofilters are as follows.

Algerian ivy				
Birds nest				
Bromeliads				
Schefflera				

Cissus grape ivy				
Ficus starlight				
Gardenia				
Hedera green vines				
Hibiscus bush				
Dracaena 'Janet Craig'				
Maidenhair				
Dracaena marginata				

Phalaenopis				
Philodendron				
Syngonium				
Dracaena warnecki				

Figure 53: Typical Plants for Biofilters

Source: Truett, Rick. (2003b), 'Biofilters'. Furbish Company, Sustainable Building.

5.4 Plants of Green Pockets

"All plants remove the Carbon Dioxide we emit during breathing and release Oxygen into the air for us to breathe. This exchange takes place during photosynthesis which most plants perform during daylight hours. All plants remove impurities from the air to a lesser or greater effect. They remove the impurities or Volatile Organic Compounds (VOCs) by absorbing them through their leaves or via their growing medium. The VOCs are moved (translocated) to the plant's roots where micro-organisms living in the root zone (rhizospere), turn the VOCs into food for the plant." _Dr.B.Wolverton,(NASA).

5.4.1 Type of Indoor Plants

There are Different varieties of indoor plants which can be used to serve different purposes. Some plants are good for day time whether some are useful for night time workers. Based on the functionality or occupancy time these plants are helpful to decorate and enhance the indoor environmental quality. According to the study be Dr. B. C. Wolverton, (2009) they are as follows:

5.4.1.1 Night time workers

Epiphytic Bromeliads, orchids and succulents exchange Oxygen and Carbon Dioxide at night rather than as most other plants do during the daytime. This makes them perfect bedroom plants to refresh the air for breathe during sleep.

5.4.1.2 Plants which raise humidity levels

As plants return 97% of the water human give them back into the air, water loving plants help to raise humidity levels. Particularly useful in centrally heated or air conditioned buildings. Examples of some water loving plants are Schefflera, Bamboos and Hemp (Wolverton, B. C., 2009).

Peace Lily: Spathiphyllum. Winner of Dutch office plant of the year 2007. A good all rounder and best at removing all toxins according to Dr Bill Wolverton in his Eco-Friendly Houseplants book.

Boston Fern: Nephrolepis exaltata and obliterate. Good air cleaner; also good for raising humidity levels and keeping the environment comfortable, particularly useful in centrally heated or air conditioned rooms/spaces.

Dracaena deremensis, marginata and fragrans. One of the best plants at removing Trichloroethylene emitted by photocopiers and printers, perfect for the home office.

Umbrella plant: Schefflera actinophylla. Good air purifier and also a water lover which means Schefflera is good for humidifying the air, like Boston ferns.

Ivy: Hedera helix. Good at cleaning the air, the plants can also help to reduce the physical signs of stress.

Palms like Areca (Chrysalidocarpus lutescens), Bamboo (Chamaedorea seifrizi); Lady (Raphis excelsa), Dwarf Date (Phoenix roebelenii), Kentia (Howea). Areca came out tops in

Wolverton's poll for cleaning the air but all of the palms are good at air cleaning.

Rubber plant/Weeping fig: Ficus robusta and bejamina. Hard working and good looking

Bromeliads. Like orchids, these plants work at night absorbing toxins and emitting oxygen to refresh the air. Perfect for the bedroom.

Mother-in-law's tongue: Sansevieria. Winner of Dutch office plant of the year 2008. Won on criteria of purifying air and ease of care.

5.4.1.3 Best air cleaning flowering plants

According to Dr Bill Wolverton (2009), stated in his Eco-Friendly Houseplants book, followings are the best air cleaning flower plants can be use in indoors.

- Chrysanthemum – no 2 in the charts for ridding the air of Formaldehyde.
- Gerbera – no 3 in the same charts.
- Orchids – clean and refresh the air at night, so perfect for the bedroom.
- Anthurium.
- Potted Tulips.

5.5 Reluctance of incorporating plants

Lack of knowledge, unwillingness to pay an extra initial installation cost for green roof, green wall, biofilter and plants and its maintenance, ignorance for environmental benefit and lack of enthusiasm are the main causes which prevent many people to take steps towards green movements. Moreover no specific building rules and regulations for incorporating plants into design are made yet by any country though some of the countries just took the initiatives. There are regulations of how to incorporate plants but none for why it should be. So people are not bound to do it. These inadequacies need to be overcome to make the builders and clients bound to design for the green plants. The procedures of integrating plants into building are new and need to be studied more. The more it should be implemented the further its drawbacks will be unfolded to eliminate, and the cost will reduce. The result will be the encouragement or increase of willingness to use of plants into buildings. The monitoring of current green establishment, collecting data on how much it is helping for energy conservation and reducing cost and the improvement of indoor and microclimate environment will provide the first hand data to the builders and clients as well the general people, encouraging them to build with green plants.

5.6 Regulations for green design

As stated earlier for green building movement, incorporating plants into building design needs to be controlled by the building and city law. Recently as the 'Green Movement' started some countries or states took initiative to make laws for green construction for the optimal use of energy saving and reduced operational cost in the building sector, environmental benefit is also a major concern. They encouraged green construction by providing Governmental funding, but the design must be abide by the new laws. In the United States the federal government, as well as many states and local communities throughout the country, have recently initiated programs intended to green the public building stock; however, very few communities have shown any inclination to enact regulations to require privately held buildings to be designed and built in compliance with green-building protocols. That will start to change once the development of green-building standards is completed, providing the basis for a regulatory structure to impose green-building requirements. Most of these standards are written specifically for adoption by state and local governments as mandatory requirements for construction permits and for compliance with building codes and other regulations governing new and existing buildings (Burton, 2007).

5.6.1 Washington State Law

During the 2005 legislative session, Washington State passed the country's first law requiring that all new buildings and renovation projects that receive state funding be built to one of three green building standards (Chapter 39.35D RCW High-performance Public Buildings). Projects that receive funds from the capital budget must achieve the Leadership in Energy and Environmental Design (LEED®) Silver standard. All K-12 schools that receive funding from the Office of the Superintendant of Public Instruction must be built either to the Washington Sustainable Schools Protocol (WSSP) or LEED Silver standard. Finally, projects that receive funding from the Department of Commerce Housing Trust Fund must comply with the Evergreen Standard for Affordable Housing (WA State Department of Ecology).

5.6.2 Green roof policies in some other countries

Green roof policy is intended to maximize the collective benefits of green roofs. Collective benefits are those which benefit the public at large, such as reduced stormwater runoff, climate moderation and thermal cooling (Ngan, 2004). Many of which have been in place for over a decade, fall into four general categories:

- Direct financial incentives;
- Indirect financial incentives;
- Ecological compensation measure; and
- Integration into development regulations.

North Rhine Westphalia: Direct Financial Incentives

The Jurisdiction

With about 18 million inhabitants, North Rhine Westphalia (NRW) is the most heavily populated state in Germany. NRW includes the intensively industrialized Ruhr area where numerous cites (Essen, Dortmund, Duisburg, Bochum and Gelsenkirchen) merge to form a highly populated unit. The population of the Ruhr area is about 9 million and the population density between Duisburg and Dortmund reaches 1200 people per square kilometer. The Ruhr is a tributary of the Rhine, along which are situated Cologne, Düsseldorf and Bonn. The resources of the state include hard coal, brown coal and iron ore deposits which supplied a productive iron and steel works industry. There was also a thriving chemical industry. For many years the hard coal mining has had to be subsidized because of lower prices in other countries. Brown coal mining has been called into question because of the negative environmental impact. Iron ore mining is no longer supported. These changes have had positive effects on the environment. In parts of the Rhine, the Ruhr and other bodies of water that were made barren by pollution, fish have returned. Air pollution has been greatly reduced. Many previously industrial areas have been converted into parks and recreational areas. In spite of industrial downturns, NRW remains an economically powerful state (Ngan, 2004).

Key Driver

The key driver for this policy is improved water quality. The idea is that stormwater source controls, including green roofs, will reduce stormwater volume and delay stormwater runoff which will result in a reduced load at water treatment plants, disconnection of surfaces from the public sewer system, reduced sewer overflow and flood control.

Description of the Policy

The "Initiative for Ecological and Sustainable Water Management" is a 320 million € ($512 million Cdn) program on state subsidy in several areas of water and wastewater management (Mainz, 2003) The program is developed by the Ministry of Environment, Consumer Protection, Nature Conservation and Agriculture (MUNLV) of NRW. The aim of the program is to conserve and improve the water quality of rivers and bodies of water. Funding for the program is generated from fees imposed on polluters according to the Wastewater Charges Act. The Act requires that these funds be used only for improving water quality and cannot be mixed into general revenue. Therefore, the subsidies are financed according to the "polluter-pay" principle for wastewater management (Ngan, 2004).

Application of the Policy

The subsidy program is administered by the municipalities through their respective engineering, tax, or environment departments. It may also be administered through municipal waste disposal companies. Information on the program is available through various levels of government and through the internet. The program consists of several areas eligible for subsidy. In the case of green roofs, it falls under Subsidy Area 6 which includes the following forms of stormwater source control (Ngan, 2004):

- For removal of impervious surfaces: 15 €/m² ($24 Cdn) of removed surface.
- For infiltration systems (source controls): 15 €/m² ($24 Cdn) of newly designed infiltration surfaces. Eligible for subsidy are the required construction and technical measures, such as conduit system or infiltration setup.
- For roof greening: 15 €/m² ($24 Cdn). In terms of roof greening, the insulation and drainage layers, the substrate and the plants are eligible for subsidy. Not eligible is the roof deck.
- For rainwater – up to 1,500 € ($2400 Cdn) per re-use system.

The program targets projects in existing urban areas. Projects in new developments are generally required to implement source control and green roofs in order to be approved so these would not be eligible. Likewise green roofs required as a compensation measure according to the Federal Nature Conservation Act are not eligible for subsidy. The subsidy can be used in combination with the stormwater fee discounts (Stadtentwässerungsbetriebe Köln, 2004). In the subsidy application form, the applicant enters the size of the green roof, the thickness of the green roof components, portion affected by stormwater runoff delay, the runoff coefficient and whether or not the roof construction load has been structurally confirmed.

Minimum Requirements

The NRW subsidy program requires that the green roof have a runoff coefficient of less than 0.3 as a measure to ensure that the aim of improving water quality is met. There are two ways that this performance goal is checked: by requiring a minimum depth (penetrable by roots) of 15 cm or by requiring proof (i.e. independent certification) that the green roof product has a runoff coefficient of less than 0.3 (Mainz, 2004). Some products can have a thickness of less than 15 cm and still meet the performance goal. This subsidy program is so important to the industry that the large green roof company, Optigrün, sells a product called "Optigrün- Extensivsubstrat Typ NRW 03" especially developed to meet the requirements of the 0.3 runoff coefficient requirement while maintaining the lowest possible thickness and weight (Optigrün, 2002).

Effectiveness

From the beginning of the program in September 1999 to the end of 2003, the MUNLV Ministry released 12,366,490 € ($19,786,384 Cdn) in grants for green roofs which resulted in the greening of approximately 825,000 m² roofs (Mainz, 2004). When the green roof areas are added to the removal of impervious surface and installation of stormwater source controls, about 59 million € ($95 million Cdn) were given out which translates into about 6 million m² of runoff-effective surfaces that could be disconnected from the public sewer system.

Cologne: Indirect Financial Incentives through Stormwater Fees

The Jurisdiction

Cologne, a city of over one million inhabitants, is situated along the Rhine River in the state of North Rhine Westphalia (NRW). It is one of the most flood prone cities in Europe. There have been 12 damaging floods (over 9.5 m) in the past 100 years, five of which occurred in the past 15 years (Umweltbundesamt, 2003). One of many flood prevention measures is minimizing impervious surface.

There are two types of green roof financial incentives employed in Cologne: the NRW subsidy program as described in section 3.1 and stormwater fee discounts as described in section 3.2 and in more detail below. Both incentives are administered by the City Drainage Corporation

(Stadtentwässerungsbetriebe Köln, AöR), a public corporation that replaced the City Drainage Department in 2001. In the case of the subsidy, the applications are forwarded to the District of Cologne for processing.

Key Driver

The key driver is a combination of improving transparency and fairness in funding wastewater disposal and a concern for the environment. Using the user-pay principle, fees are based on drained area and stormwater source control is encouraged. In this case, green roofs are just one of several stormwater source controls that are eligible for reduced stormwater fees.

Description of the Policy

Whoever wishes to connect or reconnect to the public sewer system must apply for permission to the City Drainage Corporation. The permit should be attached to any building permit application. Then the owner requires a construction permit for the connection. The City Drainage Corporation then sends out a list of eligible contractors for the job. Wastewater fees are charged after the first use of drinking water. The fee for stormwater disposal is currently 1.10 €/m²/yr ($1.80 Cdn) (Stadtentwässerungsbetriebe Köln, 2004), so the annual stormwater fee for every square meter of impervious surface is a considerable cost to the property owner. To earn a stormwater fee discount for green roofs as well as other types of source control, the owner must supply the following: a site plan (1:500 or 1:250) which shows stormwater source control measures, a written declaration by the green roof supplier confirming the runoff coefficient of the chosen green roof construction and a completed form entitled, "Stormwater Infiltration Data." The form requires the following information:

- type and area of each surface;
- details about where and how the overflow will be conveyed;
- details about the proposed infiltration systems including roof slope, thickness and runoff coefficient for green roofs;
- whether the applicant has permission from the water authority to infiltrate water on the site;
- whether the proposed drainage will affect the neighboring properties; and
- whether any connection exists between the infiltration system and the public sewer system.

