Green Roofs and Green Walls: Potential Energy Savings in the Winter

Article · January 2007

Brad Bass
Environment Canada

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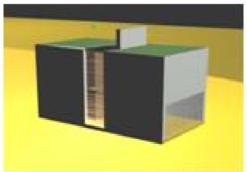

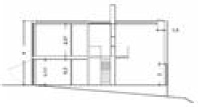

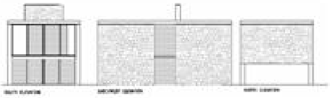

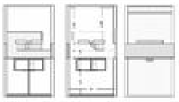

Report on Phase 1
March 31 2007

Brad Bass
Adaptation & Impacts Research Division
Environment Canada at the University of Toronto
Centre for Environment

Green Roofs and Green Walls: Potential Energy Savings in the Winter

Executive Summary

This report summarizes the Phase 1 results of research into the potential of green roofs and green walls as energy conservation technologies in the winter. Green walls are included because they can be installed for a relatively low cost and the potential benefits are very high. In addition, the green wall analysis suggests criteria for green roof performance in the winter. Although the summer energy savings have been documented, very little attention has been given to the winter scenario for four possible reasons:

1. The green roof market is dominated by extensive designs with shallow growing mediums and deciduous plants that offer little potential for winter energy conservation.
2. Green roofs are often compared to white roofs, which are only used to reduce the amount of heat entering a building or to reduce the urban heat island in the summer
3. Due to climate change, energy consumption for air conditioning is expected to be a larger concern in many parts of the world in the 21st century.
4. Green walls are not usually considered as a standard technology for greening walls does not exist in the market place.

This phase of the research has used two different models to assess winter energy consumption with green walls and green roofs. The green wall work was part of another study, funded by the Program on Energy Research and Development (PERD), on community-scale initiatives. The analysis was conducted with the United States Department of Agriculture (USDA) Urban Forest Effects (UFORE) package for the Midtown area of Toronto. This area was chosen because UFORE was already calibrated to this area. The results indicate that green walls increase energy consumption in the winter due to the shading of a building, but the effect of climate modification and wind speed reduction more than compensates leading to substantial reduction in energy consumption. Green walls were shown to be more effective than the baseline urban forest scenario and strategy worth considering in areas undergoing extreme intensification.

The green roof performance could not be undertaken with UFORE. The energy consumption of two buildings was simulated with the Environmental Services Performance – research (ESP-r) model. One building was a two-story residential structure in Ottawa designed to minimize energy consumption and the other building was a three-storey mixed residential-commercial structure that is typical of downtown Toronto. As expected, the contribution of the green roof on the house in Ottawa was small (between 6 and 7 % reduction in energy consumption) and was consistent with an earlier study from 2005. The impact on the building in Toronto was dramatic as energy consumption was reduced by 30%. This is consistent with a summer simulation on that building and is likely due to the age of the building and the fact that the roof is one of the largest exposed surfaces as two walls are shared with adjoining buildings.

The simulation modelled the intensive green roof that is being monitored at the National Research Council campus in Ottawa. This roof has 30 mm of growing medium and is planted with Juniper shrubs. Unlike the green wall analysis, the impacts of shading, climate modification and reducing wind speed were minor, although more significant on the test house Ottawa where the green roof was not as a big a factor in reducing energy consumption. This could be due in part to how these factors were added to the simulation and in part due to the thickness of the growing medium.

In the next phase of the work, the effect of vegetation on winds speed will be added to the ESP-r code and simulated dynamically. Currently it is added as a static parameter, and the true effect of the vegetation may have been underestimated by this initial procedure. Experiments will be conducted with growing mediums ranging from 8 cm to 15 cm if coniferous plants have been identified that survive the winter I these shallower depths. These depths correspond with experiments that were recently carried out at Penn State University on plant survivability during the winter. In addition, comparisons will be made with black roofs and further green wall simulations will be carried out with ESP-r.

This work was carried out by Brad Bass of the Adaptation & Impacts Research Division (AIRD) under a Memorandum of Agreement between Gaz Métropolitain and

Environment Canada. The work was funded by Gaz Métropolitain and AIRD as a contribution to a research project on green roofs funded by PERD with the Department of Public Works and the Institute for Research in Construction at the National Research Council.

Dr. Bass would like to acknowledge the contributions of Sadia Butt, Beth Anne Currie, Dr. Andrew Kenney, Ryan Martens, Jordan Richie, Erica Pinto and Dave Nowak’s urban forest research team at the USDA. The image on the title page is a cold climate house with a green roof designed by Susana Saiz-Alcazar for the Design for the Cold Event in November 2005.

1: INTRODUCTION, STUDY BACKGROUND AND ASSUMPTIONS

Introduction

The use of vegetation on walls and roofs of buildings, particularly roofs, is a common practice in the architecture of older buildings in countries like Iceland, Scandinavia, Switzerland, Germany and Tanzania. Historically, people in these countries utilized vegetation in the form of vines on walls, shade trees near buildings and grass on roofs, hitherto known as green roofs, to provide protection from the wind and insulation for winter warmth, shade and cooling during hot summers, and to enhance the aesthetic value of the building. Today, a thriving green roof industry prevails in many parts of the world, as jurisdictions recognize the myriad environmental benefits associated with the technology. Throughout Europe, particularly Germany, the last thirty years have produced a wide complement of academic green roof research, predictable research funding and a proliferation of green roof installations. These accumulated study results have helped to formalize European municipal policy guidelines, regulations and financial incentives that today, support a thriving European green roof economy (1 - 4). While North American green roof research began later than the effort in Europe, these studies are beginning to lend support and precision to the many of the environmental benefits associated with green roofs and green walls in urban areas.

