THERMAL PERFORMANCE OF GREEN ROOF PANELS IN SUB-ZERO TEMPERATURES

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ABSTRACT

To date, much of the research on green roof technology has focused on the capacity for these systems to contribute to the cooling of buildings during summer months. The thermal performance of green roofs in cold climate conditions is critical to understanding the potential of these roofs to decrease energy use in buildings during winter. This paper compares the behavior of two green roof systems with that of a conventional built-up roof by making use of a novel hot box testing apparatus.

The green roofs tested are classified as extensive systems. Each system included: a 3 mm thick styrene butadiene rubber waterproofing membrane, 0.2 mm thick polyethylene slip sheet, a 76 mm thick extruded polystyrene insulation layer, 2 mm thick filter fabric, a 51 mm drainage layer followed by a 2 mm thick filter cloth, either 100 mm or 150 mm growing medium, and a 25 mm thick wild flower vegetated mat. The conventional roof consisted of a 2 mm thick layer of Kraft™ vapour retarder bonded with insulation adhesive, 51 mm of isocyanurate insulation, 25 mm of fibreboard, a three ply (2 mm) cold-applied built-up roof membrane, and a gravel ballast finish 51 mm thick.

Each roof was subjected to temperatures between 0°C and –25°C, while the temperature within the hot box was held at 21°C. The effect of vegetation on a green roof to reduce wind speeds or increase snow cover were not considered in this study. The power required, as well as the temperatures throughout each system at steady state conditions, were monitored for 5 hours. The data collected from thermal testing suggests that the R-value of green roofs with 100 mm or 150 mm thick layers of growing medium is 37% higher than a conventional roof when subjected to temperatures of 0°C to –25°C.

KEYWORDS

green roofs, thermal performance, R-value, low temperature, hot box tests

INTRODUCTION

Green roofs are engineered systems that include vegetation, growing medium (substrate), filter cloth, a drainage layer, a root repellent system and a waterproofing membrane (Peck et al., 1999). The typical components are shown in Figure 1.

There have been numerous studies of the benefits of green roofs. Sailor (2008) examined the energy savings that are possible with the installation of a green roof. The annual electricity consumption for a building with a green roof was 2% while natural gas consumption was 9–11% lower. Takebayashi and Moriyama (2007) measured roof temperatures and showed that green roof temperatures in summer months are up to 10°C lower than a concrete roof. For this reason, green roofs have the potential to reduce the urban heat island effect. Getter et al. (2007) showed that green roofs have a higher stormwater retention than traditional roofs, and so can help reduce the potential for flooding. Getter et al. (2009) examined the carbon sequestration potential for green roofs. Their analysis indicated that for

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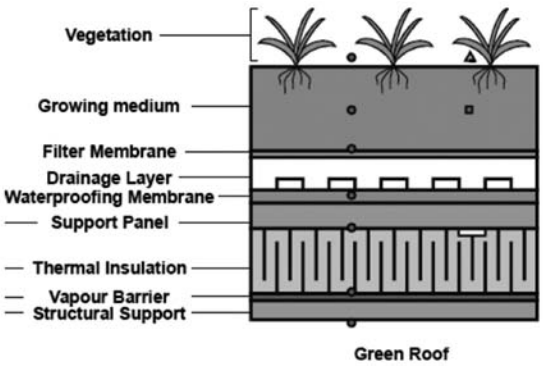
FIGURE 1. Typical components of a green roof (Liu and Baskaran, 2003).



a city the size of Detroit, use of green roofs on all available roofs would result in 55 252 t of carbon sequestered, equivalent to removing 10 000 mid-sized SUVs or trucks from the road for a year.

There has been comparatively little research on the performance of green roofs in cold climates. Liu and Bass (2005) showed that the heat flow through green roof was reduced by 70%–90% in the summer, but only 10%–30% in the winter, as compared to a conventional roof. These measurements were made on green roofs installed on a building in Toronto, Canada.

As the number of green roofs installed increases in cold climate regions such as the northern United States and Canada, there is a need for data on the performance of these systems at low temperatures. The objective of this paper is to compare experimentally the thermal performance of a green roof system with that of a conventional roof at sub-zero degree Celsius temperatures. To achieve this objective, a hot-box apparatus has been fabricated for assessing the thermal performance of roof configurations. Two small-scale green roof assemblies and a conventional roof assembly are tested in the hot box and their thermal performance compared. The results of these tests are used to quantify the potential energy savings in winter months for a building with a green roof installed. In quantifying the thermal performance of green roofs, the effect of vegetation has been ignored in this study. Vegetation may add to the thermal performance of a green roof in the field by reducing windpseed and trapping insulative snow cover.

APPARATUS

Tests of green roofs subjected to temperatures below 0°C were undertaken using the custom designed hot box apparatus shown in Figure 2. The testing procedure was a modified version of ASTM C1363-97 (ASTM 1997). The hot box is 1461 mm × 1461 mm × 1461 mm. The interior is lined with two layers of 51 mm thick extruded polystyrene (XPS) foam insulation boards. A custom designed 400 watt heating element (Figure 2) was located 610 mm above the floor of the hot box. The heating element is comprised of two incandescent 200W light bulbs, housed inside two 305 mm outside diameter circular aluminum tubes. A 76 mm diameter fan continuously circulated air inside the hot box. A vertical metal tripod, to which a clamp was attached, was used to mount sensing and control thermocouples at the precise centre of the hot box interior. The thermocouples provided feedback to a temperature controller which maintained a hot box internal temperature of 21°C by turning the light bulbs on and off as necessary.