Performance Goals

Unlike with the NRW subsidy, there is no minimum performance goal like the 0.3 runoff coefficient. Instead performance is measured on a sliding scale so the owner may choose from a wide range of construction types. The stormwater fee discounts (Table 10) for green roofs are based directly on runoff coefficients (Schneider, 2004). Runoff coefficients are determined by the FLL guidelines and confirmed by the green roof supplier.

Table 10: Excerpt from the Wastewater Fee Bylaw of 14.12.2003. Source: Stadt Köln (2003)

Runoff Coefficient	Reduction in fees
C=0.1	90%
C=0.2	80%
C=0.3	70%
C=0.4	60%
C=0.5	50%
C=0.6	40%
C=0.7	30%

If there are changes to impervious surfaces that would change stormwater fees, the Tax Department is notified. Each green roof is inspected by the City Drainage Corporation to see that it conforms to the requirements as set out in the NRW subsidy and/or the stormwater fee discounts (Schneider, 2004).

Effectiveness

One of the aims of the City Drainage Corporation was to stabilize the wastewater fees. They have succeeded not only in keeping them stable but also in keeping them below 1993 levels (Stadtentwässerungsbetriebe Köln, 2004).

Berlin: Unique Policies

The Jurisdiction

After the fall of the wall, Berlin became the new federal capital of Germany. Berlin is one of three German city-states, combining the functions of city and state in one – with the Senate having executive function of the government. There are 12 boroughs each with a mayor and six councilors. The population of Berlin is almost 3.4 million. Berlin is a great learning ground because fresh new approaches to urban design have been and continue to be applied to relatively large and important projects. The unique opportunity to develop the vast central area after reunification of the East and West sectors provided a testing ground for innovative large-scale projects. The oasis of green urban planning is largely a result of the Landscape Program for Berlin 1984/1994 with its four master plans (for the protection of nature and wildlife, natural resources, landscape and recreation areas) in which values for the relative importance of qualities of nature were defined. Landscape planners in the administration of Berlin are surprisingly comfortable with new and innovative ideas and are willing to be adventuresome trend-setters with green issues, particularly with the protection of natural resources within the boundaries of the city. Their intuitive acceptance of the less quantifiable, yet scientifically-based green roofs benefits has allowed Berliners to enjoy the many advantages of green roof policy. This trend is one that Canadian cities would do well to adopt.

History

Berlin has an interesting history of green roof policies. In the 1970's researchers from the Technical University of Berlin began examining the city's green roofs from an ecological perspective while at the same time citizens began pressing for the support of more environmentally friendly cities. Many projects, some of them high profile, were energetically implemented, having been driven by the environmental movement. Between 1983 and 1996, there was the Courtyard Greening Program, aimed at adding green space in the form of green roofs, green facades and backyard community gardens to the most densely sealed areas of the city. Through the program approximately 65,750 m² of extensive green roofs were subsidized (Koehler, 2003c). Residents received a reimbursement for about half, 25 – 60 €/m² ($40 - $96 Cdn), of their expenses for the cost of green roof installation. "By 1983, at least 24 German cities had begun incentive programs which supported urban greening projects such as green roofs, green facades, and courtyard greening projects (Fiebig and Krause, 1983)" (Koehler, 2003c). Later, national and local legislation and policies were implemented that recognized the environmental benefits of green roofs. Direct financial incentives were common during the 1980's and 1990's. Berlin has since suffered from deficits and can no longer afford to offer direct financial incentives; it has turned instead to fees and regulations. Berlin's stormwater fees are administered by the Berlin Water Corporation, a corporation 50.1% of which is publicly owned. The stormwater fee for 2004 is 1.407 €/m²/yr ($2.25 Cdn) based on impervious surface (BWB, 2004). Green roofs do not earn a discount. However, if the runoff is not connected to the storm drain, the roof area is not counted. The goal is to completely control stormwater at the source, such as by connecting green roofs to swale-trench systems. Green roofs are sometimes integrated into local land-use plans both as source control measures or as nature compensation measures and this is administered by the boroughs. Water protection is administered by the Senate and this may require green roofs as a method for reducing loading on sewer networks and improving water quality. Finally, there is the Berlin Biotope Factor which is examined more closely below.

Biotope Area Factor

Key drivers

New ideas were required to reduce the environmental impact of high density districts in Berlin. Densely developed land is severely limited in its function by:

- a high degree of soil sealing;
- inadequate replenishment of groundwater resulting from rapid
- runoff of rainfall into the sewage system;
    - lack of humidity and excess warming of air; and
    - a constant decrease in plant and animal habitat due to inadequate green space.

Description of the policy

The Biotope Area Factor (BAF or BFF for BiotopFlächenFaktor in German) was developed in the 1980's in the western sector before reunification. It is a policy tool intended to address the environmental issues listed above. It resembles other urban planning instruments such as floor space ratio. The BAF contributes to standardizing the following environmental goals:

- safeguarding and improving the microclimate and atmospheric hygiene;
- safeguarding and developing soil function and water balance;
- creating and enhancing the quality of the plant and animal habitat especially wild species;
- improving the residential environment.

The BAF is required in areas with a legally binding landscape plan. There are about 13 such areas in Berlin. Outside these areas, the BAF is voluntary and can be used as a guideline for environmental measures when changes to the existing building structures are proposed. Because of its simplicity and the rising knowledge of environmental issues, architects as well as property owners tend to use the BAF when recommended by experts.

$$BAF = \frac{\text{ecologically-effective surface}}{\text{total land}}$$

Calculating the BAF

The BAF expresses the ratio between the ecologically effective surface area and the total land area.

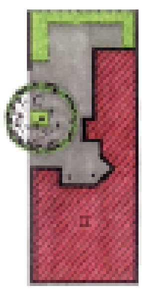
For each type of urban form, planners set a particular BAF target value. For example, new residential structures have a BAF target of 0.60 and new commercial structures have a BAF target of 0.30. For renovations, the BAF target may fluctuate depending on the existing degree of coverage. For instance, a residential renovation with a degree of coverage of more than 0.50 has a BAF target of 0.30. Each type of surface on the proposed plan is measured and assigned a measure of relative importance according to its "ecological value" (see Table 11). For example, sealed surfaces have a 0.0 weighting factor per m² and green roofs have 0.7.

Table 11: Weighting factors. Source: SenStadtUm (2004b)

Calculation example

This example is taken (with editing modifications) from the BAF website of the SenStadtUm (2004b).

<u>BAF ground state:</u>



This sample project has a BAF target of 0.30 (residential renovation with existing degree of coverage of over 0.50). The courtyard is mainly covered with asphalt. There is gravel with grass coverage on the periphery and the tree grows in a soil bed that measures 1 m².

Land area	479 m²
Building area	279 m²
140 m² asphalt	x 0.0 = 0.0 m²
59 m² gravel with grass coverage	x 0.5 = 30.0 m²
1 m² open soil	x 1.0 = 1.0 m²

BAF 31/479 = **0.06**

BAF target = **0.30**

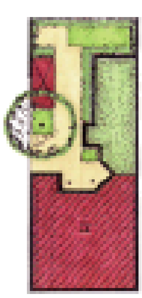
<u>Planning variant 1:</u>

Achieving the targeted BAF will require additional measures that amount to a BAF of 0.24. By reducing the area covered by asphalt and changing the type of surfacing, as well as by significantly expanding the area covered by vegetation, a BAF of 0.30 can be realized.

Land area	479 m²
Building area	279 m²
115 m² area covered by vegetation	x 1.0 = 115.0 m²
85 m² mosaic paving	x 0.3 = 25.5 m²

BAF 140.5/479 = **0.30**

<u>Planning variant 2:</u>



Building a covered bicycle stand means that the portion of partially sealed surfaces must be increased. It is therefore necessary to utilize roof and fire wall surfaces in order to achieve the required BAF.

Land area	479 m²
Building area	279 m²
21 m² concrete surface	x 0.0 = 0.0 m²
79 m² area covered by vegetation	x 1.0 = 79.0 m²
100 m² mosaic paving	x 0.3 = 30.0 m²
10 m² greenery covering walls	x 0.5 = 5.0 m²
41 m² greenery covering rooftop	x 0.7 = 29.0 m²

BAF 143/479 = **0.30**

BAF and green roofs

There are no specific design requirements or performance goals for green roofs. They must simply conform to industry standards. That said, technical issues are extremely important. In the early days when standards were not well-developed and workers lacked knowledge and experience, there were problems such as erosion of substrates, leaks in the waterproofing and inadequate maintenance leading to the growth of pioneer plant species whose roots sometimes caused damage to the waterproofing (Lenk, 2003). Training of city staff for the BAF is fairly straightforward because of the BAF's similarity to other planning instruments. However, a shortage of staff has made it difficult to check for compliance. Several years may pass before a green roof is inspected (Lenk, 2003).

Effectiveness

The goals of this policy are numerous and aimed at improving the general quality of the urban landscape. There are so many factors involved that accurately quantifying all the benefits is not possible (Lenk, 2003). City planners have received positive feedback from architects and property owners who like the BAF because it is easy to use and there are immediate visual improvements as well as energy savings (Lenk, 2003). In addition, it leaves designers and property owners with room for individuality, creativity and flexibility. City planners appreciate that it is formed in the same logic as other planning indices and ratios. Gille (2003) explained that the BAF works well in older existing neighborhoods where there is a lack of green space. There is a political decision taken that in cities with limited space, property owners have a responsibility to the greater community to provide green space. In the German constitution, there is clause about private property owners having responsibilities to social good and, in her opinion; this is an important basis for the policy. However, she doesn't recommend it for new developments (Ngan, 2004).

6 Chapter 6: Case Studies

The practice of incorporating plants into buildings became popular in the recent days, which is a different type of its own. The main focus of this concept is to make the skyscraper biologically lively, to incorporate nature into the pile of vertical spaces. This concept also consider local climate for its lighting and ventilation according with the use plants for cooling and refreshing the indoor environment and help decrease the heat gain from the outdoor, thus reduce the use of mechanical HVAC systems and resulting less use of energy. A number of cases are considered here to study the recent typology of practices according with their views and concepts.

6.1 Ecological-Skyscrapers

Architect Ken Yeang is one of the pioneers to include green plants into his design of Skyscrapers. He named this type of design as “Ecological design”. According to Yeang (2006), Ecological design or ecodesign is the use of ecological design principles and strategies to design the built environment and the ways of life so that they integrate benignly and seamlessly with the natural environment that includes the biosphere, which contains all the forms of life that exist on earth. The goal must be fundamental basis for the design of all our human-made environments.

6.1.1 The EDITT Tower, Singapore

The EDITT Tower in Singapore is an ecological skyscraper of Ken Yeang. This 26 stories building sited on tropical climatic zone and rainforest vegetation zone. Its building façade elements, incorporated with green plants to enhance the indoor air quality, decrease energy consumption, etc. The tower is on a typical city center ‘zero culture’ site. The land is a devastated urban ecosystem that has none of its flora and fauna remaining. The design response biologically rehabilitates the site’s almost entirely inorganic character with a well planted façade with garden terraces in the form of a continuous ‘landscaped ramp’ that waves it way upwards from the ground plan to summit of the tower (Yeang, K., 2007). The continuous vegetated areas occupy a surface area of biomass that equals approximately half the gross area of the entire tower in an exceptionally high ratio of abiotic to biotic components in this human made ecosystem. The selection of the new planting species is derived from a survey of the locality's biodiversity. The planting contributes to the ambient cooling of the facades through evapo-transpiration. The landscaped ramp coupled with the continuously shifting organic plan from results in built form that is literally a vertical landscape.

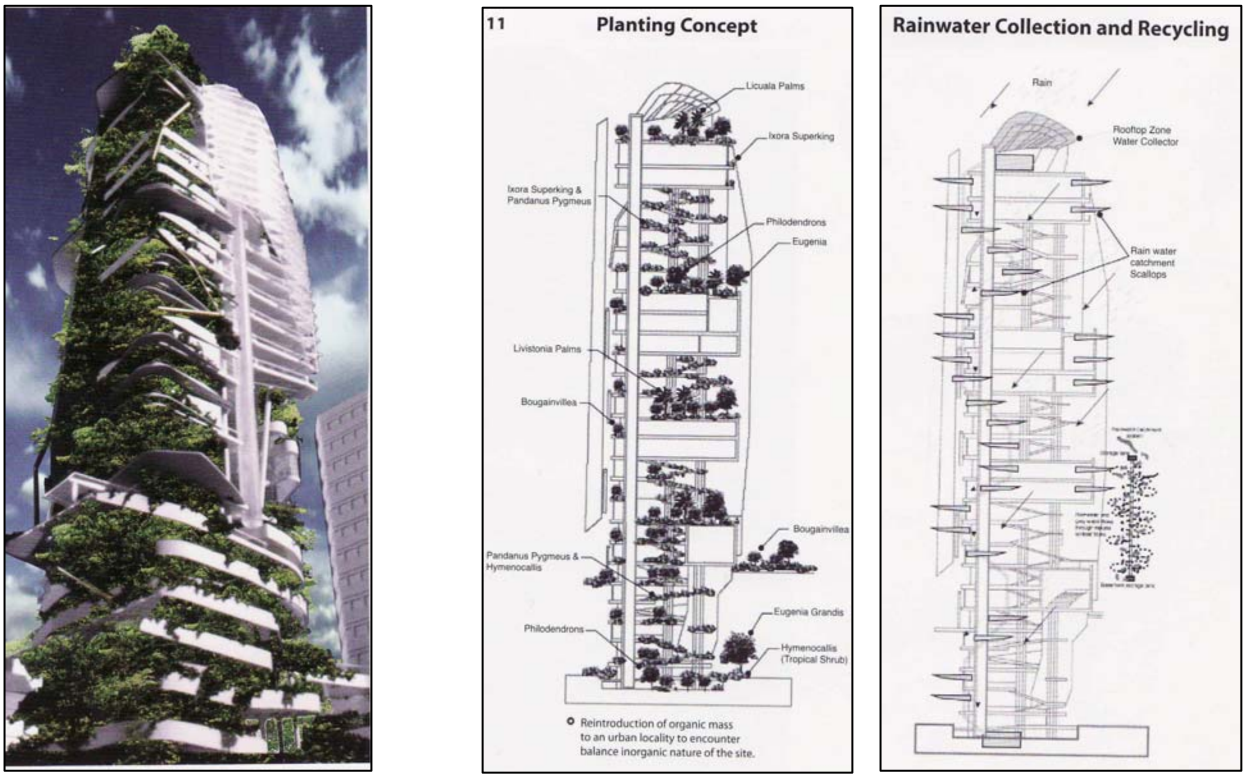


Figure 54: EDITT Tower, Singapore, example of an 'Ecological Skyscraper. The Planting concept and rain water collection and recycling process. Source: Yeang, 2006.