Much of the research in North America has focused on stormwater runoff, plant viability and issues of design. The small amount of research on energy conservation has been directed towards the reduction of air conditioning during the summer with little thought to the potential of green roofs and green walls to conserve energy in the winter. The reason for this may lie in the overall thrust of the market towards extensive green roofs which, being lighter, tend to be less expensive, are more adaptable to a wider range of roofs and require less maintenance. As the vegetation on these roofs dies back in the winter, the growing medium can freeze and/or be covered by snow, providing very little added benefit towards energy conservation in the winter. However, the same cannot be said for coniferous vegetation on green walls or intensive green roofs.

This research focuses on those two technologies using two different models for estimating the energy savings on a building with a green roof and in a community with different levels of green wall coverage. The modelling results are extended to extensive roofs as well because they are dominant in the market and the applicability to these roofs is discussed in this report.

Study Background

The research was funded in part by the Gaz Métropolitain Fonds en Efficacité Énergétique and Natural Resources Canada's Program on Energy Research and Development (PERD). This report is Phase 1 of a two-year project to assess the potential of green roofs to conserve energy in the winter in Montreal. The winter performance work complements a project funded by PERD to assess the benefits of green roofs. The green wall assessment is part of a second PERD project on reducing community energy consumption through implementing green roofs and integrating those green roofs with green walls and urban forestry. Although reductiosn in energy consumption have been identified for the summer, these benefits have not been identified for the winter situation as the market favours extensive green roofs that typically do not add any benefits during the winter. Specific objectives of this report include:

1. Estimating the reductions in energy for space conditioning in the winter at a community scale with the adoption of green walls within the context of an existing urban forest.
2. Estimating the reductions in energy for space conditioning in the winter from a green roof.

The results of the first objective are based on the UFORE (Urban Forest Effects) Computer Model, developed by the United States Department of Agriculture. The UFORE Model was chosen because of its accepted use within the scientific community of urban and regional foresters throughout North America. UFORE uses measured field data inputs as well as local hourly meteorological data and air pollutant concentration measurements (collected from Environment Canada, 1998) to quantify neighbourhood-specific vegetation effects on urban air pollutant concentrations (5). Although UFORE was used to quantify the mitigation effect of green roofs, green walls and trees on levels of air pollutants or contaminants in a study area within the City of Toronto, it also provided estimates of energy reductions for green walls and for trees in both summer and winter. The winter results are included in the Phase 1 report as they are relevant to

Gaz Métro and may be useful for working with municipal governments on issues of urban forestry.

Many factors influence heat and mass flows throughout a building and accounting for these factors while performing a building energy simulation is not a simple problem to overcome. Many tools currently on the market provide only net energy fluxes on a daily basis. Although this capability is useful when performing a building energy analysis, such techniques do not provide the complete picture. A dynamic simulation tool is necessary to examine conditions within the building at hourly, or even finer, intervals. To calculate the energy consumption of a building, the Environment Canada researchers use the Environmental Systems Performance – research (ESP-r) software as a tool for modelling the energy consumption of buildings with and without green roofs.

2: WHAT IS A GREEN ROOF AND A GREEN WALL?

Green Roofs

For the purposes of this study, green roofs will refer to those conventional flat or sloped roofs that have been amended with some or all of the following layers or elements: structural support, vapour control, thermal insulation, a water proofing membrane, a roof drainage layer, a root-protection layer, synthetic planting media and hardy, drought-resistant plants. These green roof layers (see Figure 1) can be adjusted or enhanced based on the needs of the designer or building owner. Typically, green roofs are classified as either extensive or intensive. Extensive green roofs tend to be lighter, require less maintenance but are not designed to be accessible green spaces. Intensive green roofs use more growing medium and can support a wider variety of plants and landscape designs. They can take the form of elaborate gardens or landscapes on a roof, even incorporating features such as wetlands and hills. In general, they are often designed to be accessible as green space in an urban area. Table 1 delineates the major characteristics that differentiate extensive green roofs from intensive green roofs. Of particular note are the differences in weight, cost, structural preparation, water retention, predicted thermal benefit and public versus private benefits.

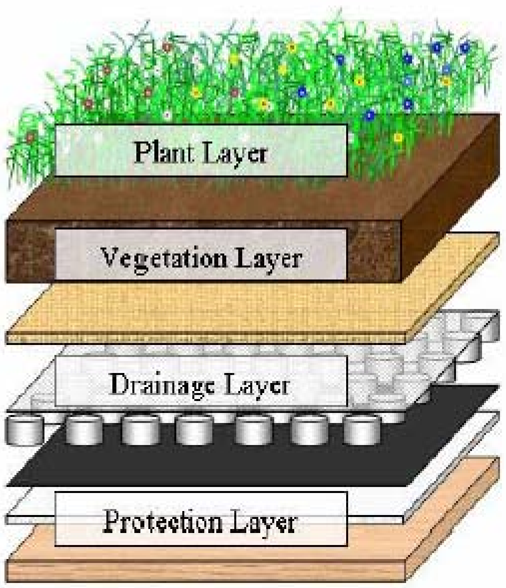

Figure 1. Green Roof Layers.

(Moran et al., 2003, p 3, reference #6)

Green Walls

Green walls, or vertical gardens as they are commonly known, are an important application of the green roof benefits to building walls. Given the amount of wall space available in most municipalities, the potential for green walls is quite large, and in many high density areas, it is more significant than the space available for green roofs. Urban developments yield a relentless supply of wall space that is currently untapped throughout downtown urban canyons. As with green roofs, green walls and vertical gardens have been shown to reduce the urban heat island, reduce building energy consumption and improve air quality.

