Green Roof Thermal and Stormwater Management Performance: The Gratz Building Case Study, New York City

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GREEN ROOF THERMAL AND STORMWATER MANAGEMENT PERFORMANCE: THE GRATZ BUILDING CASE STUDY, NEW YORK CITY

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NOTICE

ABSTRACT

This report summarizes the findings for data collection from October 2006 to September 2007 on the Gratz Industries Green Roof Research Station. Notable for its large-scale innovative research design, this project addresses the deficiency in green roof thermal and stormwater data specific to the New York City region. In conjunction with the in-situ monitoring data and analysis, this report also includes thermal modeling of the Gratz building given conventional and green roof scenarios as well as runoff water quality results. The results of the monitoring during this period showed that green roofs are capable of lowering the maximum conventional roof membrane (surface) temperatures by as much as 35^{o}C and reduces diurnal temperature fluctuations by as much as 30^{o}C. While the conventional roof membrane temperatures frequently exceeded 70^{o}C in the summer months, for the green roof the temperatures were consistently below 50^{o}C. Reductions in temperature fluctuations decrease the stress on roof membranes thereby extending its useful duration. In this study, differentiation between the green roof and conventional roof in terms of inside building temperature and outdoor ambient temperatures (6” above surface) was not clearly apparent. However, the vegetated roof areas had a modulated daily heat flux pattern and summer heat flux monthly totals that were negative (building heat loss). This is in comparison to the conventional roof where the diurnal amplitude was pronounced and summer monthly totals were positive (building heat gain). These results demonstrate the potential for green roofs to reduce the need for air conditioning. The stormwater analysis showed that green roofs are able to absorb most of the precipitation associated with minor rain events and attenuate and delay runoff for more intense events. Overall, the Gratz green roof retained 40% of incident precipitation and was most effective in the summer for a year that had above average precipitation. Green roofs’ capacity to retain stormwater could be helpful for reducing the occurrence of combined sewage overflow events. Runoff water quality results indicated a decrease in heavy metal concentration for the green roof, a higher hardness and phosphorus level, and a lowered biological oxygen demand and total suspended solids. The primary data collection for this monitoring period faced issues regarding plant survivability and equipment faltering, which are typical of a new installation and were subsequently addressed. The overall results of this analysis speak to the significant benefits of green roofs in terms of thermal performance and stormwater management.

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SUMMARY

Extensive green roofs are rapidly being accepted as a stormwater Best Management Practice (BMP) in North America (Pa.DEP. 2006). A simple extensive green roof in North America designed as a stormwater BMP consists of a drainage layer covered with 2-6 inches of a lightweight growing medium and vegetation. While the benefits of green roofs in terms of stormwater management and reduced thermal loading have been demonstrated for locations from Portland to Athens, there is a paucity of empirical data specific to the New York City region. As the impact of green roofs is highly contingent upon environmental conditions, local studies are critical components of city-scale cost benefit analysis. Additionally, there is a decided need for in-situ monitoring of established green roofs to better assess real-world performance.

The Gratz Industries Green Roof Research Project was designed to address these issues and investigate the thermal and stormwater function of a green roof in comparison to conventional roofing. The research station was situated at the 10,000 ft^2 Gratz Industries building in Long Island City, New York. The roof of this building was divided into four quadrants by two feet high knee-walls: three vegetated (extensive green roof) and one non-vegetated (black tar roof). The non-vegetated roof consists of a layer of insulation and a waterproofing membrane. Roof assembly in the vegetated quadrants consists of five layers placed over the existing roof in the following order from bottom to top: insulation, water proofing membrane, drainage layer, water retention layer, and growing media. The growing medium in the vegetated quadrants is 2-to-3 inches deep except for in the 10lb/sq. ft. load bearing zones where the depth is limited to an average of two inches (according to Greener by Designs and Balmori Associates). The 10lb/sq. ft. zones comprise less than 1/5 of the total area of each quadrant.

The roof quadrants were instrumented to measure vertical temperature gradient, heat flux into the building, and stormwater runoff. The temperature, heat-flux, and soil moisture sensors were installed at different layers of the roof assembly in the monitored quadrants. A weather station installed on the roof measured relative humidity, air temperature, insolation, wind speed and direction, and precipitation. Formal data collection commenced on October 1, 2006. This report includes results for 12 months of data collected until September 30, 2007. Earth Pledge collaborated with the Pratt Center for Community Development, Balmori Associates, and Allied Construction to build and monitor this project and provide localized data on green roof performance to the New York State Energy Research and Development Authority (NYSERDA).

Water sample analysis was also conducted at the Gratz Industry and Silvercup Studios Green Roof Research Station to study the water filtration potentials of a vegetated roof compared to a conventional roof. The parameters were chosen from the New York City Drinking Water Quality Tests and Environmental Protection Agency's (EPA) National Primary Drinking Water Standards.

Temperature Results

The temperature responses observed for the Gratz roof were similar to those reported for other roofs in the literature. The most striking difference between the green and non-green roofs was observed in roof membrane surface temperature. The membrane surface temperature of the non-green roof fluctuated much more that that observed for the green roof, with high temperatures above 70°C in the summer and lows of -15°C in the winter. This compares to high temperatures for the green roof waterproofing membrane in the 30-40°C range most of the warm season and winter lows seldom below 0°C. This reduction in temperature maxima and fluctuation can have a substantial influence on the life of the roof membrane. Temperature extremes and the resultant expansion and contraction of the membrane contribute to membrane aging and premature failure. The waterproofing membrane under the green roof is being protected from these extremes and thus should last longer, reducing long-term building maintenance costs, and reducing the environmental impact of roofing material disposal and replacement.

Heat Flux Results

The green roof greatly influenced heat flux through the roof of the building. The non-green control roofs heated during the day and cooled in the afternoon and evening, resulting in large fluxes of heat into and out of the roof every day. In contrast, the green roof heat flux was much less dramatic. During the summer months, the average total heat flux for the conventional roof was positive, indicating a general heating of the building that would increase air conditioning demand. The heat flux total through the green roof in summer remained negative. In the winter months, the total flux through both the non-green and the green roof was negative, with the negative flux through the green roof being greater. This is an interesting result owing to the heating of the non-green roof surface since it is a black tar material with a low albedo. While this is a negative impact in the summer, the heat gained in the winter is actually a benefit since it helps offset the overall heating demand of the building. This result points to the shortcoming common in the green roof industry of wanting to treat the green roof as an insulator similar to fiberglass or Styrofoam. The green roof does not function this way. It is primarily affecting building energy as an evaporative cooler in the summer, and a thermal mass buffering the flow of energy year round. This is well illustrated by this data set and demonstrates the importance of local climatic conditions for estimating green roof energy benefits.

Stormwater Results

The Gratz green roof effectively reduced the amount of stormwater runoff contributed to the city stormwater drainage system by about 40%, or over 74,400 gallons from the two monitored sections during the period studied. The roof was most effective in the summer and least effective in the winter. The roof was most effective at retaining typical small summer rains of less than 1”, frequently retaining 100% of these events. Winter precipitation retention was limited by the lack of evaporation and evapotranspiration as indicated by relatively high soil moisture during this period. In extreme events, the roof retained water up to the field capacity of the media (approximately 1.5”) followed by runoff similar to that from the non-green control roof section. Even when saturated, the green roof affected peak flows and held gravitational water in macropores. It resulted in lower peak flows and runoff that continued for a period after the storm event had ended. The soil moisture probes functioned well and could be used in conjunction with a rain gage to evaluate the effectiveness of a green roof that is not equipped with a runoff measurement system.

Water Quality Results

The water quality analysis of both green roof research stations demonstrated that storm water quality improves as it travels through a vegetated area. Green roofs act as a filter trapping suspended solids, organic material, and heavy metals. When comparing green and conventional roof results, heavy metals were significantly reduced in all parameters tested. As a result from heavy metal filtering, chemical oxygen demand levels were also reduced.

Something to consider is the type of pipes used in an irrigation and drainage systems of green roofs. The copper tubing used at Gratz could have contributed to the high levels of copper in the analysis. Nevertheless, this analysis still showed green roofs reducing the copper amount in water runoff.

Since organic material is captured in a green roof, the results showed low levels of biological oxygen demand. Suspended solids were also filtered out, lowering the amount of total suspended solids in runoff.

Green roofs will increase the hardness level because of the calcium and magnesium content in the growing medium, but will not have any significant affects to the water quality. Green roofs will also have a higher content of phosphate. The phosphate is derived from the growing medium. Orthophosphate is used in water treatment plants to improve water quality. It forms a protective coating inside pipes to prevent lead from leaching, so it may become beneficial to a buildings plumbing system.

Green roofs naturally absorb nitrogen content. Since there was not much nitrogen in the storm water, the total nitrogen as well as nitrate, nitrite, and ammonia levels were insignificant. There were some amounts of nitrate detected in the precipitation, and results showed nitrate levels reduced in green roof runoff.

Coliform analysis was inconclusive. Gratz results show contents of total and fecal coliform too numerous to count. These coliform levels were high due to fecal matter from pigeons. Pigeons were observed at Gratz green roof and Silvercup green roof. Concentration of coliform was probably high in water that collected in each of the three (3) drainage pipes. It is assumed that water from the first flush, containing high levels of coliform, was still in the pipes. The preliminary results at Silvercup showed very high levels of total and fecal coliform as well, but during the secondary testing the results were low.

Energy Modeling Results

A preliminary heat transfer analysis was conducted of the roof system on the Gratz Industries building. This building has features common of typical existing one-story manufacturing facility. The manufacturing floor (approximately 90% of building) is heated in the winter, but not air conditioned in the summer. Large-dampered exhaust fans are permanently mounted in window frames to cool the manufacturing floor during the summer. A small enclosed office area (approximately 10% of the building) is heated and air conditioned. Above the office is an open storage loft that is directly beneath the underside of the roof deck. Four different roof configurations were modeled and analyzed: the existing roof as a reference, the existing roof with a black surface plus an additional 2-inches of rigid insulation, a 4-inch extensive vegetated roof and an 8-inch intensive vegetated roof.

The modeling results are presented in the following table.

	Exhaust Fan Power Cons. kWh	**Office A/C Power Cons. kWh**	**Heating Fuel Consumption Mbtu**	**Total Annual Energy Savings from Reference Roof**
Reference Roof	13,140	1,460	301	n/a
Ins. Black Roof	15,120	1,680	223	$652
Extensive GR	11,700	1,300	211	$1,580
Intensive GR	11,070	1,230	202	$1,846

These results indicate that extensive and intensive green roofs have the potential to significantly reduce the heating requirements and noticeably reduce cooling requirements for this building. The green roof energy savings are more than twice that achieved by the insulated black roof. While the insulated black produced significant heating savings, they were not as large as those by the green roof. The insulated black roof also produced negative savings (consumed more energy) compared to the reference roof for cooling.

While the green roof provided energy savings, when the energy savings are monetized, their financial impact is small relative to the installed cost of a green roof. Excluding the costs for the roof membrane, insulation, and carpentry for monitoring reasons, the estimated installed cost for the green roof at the Gratz Building was $70,000. Based on this analysis, the payback period based on energy savings benefits alone could exceed the expected useful life of this building. If the stormwater management benefits of a green roof could be monetized and included in this financial evaluation, this payback period would be reduced. The research required to determine a financial value for the stormwater management benefits was beyond the scope of this project.

1. INTRODUCTION

Extensive green roofs are rapidly being accepted as a stormwater Best Management Practice (BMP) in North America (Pa.DEP. 2006). A simple extensive green roof in North America designed as a stormwater BMP consists of a drainage layer covered with 2-6 inches of a lightweight growing medium and vegetation. Numerous studies have concluded that a green roof with about 4 inches of medium can retain 40-60% of the annual precipitation in the Northeastern US, with nearly 90% of many summer storms retained (Denardo et al. 2005). In addition, green roofs have been shown to detain runoff, reducing peak flows that can cause flooding and lead to combined sewage system overflows. Through the assimilation of natural land cover features, green roofs restore the evapotranspirative (ET) component of the hydrologic cycle (Kramer and Boyer, 1995).

It has been suggested that most of the stormwater retention for a green roof is a function of the growing medium (VanWoert et al. 2005). The lightweight media used are designed to retain as much as 50% water by volume (FLL, 2002), so a 4" roof in theory could retain a maximum of 2" of precipitation. In practice, this is seldom the case. Event frequency, environmental conditions between events and tightly held matric water in the media reduce the holding potential. For a green roof located in Pennsylvania with 4" of growing media, approximately 0.5 to 1.25" of rainfall was retained for the majority of summer storms (Denardo et al., 2005). Media components contribute to storage capacity in different ways. In a summary of test results from the Penn State Agricultural Analytical Testing Laboratory, the average water holding capacity for 39 multi-course green roof media samples (standard extensive roof media test) was 46.1% with a low of 14.7% and high of 65.2% (Berghage, 2007). Although water storage capacity obviously affects retention for individual storms, it has surprisingly little effect on total annual retention (Jarrett et al., 2006). Using a model based on evapotranspiration data and stormwater records, Jarrett, et al., 2006 reported a minimal increase in annual retention as water storage capacity was increased from 40 to 79mm. In fact, even with only 3mm of storage, more than 30% of the annual precipitation was predicted to be retained for a central Pennsylvania green roof.

Although the majority of the water retention capacity of a green roof is contributed by the growing medium, plants also store water. The plants most commonly used on extensive green roofs are low growing succulents such as sedum, delosperma, and sempervivum (Snodgrass and Snodgrass, 2006). These succulent plants can store considerable water in their tissues. A mature population of *Sedum spurium* can weigh 1g/cm2, of which 80-90% can be water. As with the soil storage, only a portion of this water is available for atmospheric exchange. Many of these succulent plants are well adapted to living in drought and have a variety of strategies to reduce water loss including lignified, waxy tissues and crassulacean acid metabolism, where stomata can remain closed during the day to reduce water loss and photosynthetic gas exchange can occur at night (Larcher, 1995). Sedums can live for weeks or months without rain (Snodgrass and Snodgrass, 2006). This ability to minimize water loss during drought and remain viable even at low water content levels makes the concept of permanent wilting point difficult to define. Additionally, quantifying transpiration rates for these species can be complicated due to their adaptive nature.