6.1.2 Tokyo Nara Tower, Tokyo

This is another example of Ken Yeang's Ecological Skyscraper. This 126 stories skyscraper will sited in cold climatic zone and deciduous forest type vegetation zone. This is a proposal for an ecologically responsive hyper tower. The tower is an extension of the park in sky idea. The design can be summarized as the architecture of the 'hollow rotating vertical spiral' using a system of shifting vertical landscaping terraces. These intermediate roof garden service a mixed use occupancy that include commercial uses, office, hotel, serviced apartments and a verity of residential accommodations. Most visually apparent is the vertical landscaping which spirals around not just externally but through and within the built form. This component of the built form performs a number of key functions. The verdant foliage protects the building by way of shading in the summer. By photosynthesis it creates a healthier microclimate at the façade. The fringing of the floors and the atrial spaces further reduces the impact of high wind speeds on the built structure. The ratio of the mass of planting relative to the built structure is favorably comparable, thereby ensuring that the biosystem components are balanced and acting symbiotically with the structure's mechanical and electrical systems as an artificial ecosystem. Located at regular intervals are larger garden skycourts that provide inhabitants with 'breaks' in the built structure. These mini green parks located high above the city are maintained by a number of external 'cherry-pickers' that run on an external spiraling track that is part of the building's management system. The greenery in the built form, act as its lungs, like a breathing life into the floors, above and below, via the internal atrial voids (Yeang, K., 2007). The green lungs also refreshing the environment, improving the air quality and provide:

1. Vegetation on façade for sun-shading and microclimatic control.
2. Decorative landscaping for interior aesthetics.
3. Vegetation pockets located at public areas as natural air fresheners.

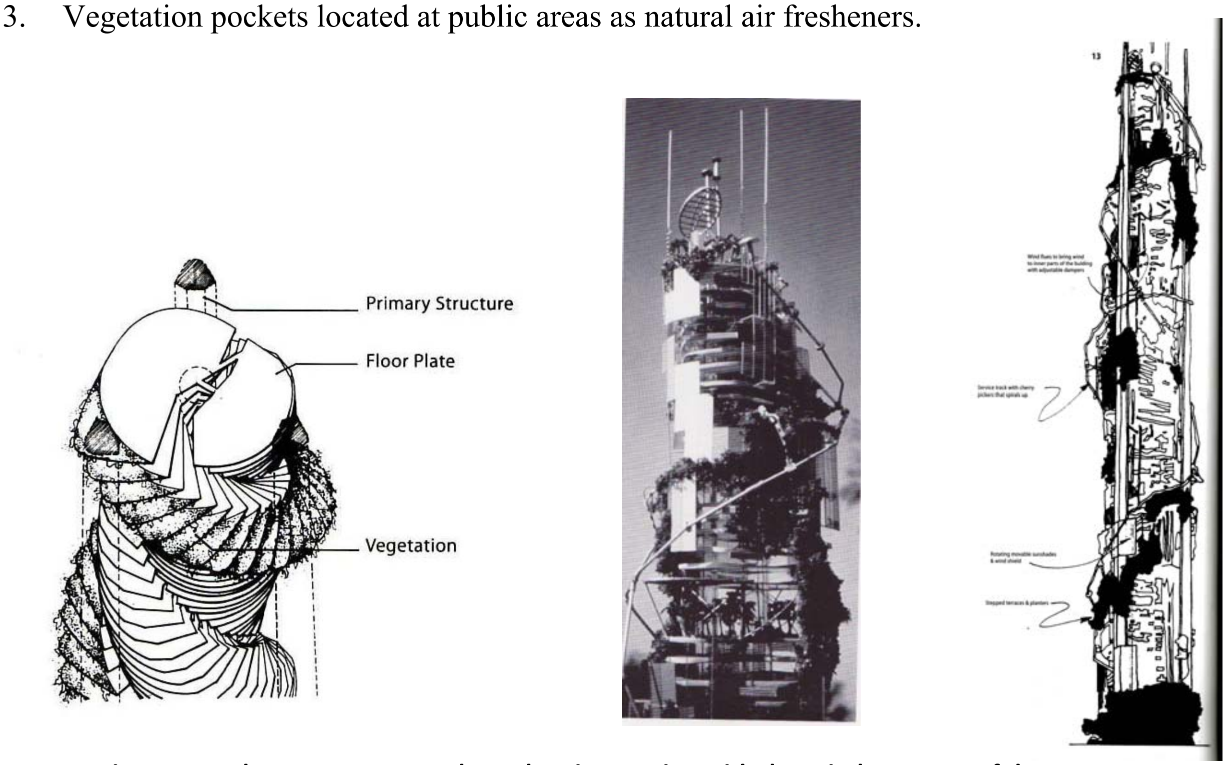


Figure 55: Tokyo Nara Tower, Tokyo. Plant integration with the spiral structure of the tower.

6.1.3 Chilean Consortia Building, Santiago, Chile

Architect: Henry Browne - Borja Huidobro

Location: Las Condes. Santiago, Chile Santiago, Chile

Owner: National Trust Insurance - Life

Built Area: 26,720 m2

Surface: 3781 m2

Green building seems to be the solution to cities who hardly have a chance to plant trees. Architects Henry Browne and Borja Huidobro have built the National Insurance building in Las Condes, Santiago, Chile. The building has various eco-friendly features that made it a sustainable one. One of the features is its interior and exterior thermo-panels vegetation that absorbs the heat of the sun. Another great green feature it has is its front wall that turns into a vegetable garden of around 3000 square meters vertical, wherein the plants changes into different looks over the years depending on the season. (Pastorelli, 2009).

It resides in Santiago; the land is bounded by Avenida El Bosque, higher flow street, and two small streets, and uses up to 48% less energy due to the exterior vegetation (Town, 2009). The building has 16 levels and it is 75mts long. The 2 volumes are responsible for setting up a gallery with access, another volume contains 3 levels. This great body is bent by its west side and aligned with the axes of Tobalaba Forest. The building was vertically separated according to the requirements of the owner. The first floor is designed for the Consortium to gain extra income. The vertical access circulations of the other 13 floors functions separately. Upper balconied have a set back from the lower level to create a visual relationship between the two. The facades were developed with particular care (Pastorelli, 2009). The western orientation of the building is protected by the double facade construction that allows vegetation to grow on a system separate from the building. The vegetated facade makes up about 3,000 square meters. From the interior, it creates a lush barrier, shading its inhabitants from the beating sun and inside creating an atmosphere more like living inside in a secret garden. When the plants are not a luscious green, they turn colors of bright reds and yellows in the fall. While MFO Park using mostly cable system for the plants to grow on, there is a second track halfway up the structure that is like a large planter that runs the length and provides a second level of vegetation. The track also has an area for maintenance workers to walk and take care of the plants and lighting (Town, 2009).

Figure 56: Colorful facade at autumn

Figure 57: Green facade at summer

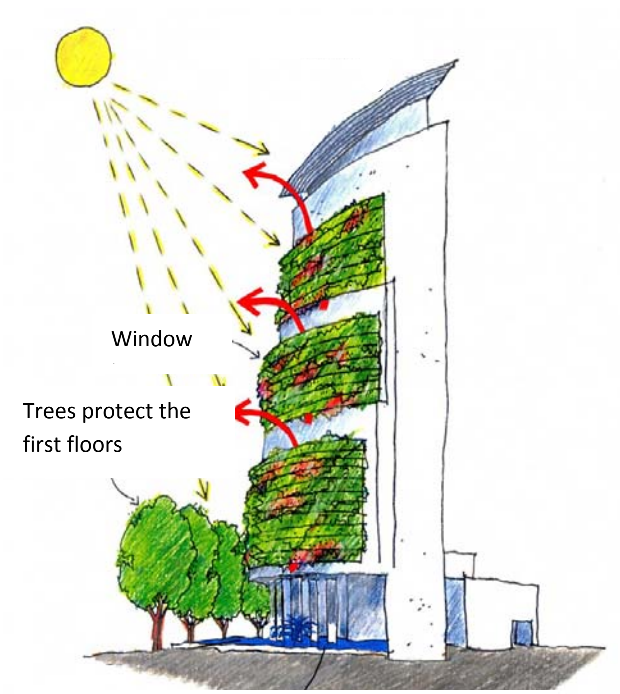


Figure 58: Concept drawing for the green façade. (Pastorelli, 2009).

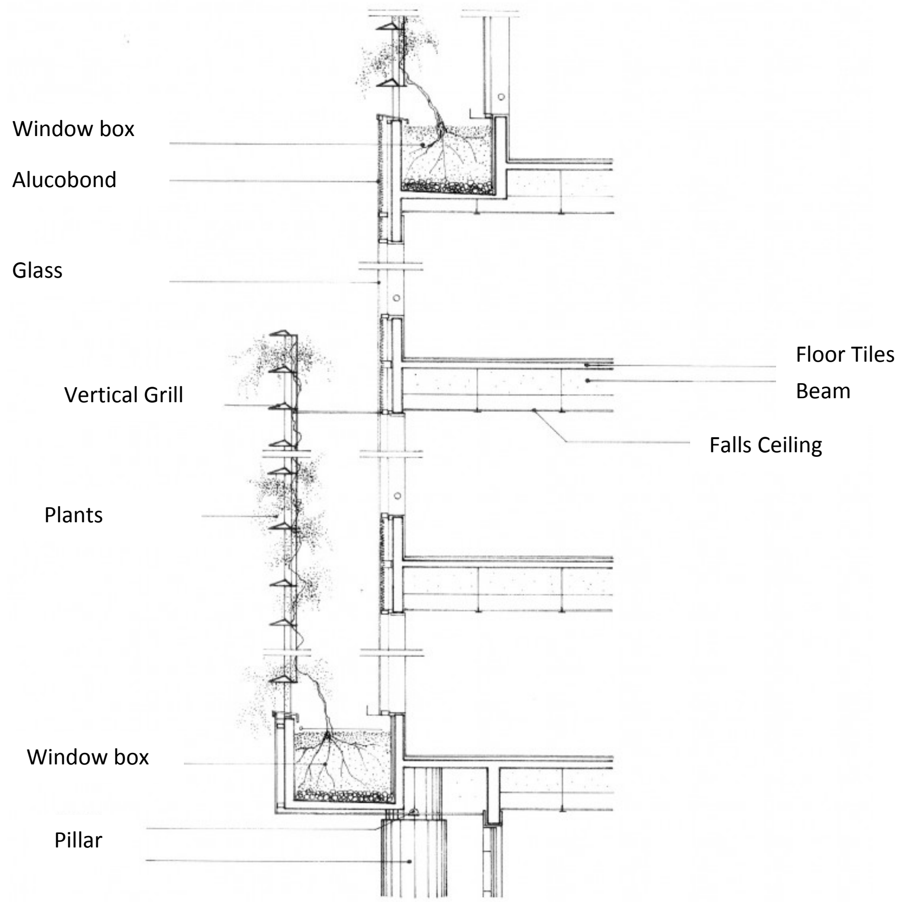


Figure 59: Detail Vertical Section. **(Pastorelli, 2009).**

Figure 60: Walking isle between the glass facade and green shell. **(Pastorelli, 2009).**

6.2 Some other case studies of designed green structure

The cases considered with green roof, green walls and biofilters are studied here for the examples. Their features and advantages according to the achievements will be discussed here with the case studies.

6.2.1 Tennessee Tower, Tennessee: Green Roof Case Study

Architect: Jack Freeman and Associates
Size / Area: 40,000 sq. ft. (40% hardscape, 60% green roof)
Principal Use: Public and private gathering place, passive use (eating lunch, relaxing, napping)
Innovative Features: All native palettes were established.

Figure 61: Tennessee Tower Green roof Design

Source: Nashville Civic Design Center • Green Roof Case Study • Nashville area Projects, 2002

Brief Description

State of Tennessee hired design team to redesign space and include a semi-intensive green roof to be used by general public and state employees. Now the Tennessee Tower is State's largest office space. New green roof design includes planters of varying depths from 27'' to 12''. It includes native canopy trees, flowering trees, shrubs, perennials and areas of lawn to accommodate larger gatherings, seating areas with benches were designed into the space, as well as several contemporary steel trellis shade structures (Nashville, 2002).