Table 1. A Profile of Extensive and Intensive Green Roofs

Roof Type	Extensive Green Roof	Intensive Green Roof
Cost	▪ 10 – 14 $ per square foot	▪ 14 – 35 $ per square foot (unlimited)
Growing media and plant selection	▪ 5 – 15 cm planting media ▪ little or no irrigation ▪ stressful conditions for plants – require low, drought-resistant species	▪ 15 – 50 cm planting media ▪ irrigation system required ▪ favourable for many varieties of plants e.g. trees, shrubs and perennials
Structural preparation	▪ light weight; (roof generally does not require structural strengthening) ▪ suitable to cover large surface areas	▪ heavier in weight and requires structural engineering ▪ used over smaller surface areas in landscaped containers
Public access	▪ suitable for public access on roofs with 0-30 degree slopes as long as parapet walls meet building code	▪ suitable for public access, more aesthetically-positive as roof can be used for meeting recreational needs and for food production
Advantages	▪ low maintenance ▪ relatively little technical expertise needed to install ▪ suitable for retrofit roof projects ▪ less expensive	▪ deeper planting media supports more biodiversity, more overall environmental benefits and more social/psychological benefits by accessing recreational roof space
Disadvantages	▪ limitation on plant species choices ▪ limited access for the public ▪ can be less aesthetically-pleasing	▪ heavier loading on the roof ▪ higher requirements for water, maintenance, and irrigation supplies ▪ more costly for expertise to design and install green roof

(Peck et al., 1999, reference #3)

3: METHOD

Study Method: UFORE

The UFORE model was used to quantify the contribution of green walls and trees in reducing winter energy consumption within an urban neighbourhood. UFORE is not a simulation model per se, but rather, uses well-established empirical relationships from the urban forestry literature on shading and wind speed reduction to estimate how much energy is conserved with trees and green walls (7). UFORE does not contain a formal green wall option. Rather, in consultation with the USDA, suitable Juniper trees were chosen and arranged as a wall. Green wall technology, as a formal industry, is 40 or 50 years behind the green roof industry with no standard means of installing a green wall. Using a dense covering of vines, shrubs or trees is one method that has been marketed under the name green walls.

In the winter, green walls are most effective at reducing the impact of windspeed along the walls of the building. There are some additional climate modifications that occur in the winter as the green wall does provide some additional insulation. The green walls and urban forest were run on a community instead of a building basis as Midtown is a medium-to-high density residential area where trees can affect more than one building and one objective of that particular analysis was to compare the urban forest to other vegetation technologies.

A geographic study area known as Midtown was selected within the City of Toronto. Midtown is constituted by parts of Ward, 22 (St. Paul's), Ward 27 (Toronto Centre-Rosedale) and Ward 20 (Trinity-Spadina) and bounded by Spadina Avenue in the west, Bloor Street in the south, Eglinton Avenue in the north and the Don Valley ravine, Bayview Avenue, Moore Street, Frobisher Street and Chaplin Street in the east (Figure 2). In a previous study of the economic and environmental profile played the urban forest in Toronto, Andy Kenney quantified the urban forest characteristics that could be estimated by the four main modules (A, B, C, and D) within the UFORE Model (8). In consultation with the UFORE modellers in Syracuse, New York, Kenney collected data from 72 randomly selected on-the-ground study plots within the Midtown neighbourhood as required by the UFORE field collection tool (7). Kenney's report provided a profile on urban forest health and a subsequent analysis that forestry managers in the City of Toronto still use today (8).

This research utilized Kenney's original criterion plot data from the 72 randomly selected plots in Midtown. In UFORE, specific data elements were manipulated to develop scenarios to investigate the effect of urban vegetation, particularly green walls and the urban forest on energy consumption in Midtown. The research team visited the 72 randomly selected plots in Midtown, by using GPS coordinates and on-the-ground plot maps, to collect each plot's municipal address, verify vegetation, identify building type and identify other plot features that were deemed relevant to the study.

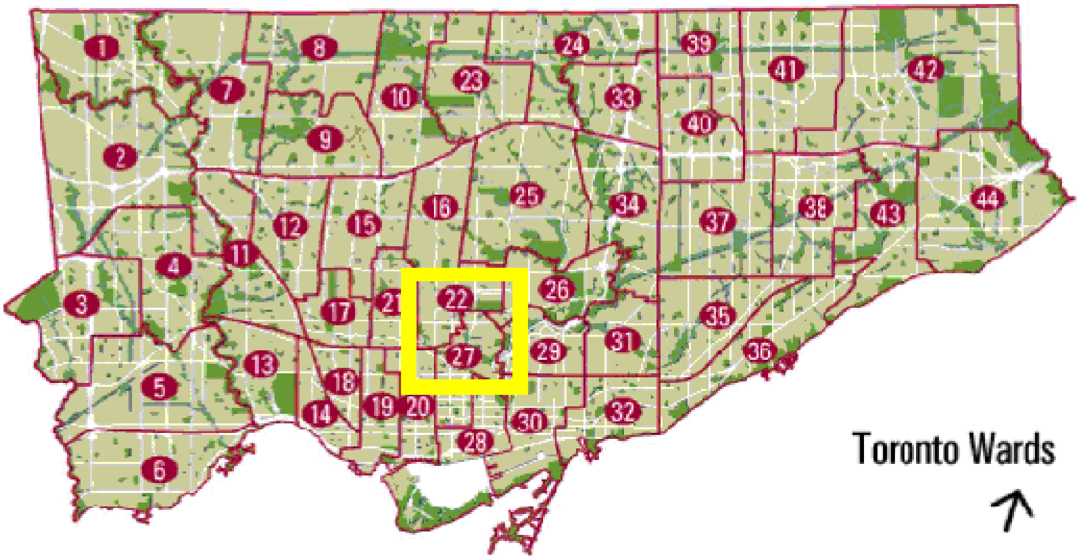

Figure 2. Toronto wards.