The biggest contribution of plants to green roof water retention is most likely through the influence of evapotranspiration on water storage. Plants use soil moisture both for growth and metabolism, and as a cooling system. Water is extracted from the soil by the root system, moves through the vascular system and exits through pores in the tissues called stomates (Kramer and Boyer, 1995). The driving force for this movement of water is the vapor pressure differential between the water saturated plant tissue and the relatively drier external air. The rate of water use is thus a function of the open surface area of the stomata and the vapor pressure of the surrounding air. Plant architecture therefore plays a large role in potential evapotranspiration and the ability of a plant community to use media water and recharge the media storage potential. Plants with large exposed surfaces and a high density of stomata have the potential to use far more water than plants with a high tissue volume to surface area ratio and few stomata. Low growing species with densely packed foliage present less exposed surface and hence lose less water. However, research studies of green roof plant water usage have shown that these plants are in many ways ideally suited for extensive shallow roof systems in the Northeast US (Berghage, 2007).

Green roofs have also been suggested as a means for reducing building energy demand and modulating the urban heat island effect. This is because a green roof acts as a thermal mass, dampening temperature fluctuation, and as an evaporative cooler. Air conditioning is a major factor in summertime electricity consumption and has substantial costs for industrial, commercial and residential users. Additionally, air conditioning causes significant peak demand and peak distribution problems for utilities. Data collected at the Penn State Center for Green Roof Research suggests that green roofs can significantly reduce air conditioning costs to the consumer and most likely reduce the associated peak demand on the utility. This occurs because evapotranspiration cools the roof surface. While the temperature of a conventional roof reached nearly 70° C in State College, PA, for a green roof, the peak was 30° C, several degrees less than the ambient air temperature. The energy balance model for green roofs compared with white roofs suggests that greened roofs have ‘equivalent albedos’ in the range of 0.7-0.85 (Gaffin et al, 2005). Reduced thermal loading results in a cooler interior temperature for the associated building and green roofs in aggregate could reduce ambient temperatures. In an air conditioned building, cooler interior temperatures means less electricity is required for air conditioning. For example, demonstration buildings with green roofs in Rock Springs, PA consumed about 10% less electricity than those with flat black roofs. Total air conditioning savings vary with the season and climate; buildings in areas with higher cooling requirements are likely to have even greater savings.

While the benefits of green roofs in terms of stormwater management and reduced thermal loading have been demonstrated for locations from Portland to Athens, there is a paucity of empirical data specific to the

New York City region. As the impact of green roofs is highly contingent upon environmental conditions, local studies are critical components of city-scale cost benefit analysis. Additionally, there is a decided need for in-situ monitoring of established green roofs to better assess real-world performance. The Gratz Industries Green Roof Research Project was designed to address these issues and investigate the thermal and stormwater function of a green roof in comparison to conventional roofing. The research station was situated at the 10,000 ft^2 Gratz Industries building in Long Island City, New York, which was divided into four quadrants: three vegetated (extensive green roof) and one non-vegetated (black tar roof). The roof quadrants were instrumented to measure vertical temperature gradient, heat flux into the building, and stormwater runoff. A weather station installed on the roof measured relative humidity, air temperature, insolation, wind speed and direction, and precipitation. Formal data collection commenced on October 1, 2006. This report includes results for 12 months of data collected until September 30, 2007. Earth Pledge collaborated with the Pratt Center for Community Development, Balmori Associates, and Allied Construction to build and monitor this project and provide localized data on green roof performance to the New York State Energy Research and Development Authority (NYSERDA).

2. PROJECT DESCRIPTION

The Gratz roof is approximately 10,000 sq. ft. The roof was divided into four quadrants: Quadrants I, II, III, and IV, which are approximately 2500 sq. ft. each (*Figure 1*). Quadrant II is slightly bigger, and Quadrant I is slightly smaller. Quadrant I, II, and III are vegetated. Quadrant IV served as the control for the experiment (conventional roof) and is non-vegetated. A total of three quadrants – vegetated Quadrants II and III, and the non-vegetated roof Quadrant IV – were monitored. The four quadrants are separated by 2 feet high knee-walls. The growing medium in the vegetated quadrants is 2 to 3 inches deep except for in the 10lb/sq. ft. load bearing zones where the depth is limited to an average of 2 inches (according to Greener by Designs and Balmori Associates). The 10lb/sq. ft. zones are indicated in *Figure 1* as areas of low load bearing capacity and comprise less than 1/5 of the total area of each quadrant.

Each of the monitored quadrants was instrumented to measure indoor and outdoor temperatures, heat-flux through the roof, soil moisture (for the green roof), and volume/rate of stormwater runoff. The temperature, heat-flux, and soil moisture sensors were installed at different layers of the roof assembly in the monitored quadrants. The non-vegetated roof consists of a layer of insulation and a waterproofing membrane. Roof assembly in the vegetated quadrants consists of five layers placed over the existing roof in the following order from bottom to top: insulation, water proofing membrane, drainage layer, water retention layer and growing media (*Figure 2)*. A weather station installed on a tripod at the center of the roof collects metrological data. Each quadrant slopes towards a center low point where it is fitted with a roof drain running into a designated plumbing line inside the building. A separate plumbing line along with the knee-wall separating the quadrants ensures that the runoff from each quadrant remains distinct from other runoff and wastewater. To assess runoff from the three monitored quadrants, an electromagnetic flow meter has been installed inside the building at each of the three separate plumbing lines. After the flow is measured, the plumbing lines empty into a single drain that exits the building (see *Annex I: Installation Pictures for Flow meter*). A gooseneck installed in Quadrant I (towards the center of the roof) conveys the inside thermocouple and flow meter wires to the rooftop (see *Annex I: Installation Pictures for Gooseneck*). All sensors are wired into the datalogger mounted on the tripod at the weather station (*Figure 1, Annex I: Installation Pictures Weather Station*) and data collection takes place remotely, although it can be performed on-site with a laptop connected to the datalogger.

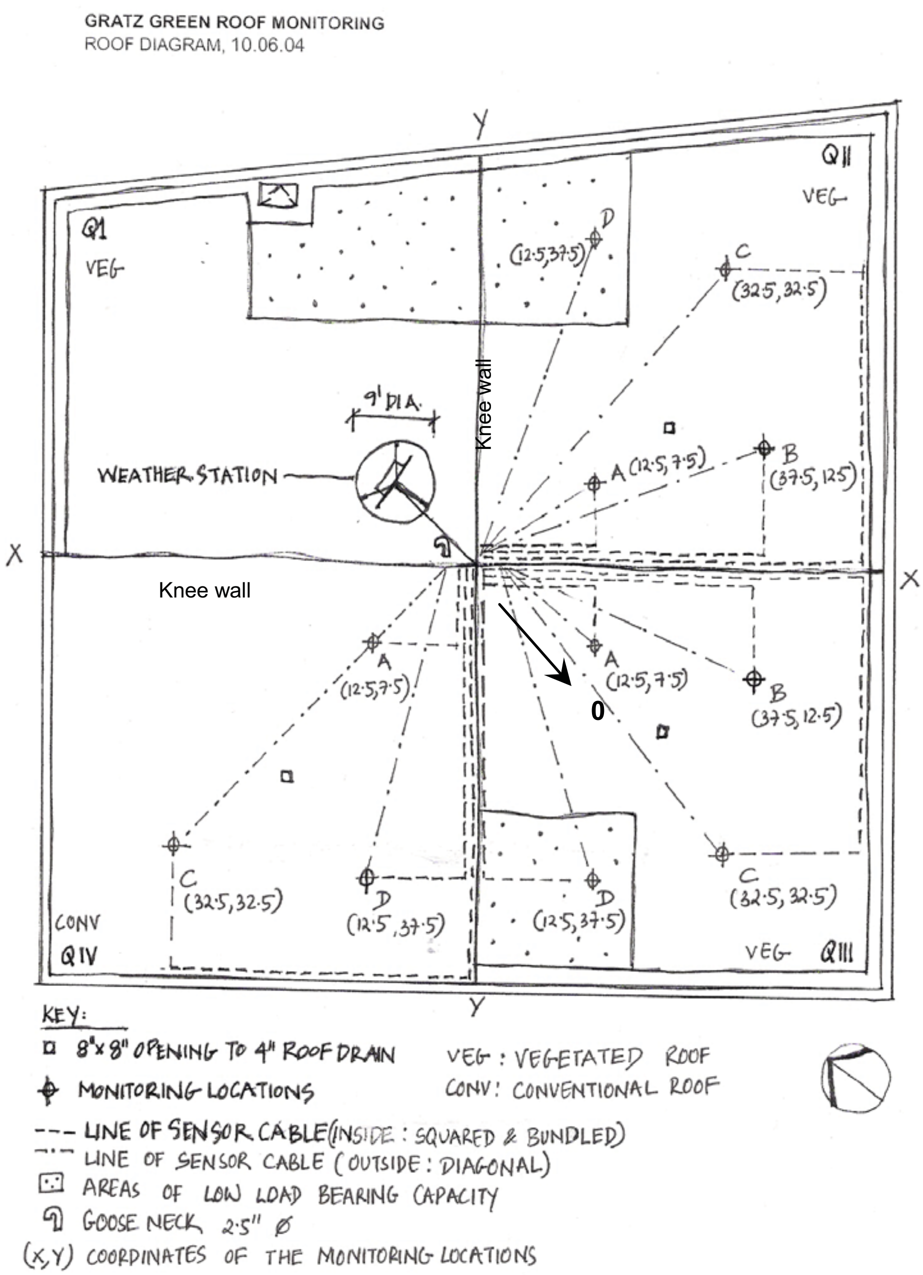

Figure 1: Roof plan and horizontal monitoring locations. The numbers are absolute values, in feet, from the origin '0'.

3. METHODOLOGY

Thermocouples and heat flux sensors were installed in each of the three monitored quadrants. Thermocouples measure temperature while heat flux sensors measure the net vertical direction and rate of energy transferred at a given surface. Water content reflectometers were installed at the vegetated quadrants to record the moisture level of the growing medium. Flow meters at the site measured stormwater runoff in terms of gallons per 15 minutes, as well as average and maximum gallons per minute (gpm) flow rates over each 15 minute sampling period. This data allows for comparison of overall runoff volume, peak discharge rates, and timing of runoff initiation and peak discharge.

The temperature gradient measured by the vertical array of thermocouples in the roof assembly provides insight into the capacity of a green roof to modulate the building's indoor temperature with respect to the outdoor temperature, and how it compares to a non-vegetated roof. The difference in outdoor ambient air temperature above the vegetated roof and non-vegetated roof quadrants will allow us to quantify the impact of a vegetated roof on its surrounding microclimate.

3.1 Experimental Setup

3.1.1 Temperature

Quadrants II and III (the two monitored vegetated quadrants) have four temperature monitoring locations: A, B, C and D (*Figures 1, 3*). At each monitoring location, four thermocouples were arranged in a vertical array through different layers in the green roof system (*Figure 2*):

a) at the ceiling inside the building (TI);
b) on the roof membrane outside the building (TM);
c) on top of the growing media (TT); and
d) in the ambient air 6" above the vegetation or the conventional roof surface (TA)

Quadrant IV (monitored non-vegetated quadrant) has three temperature monitoring locations: A, C and D and a vertical array of three thermocouples: TI, TM and TA at each location. The A, B, C and D locations are chosen to get representative measurements in each quadrant and to avoid the metal beams at the ceiling, which can potentially affect the temperature measurements of the indoor thermocouples - TI. There are a total of 41 thermocouples installed at the three monitored quadrants (Quadrants II, III and IV) (*Figures 1, 3)*. Of the 41 thermocouples, 11 are at the ceiling inside the building, and 30 are on the rooftop outside the building. In terms of separation among quadrants, the non-vegetated quadrant has nine of the thermocouples and the two monitored vegetated quadrants have the remaining 32. The ambient thermocouples were sheltered with radiation shields to protect the sensors from direct solar radiation. The TT thermocouples at the vegetated roof quadrants' surface were lightly covered with approximately 0.5

inches of growing media for protection from direct solar radiation. The TM thermocouples at the conventional quadrant were each covered with a patch of the black roofing material.

The TI thermocouples were installed on March 28, 2006; TM thermocouples were installed on May 2, 2006; and TT thermocouples were installed on June 1, 2006. The TA thermocouples along with the radiation shields were installed on August 7, 2006.

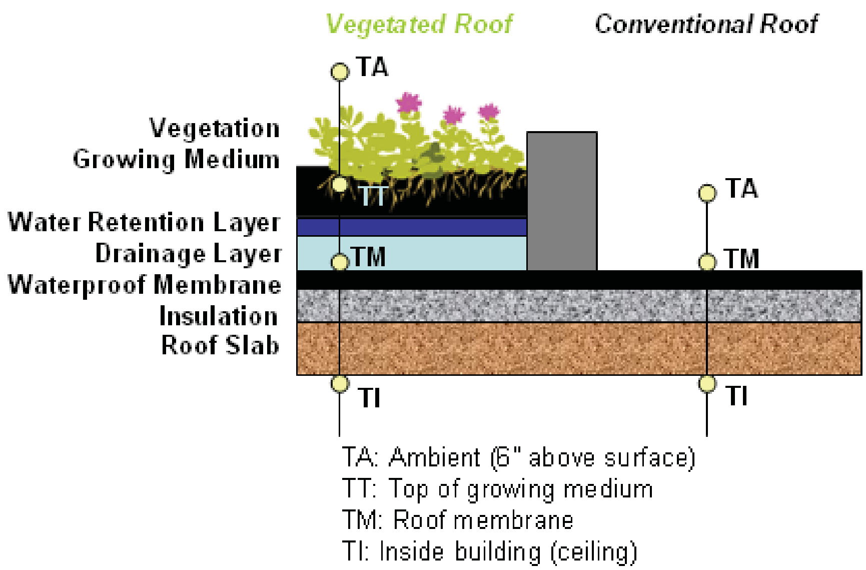

Figure 2: Vertical placement of thermocouples.