6.2.2 The Pinnacle at Symphony Center: Green Roof Case Study

Architects: Everton Oglesby Architects.

Size / Area: 30,000 sq. ft. green roof.

Principal Use: mixed use with office space, restaurant, retail space fitness facility and parking.

Innovative Features: It will recycle its own and collected rain water to flush toilets, urinals and irrigating the building. (Nashville, 2002).

Brief Description

It is a 29 story building. Its green roof will be above parking area which accounts for about half of the building's 1,2 million square feet. The green roof should be overlooking Nashville with seating and wireless Internet access. The green roof includes two major gather areas: 1st area is the multi-tenant space designed to allow large tent events and 2nd area is created for a more intimate setting, allows people to get to the edge and maximize the views. The private terrace provided for a single tenant. It takes advantage of views to skyline, bridge and river. It consists of 48 seats. The roof designed as 25% semi-intensive green roof and 75% extensive green roof which helps of 63% reduction of stormwater run-off (Nashville, 2002).

Figure 62: The Pinnacle Green Roof Plan

Source: Nashville Civic Design Center • Green Roof Case Study • Nashville area Projects , 2002

6.2.3 Cambridge City Hall: Green Wall Case Study

Cambridge City Hall is the largest capital project in the municipality's history and is setting the pace for Canadian building experts. It's the first city hall in Canada to achieve the ranking of gold in the Leadership in Energy and Environmental Design (LEED®) from the Canada Green Building Council. And it has revitalized the downtown and become the integral piece that joins together the Civic Square as a community meeting place. "Building green and sustainable buildings for our public infrastructure is going to be fundamental to our ability to address the challenges of climate change and in reducing our greenhouse gas emissions," remarked Gerretsen. The building incorporates features of sustainable design and is the wave of the future in the field of architecture. Completed at a cost of $30 million (on time and on budget), the annual energy savings to the corporation and the citizens of Cambridge are about 42 per cent compared to a traditional building – that means over $160,000 savings per year (Fegan, Linda, 2009).

Inside, the staircases are a prominent feature – highly visible as a way to encourage the healthy approach of taking the stairs. The focal point of the atrium is a "living wall" of tropical plants that cleanse the air of pollutants such as formaldehyde, volatile organic compounds, dust, and spores. Designed by Dr. Allan Darlington of Nedlaw, it's all about healthy environment and the plant wall has a running water supply behind it which provides humidity during the winter months, and the soothing sounds all year long. The open concept allows for greater air flow, reducing cooling costs and increasing the penetration of natural light to offset other light sources.

Some of the other features of new Cambridge City Hall:

• A semi-intensive, 135-metre-squared, green roof with plants and shrubs.

• Over 3,000 plants in the building – a natural biofilter.

• A 10,000-litre cistern collects rainfall which is recycled for toilets.

• Seventy-five per cent of the building has natural light available, which makes it easy to work without supplementing lights.

• No new tax dollars were used to build Cambridge City Hall.

Figure 63: Green Wall, Cambridge City Hall¸ Ontario (Source: Fegan, Linda, 2009).

• There's a weather station on the roof which sends signals about temperature, barometer, wind direction and speed.

• An automated system tracks indoor temperature and humidity, and carbon dioxide sensors help detect ventilation needs.

• All partitions and open office furniture are Global's GREENGUARD certified products as materials were selected because they do not emit harmful levels of pollutants (Fegan, Linda, 2009).

• The building is also the community's Emergency Operations Centre.

• Bullfrog Power supplies green power to city hall.

6.2.4 The Living Wall at Club Monaco: An Urban Biofiltration Case Study

The concrete-and-steel of downtown Toronto is not generally thought of as environmentally friendly. But a number of office buildings in the heart of Canada's largest city have become involved in an exciting new "eco-engineering" application. Over the past three years, Canada Life, Panasonic and the Club Monaco clothing chain have each had a self-sustaining ecosystem or "breathing wall" installed in their Toronto headquarters. Far from a few token plants, these ecosystems are complex combinations of water, rock, frogs, fish, insects and over 400 species of plant life (Valvasori and et al. 1999). Besides its aesthetic value, the breathing wall also serves a very practical purpose: It acts as a biofilter, removing contaminants from the air and then circulating clean air through the office naturally.

These new-wave urban gardens are the brainchild of Toronto biologist Wolfgang Amelung. Through his company, Genetron Systems Inc., the self-described "experimental engineer" has been creating his miniature ecosystems on a smaller scale for more than a decade. The larger corporate applications represent a major leap forward. "About 20 years ago, I began to think about building self-sustaining ecosystems, to develop a philosophy behind it," says Amelung. "You can't simply bring the outside inside, you have to recognize all the relationships that are involved." In the breathing wall, water flows over a lava rock wall covered by moss and other plants, then into a small pond. Contaminants in the air are absorbed by the vegetation and consumed by micro-organisms in the soil. Any excess waste is carried to the pond, where it is eaten by fish, frogs or insects. "Everything acts as a filter," explains Amelung, and studies conducted by Guelph University confirm the biofilter's success.

Genetron's latest project is a 40-foot-square installation at the Toronto offices of Club Monaco. Employees of the club had complained of frequent headaches, red eyes and lethargy, signs of "sick building syndrome." Club Monaco CEO Joe Miriam says there was a noticeable improvement in air quality shortly after the installation opened. "Not only did the air smell sweeter, but I also noticed a higher energy level among the staff," he says. "The plants helped increase the humidity and eliminate the dryness common to office buildings." (Valvasori and et al. 1999).

Biofiltration itself isn't entirely new: Ocean Arks International has installed similar "greenhouse" tank filtration systems to process sewage, and NASA's Dr. Bill Wolverton created an entire "living" complex at the University of Mississippi. But bringing the technology inside and having it address air quality is Amelung's special innovation. "Eco-engineering requires working with nature rather than against it," he says. "Once people align themselves to this way of thinking, the technology will take us to places we have yet to imagine." (Valvasori and et al. 1999).

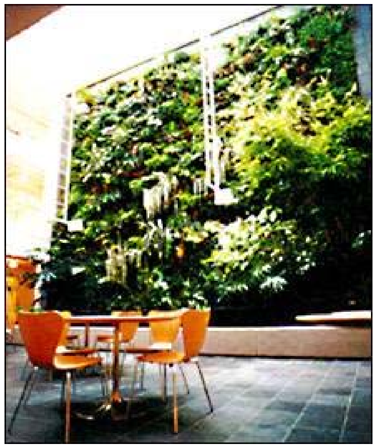


Figure 64: The air smells sweeter at Toronto's Club Monaco after it installed a 40 square foot "living wall." (Valvasori and et al. 1999).

6.2.5 The Genzyme Center: Case Study of Indoor Planting

Winning companies show a consistent attitude about creating a positive workplace for interaction among employees. The Genzyme Center is an example of a company doing the right things and this building was chosen as an AIA Top Ten Green Project for 2004. Genzyme Center's corporate headquarters offices 900 employees and includes an employee cafeteria, a library, eighteen indoor gardens, training rooms, a conference center, cafes, and public retail space. Genzyme Center was created as a symbol of progress to represent a point of identification for the company, its employees, and visitors (Fjeld, T., et al., 1998).

The goal of the design was to develop a building from the inside out, from the individual working environment to the overall complex structure of the building. Largely due to the collaboration of the design team, developer, client, and construction team, this led to an environmentally friendly, highly communicative, and innovative signature building. According to Architect Stephan Behnisch, "*The design of this building has been focused from the outset on the people who work and live in this building. It is our conviction that since people spend a significant portion of their lives working, that their working place should be as friendly, as human as possible. As we know humans are not normative — they are individuals, and we should help create an appropriate environment. An environment that they can influence, that they can adapt, that allows them to connect to the real world and the natural world. Together with the client (and it takes a great client* *to build a great building) we discussed the possibility of creating a place for the responsible human to live and work.*"

There are eighteen gardens contributed to the green building concept. The building act as a living organism that would provide a connection to the outside through a visual connection with the outside, to look outside at the green and to bring that green into the building through the gardens and it was a high level of commitment to include the interior plants because it was the right thing to do for a green building.

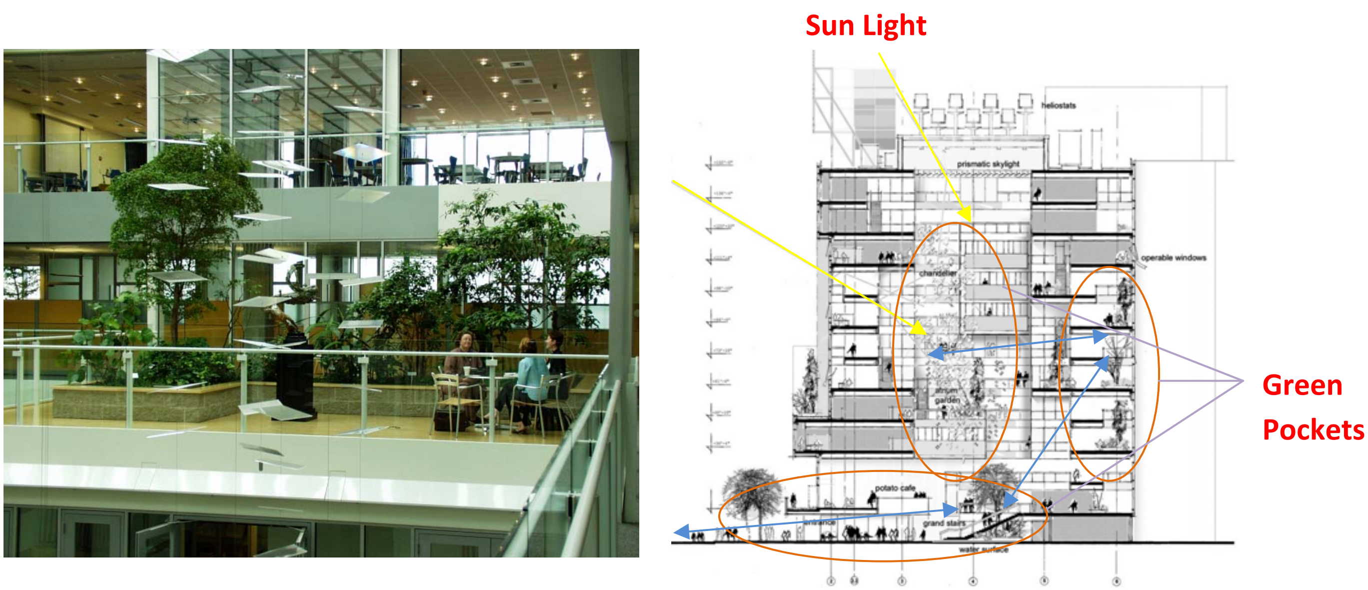


Figure 65: Indoor Planting in Genzyme Center. (Fjeld, T., et al., 1998).

The Genzyme Center is a symbol of progress representing a point of identification for the company, its employees and its visitors. They built the project from the inside out, from the individual working environment to the overall complex structure of the building. Largely due to the collaboration of the design team, developer, client and construction team, this led to an environmentally friendly, highly communicative, and innovative signature building (Fjeld, T., et al., 1998).

Experience

Interior planting in this building has mostly been met with a positive response.

The air quality in the buildings is excellent, the shading and air-conditioning functions and also the aesthetic effect indoors are viewed positively. In administrative buildings, the number of staff off sick has decreased – the individuality of the workplace plays a role here.

7 Chapter 7: Discussion

7.1 Introduction

'Sustainability' and 'green buildings' are buzzwords among building operators and developers. The recent launch of the new United Kingdom Green Building Council (UKGBC) is likely to increase the awareness. The Green Building movement is becoming ever more important as architects and developers strive to find ways of constructing and managing buildings in a sustainable and environmentally-friendly fashion.

7.2 Discussion about the findings

The study presented many ways to incorporate plants into buildings, as in roof, vertical walls, biofilters and in indoor potting plants. All these provisions have their own typology, technology of installation and maintenance as well as some drawbacks which need more extensive research to overcome. For example for the design of green wall the panel is used so far is up to 4 storied building façade. While for a skyscraper extra extensive structure is needed for clipping the panels with the façade which can endure with excessive wind pressure. Also the type of plants can survive in a particular wind load needs to be experimented. Another aspect that should be brought under consideration for highly reflective glass façades of the existing skyscrapers is the use of green walls as much as possible to prevent the bird's kill. Proper technology for clipping the green wall module with the glass curtain needs to be invented. Otherwise the "Stand-off" bracket system can be used for covering the extensive glass curtain. Besides preventing birds kill it will also help to reduce the direct solar heat gain on its huge elevation walls as well as prevent the greenhouse effect for inside the building, and lower the pressure on HVAC system. As stated in Yeang (2006), the complete covering of the façade can greatly contribute to lowering the ambient temperature. Externally vegetation can contribute to lowering urban temperature in the boundary layer by 1 degree centigrade while vegetative canopies (i.e. trees) may lower external ambient temperature by an additional 2 degree centigrade in the area under the canopy.