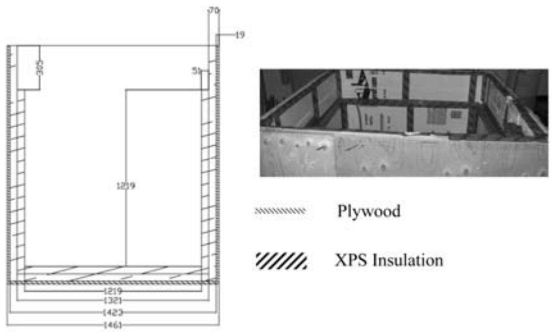
A total of four systems were tested. Two green and one conventional built-up roof systems were tested. In addition, a "calibration panel", shown in Figure 2(c), was also tested. The calibration panel consisted of two layers of 51 mm thick extruded polystyrene foam and one layer of 19 mm plywood, and fit snuggly in the top of the hot box.

Each roof was assembled in an aluminum testing cradle, shown in Figure 3. The test cradle was then placed on the top of the hot box. The components of the conventional roof are shown in Figure 4, and consisted of a 2 mm thick layer of Kraft™ vapour retarder bonded with insulation adhesive, 51 mm of isocyanurate insulation, 25 mm of fibreboard, a three ply (2 mm) cold-applied built-up roof membrane, and a gravel ballast finish 51 mm thick. Seven Constantine-Copper (T-type) thermocouples were placed through the layers of the roof.

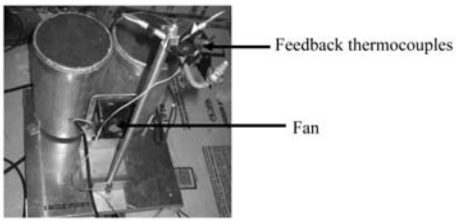
The green roof systems were identical except for their nominal growing medium depths (100 mm and 150 mm). The system installed is classified as "extensive". Extensive green roof are lightweight and low-maintenance compared to "intensive" green roof systems.

The construction of the two systems began with the installation of inverted roof systems, includ-

FIGURE 2. Hot box details: (a) Vertical section view of hot box (units: mm); (b) Heating element; (c) Calibration panel.



(a)



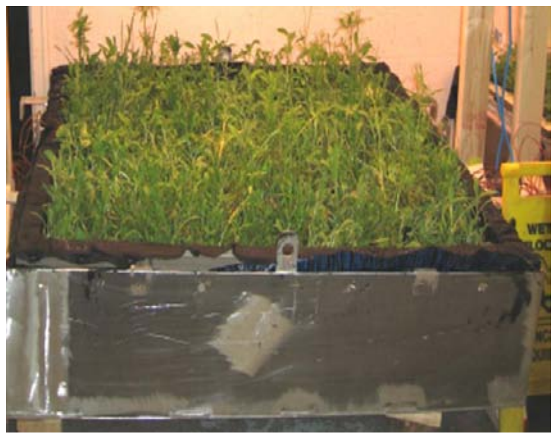
(b)

(c)

ing: a 3 mm thick styrene butadiene rubber (SBR) waterproofing membrane, which was fully adhered in cold roofing adhesive (preventing water from reaching the roof decking in an actual field installation), a 0.2 mm thick polyethylene slip sheet which allows any moisture in the waterproofing membrane to exit the system, a 76 mm thick layer of extruded polystyrene insulation, and a 2 mm thick fabrene filter fabric. Atop this inverted base was placed a 51 mm thick polyethylene drainage system (tradename Cupolex) produced by Pontarolo Engineering. The drainage system collects excess water from the growing medium. A 2 mm thick filter cloth on top of the drainage system prevents the growing medium from being transported into the layers beneath. The

FIGURE 3. Installation of panels for thermal testing: (a) Installation of green roof in aluminum cradle and installation of thermocouples; (b) Installation of vegetative mats; (c) Hot box in environmental chamber.

(a)



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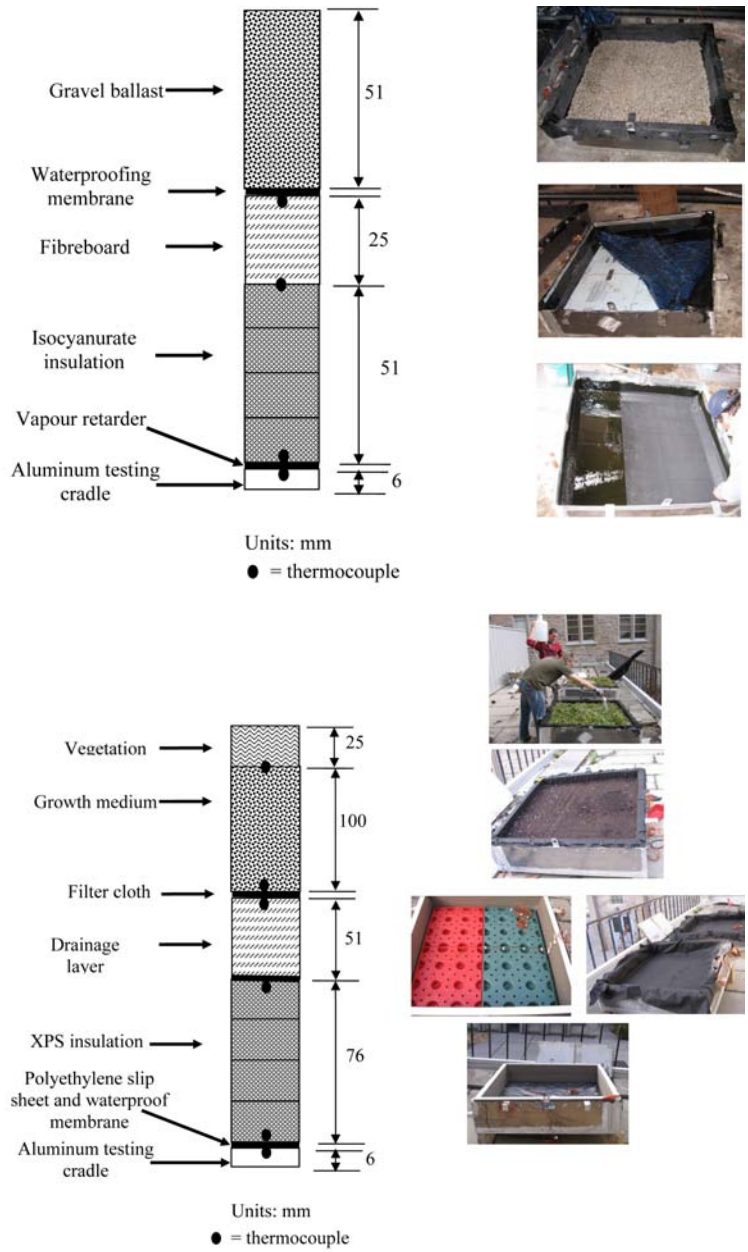