One heat flow sensor was installed in each of the three monitored quadrants (Quadrants II, III and IV), at location E, on top of the roof membrane (*Figures 3*). They were installed about 2-3 ft. away from the drain to avoid trampling due to any potential maintenance activity in the drain area. The heat flow sensor at the non-vegetated quadrant was covered with a patch of the roofing material, as was also done for the conventional membrane thermocouples, so as not to directly expose it to the ambient conditions and to more closely follow the placement in the vegetated quadrants.

Heat flow sensors were installed at Quadrants II and III on May 2, 2006, and at Quadrant IV on September 28, 2006.

A water-content reflectometer is installed within each of the two vegetated quadrants (Quadrants II and III) at location E, 1-2 inches from the top of the growing media and about 2-3 ft. away from the drain. (*Figures 1, 3)*

The water content reflectometers were installed on June 1, 2006.

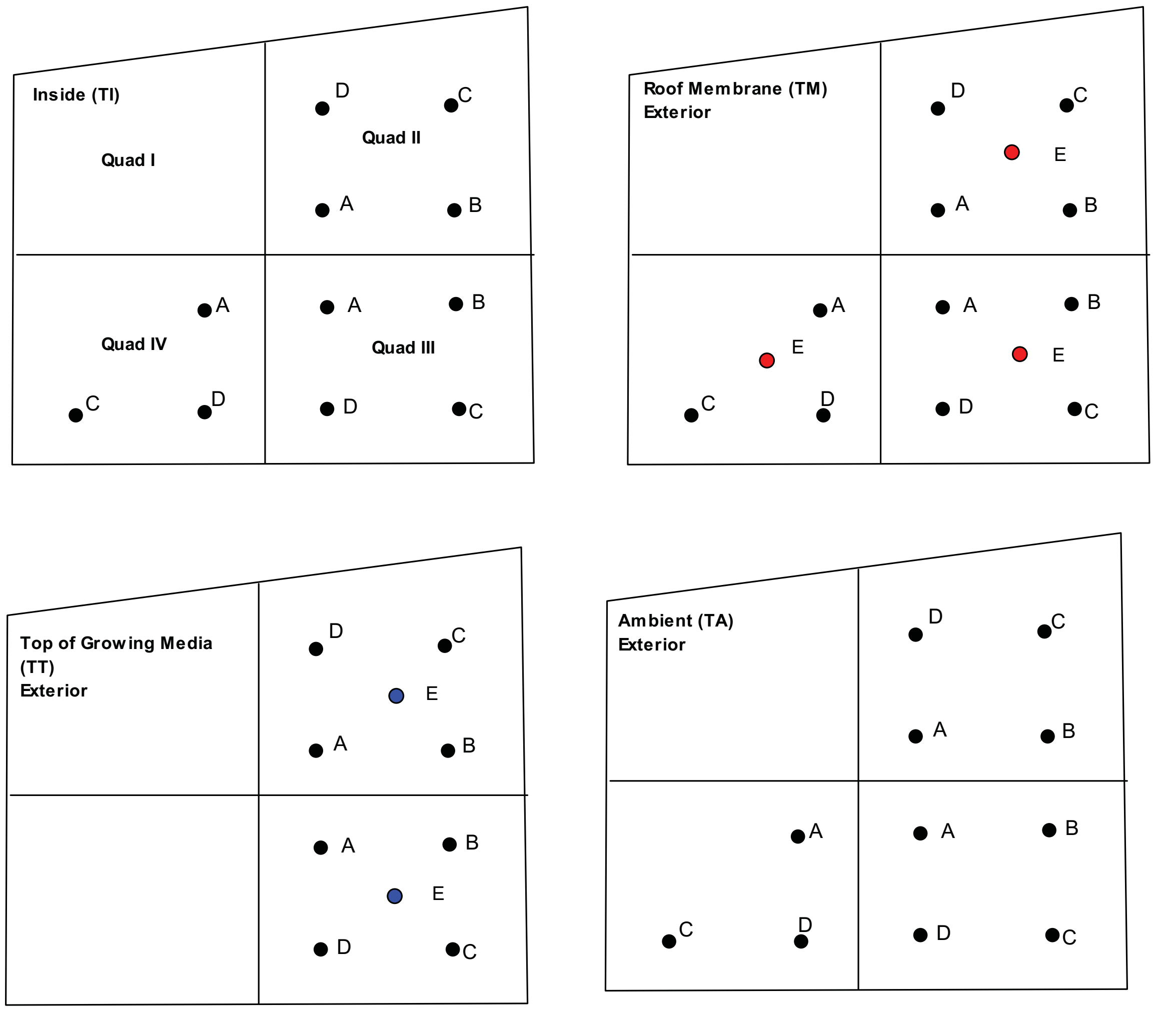

Figure 3: Sensor placement. Layout of thermocouples (●): exterior, interior and vertical locations in the quadrants (A, B, C, & D). E is the location for heat flow sensors (● - on the roof membrane) and in the vegetated quadrants, the water content reflectometers (● - in the growing media).

3.1.2 Stormwater

Three electromagnetic flow meters were installed into the plumbing lines in the building beneath the three monitored quadrants (II, III and IV). The plumbing for each quadrant consists of a 4" roof drain that splits into two other 4" cast iron pipes, one to the flow meter and the other serving as overflow piping (see *Annex I – Installation Pictures for Flow meter*). The 4" pipelines were connected to the flow meters with 1" copper pipe to accommodate the smaller diameter of the flow meter. A sediment trap in the piping preceding each flow meter prevents clogs and provides an outlet for cleaning the system. The electromagnetic flow meter is capable of handling flow rates of 10 to 200 L/min. The flow meter and plumbing layout takes locally relevant minimum and maximum precipitation rates, collection area, and creation of sufficient head pressure (for precise measurements) into consideration. The 0.01 to 2.0 in/hr of rainfall is estimated to generate storm runoff of 0.97 to 200 L/min from a non-vegetated roof and 0.5 to

100 L/min from green roofs. The flow meters will monitor the time and rate at which the rainwater enters the drain during a storm event. For example, on a non-vegetated roof we can assume that rain will immediately begin to flow towards the drain. However, the green roof will delay the flow of stormwater to the drain, and will retain a certain amount of water in the roof matrix itself. Using the rainfall and runoff data, we will be able to determine the percentage of stormwater retained.

The flow meters were installed in April 17, 2006 and data collection commenced with the green roof and weather station installation in August 2006. Unfortunately, problems with the runoff collection systems compromised the flow meter data. Data from the vegetated quadrant III was viable for the period October 2006 to September 2007, but due to pipe obstructions, the vegetated quadrant II and conventional flow meter data is limited to mid-March 2007 to September 2007.

3.1.3 Weather Station

A weather station was installed on a tripod secured to the knee walls at the center of the roof (*Figure 1*). The three legs of the tripod sit on top of the three knee-walls facing east. The weather station contains a temperature/relative humidity probe, pyranometer, precipitation gauge, and an anemometer, which collected data on air temperature/relative humidity, solar radiation, rainfall, and wind speed/direction, respectively. The weather station provides the baseline data as a point of comparison for the thermocouples, heat flux sensors and flow meter readings. The weather station also contains a modem for remote data collection. A line sharing switch device (*TELTONE LLS, Model #394-B-01*) was installed at the site to share the Gratz fax line with our modem line. The fax line is set as the primary line in ports 1 and 2 of the switch device, and port 3 is used for our modem (see *Annex II - List of instruments and sensors*).

The weather station was installed on July 18, 2006. The precipitation gauge was dismantled for winter on October 31, 2006, to avoid frost.

3.1.4 Green Roof Plants

Seventeen species of sedums were planted on the vegetated roof quadrants in July 2006 and were irrigated regularly by Greener by Designs, the landscaper. The plant species were *Sedum cauticola 'Lidakense'*, *S. reflexum*, *S. ruprestre Angelina*, *S. spurium 'White Form'*, *S. 'Rose Carpet'*, *S. floriferum*, *S. acre 'Aureum'*, *S. sexangulare*, *S. seiboldii*, *S. spurium fuldaglut*, *S. hybridum 'Immergrumchen'*, *S. 'Bertram Anderson'*, *S. spurium 'John Creech'*, *S. spurium 'Voodoo'*, *S. spurium Roseum, Orostachys boehmeri*, and *Delosperma nubigenum*.

4. HEAT TRANSFER MODELING

A preliminary heat transfer analysis was conducted of the roof system on the Gratz Industries building in Long Island City, New York, for the Earth Pledge Green Roof Initiative. Four different roof configurations were modeled and analyzed: the existing roof as a reference, the existing roof with a black surface plus an additional 2 inches of rigid insulation, a 4 inch extensive vegetated roof (ExtGR) and an 8 inch intensive vegetated roof (IntGR).

Physical Description

- The building is mostly shaded in the afternoon by elevated bridge onramps.
- Building walls are 16" cinderblock, no insulation. The SW wall (108'- 2") has galvanized steel sheet metal- no exposed brick- from the ground to the roof (no windows).
- Top windows surround the entire lengths of the other three walls. The tops of the windows are approximately 20" below the roof. They are 80" high, and are made of single panes. (Each pane is 16"H x 20"W.) There are three sets of industrial fans, approximately 40 inches each, in place of windows – two on the NW side and one on the SE side. All fans blow out.
- Overall, the building is not air conditioned. However, there is an office area that was constructed that is air conditioned. Above the one story office, there is an open storage loft.
- A standard service door and a 13' garage door are located on the NE and NW sides.
- The building is approximately 20' high.
- There is little mechanical equipment on the roof. There are several existing chimneys and vents.
- In verbal communication with the contractor, the existing roofing cross section is 2-4" gypsum, asbestos felt in hot tar, and ¾" bitumen modified asphaltic membrane roofing system. The top is smooth silver.
- Building is occupied from 7 am to 6 pm, Monday to Friday by 30 people.
- Exhaust fans are operated during the summer "as needed".
- The black insulated roof design and the green roof systems each have additional R-14 insulation.
- The green roof systems have an additional membrane and a 1.5 inch geo-textile drain layer.

Assumptions in addition to these specifications

- ExtGR contains 4 inches growth media and various sedums.
- IntGR contains 8 inches growth media and various low shrubs and wildflowers.
- Growing season (sedum fully green) is from April through October.
- Interior temperature is uniform throughout - air is fully mixed.
- Exhaust fans replace interior air at a total rate of 10,000 cfm at a total power rate of 6 kW.
- Exhaust fans are turned on when interior temperature is over 71 deg. F, regardless of occupancy.

- Total heat generation from equipment and lights during occupancy is 12 kW.
- Thermostat is set for heating at 64 deg. while unoccupied and 68 deg. while occupied.
- The office is kept at 73 deg. during the summer.
- Heating efficiency = 0.8.
- Air-conditioning coefficient of performance of 2.7.
- 20% cloud cover year-round.

4.1 Analysis Procedure

The analysis of each configuration was performed by determining the internal and other non-roof thermal loads from a DOE-2 analysis of the reference case. The non-roof loads were then entered in the SHADE model where changes in the roof system configurations were isolated, providing a direct comparison between energy results for the various roof cases. The model uses an iterative process to calculate heat transfer data for an average representative day of a typical month. An energy balance is performed at each of the roof layers shown in Figure 1. The climate data was for an average day of a typical month derived from the TMY2 data base produced by the National Renewable Energy Laboratory (NREL) with solar radiation uncertainties approximately 10% and weather uncertainties consistent with those used by the National Weather Service. Calculation errors were within 2%.

Inputs for the preliminary study were theoretical and typical. Fan energy, air conditioning energy, and heating fuel consumption results were acquired and reported from the eQUEST DOE-2 whole building energy analysis computer program. All results were acquired and reported from proprietary roof system heat transfer software developed by SHADE Consulting, LLC.

Note: Since the building is not air-conditioned except for the office, and no specific performance information was available regarding the flow rates, power consumption, or operating schedules of the exhaust fans, broad assumptions had to be made regarding the amount of heat being removed by the fans. This study should only be used for reference purposes.

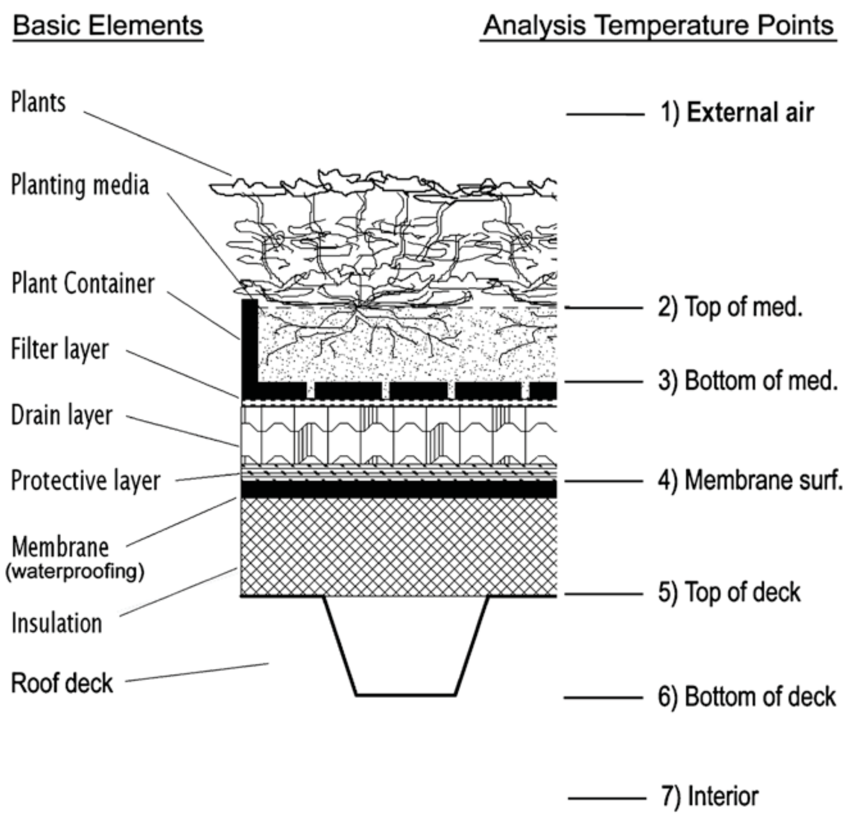

Figure 4: Green Roof Layer Diagram

4.2 Results

4.2.1 Temperature Maps

Temperature profile maps for July are shown in Figures 5 to 8. All temperatures are reported in degrees Fahrenheit. The following should be noted regarding these graphs:

- Minimum and maximum indoor temperatures for the manufacturing area were:
  - Reference roof: min = 75^{O}, max = 86^{O}
  - Ins. black roof: min = 75^{O}, max = 85^{O}
  - ExtGR: min = 75^{O}, max = 85^{O}
  - IntGR: min = 74^{O}, max = 85^{O}

  Since the exhaust fans run nearly constantly during peak summer conditions and the building has reasonable cross ventilation, the daytime indoor temperature remains close to the outdoor temperature for all cases.