So trees can be planted on the roof top of skyscrapers for additional shading, considering the load bearing capacity. On this point it can be suggested that, intensive green roof with large trees is better than the extensive one, which only is covered with small grasses. But where intensive roof installation is not possible, extensive roof with medicinal shrubs or herbs can be planted which additionally bring some money. These roof gardens can also be used as the breeding ground for honey bees, to produce honey as well. Thus green roofs can be used for multiple purposes for generating money a part of which can be spent for its maintenance. But for many existing buildings where no green roofs can be installed for structural or monetary reasons, just keeping potting trees will help to some extent. The shadows of the plants will help to reduce the direct heat gain of the roof, but what is needed is regular watering.

In case of the indoor environment quality "Active Biofilter" is more successful to filter the VOCs then passive wall and potting plants, as it draws the air forcefully, removes the pollutants and disseminates through the space by the building's HVAC system. But it is on the other hand more costly then the passive wall which act as a natural process of biofiltration. Though a little expensive but in the long run the active wall is cost effective, and it also has the greater capacity for purifying a larger amount of indoor air. The costs of the biofilter can only be reduced if, more companies come to produce and provide living walls and biofilters. Only the greater competition can help to increase the quality and service and decrease the cost. Public awareness and advertisement is the other procedure to encourage people for these green installations.

Cost effective incorporation of innovative systems into project design requires whole systems thinking and early planning. The economic benefit of any building system should be evaluated by its impact on the overall project costs; not just the cost of the specific product. That is, paying more for a particular product may be cost justified by savings generated elsewhere in the project. For example, a living roof is a storm water management system to be evaluated during the civil engineering process; not a roofing system to be compared to other roofing options. The cost of a living roof is never appealing when compared to other roofing. Rather, it is justified by reduction of on-ground stormwater management infrastructure costs. Sometimes, the reduction of the on-ground stormwater management systems (such as a smaller retention pond) allows for greater building density on the site. Only a small increase in FAR provides increased asset value far exceeding the additional cost of a living roof. It is this whole-systems thinking that fosters the successful incorporation of innovative products into building design.

7.3 Recommendations

Beside these aspects there are some other issues which must be taken into great consideration for designing green skyscraper in the habitat.

7.3.1 Vegetation based on Building's location

Location of the green roof plays an important role in the design process. The height of the roof above grade, its exposure to wind, the roof's orientation to the sun and shading by surrounding buildings during parts of the day will have an impact. The general climate of the area and the specific microclimate on the roof must be considered. Views to and from the roof may also determine where certain elements are located for maximum effect. Especially for the skyscrapers above 40 floors, where the wind load must be considered for extensive green roof design. It would be a mistake to consider the roofs or the upper parts of the tall buildings as too inhospitable an environment for climatically significant amounts of plant life. Hardy plants can adapt to such environment with minimum soil depth or humus content. Certain plants can grow on only 7 centimeter of soil consisting of pea gravel and silt sand. The depth of soil needed depends on the type of plants. For example, grasses need 150 to 300 millimeters (mm) ground cover, vine needs 300 mm, medium shrubs, 600 to 750 mm, large shrubs and trees, 600 to 1050 mm. so, roof gardens can be used for urban agriculture as most vegetables need no more than 200 mm of soil (Yeang, 2006).

7.3.2 Location of deep soil for extensive roof

For the load bearing issues on the roof for existing and designed, the depth of soil according to the size of mature trees should be considered based on the location of the load bearing columns. Deep soil should be placed only above the structural columns. Or large trees can be mound in potting soil on the roof top.

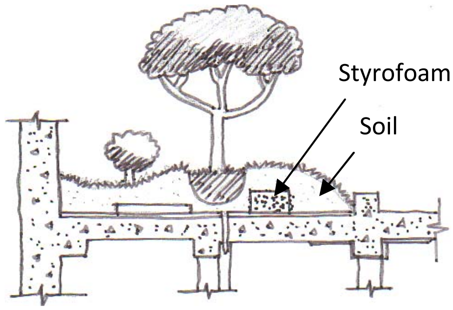


Figure 67: Deep Soil over Structural columns.

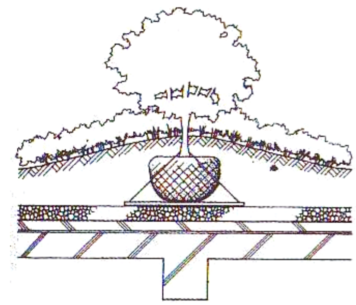


Figure 66: Mound for large plants for rooftop planting. Wong, Nyuk Hien and et al., (2002).

7.3.3 Green wall support for skyscrapers

For the green vegetated wall the maximum height, built so far is about 40 feet high and 120 feet wide. For the skyscrapers which are above 50 stories or about 100 stories have a large amount of wall surfaces exposed to sun need to be covered with the green wall. But the excessive height and the wind pressure need to be considered at the upper parts of the building. Some design consideration suggested could be as follows.

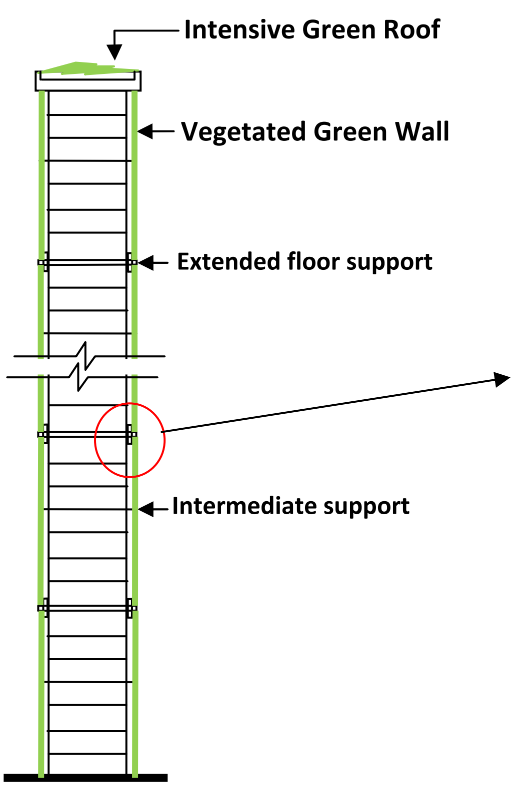


Figure 69: Proposal for green wall installation in the skyscraper.

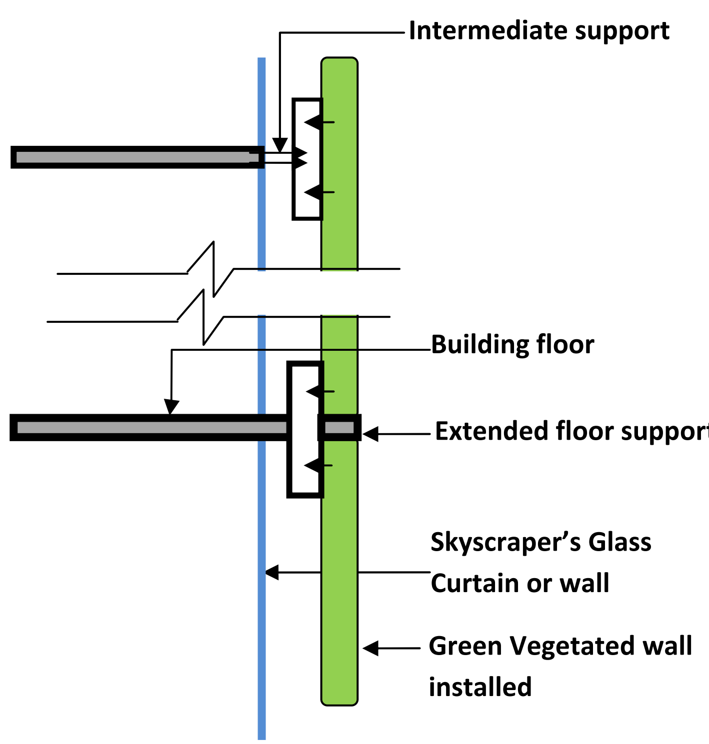


Figure 68: Green wall installation details in the skyscraper.

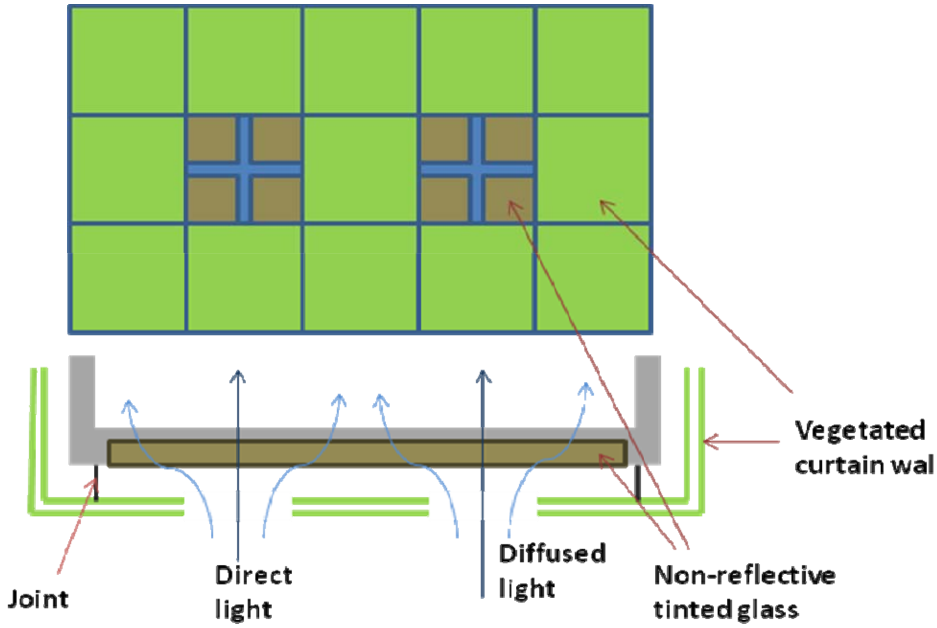


Figure 70: Sectional detail for vegetated curtain wall.

For installing the panel of green wall in high-rise buildings or in skyscrapers, some structural support is suggested in-between floors. At a 4 to 7 floors interval, the extended floors could bear the load of green panels. Proper drainage and water supply techniques need to be installed with a provision of maintenance. At the upper most floors of a skyscraper, where height and wind pressure is excessive, more frequent intermediate supports or structural joints are suggested. Vegetation can be used as a curtain wall to cover the excessive glass surface of the skyscrapers. The glass windows need to be tinted instead of a highly reflective one. Adequate natural lighting and ventilation through the glass windows should be ensured.

7.3.4 Design options for green wall in skyscrapers

There are options as stated earlier, for the green wall design. It could be the climbing plants or the modular panels. For the skyscraper design both the options could be used together. For the lower levels the climbing plants, while rooted on the ground could be used in a designed manner, the hanging plants could be planted at the roof top which will cover the top most level's wall, while the modular panels could be used for the rest of middle floors. It could save time and money for the maintenance as those types of plants require little or no maintenance than the green panels.

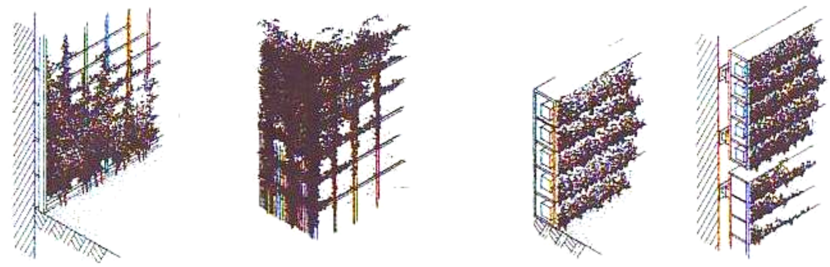


Figure 71: Variations of green wall design. (Source: Yeang 2006)

7.3.5 Ecological Nexus: Design to make it environmentally viable

Ecologically it is crucial for the designer to ensure physical continuity in the designed system by planting in the biomass to encourage species migration and contribute to greater diversity (Yeang, 2006). To achieve viable continuity by 'vertical landscaping' of the urban skyscraper, the system should be linked e.g. stepped planter-boxes organized as 'continuous planting zones' up the face of the building. These should permit some extent of species interaction and migration, and provide a link to the ecosystem at the ground level. As a general design strategy indigenous vegetation should be introduced for the locality, as far as possible. If the indigenous vegetation reintroduced correctly within its own climatic range, typically it will requires less maintenance and makes fewer demands on other scarce resources such as water, fertilizer and energy.