(a)

(b)

FIGURE 4. Installation of roof components: (a) Conventional roof; (b) Green roof.

growing medium was Rooftop Biomix, produced by LandSource Organix Inc. It contains 40% organic material, consisting of well-composted, stable and mature green organic waste matter and composted pine bark. It includes 5 % polystyrene foam for moisture retention. The maximum saturated density is 850 kg/m^3 and the pH ranges from 6.0 to 7.4. A 100 mm depth of growing medium was placed in the 100 mm nominal Green roof testing panel during its fabrication, while 150 mm of growing medium was used in the 150 mm nominal Green roof.

The growing medium used in green roof applications is chosen so as to serve a threefold purpose: to act as an insulation layer against heat transfer in both summer and winter (i.e. energy loss due to both heating and cooling); to protect the roof layers beneath the green roof components from direct sunlight and cold temperatures, reducing the temperature fluctuations experienced by the waterproofing membrane, roof deck and thermal insulation layers, and consequently increasing the service life of the roof; and to support the anchorage and ongoing growth of the vegetation (Tsiotsiopoulou et al., 2003). The advantage to using vegetated mats is that the vegetation is pre-grown so that the roots are established in the thin substrate layer in which they are planted, and the installed the plants grow quickly. In addition, the mats are easily installed; they are rolled into place over the growing medium in a similar fashion as would be done for rolls of sod.

As with the construction of the conventional built-up roof test panel, thermocouples were placed at the plan centre of each layer of the testing panels. One T-type thermocouple each was placed at the bottom of the inverted roof assembly of each green roof, as well as above the waterproofing membrane, polyethylene slip sheet, filter fabric, drainage layer, filter cloth, and the hand tamped growing media of the two green roof systems.

XPS foam was used to insulate the side walls and top edges of the testing cradles so as to prevent thermal bridging by the cradles. The seams between the aluminum and XPS were sealed with expanding insulation foam, with the areas where pieces of the XPS came into contact with the hot box or XPS insulation pieces sealed with contractors sheathing tape.

During the interim three month period between green roof installation and testing, the green roof test panels were stored indoors beneath fluorescent light bulbs to simulate sunlight needed for plant growth. The vegetation was also watered every other day, and allowed to drain freely by way of scuppers installed in one side of each the three aluminum testing cradles. The growing media of the 100 mm and 150 mm nominal growing medium green roofs experienced some settling during this period due to the poor compaction achieved from hand tamping. The actual average depths of the growing medium of the 100 mm and 150 mm nominal green roofs at testing were 82 mm and 127 mm respectively.

The entire hot box assembly including the roof system to be tested was placed inside a larger 6100 mm–4500 mm plan dimensioned environmental chamber (Figure 3), controlled by a 2104 Chromalox™ temperature controller with a ±1°C accuracy.

TEST PROCEDURE

Just prior to testing, the green roof test panels were irrigated until water pooled at the top of the growing media. The green roofs were then allowed to drain by gravity to field moisture conditions, after which they were set into the top opening of the hot box.

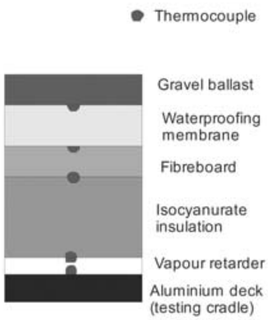
The environmental chamber was then set to the desired outside testing temperature (between 0°C and –25°C), while the temperature within the hot box was set at 21°C. The system was monitored for 24 hours until steady-state conditions were achieved (i.e., the inside temperature of the hot box was consistently at 21°C and the temperature outside the hot box was consistently at the desired testing temperature). Once at steady-state, power use and temperature variation for each system was measured. Each run was carried out for a total of five hours at each environmental chamber temperature. Once a five hour period was over, the environmental chamber temperature was reduced by 5°C and steady-state was again established before testing was re-commenced. This sequence was repeated for the green roof test panels, the conventional test panel, and the calibration panel, although the conventional and calibration panels were not watered.

RESULTS

Roof Temperature Variation

Most of the insulation of the conventional roof is provided by the isocyanurate insulation and the fibreboard (Figure 5). The thermocouples below the vapour retarder are all close to the hot box temperature of 21 °C. The thermocouples at the top of the fibreboard and above are all close to the environmental chamber temperature. This indicates that The isocyanurate insulation accounted for about 72% of the difference, and the fibreboard accounted for 20 % of the total temperature decrease. This is consistent with published R-values for these materials (the R-value of the isocyanurate is 2.13 $m^2 \cdot K/W$ and that of fibreboard 0.52 $m^2 \cdot K/W$).

FIGURE 5. Insulating layers of the conventional built-up roof: Temperature variation of the roof components with depth of thermocouples.