- Minimum and maximum membrane temperatures were:
  - Reference Roof: min = 69^{O}, max = 103^{O}
  - Insulated Black Roof: min = 64^{O}, max = 132^{O}
  - ExtGR: min = 74^{O}, max = 86^{O}
  - IntGR: min = 72^{O}, max = 83^{O}
- Both green roofs dramatically dampened the daily membrane temperature fluctuations.
- The IntGR was able to absorb more heat than the ExtGR but the effect was dampened by the added insulation.
- Night-time membrane temperatures for the Black Insulated Roof were ~ 6 degrees lower than the outside air temperature due to the high long-wave emissivity of the black surface. This was helped by the indoor heat below the insulation being removed by the fans.
- Night-time rooftop temperatures for the green roofs are also high because of the thermal mass of the planting medium and intermediate insulation.

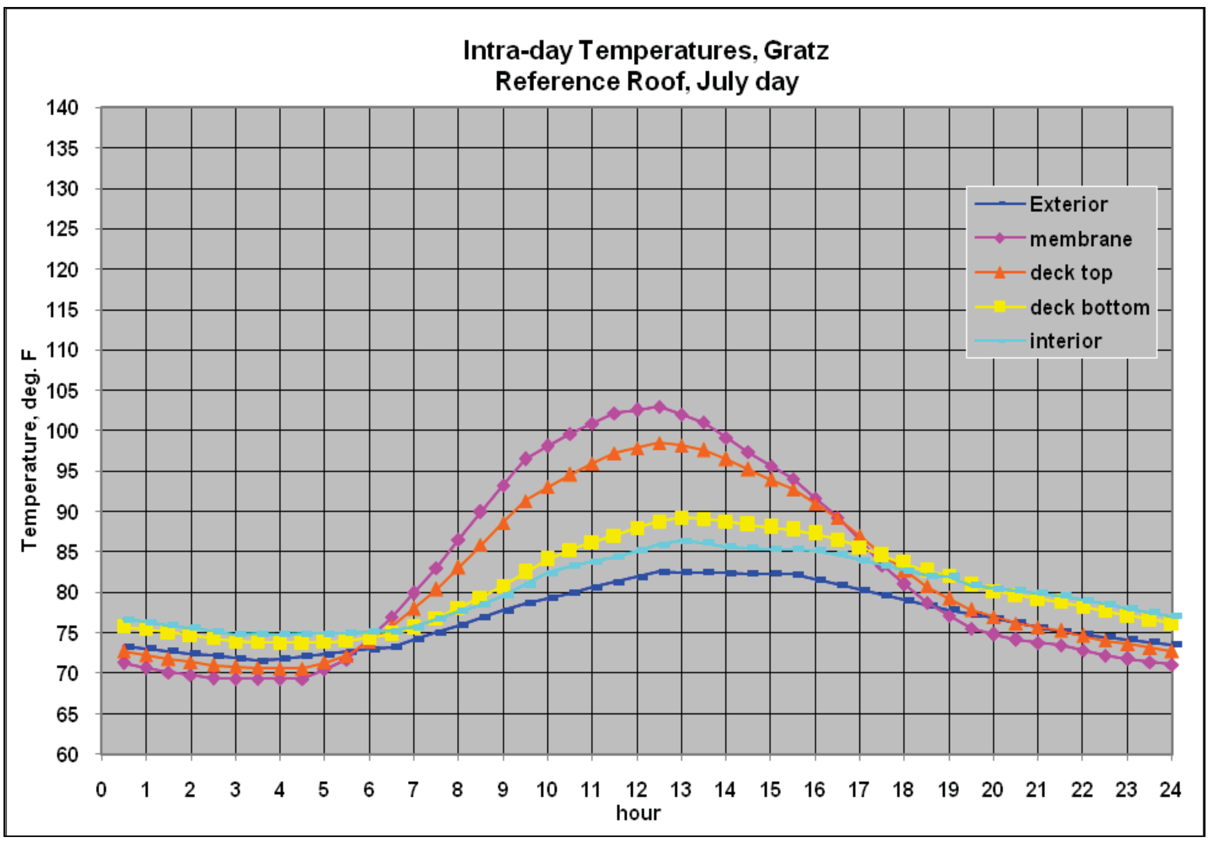

Figure 5: Intra-day Temperatures, Gratz Reference Roof (July)

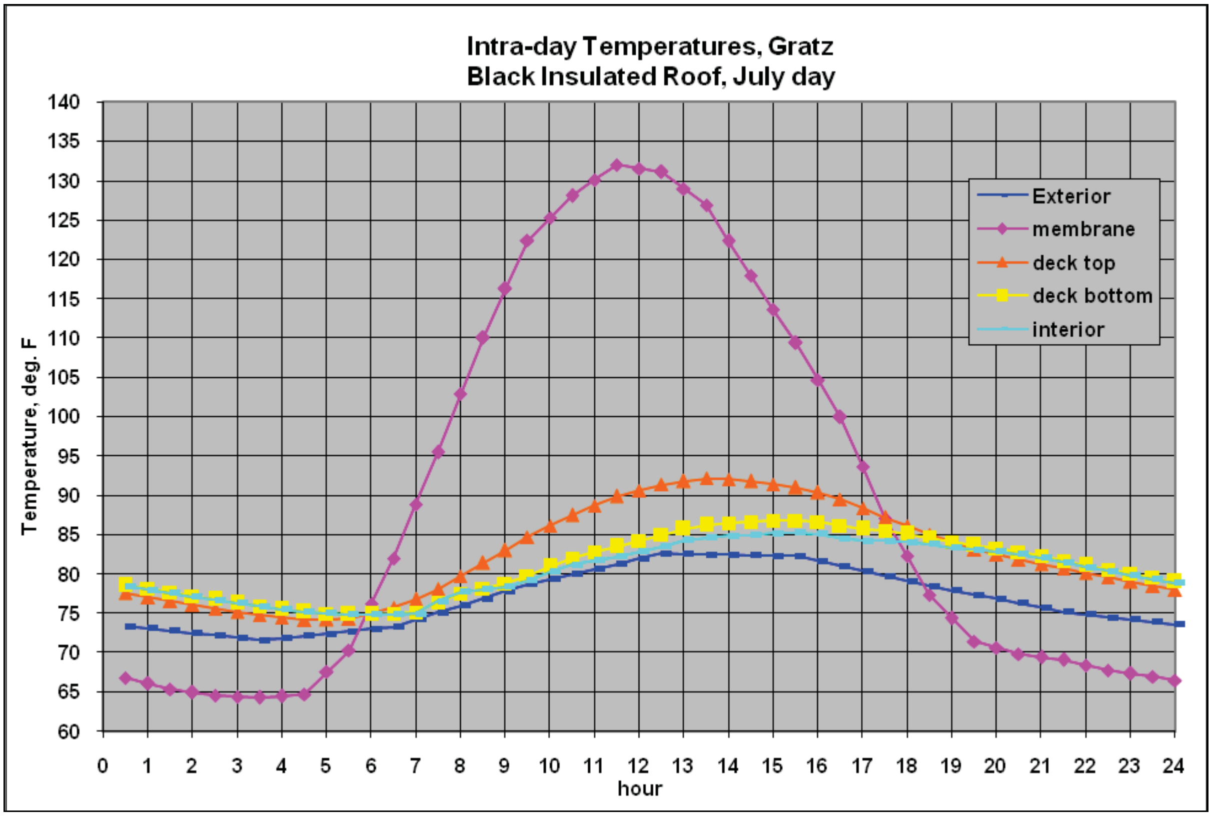

Figure 6: Intra-dayTemperatures, Gratz Black Insulated Roof

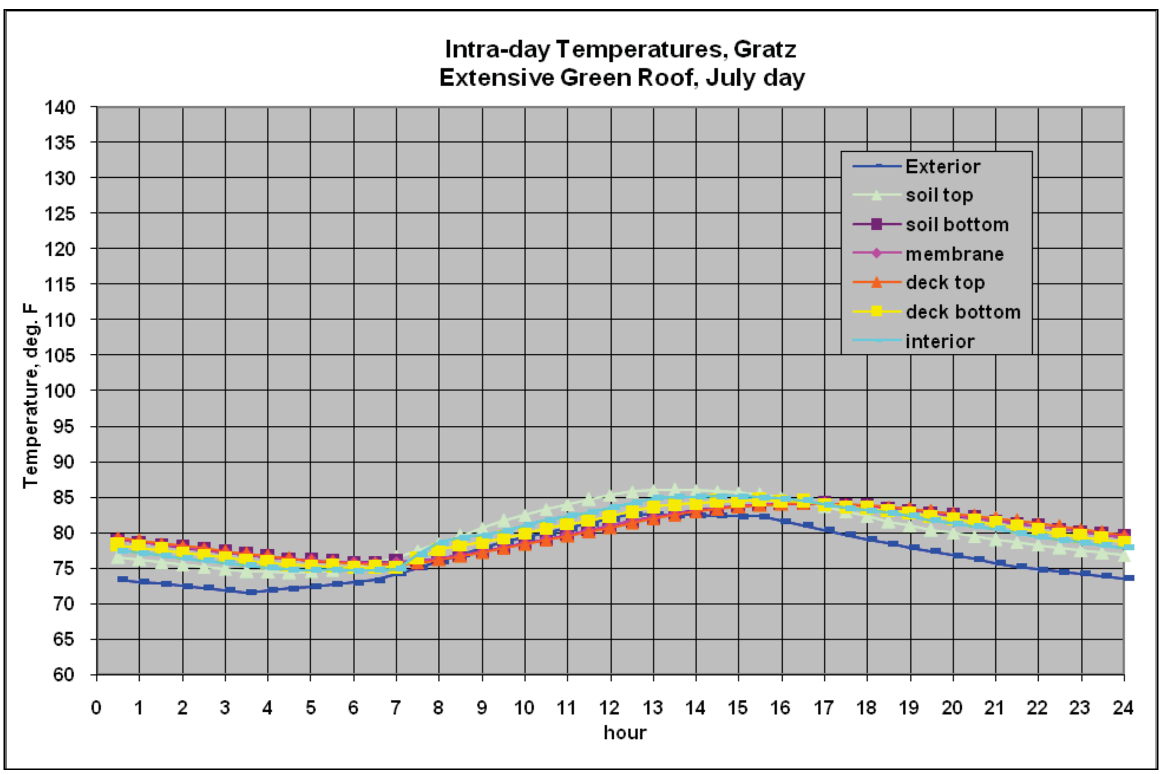

Figure 7: Intra-day Temperatures, Gratz Extensive Roof (July)

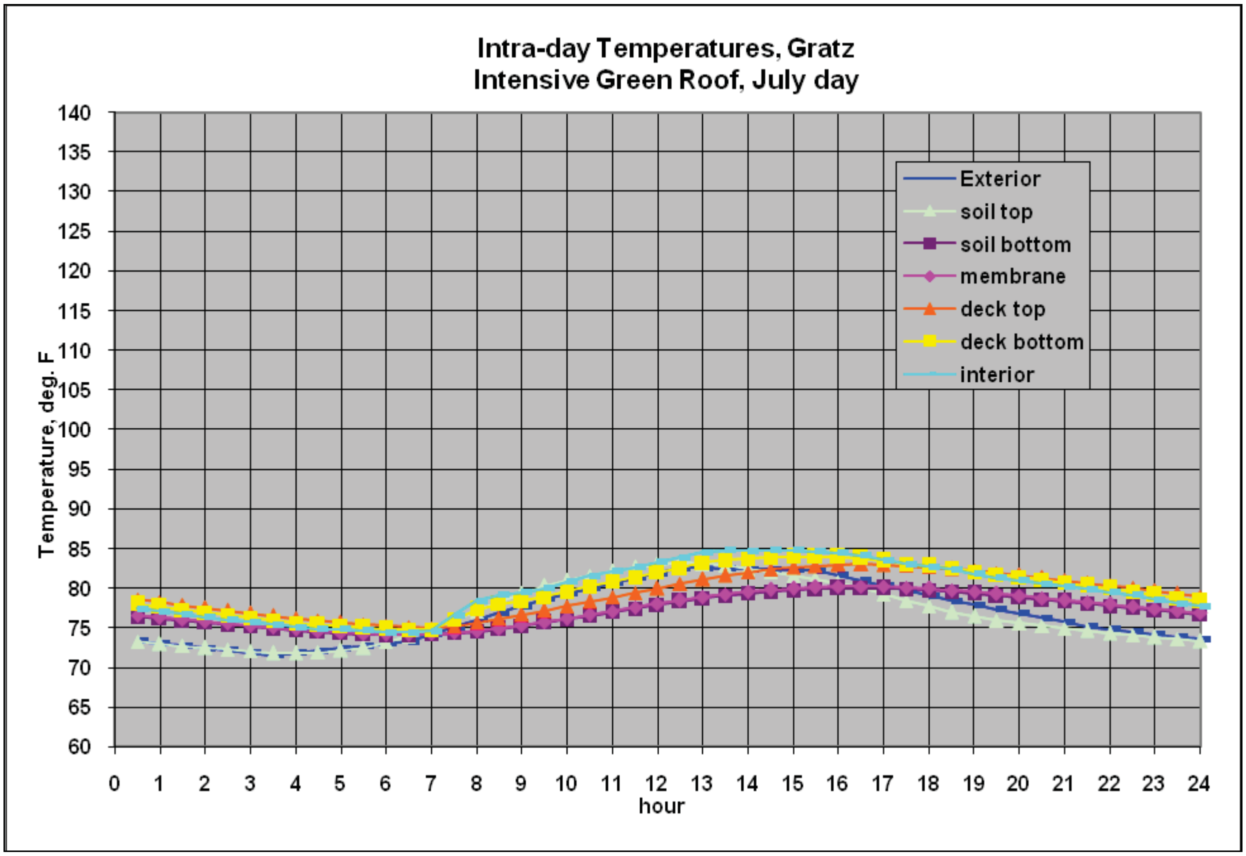

Figure 8: Intra-day Temperatures, Gratz Intensive Roof (July)

Temperature profile maps for January are shown in Figures 9-12. The following should be noted regarding these graphs:

- Minimum and maximum indoor temperatures for the manufacturing area were:
  - Reference roof: min = 75^{O}, max = 86^{O}
  - Ins. black roof: min = 75^{O}, max = 85^{O}
  - ExtGR: min = 75^{O}, max = 85^{O}
  - IntGR: min = 74^{O}, max = 85^{O}

  Since the exhaust fans run nearly constantly during peak summer conditions and the building has reasonable cross ventilation, the daytime indoor temperature remains close to the outdoor temperature for all cases.