(Adapted Map of City - Toronto Wards (2001), Map Library, University of Toronto, with Midtown study area highlighted in yellow; from www.toronto.ca)

Each sample plot was circular with a radius of 11.287 meters and provided a total surface area of 400 m^2 or 0.04 ha per plot (Figure 3). The total sampled area was 28,800 m^2 or 2.88 ha within Midtown. The total area of the Midtown neighbourhood was approximately 1,216 ha within the City of Toronto. Plots were selected from land-use types by randomly selecting points from a 50 m x 50 m grid overlaid on a GIS-based map of Midtown, using Arc View GIS 3.1. Colour orthophotos of the area were analyzed using Arc View GIS 3.1 to derive the plot details as required by UFORE. Each orthophoto was examined separately at a scale of approximately 1:5000. Within each plot, a forest surveyor's transit was utilized to determine the UTM (Universal Transverse Mercator) co-ordinates of each feature within the plot relative to a GPS-established plot center (8).

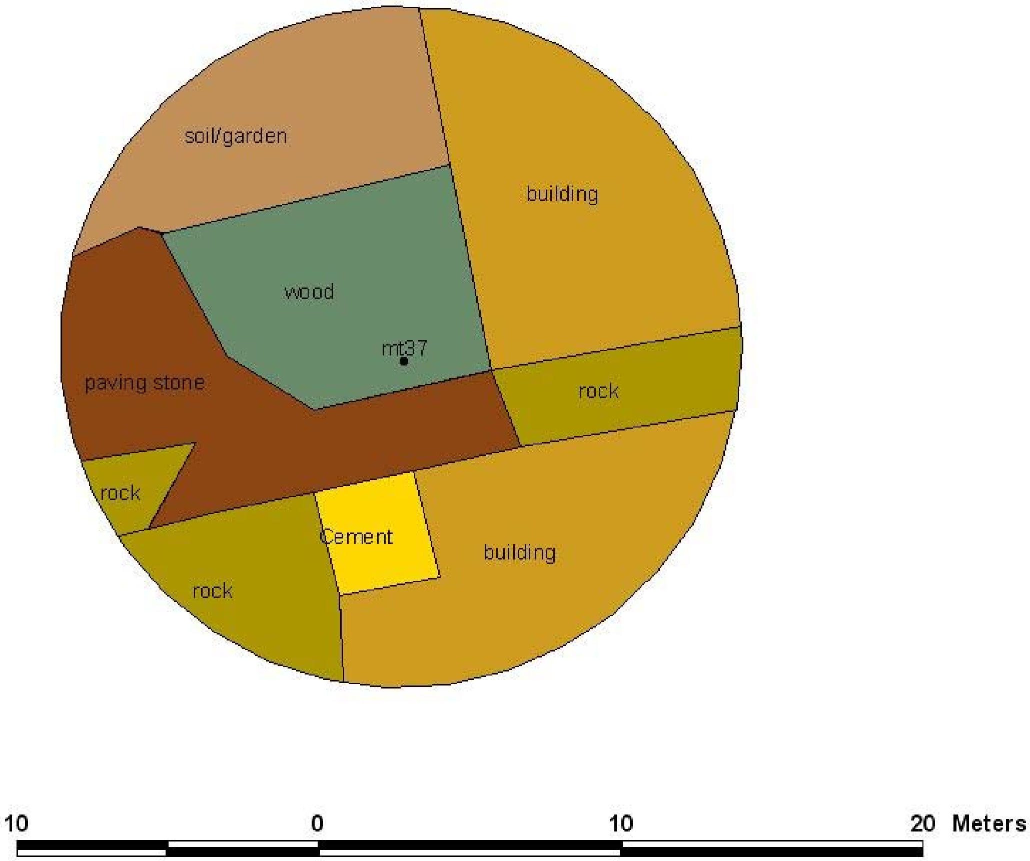

Figure 3. Sample Plot in Midtown

The method for plot classification within Midtown was developed by Nowak and Crane at the United States Department of Agriculture (7). Midtown was stratified into eight land-use classes: low, medium and high residential; commercial; industrial; institutional; unclassified; and open areas, including parks, ravines, cemeteries, transportation corridors and golf courses. These categories were derived from GIS data obtained from CanMap ® Streetfiles V2.0 from DMTI Spatial 2000 (8).

Study Method: ESP-r

ESP-r is an integrated modelling package for simulation of the thermal, visual and acoustic performance of buildings and is used mainly for design decision support (9). Before an ESP-r simulation may be performed, a model of the building and its inherent systems needs to be constructed. This stage is perhaps the most difficult part of a simulation, as a large amount of data must be input to define a complicated system. ESP-r attempts to facilitate this procedure by providing a graphical Project Manager to aid in data input, as well as by providing databases of values for a variety of construction materials and other properties.

ESP-r software is equipped to model heat, air, moisture and electrical power flows at user-determined resolutions. ESP-r is based on the finite element approach allowing the building to be modelled as a number of zones that could represent floors, rooms, or even layers within walls. The building's geometry, construction, operation, leakage distribution and other characteristics are transformed into a set of conservation equations (for energy, mass, momentum, etc.), which are then integrated as a function of time in response to climate, occupant and control variables. For our purposes, the outputs extracted from the model are energy consumption.

To simulate the indoor performance of the building, a building is divided into zones based on how the building is used and the number of floor levels. Many zones may be differentiated in ESP-r. Each zone is described in terms of surface area, volume, physical and thermal surface characteristics and adjacent environments such as outdoor and unheated spaces. For each zone, thermal loads are predicted based on occupancy. For example, a 2-person apartment will have internal head loads due to lighting and appliances. The heat loads due to human occupancy depend on the human-body area and the level of human activity predicted to occur in the space.