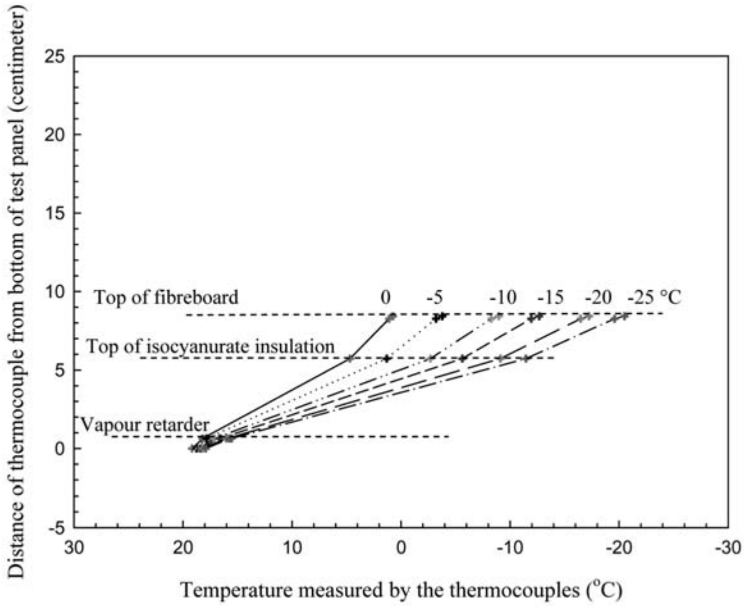
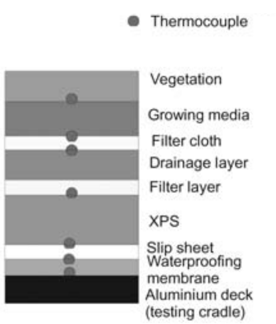
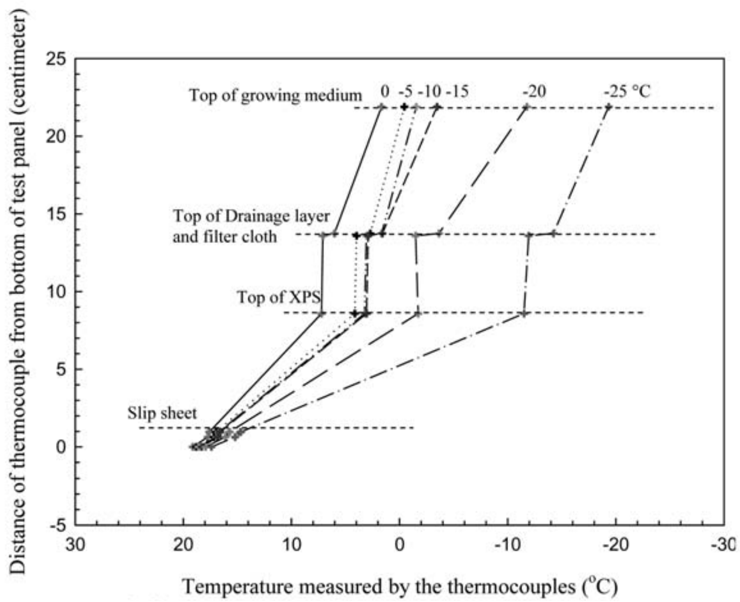


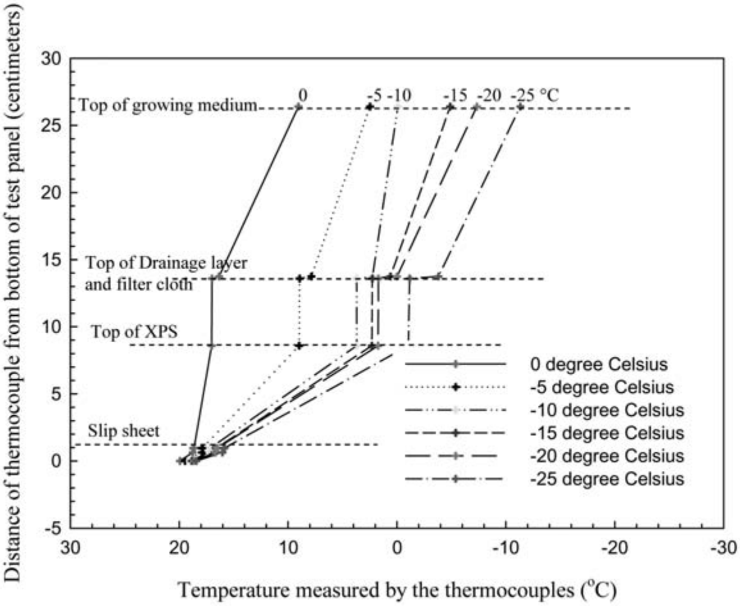
FIGURE 6. Temperature variation through 100 mm thick growing medium green roof.





The XPS insulation contributed approximately 66%, and the growing medium contributed approximately 19% to the insulating capacity of the nominal 100 mm green roof for the range of environmental chamber temperatures (Figure 6). This is consistent with the published R-values of XPS (2.64 $m^2 \cdot K/W$) and of polyurethane foam (0.97 $m^2 \cdot K/W$), the pieces of which were incorporated into the matrix of the growing media.

The thermal performance of the nominal 150 mm green roof was again most dependent on the XPS and growing medium layers (these layers accounted for 64.0% and 19.0% of the insulation capacity respectively) at environmental chamber



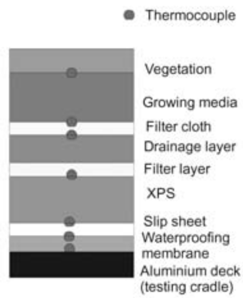


FIGURE 7. Temperature variation through 150 mm thick growing medium green roof.

temperatures between –5°C and –25°C (Figure 7). However, at an environmental chamber set point temperature of 0°C, the growing medium most impacted (about 67.0% of the insulation capacity of the test panel) the thermal performance of this green roof. The XPS insulation accounted for 15.0% of the total insulation capacity of the test panel at this temperature. Although difficult to reconcile in light of the trends observed for the 100 mm thick growing medium green roof and at other set point temperatures for the 150 mm thick growing medium green roof, the deviation in performance of the 150 mm thick growing medium green roof at 0°C may have been due to the presence of moisture (moisture may decrease the thermal resistance of materials, Wilkes et al., 1991) in the XPS layer at the start of testing, but which later dried out.