- Minimum and maximum membrane temperatures were:
  - Reference Roof: min = 69^{O}, max = 103^{O}
  - Insulated Black Roof: min = 64^{O}, max = 132^{O}
  - ExtGR: min = 74^{O}, max = 86^{O}
  - IntGR: min = 72^{O}, max = 83^{O}

- Both green roofs dramatically dampened the daily membrane temperature fluctuations.
- The IntGR was able to absorb more heat than the ExtGR but the effect was dampened by the added insulation.
- Night-time membrane temperatures for the Black Insulated Roof were ~ 6 degrees lower than the outside air temperature due to the high long-wave emissivity of the black surface. This was helped by the indoor heat below the insulation being removed by the fans.
- Night-time rooftop temperatures for the green roofs are also high because of the thermal mass of the planting medium and intermediate insulation.

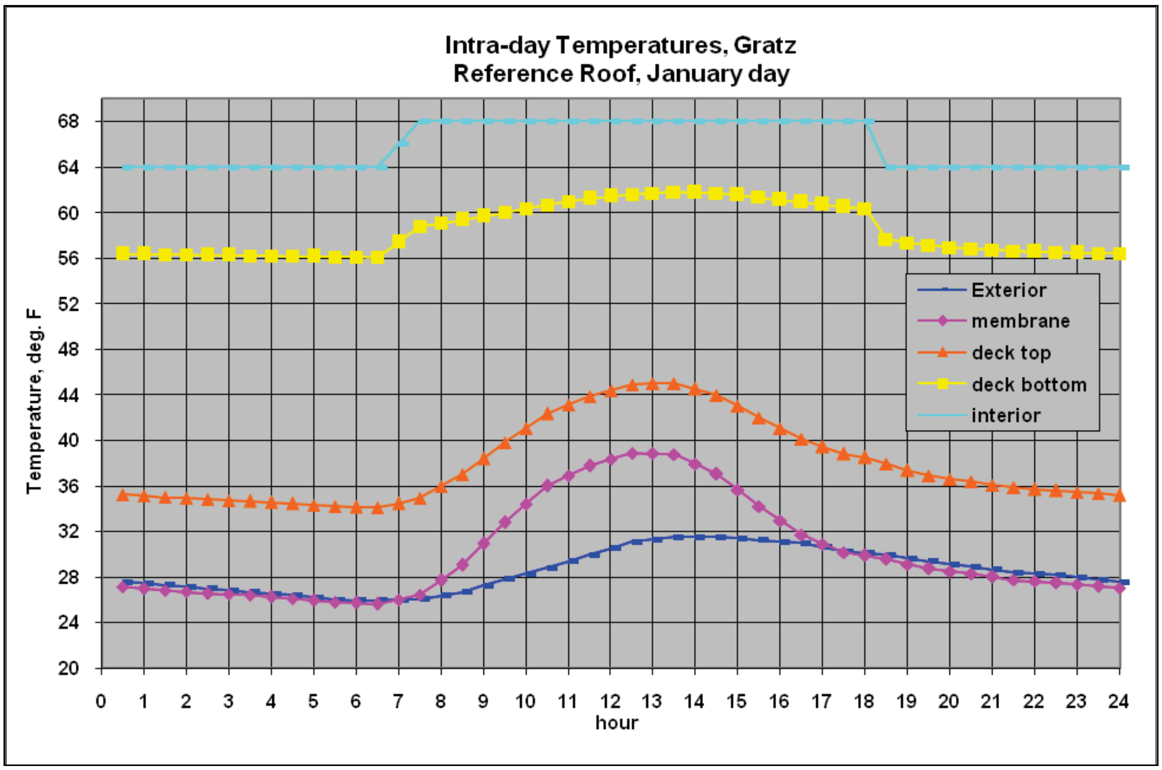

Figure 9: Intra-day Temperatures, Gratz Reference Roof (January)

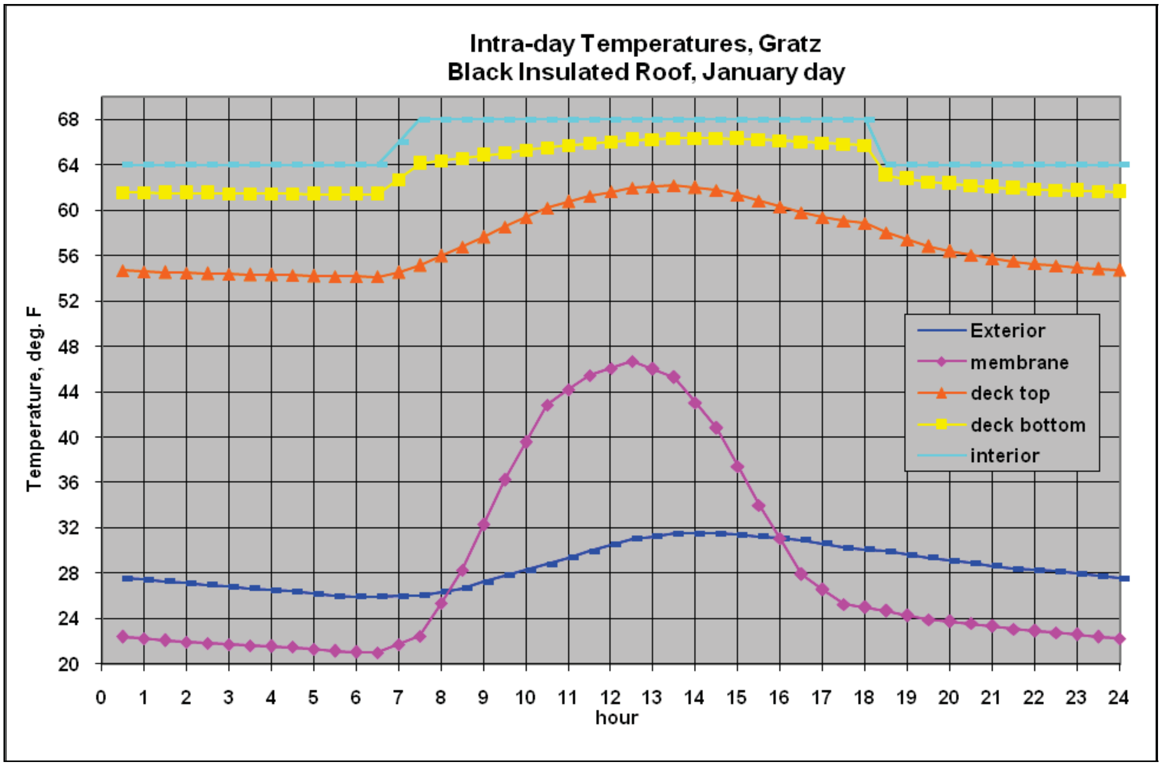

Figure 10: Intra-day Temperatures, Gratz Black Insulated Roof (January)

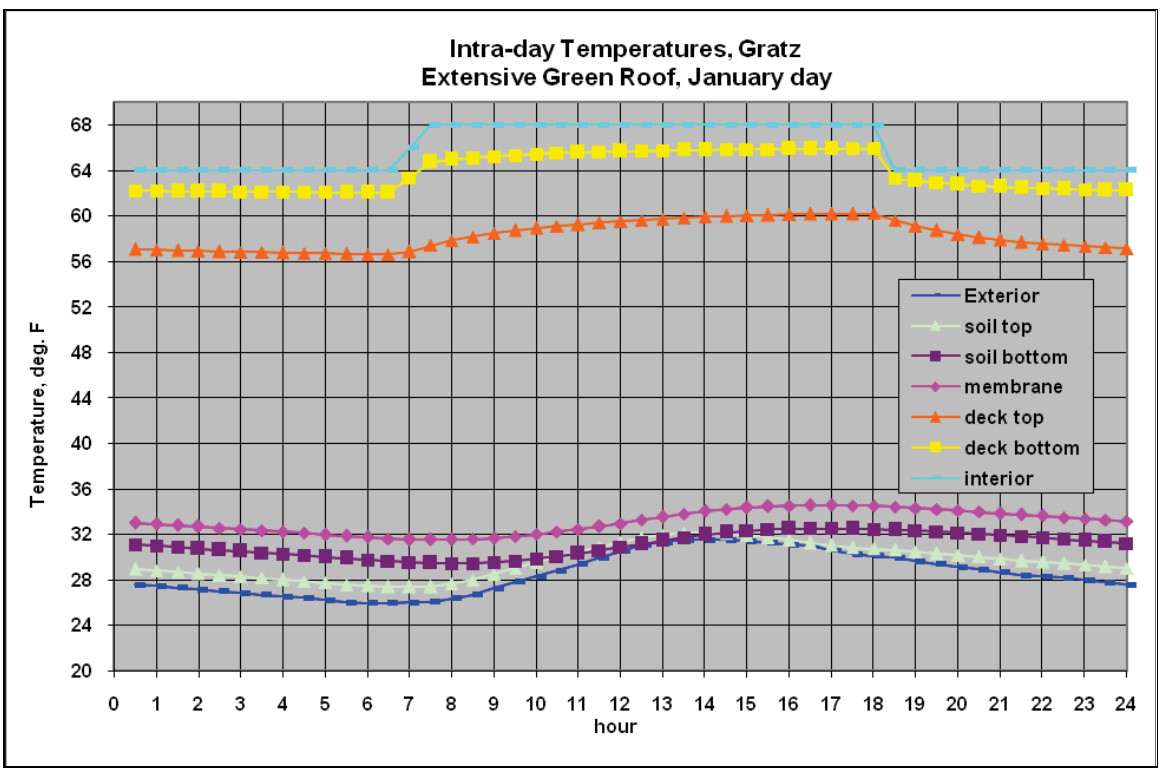

Figure 11: Intra-day Temperatures, Gratz Extensive Roof (January)

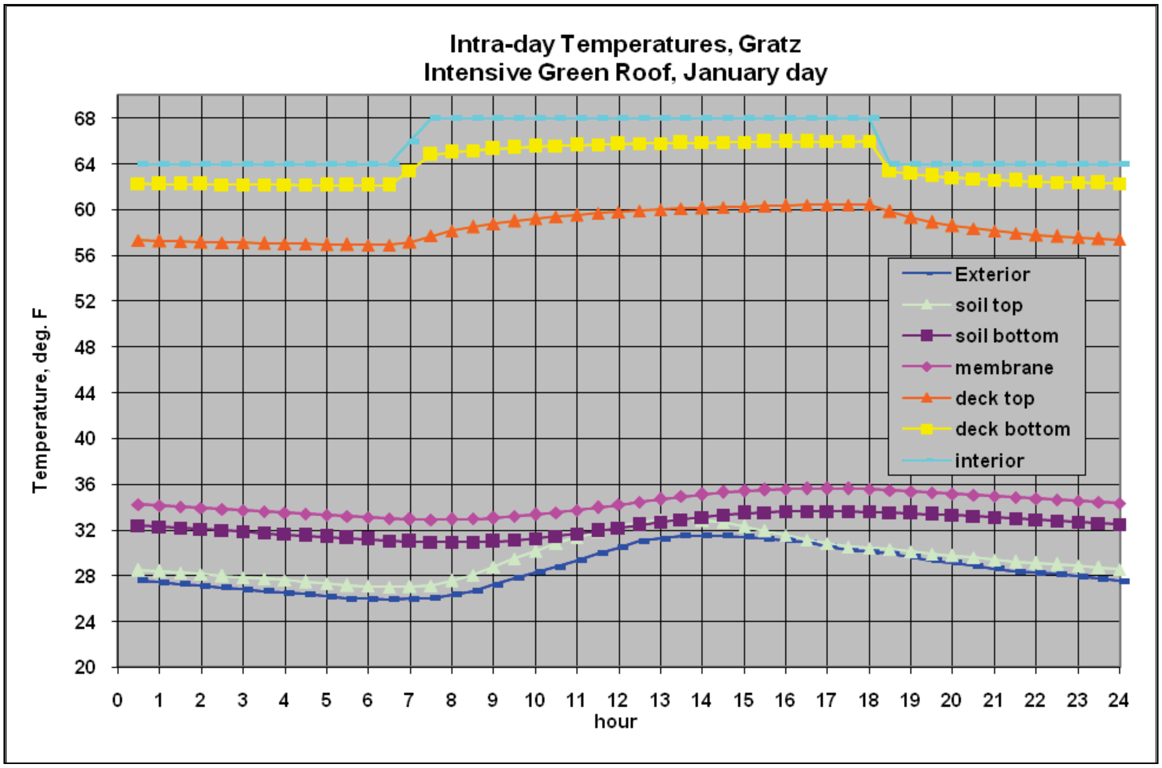

Figure 12: Intra-day Temperatures, Gratz Intensive Roof (January)

4.1.2 Heat Transfer Rates

The following is a comparison of the intra-day heat transfer rates in kW for each roof system. The rates are through the ceiling into the interior (from the deck bottom to the interior).