Green Roofs, Building Energy and Heat Flux

There are several energy flux[1] terms that require consideration within a green roof energy balance system. Seven main terms are considered in most green roof discussions: (i) shortwave radiation incoming; (ii) shortwave radiation reflected; (iii) longwave radiation incoming; (iv) longwave radiation emitted upwards; (v) sensible heat loss or gain; (vi) latent heat loss; and (vii) heat conduction downwards or upwards from the room below the roof. Equations for most of these flux terms are available from standard atmospheric science and heat transfer studies and are not to be considered in this report (10). For the winter case study, evaporative cooling is not a factor in reducint energy consumption. The key terms include incoming radiation, sensible heat loss, conduction and the reduction of wind speed due to the physical characteristics of the vegetation canopy, which has to be added as a new program or a parameter in ESP-r..

Methodology

For this study, two buildings were replicated for simulation. The first is one of two twin houses located at the Canadian Centre for Housing Technology (CCHT) in Ottawa (Figure 4). The houses were built in 1998 to assess the performance of new and innovative energy efficient technologies for homes. They feature approximately 210 m^2 of liveable area, with two above-grade storeys, a fully conditioned basement and a two-car garage. The houses were built to the R-2000 energy efficiency standard and represent a typical suburban energy efficient Canadian house (9). The second building is a typical 3-story combined commercial and residential space in downtown Toronto. This building, dating back to the 1940’s, features a southern and northern exposure of brick and glass. The east and west walls are not exposed to the external environment as they are shared with the adjoining buildings.

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[1] “Flux” means energy passing through a unit area per unit time, such ‘Watts / $meter^2$ per hour’ or ‘BTU / $foot^2$ per hour’.

Figure 4. CCHT houses.

The CCHT houses contained a standard set of major appliances found in many North American homes. Home-automation technologies were used to simulate occupancy by turning appliances, lighting, and equipment on and off. In the model, six thermal zones were used to represent the house: one each for the main floor, the second floor, the stairwell, the basement, the attic space, and the attached garage (Figure 5). Thermal loads were assigned to each zone in accordance with the simulated occupancy profiles described in (11). The main floor, second floor, stairwell, and basement were conditioned by the house's HVAC system while the attic and garage were "free floating", i.e. their temperature varied varying in response to thermal contact with the other zones and the outdoor environment (9). A heating set point temperature of 20°C was maintained throughout the conditioned zones.

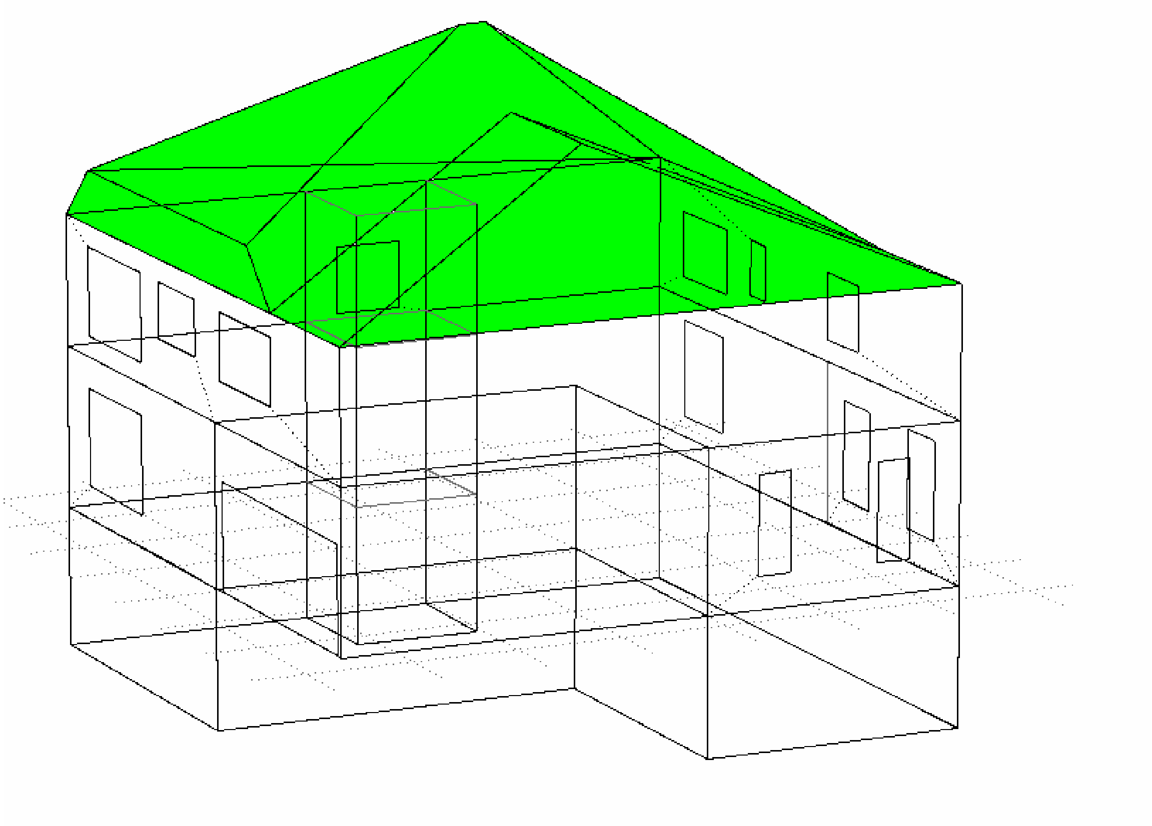

Figure 5. ESP-r model of CCHT house.

The materials used to model the building envelope corresponded to the actual construction materials used in the CCHT houses.

The data for the mixed residential-commercial building had to be estimated from a series of visits to the site. In the model, six zones were used to represent the building (Figure 6). The half basement is unfinished and unconditioned. The first and second floors are used by a bicycle shop. The third floor is an apartment shared by two or three people. The fourth floor is an unconditioned aluminium storage space addition. There is an additional small, concealed, wedge-shaped air space between the third and fourth floors. The shop is attached to other commercial buildings on both sides of the first floor and the west side of the second floor. The external environments corresponding to the western and eastern walls were modelled as internal environments to represent the effect of the adjoining buildings.