Power Use and Effective Thermal Resistance

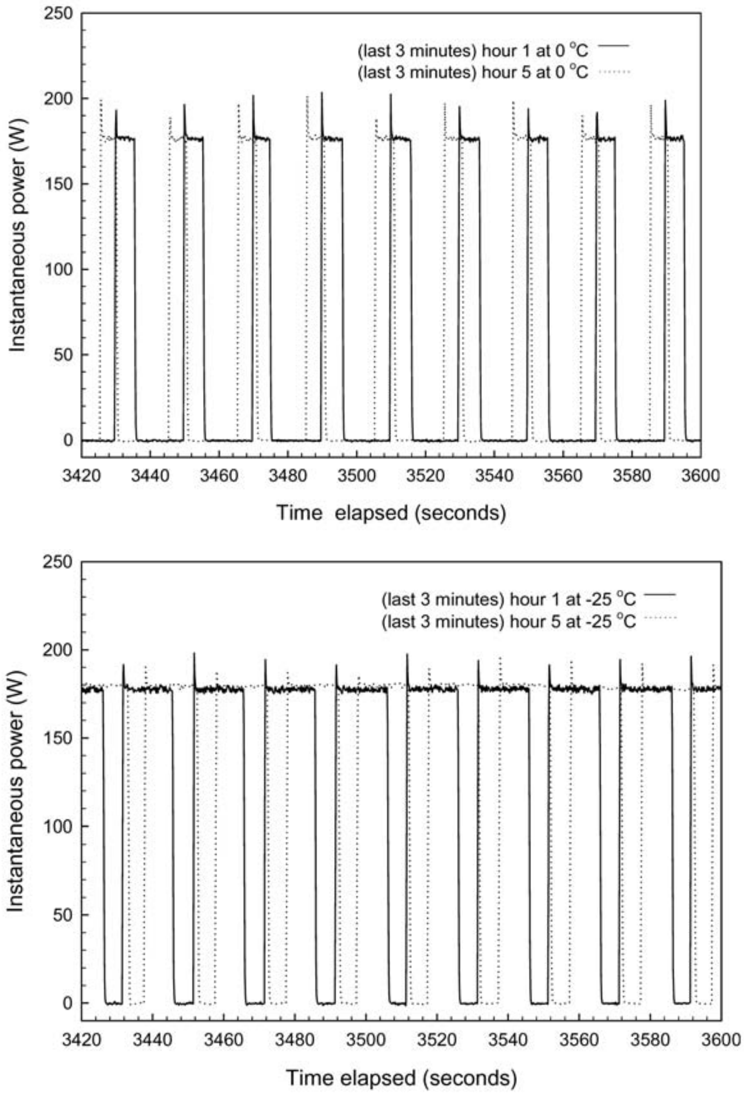
The power to heat each system was supplied intermittently, with short-lived peaks appearing at the start of the "on" phase of the heating system (Figure 8). The width of the approximate square waves increase as the set point temperature of the environmental chamber decreased, indicating that the heating element remained "on" for longer periods in order to maintain steady-state temperature within the hot box.

The total energy used by each of the three test panels was determined by numerically integrating the area beneath plots of instantaneous supplied power versus time. The 100 mm growing medium roof used 13.0% to 29.0%, and the 150 mm growing medium roof used 12.0% to 36.0%, less power than the conventional built-up roof (Figure 9). This indicates that the green roofs provide better thermal insulation than a conventional roof.

The power use for the hot box with the calibration panel in place is shown in Table 1. The heat loss for each specific roof system panel was determined by subtracting 5/6 of the total energy used by the hot box fitted with the calibration panel at the same environmental chamber temperature. The assumption was that because all five hot box walls and the calibration panel were constructed identically, the heat lost through each face would be identical throughout testing, and as such each wall would account for 1/6 of the energy used to maintain steady-state temperature of the entire hot box during testing.

The heat loss values for the three roof panels were compared (Figure 10). There is some scatter in the data for the green roofs. In fact, between temperatures –5°C and –20°C, the 150 mm green roof data generally has a greater heat loss than the 100 mm green roof. However, an analysis of variance indicated that the differences between the two green

FIGURE 8. Power use during the testing of the 150 mm thick growing medium green roof test panel: (a) Environmental chamber set point temperature of 0°C; (b) Environmental chamber set point temperature of –25°C.



roofs are not statistically significant. On the other hand, the difference in heat loss for the conventional roof compared to the green roofs is statistically significant at the 99% confidence level.

Effective R-values were calculated according to ASTM standards C168-03 and C1045-01 (ASTM, 2003; ASTM, 2001) for the conventional built-up and two green roof test panels, as well as the calibration panel. These values can only be regarded as "effective" since parameters which are normally determined for standard testing of building envelope components such as the convective heat transfer coefficients inside and outside the hot box, and flanking losses resulting from edge effects in the testing panels could not be accurately determined. The effective R-values of the three roof test panels are only a comparison of the thermal behavior of these test panels.