Heat transfer rates for an average July day are shown in Figure 13. The following points should be noted from this graph:

- The Reference roof transfer rate increases in the morning before occupation as the outdoor air warms and the sun rises but no heat has been generated indoors yet. It continues to increase because the interior heat generation is less than the solar heat gain. That trend reverses as the afternoon sun angle increases and shading from the elevated highway increases.
- The green roof transfer rates decrease in the morning as they absorb the solar heat on one side of the insulation and the interior heat on the other. The transfer rate gradually increases throughout the day as the thermal mass of the roof system becomes less capable of absorbing heat.
- The two green roofs have nearly identical heat transfer characteristics because the radiative and convective properties are very similar. The conductivities are also very similar because of the moisture content of the media and the fact that they both have the same integrated insulation on a roof with no other existing insulation.

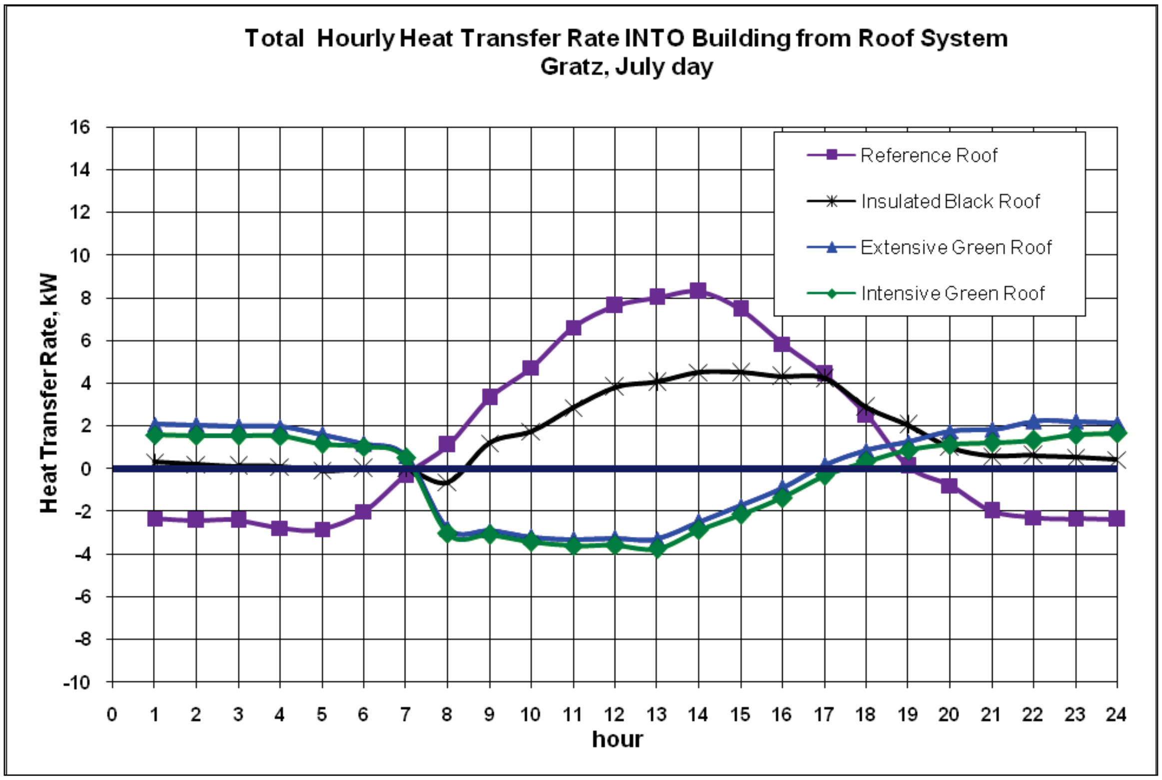

Figure 13: Total Hourly Heat Transfer Rate Into Building, Gratz (July)

Heat transfer rates for an average January day are shown in Figure 14. The following points should be noted from this graph:

- The additional rigid insulation dramatically reduced heat loss.
- The additional thermal mass of the green roofs provided slightly better performance over the Black Insulated roof.
- The heat loss increased suddenly in the morning at opening as the roof absorbed the increased heat generation. Likewise, the heat loss decreased suddenly in the evening at closing as the internal heat generation stopped.
- The two green roofs have nearly identical heat transfer characteristics because the radiative and convective properties are very similar. The conductivities are also very similar because of the moisture content of the media and the fact that they both have the same integrated insulation on a roof with no other existing insulation.

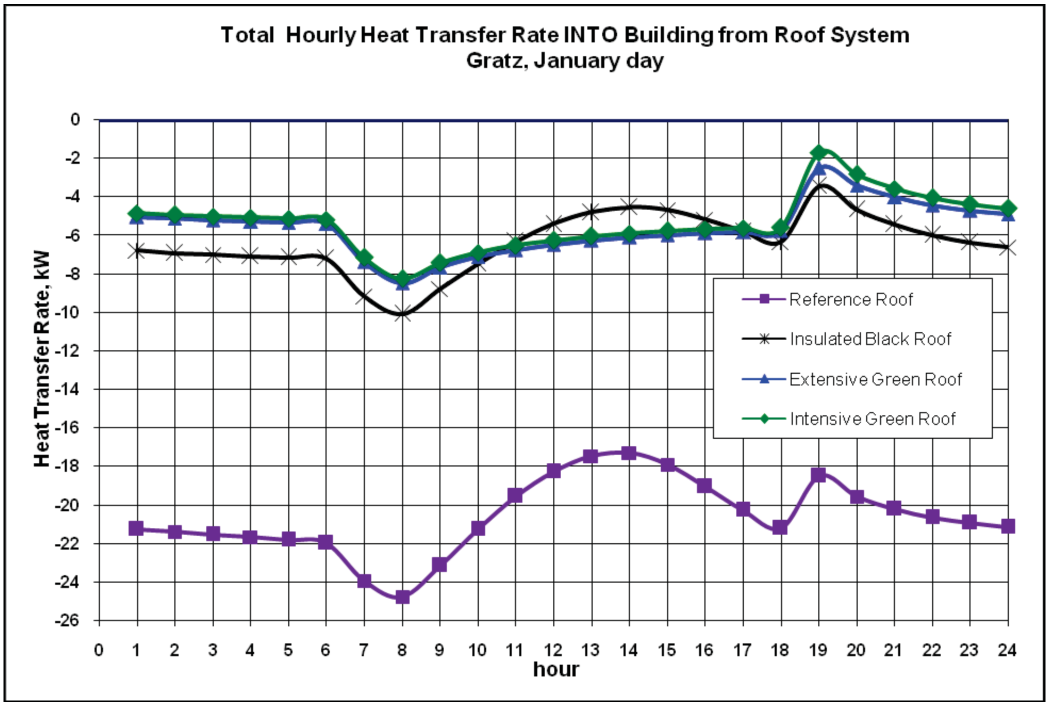

Figure 14: Total Hourly Heat Transfer Rate Into Building, Gratz (January)

4.1.3 Monthly Loads

The total monthly heating and cooling loads for the building are summarized here. Some of the baseline results differ slightly from the DOE-2 analysis for the whole building primarily because of differences in techniques for calculating thermal mass in the roof system . and the SHADE program uses averaged inputs for each month rather than summed daily calculations.

Figure 15 shows a summary of the monthly heat gains through each roof system in kW-hr / month. During the summer, the relative impact of the Green Roof followed the patterns seen in intra-day data.

Figure 16 shows a summary of the monthly electricity consumed by the exhaust fans in kW-hr / month. As noted previously, since the main part of the building is not air conditioned, the exhaust fans run nearly constantly, minimizing the difference between the Reference, Black and Green roofs during peak summer months. A greater difference was seen in May and September when the fans were turned on later in the morning for the Green Roof cases.

Figure 17 shows a summary of the monthly electricity consumed by the office air conditioning. Assuming that some sort of economizing exists (part of mechanical system or manually open windows), the A/C power consumption was typically equal to 11% of the fan power, +/- 1.5%. This is primarily due to the office being exposed to the rest of the building on 3 sides, particularly the ceiling.