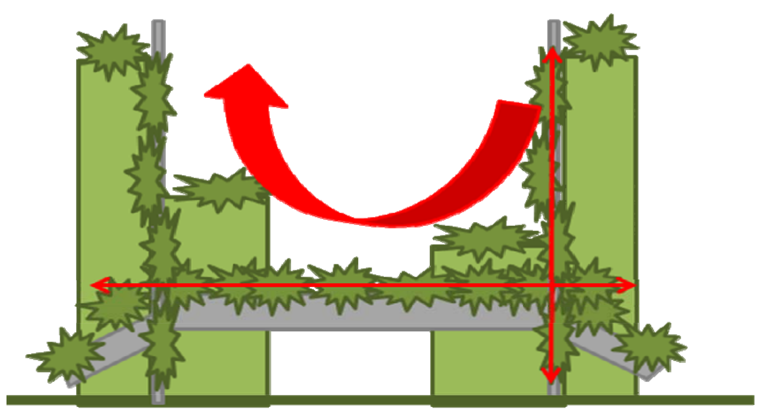


Figure 72: Landscape bridge connection for fragmented green areas

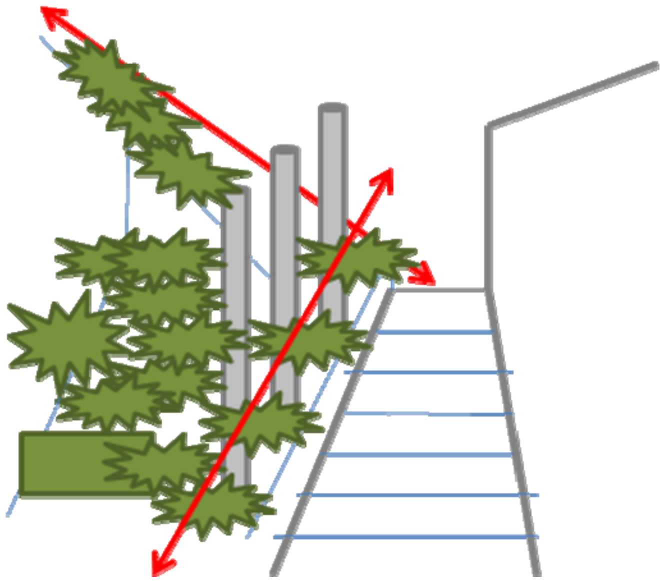


Figure 75: Continuously integrated planting zone from ground to roof

There are three basic strategies for designing plant and non-human biomass spatially into built system: Juxtaposition, intermixing and integrating (Yeang, 2006). Juxtaposing is the concentrated placement of greening material at one or a few locations in the built form. Integrating is the distributed and patchy placement of greening material. Integrating consists of a woven blending of the greening material with the built form, which has the link from ground to the roof level. This type of planting can ensure the species interaction and migration, thus contribute to the diversity. The alternate option would be to separate the planting into unconnected boxes. But these can lead to species homogeneity, which requires greater external inputs and regular human maintenance to remain ecologically stable. There are many examples, where the creation of these urban habitats encourages species returning to the urban environment where they exist previously.

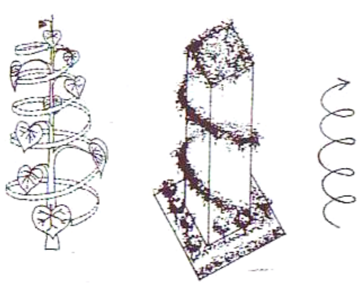


Figure 74: Continuous vertical landscaping. Source: Yeang, 2006

Figure 73: Designing plants and non-human biomass into built system. Source: Yeang, 2006

7.3.6 Planting design in built forms for economic, social and environmental benefit

Ground coverage, green walls, sky courts, indoor plants and roof top gardens works together to make the skyscraper 'Green'. The vertical landscaping is one variation on the creation of roof top gardening; another variation is the green wall, which encapsulates the principle of a single element with multiple functions (Yeang, 2006). The breathing wall with vegetated façade according with the sky courts tends to focus to develop the building as an ecologically complex and stable plant, microbial and human community, that helps to improve the air quality in an interface between natural processes and the built structure's environmental system. The whole system works for the social, ecological and environmental benefits. If this system multiplies and implemented to all the skyscrapers in an urban area the beneficiary will be all the species including the humans. The results will be the noticeable decrease in urban heat island, rapid reduction of energy consumption and refreshing air for a healthy environment.

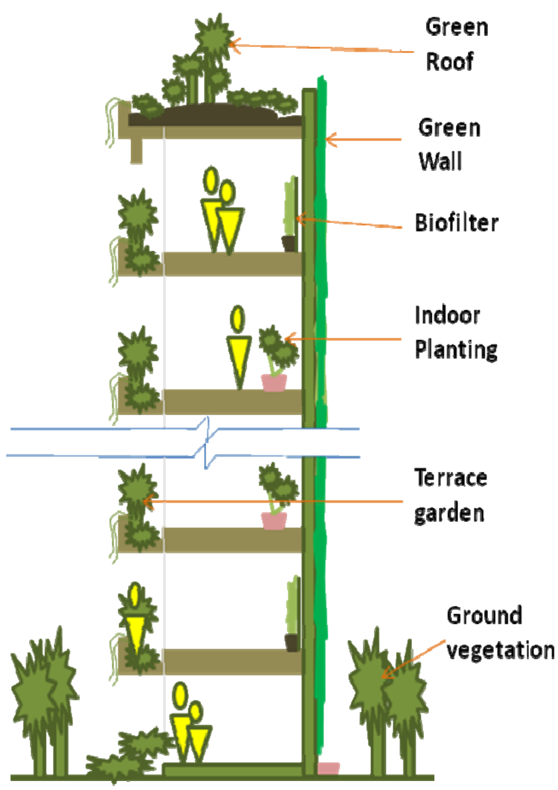


Figure 76: Green Skyscraper: Integrated planting design.

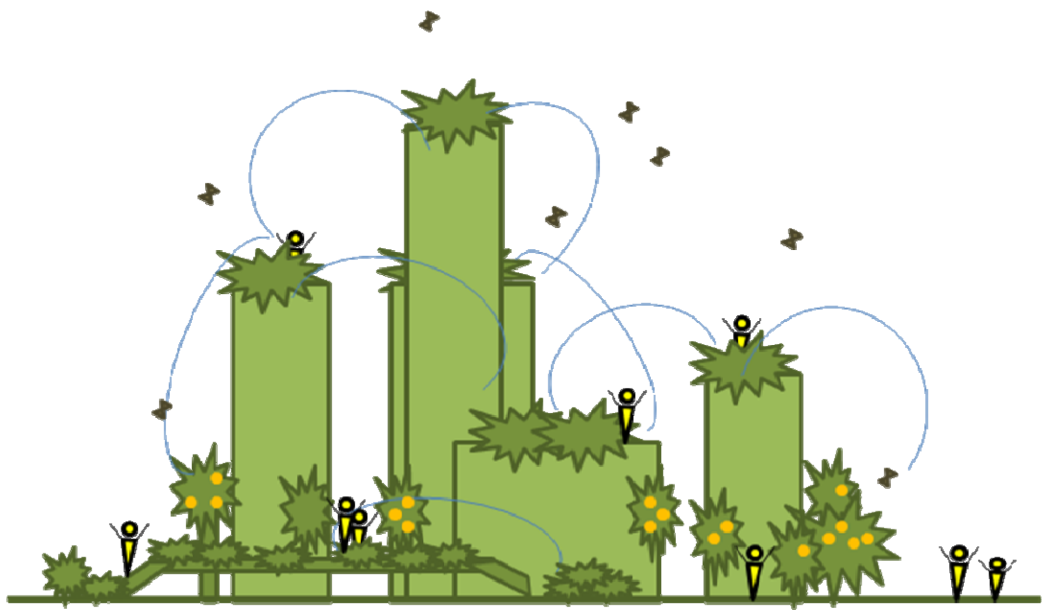


Figure 77: Green Roof, sky courts and green walls create new urban habitats, and restore the previous one

7.3.7 Green roofs in a greater scale

To cover a significant amount of roof area in a jurisdiction, GIS or Geographic Information System can be used to mark and calculate the total amount of possible roof tops that can be converted into green roofs. With GIS environment a methodology can be produce to examine the characteristics and distributions of actual rooftops across the area. As GIS technology represents landscape features, such as buildings, streets, stormwater infrastructure, and watersheds in terms of their geographic positions, this will enable digital representations of features and their attributes to be related to one another as they are on the ground. So GIS modeling can be produce for data management, for numerical analysis (in conjunction with spreadsheets) and for developing materials regarding stormwater and combined sewer systems, air quality, the urban heat island, building-energy use and monetization of benefits of green roof.

7.4 Some policy guidelines

For the right practice and good maintenance requires a set of policies and guidelines for green roof, green walls and living wall design. These policies should guide the manufacturer, installer and the user for a better quality, performance and cost. Under this section some of the policy guidelines will discuss and proposed.

7.4.1 Educational Benefit of green roof and green wall: A socially viable issue

Green Roofs and Walls are the perfect tools to teach about the environment. The next generation needs to learn about the environmental concerns of today and how we addressing them. Problems like the Heat Island Effect, Global Warming, CO2 reduction in cities are all addressed by Green Roofs and Walls. Just a few of the topics that Green Roofs and Walls may be used for in education are:

- Ecological Observation
- Growing Plants and Vegetables
- Identifying the Protection of Buildings

Thus the educational opportunities are endless.

7.4.2 Economic Value for building "Green"

It is believed that the "Green" approaches lead to higher value buildings. The demand for real green innovations is crucial today. The market place is drawn to substantive green building solutions (not green washing). According to Truett, R. (2003), Buildings are valued based upon cash flow, property appreciation, and risk.

- Cash flow is higher when buildings rent faster, tenants roll over less and operating expenses are lower. Utilizing the sustainable building systems delivers these. Living roofs have substantial impact on stormwater and increase PR boost - they help leasing and sales pitch thus faster lease up. Biofilters provide dramatic beauty and real health benefits (lower absenteeism easily pays for the biofilter). Vegetated retaining walls create vertical green space and reduce hardscape. This creates curb appeal and increases market appeal.
- Property appreciation is a function of the building and its surrounding community. The more viable the neighborhood, the greater the property appreciation. Fostering healthy communities creates underlying value. So, creating buildings that support the local community - reducing negative impacts on neighbors, fostering self-reliance of the local community - ultimately drives asset value.

- Risk in buildings has historically been associated with fire, earthquake, hurricanes, floods with regard to building occupants. Increasingly, risk is being more broadly defined to include impact on communities from which natural resources were extracted, products were manufactured, waste is disposed, as well as safety to occupants within the building. Large, centralized systems (the grid) are increasingly being viewed as higher risk than small, decentralized, local systems. Thus, the perception of risk is shifting to smaller scale, lower impact, simpler systems - sustainable buildings.

7.4.3. Reducing Ecological Impact for environmental benefit

If green roofs and green walls are to be proposed as solutions to environmental problems, then it follows that the construction of green roofs and walls should also be as environmentally sound as possible. Green roofs are constructed out of a number of materials, some of which require high amounts of energy to produce (expanded clay and slate), others which must be transported from distant places (lava rock) and others which are not recyclable (plastic drainage mats, filter cloth) (Krupka, 2001). Waterproofing membranes also contain materials (PVC, root repellent chemicals) with negative ecological impact. Green walls are constructed with plastic base modules. There is a movement towards reducing the ecological impact of building green roofs and walls. The German Roof Garden Association proposes these "Ecological Guidelines for Roof and Wall Greening" (DDV, 2004):

Production: Use of recycled materials, consideration of the energy balance for materials, new or recycled.

Manufacturing: Reduced environmental impact of manufacturing through resource and energy savings.

Transport: Minimizing the transportation distances by building and/or extending a logistics system.

Application: Sustainable use of materials through long lifespan (durability).

Waste disposal: Disposal safeguard through re-utilization.

An area that requires further research is the use of recycled materials for green roof and wall components. One that is used often and successfully in Germany is recycled crushed brick which is suitable for use in growing media and drainage layers for roofs. It is easily available in the country so it need not be transported far. Using recycled brick relieves pressure on landfills as well as saving on raw materials (DDV, 2004). Finding local materials appropriate for green wall and roof construction will be one of the important tasks in developing the green industry in Canada. Detailed product-independent specifications like for the various materials necessary for green wall and roof construction will become very useful.

7.4.4. Performance Rating Systems

One of the main concerns with green policy is how to ensure that performance goals are met and continue to be met over the long-term for installed green roofs, walls and biofilters. Performance rating systems are tools used for this purpose. Stefan Zeller has been examining the different types of performance rating systems used in Germany. In his survey of 355 total responses, he found that out of 29 municipalities (8% of responses) that used a standard performance rating system, there were 24 different types used (Zeller, 2002). The most frequently used system (4 responses) was the one developed by the FLL (1998). The basis of the rating system is the thickness of the green roof construction penetrable by roots, from which 10 base points per cm are calculated. These points are dependent on the particular roof construction meeting minimum requirements for some specific parameters. It appears that many jurisdictions have devised their own system which may be as simple as a verbal agreement. Perhaps even more common is not using any system at all. For reasons of comparison, monitoring, justice and legal conformity, there must be some motivation to develop a national performance rating system for green roofs and green walls as well (Zeller, 2003).

7.4.5 Other Policy Initiatives and Tools: Competitions and Media Coverage

Public awareness is an important tool in encouraging green roofs, green walls, biofilters and should be a part of any green initiative. In Mühlheim, where there is an enormous amount of green roof construction, public awareness plays a large role. Rudolf Gix, also known as the "green roofer of Mühlheim," has been very successful in promoting the green roof industry. Competitions, he says, being voluntary initiatives are more positive than regulations which many owners see as a burden. In addition, competitions increase the profile of green roofs in the public eye. This is an important factor because often the roofs are not physically visible or accessible to the public. Competitions and associated media coverage ensure that green roofs are seen and appreciated. The significant number of green roofs in Mühlheim is largely the result of positive media coverage which consistently publishes articles on green roofs (Gix, 2003). The city of Karlsruhe organizes competitions for greening projects in industrial areas. The competitions encourage attractive designs, including green roofs, in the urban fringe where visitors form their first impressions of the city. Same methodology can be implemented for making public awareness for the green wall and biofilter design. The more the interests the better the competition for product, increased its quality and decrease the cost

7.4.6 Greening of Public Buildings

Greening the public buildings increase the initiative amongst the private companies and grow the interest of general people. These will act as a set of example in front of the nation. The state of North Rhine Westphalia is attempting to set an exemplary model of environmental sensitivity by implementing green roofs on state owned buildings. In a circular by the Ministry for Urban Design, Housing, Culture and Sport from 21.12.1998 under section 3.1.2.3 Building Ecology Aims, it includes in the list, "greening of roofs with a slope of less than 25 degrees with location-appropriate plantings" (Mainz, 2004). Thus every state can take the initiative to convert their glass-concrete pillars into eco-friendly green urban habitat.