The effective R-value was determined for the three test panels at each environmental chamber testing temperature using the ambient air temperature of the environmental chamber (environmental chamber set point temperature) and the air temperature inside the hot box (measured by the hot box

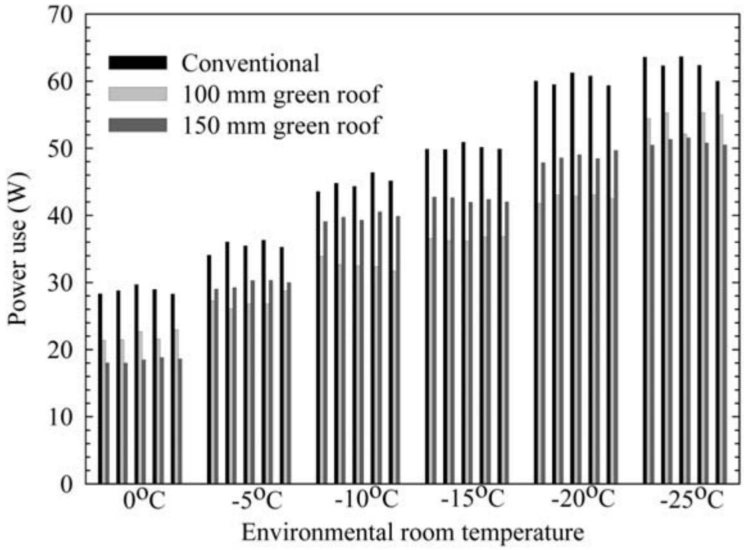


FIGURE 9. Power use of the three test panels for each of the five hours of testing at the various environmental set point temperatures.

TABLE 1. Power use for each hour of testing at various environmental chamber set point temperatures for the calibration panel.

Hour #	Power Use (W)					
	0°C	–5°C	–10°C	–15°C	–20°C	–25°C
1	6.5	8.3	10.5	12.3	14.2	16.0
2	6.4	8.5	10.4	12.2	14.1	16.1
3	6.7	8.5	10.4	12.3	14.0	15.9
4	6.4	8.5	10.4	12.4	14.1	16.1
5	6.5	8.4	10.1	12.2	14.0	15.9
Average	6.5	8.4	10.4	12.3	14.1	16.0
Standard deviation	0.1	0.1	0.2	0.1	0.1	0.1

temperature controller/feedback thermocouple and taking the time-averaged temperature for each hour of testing) (ASTM, 2001):

$$R = \frac{A(T_h - T_c)}{Q} \quad (1)$$

where A is the specimen area (m^2) normal to the heat flux direction; Q is the time rate of one-dimensional heat flow through the metering area of the test roof (W); and T_h and T_c are the area-weighted and time-averaged temperatures of each test panel's hot and cold surface temperatures (K) during the full hour of testing, respectively. The specimen area normal to the direction of heat flow was 1.49 m^2 for the three test panels.

Table 2 presents the R-values obtained for the calibration panel at environmental chamber set point temperatures ranging from 0°C to –25°C. For comparison, a thermal resistance value of 3.64 m^2K/W should be expected based on a 5-year laboratory aging period (CAN/ULC S770; Underwriters' Laboratories of Canada, 2007). The experimental R-values were actually 8.0% to 18.0% greater than those expected on the basis of available published R-values for the calibration panel's components (tabular R-values). This difference is small, given the various possible sources of error, and it is encouraging to note that the experimental R-values are indeed quite close to the expected values. The observed differences may be due to small air gaps

FIGURE 10. Power use of all three test panels.

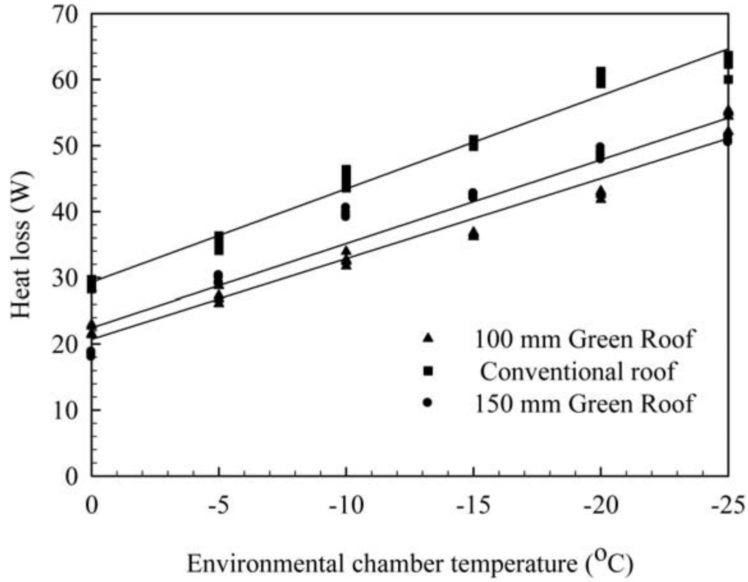
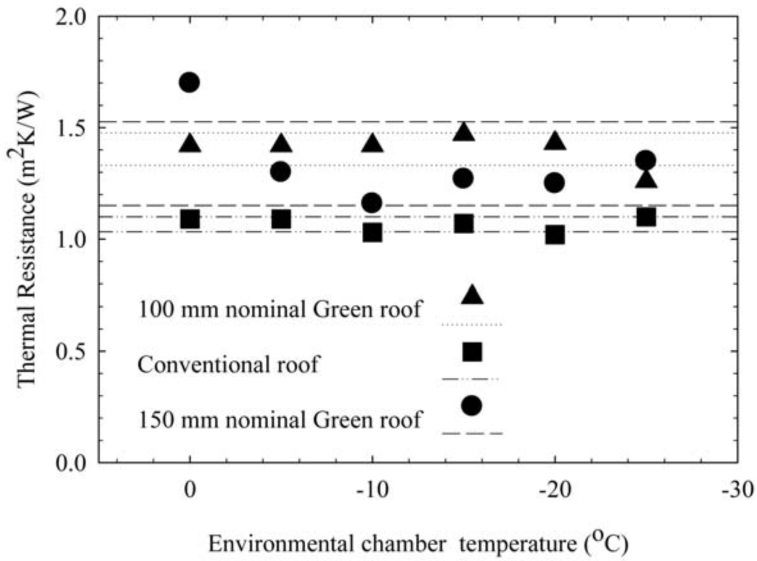


TABLE 2. Tabular and experimental thermal resistance values for the calibration panel at various environmental chamber set point temperatures.