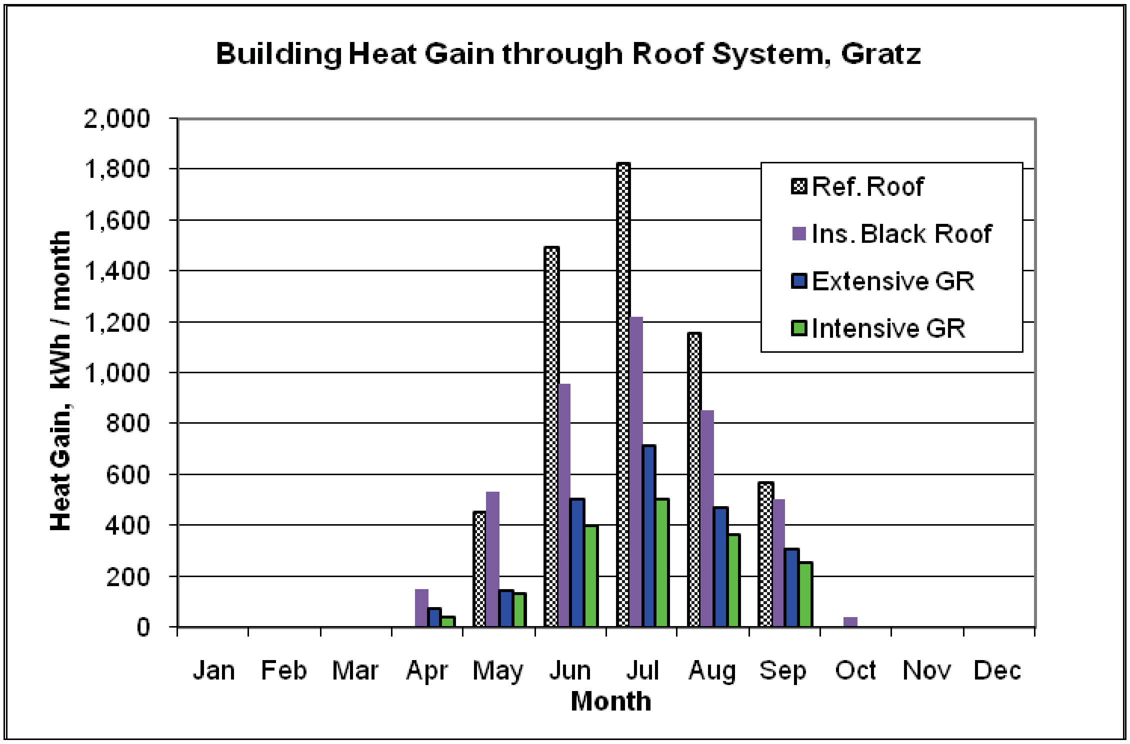

Figure 15: Building Heat Gain, Monthly

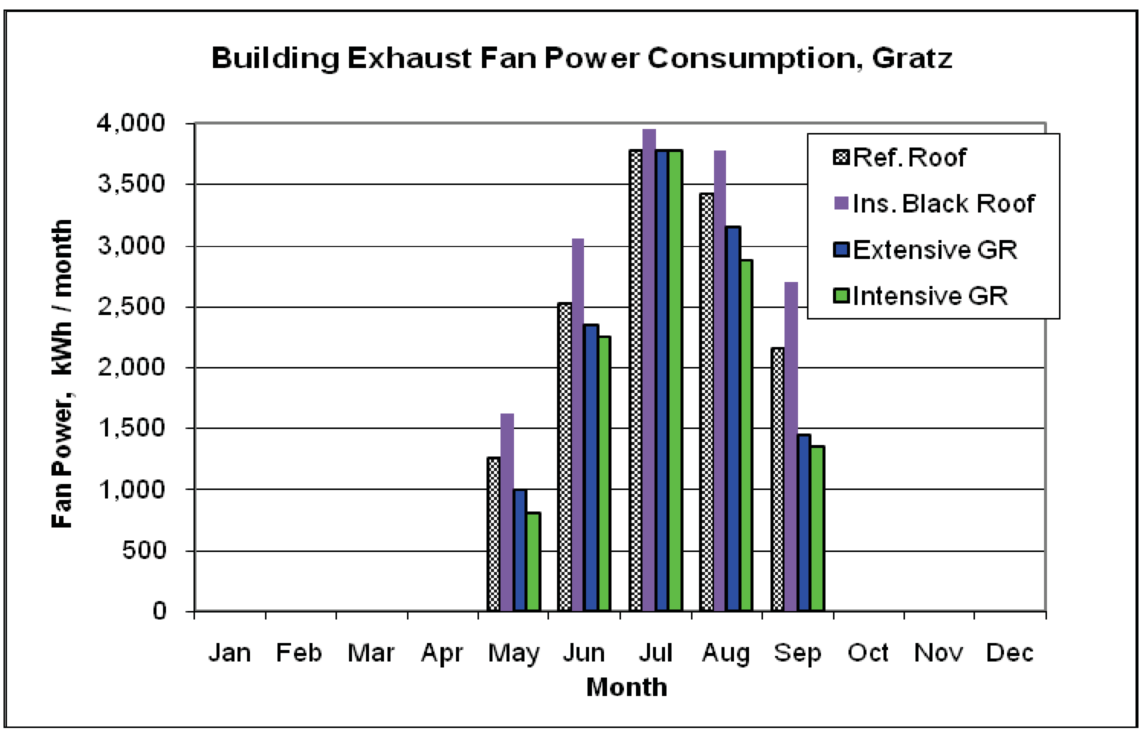

Figure 16: Building Exhaust Fan Power Consumption, Monthly

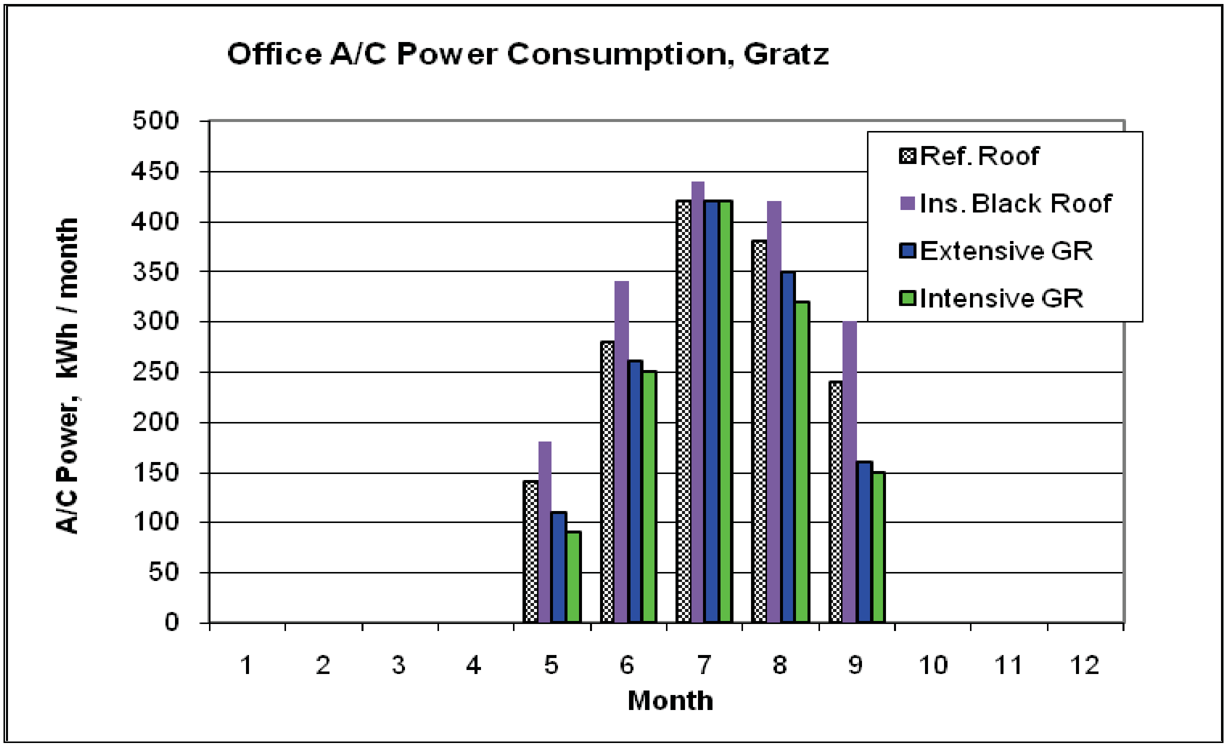

Figure 17: Office A/C Power Consumption, Monthly

Figure 18 is a summary of the monthly heat losses through the roof system. The Black Insulated and Green Roof losses were ~ 60% less than the Reference Roof during the winter because of the increased insulation. The Green Roof heat loss was slightly lower in the winter and slightly higher in the spring-summer than the Black Insulated Roof because of the added thermal mass.

Figure 19 is a summary of the monthly fuel (natural gas) consumed by the heating system for the entire building in kW-hr / month. The overall difference between the roof systems was minimized by the greater impact of heat loss through the windows. During the spring and fall, the green roof systems show an advantage by helping to dampen the wider temperature swings between warm days and cold nights - they lose less heat at night while staying cooler during the day, particularly the Intensive GR.

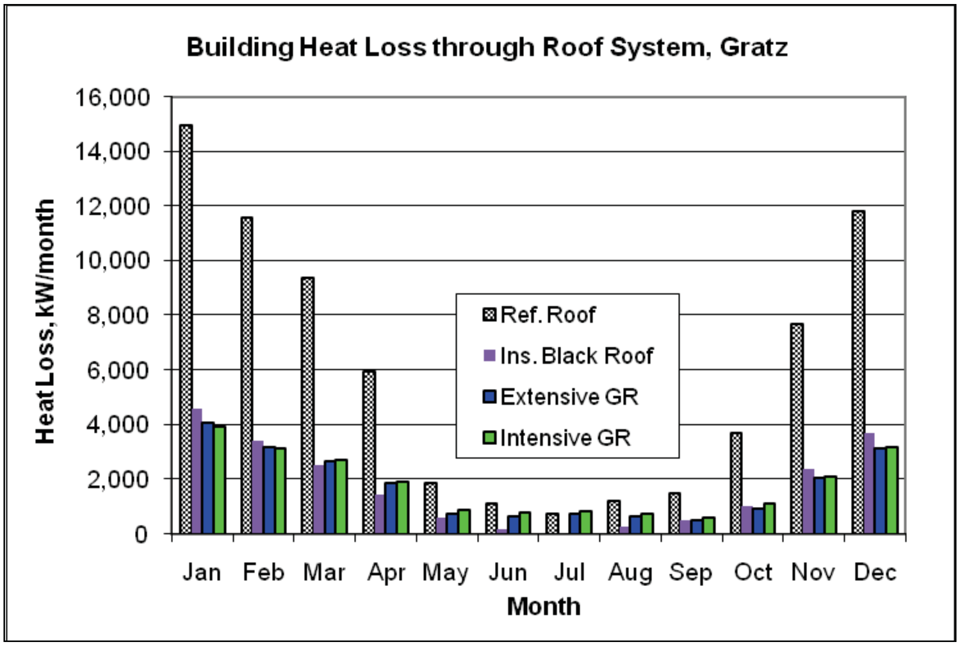

Figure 18: Building Heat Loss, Monthly

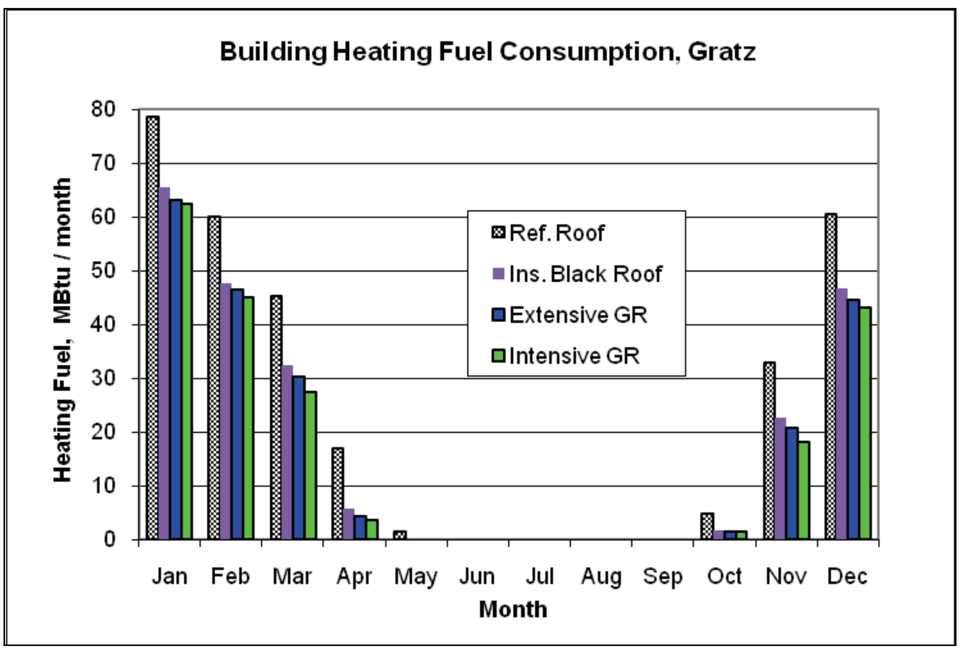

Figure 19: Building Heating Fuel Consumption, Monthly

The annual totals for the entire roof heat transfer are shown in the following table:

Table 1: Gratz Heat Transfer Totals

Gratz	Heat Gain through Roof **kWh**	Heat Loss through Roof **kWh**	Exhaust Fan Power Cons. **kWh**	Office A/C Power Cons. kWh	Heating Fuel Consumption **Mbtu**
Reference Roof	5,517	71,540	**13,140**	**1,460**	**301**
Ins. Black Roof	4,215	20,772	**15,120**	**1,680**	**223**
ExtGR	2,217	21,183	**11,700**	**1,300**	**211**
IntGR	1,708	21,927	**11,070**	**1,230**	**202**

Assuming an electricity price of $0.20/kWh and natural gas price of $14/MBtu, the potential savings for the various options can be estimated as follows.

	Total Electricity cost for Exhaust fans and office a/c	**Total heating fuel cost**	**Total Energy Cost**	**Savings relative to reference roof**
Reference Roof	$2,920	$4,214	$7,134	n.a.
Ins. Black Roof	$3,360	$3,122	$6,482	$652
ExtGR	$2,600	$2,954	$5,554	$1,580
IntGR	$2,460	$2,828	$5,288	$1,846

This analysis neglects electrical demand implications of the green roof. The exhaust fan operated at constant speed and the air conditioning system provided a constant output. The existing exhaust fans and the office air conditioner are estimated to have a combined load of less than 10kW. If hypthethically the green roof could reduce the demand by 15% during summer months, the potential financial benefit might be an additional $120 to the annual energy savings (assumes demand charge of $20/kW per month).

5. THERMAL CHARACTERIZATION

5.1 Background

The demand and costs of energy used for buildings, and the associated carbon output is becoming a major concern in North America and around the world. In addition, the heat island effect associated with urban areas is becoming greater and more troubling for Americans living in and around cities. Urban and suburban temperatures that are 2 to 10°F (1 to 6°C) hotter than nearby rural areas are common. These elevated temperatures can impact communities by increasing peak energy demand, air conditioning costs, air pollution levels, and heat-related illness and mortality. The thermal loading of building roofs contributes to the urban heat island effect.

Temperature data of the roof waterproofing surface is also important for architects, engineers and waterproofing manufacturers considering the stress impact of heat and ultraviolet radiation on the roofing material. The waterproofing of a roof is a major cost factor during the construction and lifetime of a building. By protecting this membrane from thermal stress, the duration of the material can be greatly extended. In addition, the effectiveness of AC-units, fans or photovoltaic systems depends directly on the near surface temperatures of roofs.

Green roofs can have advantageous impacts both in terms of reducing AC costs and extending the lifetime of waterproofing membrane. Evapotranspiration by the green roof plants can directly cool the roof surface and the building spaces underneath, thereby reducing AC load. Also by covering the waterproofing with a layer of media and plants, dramatic thermal fluctuations are modulated. They which would otherwise deleteriously affect the membrane.

5.2 Data and Methods

The objective of the thermal component of this project was to monitor and evaluate the temperatures of and around the Gratz green roof. Thermocouple and heat flux data considered in this report were collected from October, 2006 through September, 2007. Data were evaluated and analyzed using Excel. Results from individual sensors were compared using means comparison and analysis of variance to determine if there were statistically significant differences among sensors in similar positions in different roof quadrants. Where similar sensors were significantly different, data were graphically evaluated to determine if the differences would preclude combination. Data from similar sensors were combined and plotted as averages. Monthly averages for similar sensors were combined to evaluate monthly and diurnal fluctuations. Data from flux sensors were combined to evaluate monthly and diurnal fluctuations.

5.3 Results and Discussion

The average annual temperatures in the building did not vary significantly among interior quadrants under vegetated and non-vegetated quadrants. The overall average temperature was about 25°C. The average interior temperatures during several months were warmer or cooler under the vegetated roof (Table 2) but there were no consistent differences. Potentially, the temperature variation, which could be attributed to the different roof types, is obscured by the thermal loading of heterogeneous building activity and use.

Likewise there were no consistent differences between the temperatures recorded by any of the air sensors. The weather station, the air sensors over vegetated sections and the air sensors over control non-vegetated sectors were nearly identical throughout the measurement period. This is similar to data observed in other studies. Even though the roof surface temperatures were different this did not translate into measurable air temperature differences above the surface. It is thought that more variation between roof-types could be observed for ambient measurements that are closer to the surface or if the roof area extent was larger.

The average membrane temperatures were higher on the non-vegetated control membrane surface particularly during summer months (Table 2). The average vegetated surface temperature (top of growing medium) was similar to the temperature at the vegetated membrane. Heat flux through the green roof totaled -255,970 Watts per square meter (W/m^2) compared with -118,860 for the non-green control. Monthly heat flux for the green roof ranged from -41,240 W/m^2 in January to -5,350 W/m^2 in June and was negative throughout the year, meaning that heat was lost from the building (*Figure 20*). In contrast, heat flux through the non-green control roof ranged from -33,880 W/m^2 in January to 12,790 in July. Flux was positive in the warm summer months (heat flux into the building) and negative in the cool months (heat flux out of the building) for the control roof. Although average temperatures provide some information on roof temperature responses, a more complete picture can be obtained by looking at monthly diurnal averages and time-series.