Thermal loads were assigned to each zone in accordance with the occupancy profiles suggested by store management. The main floor, second floor, third floor and the air space were conditioned by the building's HVAC system while the aluminium storage area on the roof and the basement were "free floating", varying in response to thermal contact with the other zones and the outdoors. A heating set point temperature of 20°C was maintained throughout the conditioned zones.

The winter green roof construction consisted of a dense layer of Juniper shrubs in addition to the layers typically used in an intensive green roof system – a 30 cm soil layer, as well as drainage and filter layers. This construction follows the design of a test roof constructed by the Institute for Research in Construction on the National Research Council's Field Roofing Facility (FRF) in Ottawa. To assess the energy performance of the shrub roof for heating, simulations were performed for the months of January and February, for a Montreal climate.

Initially, the model was simulated with a conventional asphalt roof to obtain a base-case energy use scenario. Two winter green roof models were then compared against the reference case. For each green roof scenario it is assumed that the vegetation reduces the conservation of heat by shading the roof, but increases the conservation of heat through reducing the wind speed and modifying the microclimate above the roof. In the more conservative green roof scenario, the shading provided by the plant canopy reduced the heating effect solar radiation would otherwise have on the roof. It was assumed that this directly counteracted the reduction in convective heat losses due to wind reduction on the roof.

The second green roof scenario, which more closely corresponds to the UFORE model discussed in this paper, assumed that the green roof's windbreak effect was much greater than the shading effect. For both scenarios, the plant cover prevents the growing medium from freezing in the winter. This growing medium adds insulation value to the roof construction.

4: RESULTS

Green Walls

Five scenarios were run with UFORE to assess the effect of both green walls and the urban forest on energy consumption. The scenarios were designed to reflect the impact of different levels of intensification that could occur under Ontario's new Regional Growth Management Strategy or under any Smart Growth strategy to contain urban sprawl.

Scenario 1

BASELINE: this scenario was based on the reductions in energy consumption provided by existing trees and shrubs in Midtown.

Scenario 2

No Trees: this scenario examined the effect on energy consumption in Midtown when all trees were removed from the area.

Scenario 3

No Big Trees: this scenario examined the effect when all big trees with a diameter-at-breast-height greater than 22cm were removed from the area.

Scenario 4

Trees off Buildings: this scenario examined the effect when trees that provided shade to buildings (within 3-5 meters) were removed.

Scenario 5

Green Walls: this scenario examined the effect when existing trees and shrubs were removed and vertical "hedges" or walls of Juniper species were added within 3 meters of residential (medium and low) houses.

The results of the analysis (Figure 7) clearly illustrate that the urban forest has a small by noticeable effect on winter energy consumption that totally disappears when all trees are removed. The decrease in savings in scenarios 3 and 4 is not as large as might have been expected due to the reduction in shade. Scenarios 1 through 4 indicate that policies of intensification will not have a dramatic effect on winter energy consumption. Scenario 5 clearly indicates the potential for both green walls in reducing energy consumption and the importance of reducing windspeed. The reduction in windspeed and climate modification that occur with a green wall more than compensates for the negative impact of shading in the winter. Both the climate modification, due to insulation, and the windbreak are important components of the green roof simulation and were used to provide some guidance as to how Juniper shrubs would act to conserve heat on a roof.

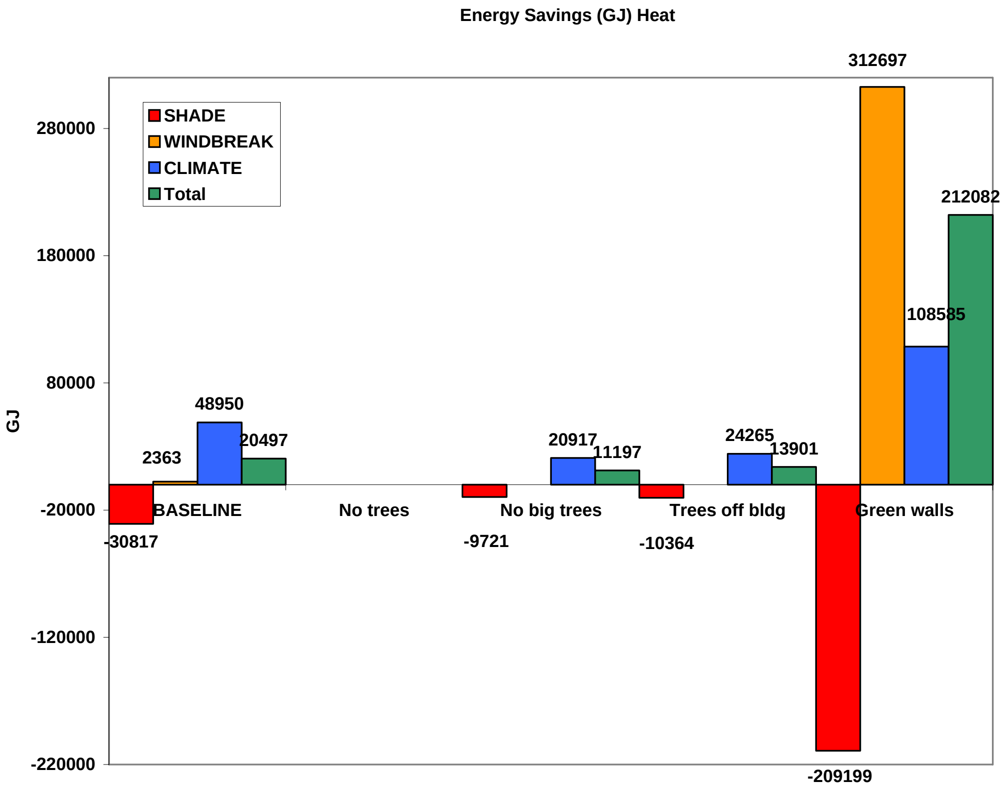

Figure 7. Reductions in energy required for heating in Midtown Toronto under five different scenarios of urban forestry and green walls.