Environmental chamber set point temperature		Thermal resistance values (m^2K/W)					
		0°C	–5°C	–10°C	–15°C	–20°C	–25°C
Calibration panel	Tabular	3.64	3.64	3.64	3.64	3.64	3.64
	Experimental	4.45	4.25	4.15	4.05	4.01	3.98

FIGURE 11. Effective R-values of the three test panels at all set point temperatures. 5 Dotted lines indicate ± one standard deviation.



which may have existed between the two XPS insulation layers, or the XPS insulation and plywood layer (the adhesive layer was not continuous over the entire bonded surface). Air gaps are well known to be thermally insulating (still air has an R-value of 0.11 m^2K/W when the direction of heat flow is upward (ASHRAE, 2005)).

The effective R-value of each test panel remained approximately constant irrespective of the environmental chamber temperature, suggesting that each panel offered roughly the same thermal insulation capacity throughout testing (Figure 11). Analysis of variance indicates that the effective R-values of the conventional roof are significantly less than the R-values of the green roofs. On average, the effective R-value of the conventional roof panel was 1.0 and the effective R-value of the green roof panels was 1.375.

DISCUSSION

Flanking Losses

The measured R-values were compared to expected R-values based on published insulation values for the materials comprising the various roof panels. A line of linear least-squares best-fit plotted through the calculated experimental XPS R-values was used to approximate the variation of R-value of XPS with temperature under the current test conditions. These best-fit XPS R-values were then used in the calculation of the predicted R-values of the two green roof test panels for all set point temperatures, by assuming that the other components performed as expected based on published R-values. The thermal contribution of the growing medium was not included in the current calculations, as published data is not currently available. This is not to suggest that the thermal component of the growing medium is not significant.

Table 3 compares the experimental R-values of the conventional built-up roof and green roof test panels to the values based on published data. The R-values of XPS insulation used in calculating the predicted R-values of the Green roof test panels for all set point temperatures were 76% of the best-fit R-values calculated for the XPS because the XPS in the calibration panel was 100 mm thick whereas that in the Green roof test panels was 76 mm thick. The R-values of the XPS used in the green roof test panel calculations were therefore 3.18 m^2K/W, 3.09 m^2K/W, 3.02 m^2K/W, 2.96 m^2K/W, 2.89 m^2K/W, and 2.82 m^2K/W for the environmental chamber set point temperatures 0°C, –5°C, –10°C, –15°C, –20°C, and –25°C respectively.

Table 3 suggests that up to 69%, 73% and 93% of the energy lost from the conventional, 100 mm, and 150 mm green roof panels, respectively, may have been due to flanking losses through the aluminum testing cradles. Obviously these losses would be larger if the thermal contribution of the growing medium had been included in the predicted R-values. The important observation is that the

TABLE 3. Approximate R-value reductions due to flanking losses through the aluminium testing cradle.

Environmental chamber set point temperature		Thermal resistance values (m^2K/W)					
		0°C	**–5°C**	**–10°C**	**–15°C**	**–20°C**	**–25°C**
Conventional built-up roof test panel	Predicted	2.82	2.82	2.82	2.82	2.82	2.82
	Experimental	0.95	0.95	0.91	0.92	0.88	0.92
	Lost thermal resistance	1.87	1.87	1.91	1.90	1.94	1.90
Nominal 100 mm Green roof test panel	Predicted	3.34	3.25	3.18	3.12	3.05	2.98
	Experimental	0.81	0.81	0.70	0.63	0.69	0.79
	Lost thermal resistance	2.53	2.44	2.48	2.49	2.36	2.19
Nominal 150 mm Green roof test panel	Predicted	3.34	3.25	3.18	3.12	3.05	2.98
	Experimental	0.24	0.53	0.58	0.58	0.52	0.57
	Lost thermal resistance	3.10	2.72	2.60	2.54	2.53	2.41

flanking losses were significant, and as a result, it is not appropriate to consider the R-values measured for the roof panels in this study to be applicable to roofs in the field. However, it is appropriate to compare the roof test panels against one another. As indicated in the Results, the green roof panels had R-values approximately 33% higher than the conventional roof. This is consistent with the findings of Liu and Bass (2005) for the performance of green roofs in winter conditions.

Heat Energy Savings

The results of the experiments are used to predict the thermal performance in winter of a building installed with a green roof. The case study is a single storey commercial building with a 3159 m^2 conventional flat roof located in Kingston, Ontario, Canada. The total energy use for the building between November 2006 and March 2007 was obtained from the city utility and presented in Table 4. The average day and night time temperatures in Kingston between November 2006 and March 2007 were obtained from Environment Canada (Environment Canada, 2007), and presented in Figure 12. These temperatures were measured at the city airport, located approximately 9 kilometers from the building.

The energy loss through the roof of the building was calculated using Equation 1. The interior temperature was assumed to be 21°C, and the cold side temperatures were obtained from the Environment Canada hourly temperature data. The area normal to the direction of heat flow was 3159 m^2. The R-value for a conventional roof was assumed to be 2.82, the value based on published data. For the green roof, it was assumed that the R-value was 30% higher than the R-value for the conventional roof. This was based on the hot-box testing of the conventional and green roofs. Thus, an R-value of 3.7 was assumed for the green roof.