7.5 Conclusion

The aim of the thesis was to find out the possible ways to integrate plants into skyscrapers and asses how the integration of plants into the skyscraper design can help reducing the energy use, and enhance the living quality. Throughout the thesis work it was studied to establish the necessity of planting to incorporate into skyscrapers, for the well being of our economy, society and the environment. To fulfill the requirements of Objectives the findings are organized accordingly throughout this thesis work. For example, the provisions of integrate plants into skyscraper includes the four possible options like, Green roof, Green wall, Biofilter and Indoor potting plants which can be incorporate into the design. The impacts of these options on energy consumption and living environment, such as the benefits of Green roof, Green wall, Biofilter and Indoor potting plants on living condition, environment, economy and society is elucidate with some of their drawbacks, and the available technologies to integrate these options into the buildings. Discussion and recommendations were made to overcome some of the drawbacks and some guidelines were proposed for good practice to make the 'Green Movement' viable economically, socially and environmentally. Some good case studies were also presented for examples. Thus the thesis work fulfilled its aim and objectives to its full extents for designing a Green Skyscraper with incorporating the plants into it.

People need nature for regeneration. Humans are only able to live on this earth through plants and vegetation in the first place, and they can learn a great deal from nature and its cycles (Schempp, D., 2009). 'Planting' concept requires integral and interdisciplinary planning. Even when determining the basics, and in the preliminary planning, it is necessary that the specialist engineers take part and contribute their knowledge. Exterior and interior planting require integral planning and a symbiosis between nature and technology. This concept is sustainable, ecological and with the correct planning, results in high acceptance and quality in both outdoor and indoor areas are achieved. The concept protects our environment. Economically, the green architecture is cost-effective and future-orientated with growing acceptance and increasing commercialization and, of course, it is beautiful.

For the ever growing cities the construction of sky high buildings could not be stopped rather the demand increases day by day. So, this is the high time to look forward to restore the nature and bring back it into the built environment. As we have seen the enormous benefits of plants, along with potential ways of incorporating technologies to integrate them in the building envelope as well as inside it, but still the process is very much slow and under knowledgeable to mass people. Proper utilization of the benefits and more public awareness on this regards can change our environment drastically within near future if all the processes are followed. For the best benefit the building orientation and the climatic condition of the site should also be necessary to consider while designing green buildings besides incorporating plants into the design. We hope that the few drawbacks of technologies should be overcome soon and more options to plant integration into the skyscrapers should draw the builder's attention. Thus we can have a better environment as well a better future for our next generation.

8 References

Acks, K. (2003), "A framework for cost-benefit analysis of green roofs: initial estimates," pers.comm.

Adams B.J. and Fabian P. (2000), Urban stormwater management planning with analytical probabilisticmodels, John Wiley Sons Inc.

Akbari H., Bretz S., Taha H., Kurn D. and Hanford J. (1990), Peak power and cooling energy savings of high- albedo roofs. Energy and Buildings-Special Issue on Urban Heat Islands and Cool Communities 25(2), 117–126.

Akbari, H., Konopacki, S., & Pomerantz, M., (1999). Cooling energy savings potential of reflective roofs for residential and commercial buildings in the United States. Energy. Vol 24, Issue 5. 391- 407.

Akbari, H., Pomerantz, M., & Taha, H., (2001). Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas. Solar Energy, 70, 3, 295-310.

Akbari, H and Konopacki, S., (2004). Energy effects of heat-island reduction strategies in Toronto, Canada. Energy. 29, 191-210 (LBL Study)

Alcazar, S.S. and Bass, B., (2005). Energy performance of green roofs in a multi storey residential building in Madrid. University of Toronto

Banting, D. et al., (2005), Ryerson University, Quantitative Findings Oct. 2005, Report on the Environmental Benefits and Costs of Green Roofing.

Bateman, I. J., Lovett, A. A., and Brainard, J. S. (2004), Applied Environmental Economics: A GIS Approach to Cost-Benefit Analysis, Cambridge University Press, Cambridge.

Bass, B., Krayenhoff, E.F., Martilli, A., Stull, R.B. and Auld, H. (2002). Modelling the impact of green roof infrastructure on the urban heat island in Toronto. Green roofs Infrastructure Monitor 4(1)

Bass, B. and B. Baskaran. (2003). Evaluating Rooftop and Vertical Gardens as an Adaptation Strategy for Urban Areas. Institute for Research and Construction, NRCC-46737, Project no. A020, CCAF Report B1046. Ottawa, Canada: National Research Council.

Bass, B., Currie, B.A., Perks, T., & So, D. (2004). Effects of Green Elements on Graduate Students Perception of Wellness - #30 Charles Street Toronto. (unpublished).

Beedle, L. S. et al; (2007), The Skyscraper and the City: Design, Technology, and Innovation, Book 1, USA, The Edwin Mellen Press, ISBN-13: 9780773453296

Brenneisen, S., (2003). The Benefits of Biodiversity from Green Roofs – Key Design Consequences. Proceedings from Greening Rooftops for Sustainable Communities, (2003), First North American Green Roof Infrastructure Conference, May 29th and 30th, Chicago, 2003.

Burton, J., (2007), Green-Building Regulations on the Horizon, Buildings: Helping Facilities Professionals Make Smarter Decisions, Web Article, Retrieved on October 06, 2009 from http://www.buildings.com/ArticleDetails/tabid/3321/ArticleID/4932/Default.aspx

BWB (Berliner Wasserbetriebe). (2004). Available from www.bwb.de

Cohnstaedt, J., Shields, J., & MacDonald, M., (2003). New workplace commons, a study of innovative support for cultural and social enterprises in both the not-for-profit and for-profit sectors (401 Richmond). Commissioned by Canadian Heritage; City of Toronto, Culture Division; and Ministry of Culture. (unpublished)

Continental Automated Building Association, (2007), Energy Efficiency Indicator Report,

Crackowski, J.M., Nasar, J.L. (2003). The restorative effects of roadside vegetation- implications for automobile driver anger and frustration. Environment and Behaviour, 35, 736-751.

Currie, Beth Anne, (2005a), Air Pollution Mitigation with Green Roofs Using the UFORE Model, Unpublished MASc Thesis, Ryerson University, Toronto.

Currie, B.A., (2005b). Urbanspace PROPERTY Group, Environment, Health and Safety Coordinator. Pers comm.

Davis, Kim. (2002). Green Roof Inventory: Preface Report. Report prepared for the Greater Vancouver Regional District, December 12, 2002.

Darlington, Alan, (2001), NEDLAW Living Walls, Retrieved on Aug 12,2009 from http://www.naturaire.com/architects_and_engineers.php#q11

Darlington and Dixon, (2002), Acclimation and Nutrition of Indoor Air Biofilters, Indoor Air Proceeding 2002, University of Guelph, Biofiltration Group CESRF, Retrieved on Aug 12,2009 from http://www.ces.uoguelph.ca/research/envweb/Home.htm

Darlington, A., (2008), "The use of biological systems in closed environments", NEDLAW Living Walls, Controlled Environment Systems Research Project at the University of Guelph, Web Publication, Retrieved on April 12, 2009, from http://www.naturaire.com/architects_and_engineers.php#q11 .

DDV (deutscher Dachgärtner Verband). (2004). Ökologische Leitlinien für Dachbegrünung. Available from www.dachgaertnerverband.de [cited 21 June 2004].

Department of Ecology, State of Washington, Green Building, Access Washington: Official State Govt. Website. Retrieved on October 02, 2009, from http://www.ecy.wa.gov/programs/swfa/greenbuilding/law.html

Dramstad, W.E., Olson, J.D. and Forman, R.T.T., (1996), Principles in Landscape Architecture and Land-Use Planning, Harvard University Graduate School of Design, Island Press, and American Society of Landscape Architects, Washington D.C.

Dunnet, N., and Kingsbury, N, (2004), Planning Green Roofs and Living Walls, Timber Press, Portland, Oregon, 254p.

England, E., Morgan, B., Usrey, L., Greiner, M., Blackmann, C. (2004), "Vegetated roofing technology: an evaluation," pers.comm.

Fjeld, T., et al., (1998), "Effect of Indoor Foliage Plants on Health and Discomfort Symptoms Among Office Workers," Indoors + Built Environment, 1998, 7:204-206. (Norway). http://greenplantsforgreenbuildings.org/pdf/Authentically%20Green%20Interiors%20Paper%20copy.pdf

FLL. (1998), *Bewertung von Dachbegrünung. Empfehlungen sur Bewertung in der Bauleitplanung, bei der Baugenehmigung und bei der Bauabnahme.* Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V. (FLL), Bonn.

Foster, Norman, (2001), Green Architecture, AD Architectural Design, Vol.71 No.4 July 2001, ISBN 0-471-49193-4

Freeman, Kenneth, (2007), "Why Plants?". Ambius. Retrieved May 21, 2009 from http://www.plants-in-buildings.com/whyplants-greenbuildings.php?PHPSESSID=e653e7b957ce5bc2b6f

Frost & Sullivan, (2008), Bright Green Buildings: Convergence of Green and Intelligent Buildings, Continental Automated Buildings Association, CABA, http://.caba.org/brightgreen

Gedge, D., (2003). From Rubble to Redstarts…Black Redstart Action Plan Working Group. Proceedings from Greening Rooftops for Sustainable Communities, First North American Green Roof Infrastructure Conference, May 29th and 30th, Chicago, 2003.

Gilhooley,M. (2002), Green green grass of work: a little bit of green can go a long way, and we aren't talking about money. Facilities Design and Management. Retrieved April 08, 2009 from http://www.iuoe.org

Gille. (2003). Landschaftsplanung Abteilung, Berlin-Mitte. Pers. comm., 18 December 2003.

Gix, Rudolf. (2003), Pers. comm., 4 December 2003.

Gonchar, J., (2009), Vertical and verdant, living wall systems sprout on two buildings, in Paris and Vancouver, Architectural Record, McGraw-Hill Construction. Retrieved on Aug 20, 2009 from http://archrecord.construction.com/features/digital/archives/0702dignews-1.asp

Green Roofs for Healthy Cities (GRHC), (2003), Public Benefits of Green Roofs, available online at http://www.green roofs.org/index.php?page=publicbenefits

Harris,Cyril M. (Ed.), (2005), Dictionary of Architecture and Construction, The McGraw-Hill Companies, Inc.,USA, ISBN-0-07-1452370

Hauth, Emily and Tom Liptan. (2003). Plant Survival Findings in the Pacific Northwest. In *Proceedings of the Greening Rooftops for Sustainable Communities Symposium.* Hosted by: Green Roofs for Healthy Cities and City of Chicago, Chicago, 29-30 May 2003.

Herman, Robert. (2003). Green Roofs in Germany: Yesterday, Today and Tomorrow. In *Proceedings of the Greening Rooftops for Sustainable Communities Symposium.* Hosted by: Green Roofs for Healthy Cities and City of Portland, Oregon, 29-30 May 2003.

Herzog, T.R., Maguire, C.P., Nebel, M.B., (2003). Assessing the restorative components of environments. Journal of Environmental Psychology, 23, 159-170.

IGBC Newsletter, (2007), Green Habitat (September, 2007), Retrieved on October 05, 2009 from http://www.igbc.in:9080/site/igbc/publication.jsp

Jacobs, Hayley. (2008a). Green Plants for Green Buildings, Retrieved on April 08, 2009 from http:// greenplantsforgreenbuildings.org/about.htm

Jacobs, Hayley. (2008b). Improving Environmental condition in the Workplace. Facility Management Journal. Retrieved on May 20, 2009 from http://greenplantsforgreenbuildings.org/pdf/fmj-julyaugust2008.pdf

Jennings, G., Hunt, B., Moran, A, (2003), A North Carolina Field Study to Evaluate Green roof Runoff Quantity, Runoff Quality, and Plant Growth, ASAE Annual International Meeting, Las Vegas, Nevada, USA, 27-30 July 2003

Johnston, J. and Newton, J., (1993), Building Green, A Guide for Using Plants on Roofs, Walls and Pavements, The London Ecology Unit, London.

Johnston, David, (2008), Bringing Green Homes within Reach,(January 2008) Environnews Focus, Environmental Health Perspectives, Vol 116, No. 1. , Web Publication, Retrieved on March 30, 2009, from http://web.ebscohost.com/ehost/pdf?vid=1&hid=120&sid=fbd7924f-a490-46d5-b4ce-52c3cbd00a24%40sessionmgr103

Kaplan, R. (1993), The role of nature in the context of the workplace. Landscape and Urban Planning, 26, 193-201.

Kats, G., (2003), The Costs and Financial Benefits of Green Buildings

King, D.,(2009), Passive design primer for offices, Building Sustainable Design - www.bsdlive.co.uk.