Green Roofs

The results from ESP-r are translated into kWh equivalents. The heating energy delivered to the entire CCHT house, as well as the percentage savings of the green roof (GR) over the conventional roof for both scenarios, is shown in Table 2.

Table 2. Heating energy delivered to all zones in CCHT house.

Heating Energy Delivered to Entire House		
Roof Model	**Sensible Heating (kWh)**	**Percentage Savings (%)**
Asphalt	7748.05	-
Winter GR Scenario #1	7311.94	5.63
Winter GR Scenario #2	7287.39	5.95

The results are also provided for the second floor as this is the occupied level closest to the green roof and the zone with the largest heating requirements, is shown in Table 3.

Table 3. Heating energy delivered to the second floor of CCHT house.

Heating Energy Delivered to Second Floor		
Roof Model	**Sensible Heating (kWh)**	**Percentage Savings (%)**
Asphalt	3481.07	-
Winter GR Scenario #1	3106.62	10.76
Winter GR Scenario #2	3085.61	11.36

The results indicate that the green roof can provide some additional benefit, even to a building designed to minimize energy consumption in cold climates. Consistent with many other studies on green roofs, the results are greater for the floor that is closest to the roof, and in this case, the floor that has the largest heating requirement. In fact, the results are consistent with results presented at the Design for the Cold event in November 2005 (11). In this simulation, the second green roof scenario with the added benefit of the windbreak and the climate modification was only marginal, suggesting that the primary role of the vegetation is to modify the climate of the growing medium.

The results for the second building are far more significant, but not surprising as the roof is a major source of heat loss. As with the CCHT house, the second scenario that includes the effect on windspeed added little in terns of energy conservation (Tables 4 and 5).

Table 4. Heating energy delivered to all zones of mixed residential-commercial building

Heating Energy Delivered to Entire House		
Roof Model	**Sensible Heating (kWh)**	**Percentage Savings (%)**
Asphalt	17691.42	-
Winter GR Scenario #1	11700.88	33.86
Winter GR Scenario #2	11650.34	34.15

Table 5. Heating energy delivered to third floor of mixed residential-commercial building

Heating Energy Delivered to Third Floor		
Roof Model	**Sensible Heating (kWh)**	**Percentage Savings (%)**
Asphalt	8836.9	-
Winter GR Scenario #1	3486.81	60.54
Winter GR Scenario #2	3444.87	61.02

5: DISCUSSION

The first part of this report clearly indicates the benefits of green walls for conserving energy used for heating during the winter. Although UFORE does not permit a detailed individual building analysis, as it is a community model, it provides a good comparison of different outcomes of intensification with respect to the urban forest and how these impacts can be overcome with green walls. In this case, green walls are not a fixed technology like green roofs, but the UFORE results suggest some important design criteria.

One, the green wall should be comprised of a very dense layer of vegetation in order to break up the wind. Using vegetation is important because it is the roughness that reduces the wind speed. The second important design criterion is that there should be some distance between the green wall and the building. This distance allowed for some additional modification of the climate between the building and the green wall. Although this modification was not as important as the wind break effect, it still accounted for ½ of the impact of shading.

These two criteria were also used in designing the intensive green roof simulation. ESP-r does provide some modification of windspeed over a roof, but it is not consistent with the effect of plants. For this phase, the outcome of the Juniper trees against the wall were translated to the Juniper shrubs on the roof in a static manner, i.e. the compensatory effect of the wind break and climate modification were added to the negative effect of the shading. However, unlike the green wall scenario run with UFORE, shading does not appear to be as important for the roof as it is for the wall; the compensatory effect of the wind break and the climate modification was quite small. The energy savings appear to be due to the depth of the growing medium and role that the vegetation plays in preventing extensive freezing, which is common on an extensive roof.

The shading on the roof may also have a different effect than the shading on the wall. The negative effect of shading is reduced due to the shorter day length in the winter, and the roof is fully exposed to the sun. Thus the effect of the wind break and the climate modification would in turn be relatively small. The wall, however, receives less exposure to the sun, especially in the winter, which would increase the effect of the shading provided by a green wall. If reducing windspeed is a minor contributor to reducing energy consumption, then the insulation effect of the growing medium could be added to the roof in other ways. Although this is true, it negates the full suite of public and private benefits that accrue from a green roof installation.

In addition, it should be noted that six months into a two year project, these results should be considered as preliminary and in fact may underestimate the impact of the vegetation on windspeed. Ideally, the windspeed over the roof should be decreased dynamically, in a manner that is consistent with the way in which vegetation affects wind speed. Programming modifications can be made in ESP-r, although it is a non-trivial task, and the development of a procedure to reduce wind and the programming adjustments will require additional time. One other consideration is the thickness of the growing medium used in this simulation. The design follows the NRC-FRF green roof to maintain consistency so that the simulation and observations can viewed as complementary and a more precise specification of the green roof model at some point in the future.

The green roof growing medium depth was consistent with intensive green roof design. This design is more expensive and is not suited to as wide a range of buildings as the more common extensive green roof. However, an extensive green roof with only 6 cm of growing medium may support vegetation through the winter. Although an extensive roof will still offer some benefit during the winter, it is unlikely to have a large effect on energy conservation. In addition, with no winter vegetation, once the extensive roof is covered with snow, it will be largely undistinguishable from the conventional roof.