The predicted energy loss through a conventional and green roof is shown in Table 4. Also shown in Table 4 is the expected total heat loss in a commercial building, assuming 32% of the total energy is required for heating (DOE 2006). Due to the higher R-value, the building with a green roof is predicted to require 22,118 kWh less energy over the five winter months than the building with a conventional roof installed. The current cost of electricity in Ontario is $0.053 CDN per kW hour for the first 600 kW hours and $0.062 CDN per kW hour for use greater than 600 kW hours. Thus, the green roof would result in about $1371 CDN savings in heating over the five winter months. The total energy bill over the same five months was $41,026.20 CDN. The green roof therefore would result in a 3.3% savings in the energy bill for this building over the winter months. The energy savings experienced during the summer months will be much larger, as the vegetation provides shading for the roof, and the impact of evapotranspiration of the plants is significant in exploiting all the thermal benefits of install-

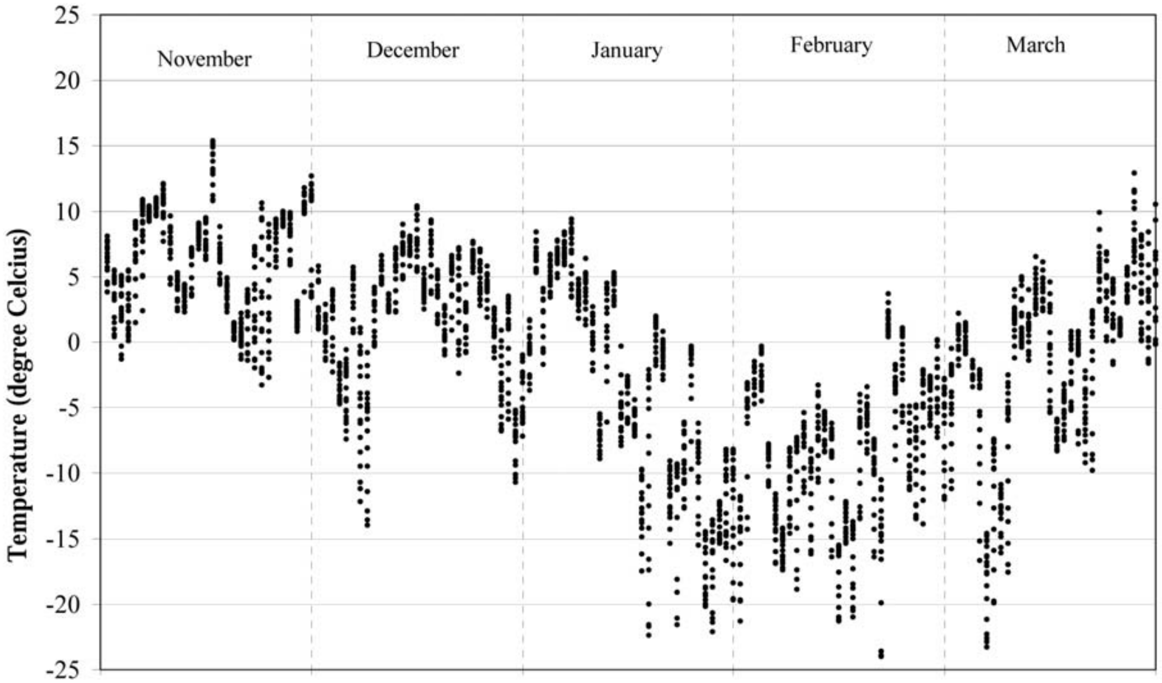
TABLE 4. Predicted energy use of a retail building in Kingston, Ontario, Canada with a green roof.

Month	Total building energy consumption[1] (kWh)	Total heat energy[2] (kWh)	Predicted Energy Loss, conventional roof (kWh)	Predicted Energy Loss, Green Roof (kWh)
November	129600	41472	12943	9751
December	139200	44544	16471	12553
January	141000	45120	22061	16814
February	123000	39360	23460	17881
March	129000	41280	17600	13418
Total	661800	211776	92535	70417

[1]Obtained from city utility

[2]Assuming 32% of energy used for heat

FIGURE 12. Hourly temperatures in Kingston, Ontario, between November 2006 and March 2007.



ing a green roof (Liu, 2006; Liu and Baskaran, 2003; Niachou et al., 2001).

These savings need to be placed in the context of the total costs and benefits possible with a green roof. The initial cost to install a green roof is higher compared to a conventional roof. Information garnered from industry suggest that the cost of installing a conventional built-up roof is about $10 CDN per 0.09 square meters (1 ft^2), while that to install a green roof is $25 CDN per 0.09 square meters (Kerim, 2007; Wylie 2007). Clark et al. (2007) demonstrated that the net present worth of a green roof is between 20.3% and 25.2% less than a conventional roof when considered over a 40 year life. The reason for this is the increased roof longevity, reduced stormwater runoff, and reduced building energy consumption of the green roof. While the cost savings that can be attributed to a green roof during the winter months may be small on an annual basis, they become significant when considered over the whole life of the building.

CONCLUSIONS AND RECOMMENDATIONS

The results of this experimental study highlighted a number of key differences in performance between the green roof and conventional built-up systems tested. The effects of vegetation on the thermal performance have not been included in this study. Vegetation may help reduce wind speed and increase snow cover in the field, both of which have the potential to improve the thermal performance beyond that quantified in this study.

1. The green roof panel with 100 mm thick growing medium used 13.0% to 29.0%, and the green roof panel with 150 mm growing medium roof 12.0% to 36.0%, less power than the conventional built-up roof to maintain an internal hot-box temperature of 21°C while the external temperature ranged from 0°C to –25°C.
2. The insulating properties of green roof systems such as the two tested appear to be most affected

in cold climates by the insulation layer. This is observed through the large variation in temperature between the surfaces of the insulation. The growing medium appears to be secondary in its effect on the thermal insulation properties of these systems.

3. There was statistically no significant difference in the effective R-value of the green roof with 100 mm thick growing medium and 150 mm thick growing medium.
4. The effective R-value of the two extensive green roofs tested was 37.5% greater than the conventional roof over the range of external temperatures ranging from 0°C to –25°C.

These results will provide a reference point for further research into the thermal performance of green roof systems under varying moisture conditions, the development of a more refined method to account for variabilities in R-values stemming from the environmental conditions under which a material is placed, and the quantification of the energy savings to be had during summer months by buildings fitted with green roofs.

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