Klem, Daniel, Jr. , (1990), "Bird Injuries, Cause of Death, and Recuperation from Collisions with Windows." *Journal of Field Ornithology*, 61(1), 1990, pp.115-119. http://www.birdsandbuildings.org/docs/BirdSafeBuildingGuidelines.pdf

Klem, Daniel Jr.,(2004), "Glass - An Unintended but Catastrophic Hazard for Birds", Animal Welfare Institute, Web Publication, Retrieved on Aug 12, 2009 from http://www.awionline.org/ht/d/ContentDetails/i/1852/pid/2507

Klem, Daniel, and et al., (2007), Bird-Friendly Development Guidelines, City of Toronto Green Development Standard, Canada. Retrieved on Aug 12, 2009 from http://www.birdsandbuildings.org/docs/TorontoDevelopGuidelines.pdf

Knowles,L.,(2005), Living Wall: A Feasibility Study for SLC, Final Report, University of Waterloo.

Kohler, M., Schmidt, M., Grimme, F.H., Laar, M., Paiva, V.L.A., and Tavares, S. (2002). Green roofs in Temperate climates and in the hot-humid tropics - far beyond the aesthetics. Environmental Management and Health. 13(4) 382-391

Köhler, Manfred. (2003a). Fachhochschule Neubrandenburg. Pers. comm., 25 November 2003.

Köhler, Manfred. (2003b). Fachhochschule Neubrandenburg. Pers. comm., 20 October 2003.

Köhler, Manfred. (2003c). The Green Roof Tradition in Germany: the Example of Berlin. In Press: in *Earthpledge Handbook: Green roofs*. Earthpledge, New York.

Köhler, Manfred. (2004). In *Proceedings of the Greening Rooftops for Sustainable Communities Symposium.* Hosted by: Green Roofs for Healthy Cities and City of Chicago, Chicago, 22-4 June 2004.

Krupka, Bernd W., (2001). *Extensive Dachbegrünung. Praxisemphelungen und Kostenbetrachtungen.* Landesinstitut für Bauwesen des Landes NRW, Aachen.

Leather, P., Pygras, M., Beale, D., Lawrence, C., (1998). Windows in the workplace: sunlight, view, and occupational stress. Environment and Behaviour, 30, 739-762.

Laumann, K., Garling, T., Morten, Stormakr, K., (2003). Selective attention and heart rate responses to natural and urban environments. Journal of Environmental Psychology, 23, 125-134.

Lenk, Claudia. (2003). Senatsverwaltung für Stadtentwicklung, Berlin.Pers. comm. 14 October 2003.

Lepik, Andres, (2004), SKYScrapers, PRESTEL, Germany, ISBN 3-7913-3155-8

Liesecke, H., (1993), Wasserruckhaltung bei extensiven dachbegrunungen, Deutscher Gartenbau, 47 (34): 2142-2147.

Liesecke, H., (1998), Das Retentionsvermogen von Dachbegrunungen, Stadt Und Grun, 47:46-53.

Linz. (2002). *Grünflächenplan der Stadt Linz 2001.* Available from Magistrat der Landeshauptstadt Linz, Planungsamt.

Liu, K., (2003), Engineering Performance of Rooftop Gardens Through field evaluation, Proceedings of the 18th International Convention of the Roof Consultants Institute: 13-16 March, 2003, Tampa, FL, pp.93-103.

Liu, K. and B. Baskaran. (2003). Thermal Performance of Green Roofs Through Field Evaluation. In Proc. Greening Rooftops for Sustainable Communities: Chicago 2003: May29-30, 2003; Chicago, Illinois.

Mainz, Christof. (2003). These 4-1: Gründächer sind wirtschaftlich und lassen sich rechnen. In *Proceedings of the EFB-FBB (Europäische Föderation der Bauwerksbegrünungsverbande – Fachvereinigung Bauwerksbegrünung e.V.) Gründachsymposium,* Ditzingen, 23 March 2003.

Mainz, Christof. (2004). Förderungen der Dachbegrünung. In *Proceedings of the 2. EFB-FBB (Europäische Föderation derBauwerksbegrünungsverbande – Fachvereinigung Bauwerksbegrünung e.V.) Gründachsymposium,* Ditzingen, 25 March 2004.

Monterusso, M., (2003), Species Selection and Stormwater Runoff Analysis from Green roof System, Department of Horticulture, Michigan State University.

Nashville, (2002), Nashville Civic Design Center • Green Roof Case Study • Nashville area Projects, 2002 http://www.sitemason.com/files/aVlWHm/Green%20Roof_CS.pdf

Ngan,Goya., (2004), "Green Roof Policies: Tools for Encouraging Sustainable Design", *Landscape Architecture Canada Foundation, Retrieved on Aug 20, 2009 from http://www.gnla.ca/assets/Policy%20report.pdf*

Nowak, D.J., & Crane, D.E., (1998), The Urban Forest Effects (UFORE) Model: Quantifying Urban Forest Structure and Functions. Integrated Tools Proceedings. Boise, Idaho, USA, August 16-20 1998.

Oke, T. R.: (1995), 'The Heat Island of the Urban Boundary Layer: Characteristics, Causes and Effects', in J. E. Cermak et al. (eds.), Wind Climate in Cities, Kluwer Academic Publishers, Dordrecht, Boston,pp. 81-107.

Oke, T. R., (1987), Boundary Layer Climates. Wiley and Sons, 372 pp.

Onmura, S., Matsumoto, M. and Hokoi, S., (2001). Study on evaporative cooling effect of roof lawn gardens Energy and Building 33, 653-666

Optigrün. (2002). *Der Optigrüner.* 3/October 2002: 4.

Pastorelli, Giuliano, (2009), Plataforma Arquitectura, Web Article, Posted in: Architecture Office, Landscaping. Retrieved on August 30, 2009, from http://www.plataformaarquitectura.cl/2009/01/21/edificio-consorcio-sede-santiago-enrique-browne-borja-huidobro/

Peck, S., Callahan, C., Kuhn, M., and Bass, B., (1999), Greenbacks from Green roofs: Forging a New Industry in Canada, CMHC, Toronto.

Powell, Robert, (1999), Rethinking the Skyscraper: The Complete Architecture of Ken Yeang, UK, Thames & Hudson Ltd., ISBN 0823045536

Rachael, Jamison, (2005), Green Building Movement, Washington State Department of Ecology, Retrieved on Aug 12, 2009 from http://www.ecy.wa.gov/programs/swfa/greenbuilding/index.html

Reichmann, Brigitte., (2003), Senatsverwaltung für Stadtentwicklung, Berlin., Pers. comm. 14 October.

Richards, Ivor, (2001), Groundscrapers+Subscrapers of Hamzah & Yeang, Grate Britain, Willy Academy, ISBN 0470843543

Richey, Warren, (1998), "New Rush of Buildings Reaching for the Clouds." The Christian Science Monitor.

Robinson, D., (2005). Moutain Equipment Coop, Social and Environment Coordinator. Pers comm..

Rowe, D., Rugh, C., Vanwoert, N., Monterusso, M., Russell, D., (2003), Green Roof Slope, Substrate Depth, and Vegetation Influence Runoff, Michigan State University Dept. of Horticulture and Michigan State University Dept. of Crop and Soil Sciences, Greening Rooftops for Sustainable Communities Conferenece, May29-30, 2003., Chicago.

Sailor,D.J., (1995). Simulated Urban Climate response to modification in surface Albedo and Vegetative Cover Journal of Applied Meteorology 34(7) 1694-1704

Schempp, Dieter, (2009), Green – Architecture, Plants in Buildings, the Cycle of Nature, Creating an Inspiring, Healthy Indoor Climate. Tübingen, Germany.

Schneider, Sabine. (2004). Stadtentwässerungsbetriebe Köln. Pers. Comm. 29 July 2004.

SenStadtUm (Senatsverwaltung für Stadtentwicklung, Umweltschutz und Technologie). (2004b). BAF – Biotope Area Factor. Available from http://www.stadtentwicklung.berlin.de/umwelt/landschaftsplanung/bff/index_en.shtml

Sharp,R., (2007), "*6 Things You Need to Know About Green Walls*", Building Design and Construction, BD&C News, Web Article, Retrieved on Aug 12,2009 from http://www.bdcnetwork.com/article/CA6459410.html

Smith, T. M. and et al., (2006), Green Building rating Systems: A comparison of the LEED and Green Globe Systems in the US, The Carpenters Industrial Council (CIC). Retrieved on Aug 30, 2009 from http://74.125.113.132/search?q=cache:fz3F_pgNEzAJ:www.bbe.umn.edu/sites/09e1b491-15c5-4507-b6c1 72ac7cf21b53/uploads/GG_LEED_10_06.pdf+debates+on+green+building+rating+systems&cd=4&hl=en&ct=clnk&gl=us

Stadtentwässerungsbetriebe Köln. (2004). Retrieved from www.stadtentwaesserungsbetriebe-koeln.de

Stadt Köln. (2003). *Amtsblatt der Stadt Köln.* Special Publication Number 58. 23 December 2003.

Taylor, A., et al., (2001) Coping with ADD: The Surprising Connection to Green Play Settings. Environment and Behavior, Vol. 33 No.1, 54-77.

Thompson, A., (1998), Grass-roofs movement in landscape architecture, The magazine of the American Society of Landscape Architects, 88:47-51.

Town, Lisa, (2009), Sustainable Cities Collective, Web Publication. Categories: Alternative Energy, Design & Architecture. Retrieved on august 30, 2009 from http://sustainablecitiescollective.com/Home/17628

Treasury Board of Canada Secretariat (1998), Benefit Cost Analysis Guide, available online at http://www.tbs-sct.gc.ca/fin/sigs/Revolving_Funds/bcag/BCA2_E.asp

Truett, Rick. (2003a), 'Living Roofs'. Furbish Company, Sustainable Building, Web Article, Retrieved Augest 10, 2009 from http://www.furbishco.com/products/roofs/rfben_stmwtr.html

Truett, Rick. (2003b), 'Biofilters'. Furbish Company, Sustainable Building, Web Article, Retrieved Augest 10, 2009 from http://www.furbishco.com/products/biofilters/index.html

Umweltbundesamt. (2003). Raumbezogene Umweltplanung – Fallstudie Köln. Available from http://www.umweltbundesamt.de/rup/fallstudien-html/fallstudiekoeln.html

U.S. Environmental Protection Agency, (2007), "Heat Island Effect: Green Roofs." http://www.epa.gov/hiri/strategies/greenroofs.html.

Valvasori, Joe, and et al. (1999), The Living Wall: Urban Biofiltration. E-Magazine, Retrieved on Aug 12, 2009 from www.emagazine.com/januaryfebruary_1999/0199inbrief.html

Wolf, K.L. (2002) , Retail and Urban Nature: Creating a Consumer Habitat", at the People/Plant Symposium, Amsterdam. Retrieved May 20, 2009 from http://www.plants-inbuildings.com/whyplants.php?PHPSESSID=e653e7b957ce5bc2b6f

Wolverton, B. C. and J. D. Wolverton, (1996), "Interior Plants: Their Influence on Airborne Microbes Inside Energy-Efficient Buildings," Journal of the Mississippi Academy of Sciences, 1996, 41(2): 99-105. (U.S.).

Wong, Nyuk Hien and et al., (2002). The Thermal Effects of Plants on Buildings, Architectural Science Review, Vol. 45, 2002.

Wong, N.H., Chen, Y., Ong, C.L. and Sia, A., (2003a). Investigation of thermal benefits of rooftop garden in the tropical environment. Building and Environment 38, 261-270

Wong, N.H., Cheong, D.K.W., Yan, H., Soh, J., Ong, C.L., Sia, A., (2003b). The effects of rooftop gardens on energy consumption of a commercial building in Singapore. Energy and Buildings. 35, 353-364

Wong, N. H., Tay S. F., Wong, R., Ong, C. L., Sia, A. (2004), "Life cycle cost analysis of rooftop gardens in Singapore," Building and Environment 38, 499-0

World Green Building Council, Retrieved August 30, 2009 from http://www.worldgbc.org/resources/faq

Yamada, H. (2008). How is energy usage reduced by green roof and walls, Gsky, Eco Innovations Inc. Engineering Department, Wakayama University. Retrieved Augest 10, 2009 from http://www.g-sky.com/Benefits_EnergySavings_Detailed.aspx

Yeang, K. (1994). Malaysia : bioclimatic skyscrapers, Berlin, Germany, Aedes Galerie und Architekturforum

Yeang, ken, (2006), Ecodesign: A Manual for Ecological Design, Wiley Academy, Great Britain. ISBN 0-470-85291-7

Yeang, K. (2007), Eco Skyscraper, Australia, Image Publishing, ISBN 9781864702682

Yok, T.P., Sia, A., (2005). A Pilot Green Roof Research Project in Singapore. Proceedings from Green Roofs for Healthy Sustainable Cities Conference, Washington D.C., May 2005.

Zeidler, M., (2005). Urbanspace PROPERTY Group, Building owner. Pers comm..

Zeller, Stefan. (2002). Bewertung begrünter Dächer in Bauleitplanung und Eingriffsregelung: Vergleich, Anwendung, Erfolgskontrolle. Diplom thesis, Fachhochschule Nürtingen, Nürtingen,Germany.

Zeller, Stefan. (2003). Begrünte Dächer in der Eingriffsregelung. *Garten+ Landschaft* 10/2003:39-40.

Zinco Roof Gardens (1997), The Green Roof Planning Guide, Holland, Zinco Inc.

Zubevich, Kipling. (2004) The Search for the Sacred in the Concrete Jungle. (via link on the Ecopsychology web site, July 2004)