Yet given the benefits of the intensive design for energy conservation, it seems prudent to investigate an extensive or semi-intensive green roof that is shallower in depth than 30 cm yet will support coniferous vegetation. Although designing such roofs is beyond the scope of this work, further experiments should be conducted with shallower depths as coniferous plants have been identified that are suitable for a shallower growing medium. Overwintering experiments have been conducted in Central Pennsylvania with 8 -15 cm of growing medium suggesting that these benefits might be extended to an extensive or semi-intensive or extensive green roof.[2] It is expected that the negative impact of shading and larger positive effects of reducing windspeed and climate modification will be more prominent with a shallower growing medium. However, for buildings that can support the additional load, it is clear that an intensive green roof of this depth will have a positive impact on winter energy consumption.

Finally, data are being collected on a similar roof in Ottawa on the FRF at the National Research Council (NRC). The lead researcher for this project is currently on Sabbatical, and these data were not available for this phase of the project. Assuming that these data can be obtained, an analysis will permit a more precise representation of this green roof design and an opportunity to study the importance of the different components of the green roof in achieving these benefits.

6: CONCLUSIONS AND FUTURE WORK

Green roofs were shown to have an impact on the amount of energy required for heating during the winter months of January and February. The impact was small for a building

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[2] These experiments were recently communicated to AIRD. AIRD will obtain specific plant lists and results in the next phase if this work.

that is well-designed for cold climates, but was quite significant in an older building, especially where the roof accounts for a large amount of the heat that is lost to the environment. Green walls were also shown to have a large impact on energy consumption during the winter, perhaps more significant than that exerted by a green roof. The green roof simulation may have underestimated the impact of the vegetation on wind speed and climate modification of the roof, yet these results were consistent with a previous study that also compared a cold-climate house with an older building.

This work should be continued for an additional 17 months to address the issues raised in the first phase of the work, particularly to extend the results to shallower growing mediums of 10-15 cm. It should also be noted that although an intensive green roof is not as suitable for as wide a range of buildings as an extensive green roof, this may change with further research into green roof design as well as with the market's willingness to accept the additional expense of intensive green roofs. In addition, under climate change, both fall and spring may become longer seasons. In these shoulder seasons, extensive roofs may be active longer into the fall and earlier in the spring, providing conservation of energy for both heating and cooling, depending on the actual temperature regime that is expected to prevail. Thus the benefits of intensive roofs noted in this study may also accrue to extensive roofs as the 21st century unfolds as a warmer than the previous century, or they may be found with shallower growing mediums that are well suited to a wider range of buildings.

Future Work

The results of this work have raised some additional issues that have already been noted in the previous section.

- Green walls suggest two important criteria for green roof winter performance: climate modification and reducing the impact of wind speed.
- These two criteria did not emerge as important, but they may have been underestimated by the static approach to simulation.
- The benefits of green roofs in the winter, especially on older buildings, warrant the investigation of a semi-intensive design.
- The data that has been collected at the NRC may assist in explaining the thermal performance of the green roof.

Within the terms of the MOU between Gaz Métropolitain and Environment Canada, as well as the role of Environment Canada in the PERD-funded study, there are a few of these issues that will be explored next year:

1. Implement a dynamic representation of the effect of a vegetation canopy on wind speed. This will involve some research and discussion with climate modelers on the best approach as well as modifying ESP-r with additional programming. This is a non-trivial task as ESP-r does not break wind up into a roof and wall component, and previous programming changes have required up to 100 modifications in different parts of the code.
2. Develop a green wall implementation for ESP-r as it would be useful to assess the UFORE results on the same buildings that are being used for the green roof study. This will also provide another tool with which to assess the performance of green walls.
3. Using the results from Penn State University, simulation experiments will be conducted with a semi-intensive green roof design.
4. Given the apparent success of green roofs in reducing winter energy conservation, ESP-r will be used to run a comparison with black roofs.
5. Apply the results to a building of interest to Gaz Métropolitain if the data required for ESP-r can be provided to Environment Canada for the simulation.

Although it would be of interest to analyze the data from the FRF, this is outside the scope of our work commitment and is a task best suited to the NRC staff. However, if the data were to become available to Environment Canada, we will attempt to incorporate it into the next phase of the work.

Date	Task
April 2 – April 30 2007	Review of report by Gaz Métropolitain
May 1 – May 15 2007	Confirmation of workplan with Environment Canada
May 15 – October 31 2007	Programming modifications to ESP-r
June 1 – July 30 2007	Assessment of feasibility of green roof design for winter with 8 – 15 cm of growing medium
August 1 – Dec 31 2007	Develop shallower green roof and green wall simulation in ESP-r

Date	Task
January 2 – Feb 28 2008	Additional Green Roof, Green Wall and Black Roof simulations
March 1 – March 31 2008	Preparation of Status Report
April 2 – April 30 2008	Review of report by Gaz Métropolitain
May 1 – May 15 2008	Confirmation of final revisions to research with Environment Canada
May 15 – June 30 2008	Apply method to building from Montréal provided data are available
July 1 – Aug 31 2008	Prepare final report for Gaz Métropolitain
Sept 1 – Sept 30 2008	Review of report by Gaz Métropolitain

This workplan is a proposal for the next 17 months. Changes in tasks to accommodate the needs of Gaz Métropolitain are possible, but may necessitate postponing or eliminating other tasks.

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BUDGET FOR 2005-07

		Contributions from			
Task	**Budget**	**Gaz Métro**	**AIRD/EC**	**Others**	**Total**
Green Wall Simulations and Analysis	60K		10K	50K	110K
ESP-r programming, maintenance and updates	15K	5K	5K	5K	30K
ESP-r Simulations	20K	5K	5K	10K	40K
Report Preparation	10K	5K	5K		20K
Total	**$105K**	**$15K**	**$25K**	**$65K**	**$210K**