Figures 21 through 44 show the monthly patterns of green and conventional roof temperatures and heat flux for October 2006-September 2007. For each month there are four charts: (1) Diurnal average temperatures by vertical position and roof type, (2) Time-series temperature data, (3) Diurnal average heat flux, and (4) Time-series heat flux data. Fixed y-axis limits are used for every month to aid comparisons. Across all months, the conventional roof membrane temperature displayed a more pronounced range than for the green roof and had higher maximum values, an effect that is exaggerated in the summer months. Also the monthly diurnal averages for green roof heat flux are very smooth and more modulated than the conventional roof, which shows greater fluctuations in the time-series data and sensitivity. The conventional roof monthly diurnal averages are consequently more varied and have noisier patterns.

In terms of data issues, there was a problem with the non-vegetated membrane sensors, which reached a peak during the day followed by a plateau (example October 2007, *Figure 21*). The cause of this error was not obvious, but occurred in all warm months. It seems likely that this was a programming or reading error in the datalogger, since the pattern was observed in all three non-vegetated membrane sensors. The non-vegetated heat flux sensor contained a temperature sensor that performed adequately throughout the measurement period. Since the flux sensor temperature on the vegetated sensor and the average vegetated membrane thermocouples were nearly identical, it is logical to assume that the non-vegetated sensor can be used to evaluate the differences between membrane temperatures on the green roof and control roofs. Additionally, the heat flux sensor in the veg. quadrant II failed in June 2007 and consequently so in place of an average, only the veg. quadrant III data was used for June-September 2007 charts.

October

The temperature responses in October 2007 illustrate the general responses observed with green and control roofs in this study (*Figure 21, Figure 22*). The diurnal temperature fluctuations at the membrane were much greater for non-vegetated than vegetated roofs (*Figure 21, Figure 22*). The temperature peak was delayed compared to the temperature peak of the control, non-vegetated sensor. The maximum temperature of the control membrane was nearly 60°C compared to 30°C for the vegetated membrane (*Figure 21*). The heat flux sensor for the vegetated roof did not fluctuate much either daily or monthly during October (*Figure 22*). The flux increased as the roof heated, but to a lesser degree than the flux through the non-green roof. The heat flux through the control roof rose rapidly as the roof heated in the day, then dropped rapidly in the late afternoon. The heat flux in the non-green roofs varied from nearly +100 W/m^2 to less than -100 W/m^2 (*Figure 22*).

November

Diurnal and daily temperature averages for November 2006 are shown in *Figure 23*. The sensors for the non-vegetated membrane did not show the same pattern in cooler months. The sensor problem appears to have occurred only at temperatures over 25°C. The fluctuation in non-vegetated roof temperatures was still much greater than the fluctuation in temperature observed with the green roof. The average monthly maximum for non-green roofs was 30°C compared to 16°C for green roofs. The temperature maximum for the green roof was delayed relative to the maximum non-green roof surface and the air temperature. The maximum surface temperature declined through the month from in excess of 40°C to 30°C for the non-green roof, while the temperature of the green roof membrane and surface were similar to the air temperature (*Figure 23*). The heat flux through the green roof ranged from -10 to about 0 W/m^2 indicating that the general direction of heat energy in the roof was out through the roof (*Figure 24*). In contrast, the heat flux through the non-green roof fluctuated from an average of -40 to +40 W/m^2. This fluctuation was less than in October.

December

The magnitude of temperature fluctuations during the day was less in December 2006 than November 2006 however the general pattern was similar (*Figure 25*). The non-green temperature fluctuated between an average of 22°C and 2°C, compared to 11°C and 5°C for the vegetated systems. As noted in November the maximum temperature was delayed relative to the non-vegetated surface. The maximum temperatures during the month were fairly consistent for non-green roofs. The heat flux through the green roof was a nearly constant -15 W/m^2, with only a small increase in the late afternoon (*Figure 26*). The flux through the non-green roof averaged between 30 and -40 W/m^2 following a similar pattern to that observed in November.

January

The average temperatures in January 2007 on the surface of a non-green roof ranged from 0°C to 15°C, compared to a fairly constant 5-6°C for the green roof. Both the high and low extremes were greater in the non-green roof. The daily maximum for the non-green roof was 35°C compared to 20°C for the green roof (*Figure 27*). At colder temperatures, there was more differentiation between the vegetated membrane and growing medium surface temperatures, with the membrane being warmer. The pattern and magnitudes of heat flux were similar to those observed in December (*Figure 28*). The maximum average energy flux in the morning was about 27 W/m^2 and the minimum was about -40.

February

Average temperatures and temperature fluctuations reached their minimum in February 2007 (*Figure 29*). The maximum average surface temperature for the conventional roof was about 17°C with a minimum of -6°C compared to 5°C and 0°C for the vegetated systems. A general pattern of increasing temperatures through the month is evident. The heat flux observed was similar to January; however the magnitude of the difference between minimum and maximum increased (*Figure 30*).

March

The average temperature and fluctuations were greater in March 2007 than in February 2007. The maximum average for the non-green roof was over 30°C compared to 15°C for the green roof (*Figure 31*). The minimums were lower for the non-green roof too, about 0°C vs. 5°C. The pattern of increased temperatures during the month continued. The maximum surface temperature of the non-green roof was nearly 60°C compared to 30°C for the green roof. Heat flux variation also increased in March with a maximum of nearly 150 W/m^2 and minimum in excess of -120 W/m^2 and averages ranging from about -50 to 50 W/m^2. The average for the green roof ranged from about -15 to 0 W/m^2 (*Figure 32*).

April

For April 2007, the surface of the non-green membrane ranged from over 70°C to -5°C with average highs of 42 and lows of just under 5°C (*Figure 33*). The vegetated roof average temperature maximum was just over 20°C and the low was about 5°C. Daily maximums increased throughout the month. Heat flux ranged from over 150 to less than -150 W/m^2 for the non-green roof with an average diurnal range of -60 to +60 W/m^2 (*Figure 34*). The green roof in comparison had heat flux from about -15 to +5 W/m^2.

May

Figure 35 and *Figure 36* depict the monthly temperature measurement and heat flux measurement data for May 2007. Maximum and minimum temperatures for the control roof were higher and lower respectively than the membrane or surface temperatures of the green roof. The maximum temperatures for both roofs were fairly consistent for May reaching about 65-75°C for the control and 35-50°C for the green roof. It is interesting to note that the green roof surface and membrane temperatures were considerably above ambient in May. Heat flux through the non-green roof ranged from -200 and 200 W/m^2 compared to about -20 to 20 W/m^2 for the green roof.

June

Average maximum temperatures in June on the waterproofing surface of the non-green control averaged 65°C and exceeded 75°C on many days (*Figure 37*). This is in contrast to the maximum average vegetated surface and vegetated membrane temperatures, which reached about 40°C. The peak temperature for the vegetated membrane was delayed compared to the peak in vegetated surface or non-vegetated membrane temperatures. One of the two vegetated roof heat flux sensors malfunctioned near the end of the month (*Figure 38*). Data from this sensor was discarded for July, August and September and was not used to determine average daily flux or total flux for the month. Heat flux from the non-vegetated control roof ranged from about -200 to +200 W/m^2 while the flux through the vegetated roof was relatively constant, ranging from about -15 to 25 W/m^2.

July

Roof temperatures observed in July 2007 were similar to those recorded in June 2007 (*Figure 39*). The maximum membrane surface temperature for the non-green roof was nearly 80°C with a daily average of about 65°C. In contrast the green roof membrane temperature reached a daily maximum average of about 35°C. Heat flux in July was likewise similar to that observed in June. Heat flux through the non-green control roof ranged from about -150 to +150 W/m^2 with an average daily high of about 90 and low of -50 W/m^2 (*Figure 40*). The vegetated roof heat flux in contrast ranged from an average daily high of about 25 to a low of -18 W/m^2.

August

In August 2007, the average maximum roof membrane surface temperatures of both the non-green control and the vegetated roof started to decline. The non-green control roof average maximum was just under 60°C while the green roof reached about 35°C (*Figure 41*). Low temperatures for the month were fairly constant, the decline was primarily observed in temperature maxima. Heat flux also showed a decrease in average minima and maxima for the non-green control roofs (*Figure 42*).

September

For September 2007, the average maximum non-vegetated roof membrane surface temperature was about 55°C compared to about 30°C for the vegetated roof (*Figure 43*). Heat flux was similarly reduced with non-vegetated maxima of about 100 W/m^2 and minima of about -100. The vegetated roof in contrast was very similar to the response observed throughout the warm season months ranging from a high of about 20 W/m^2 to a low of almost -20 (*Figure 44*).

5.4 Conclusions

The temperature responses observed for the Gratz roof were similar to those reported for other roofs in the literature. The most striking difference between the green and non-green roofs was observed in roof membrane surface temperature. The membrane surface temperature of the non-green roof fluctuated much more that that observed for the green roof, with high temperatures above 70°C in the summer and lows of -15°C in the winter. This compares to high temperatures for the green roof waterproofing membrane in the 30-40°C range most of the warm season and winter lows seldom below 0°C. This reduction in temperature maxima and fluctuation can have a substantial influence on the life of the roof membrane. Temperature extremes and the resultant expansion and contraction of the membrane contribute to membrane aging and premature failure. The waterproofing membrane under the green roof is being protected from these extremes and thus should last longer, reducing long-term building maintenance costs and reducing the environmental impact of roofing material disposal and replacement.

The green roof also greatly influenced heat flux through the roof of the building. The non-green control roofs heated during the day and cooled in the afternoon and evening, resulting in large fluxes of heat into and out of the roof every day. In contrast, the green roof heat flux was much less dramatic. During the summer months, the average total heat flux for the conventional roof was positive indicating a general heating of the building that would increase air conditioning demand. The heat flux total through the green roof in summer remained negative. In the winter months, the total flux through both the non-green and the green roof was negative, with the negative flux through the green roof being greater. This is an interesting result owing to the heating of the non-green roof surface since it is a black tar material with a low albedo. While this is a negative impact in the summer, the heat gained in the winter is actually a benefit since it helps offset the overall heating demand of the building. This result points to the shortcoming common in the green roof industry of wanting to treat the green roof as an insulator similar to fiberglass or Styrofoam. The green roof does not function this way. It is primarily affecting building energy as an evaporative cooler in the summer and a thermal mass buffering the flow of energy year round. This is well illustrated by this data set and demonstrates the importance of local climatic conditions for estimating green roof energy benefits.

Table 2: Temperature summary data. Monthly averages for probes in each location in °C.

	Interior temperature		Membrane		Surface	Air	Air
	Vegetated	Control	Vegetated	Control	Vegetated	Vegetated	Control
October, 2006	23.6	24	14.6	17.6	14.1	14.6	14.8
November, 2006	23.9	25.3	11.9	13.8	11.1	11.7	11.8
December, 2006	24.2	24.1	7.8	9.2	6.2	7.3	7.4
January, 2007	25.6	25.1	6.7	4.9	5.5	5.6	5.6
February, 2007	23.4	22.7	1.4	1.5	-1.2	-1.4	-1.3
March. 2007	23.9	23.5	8.3	9.1	7.2	6.3	6.4
April, 2007	24.7	25.8	13	14.2	12.3	10.7	10.7
May, 2007	24.9	24.8	22.6	23.9	22.7	19.6	19.7
June, 2007	27.7	27.8	26.4	27.7	26.5	23.5	23.6
July, 2007	29.4	29.5	27.3	30.1	27.8	25.7	26
August, 2007	29.4	29.2	25.8	28.7	26.2	25.2	25.4
September, 2007	29	28.7	25.2	27.8	25.4	24.2	23.8

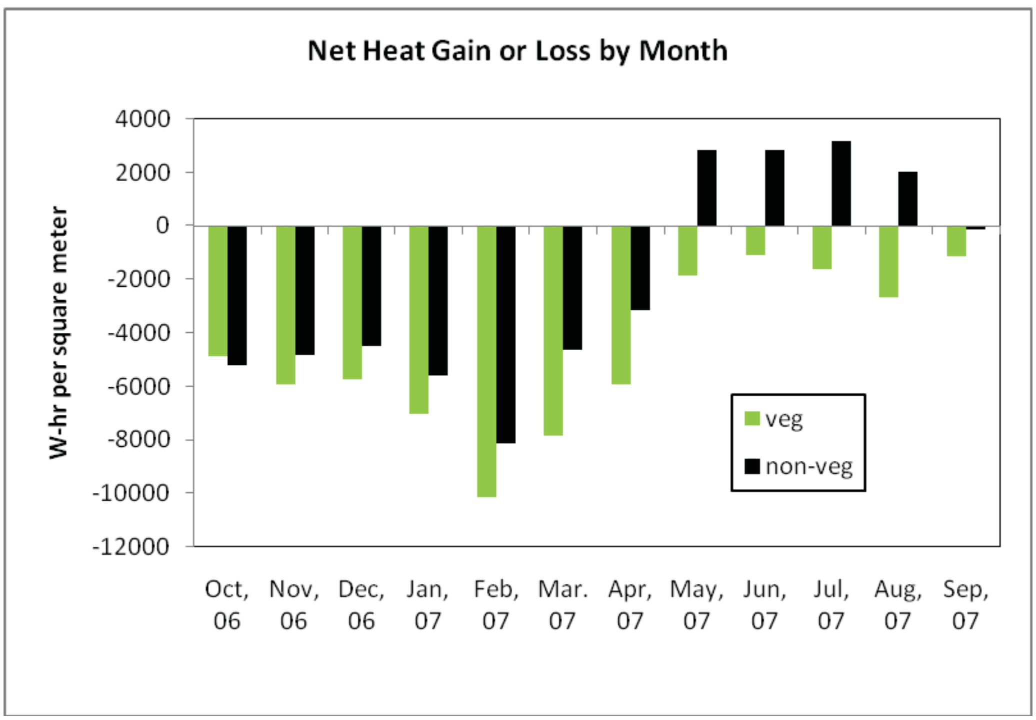

Figure 20: Net heat gain or loss by month for vegetated and non-vegetated roof. Vegetated heat flux sensor averages were used for Oct 2006-May 2007. Due to sensor failure, only VHFQ3E (veg. quad III) data were used for June-September 2007.

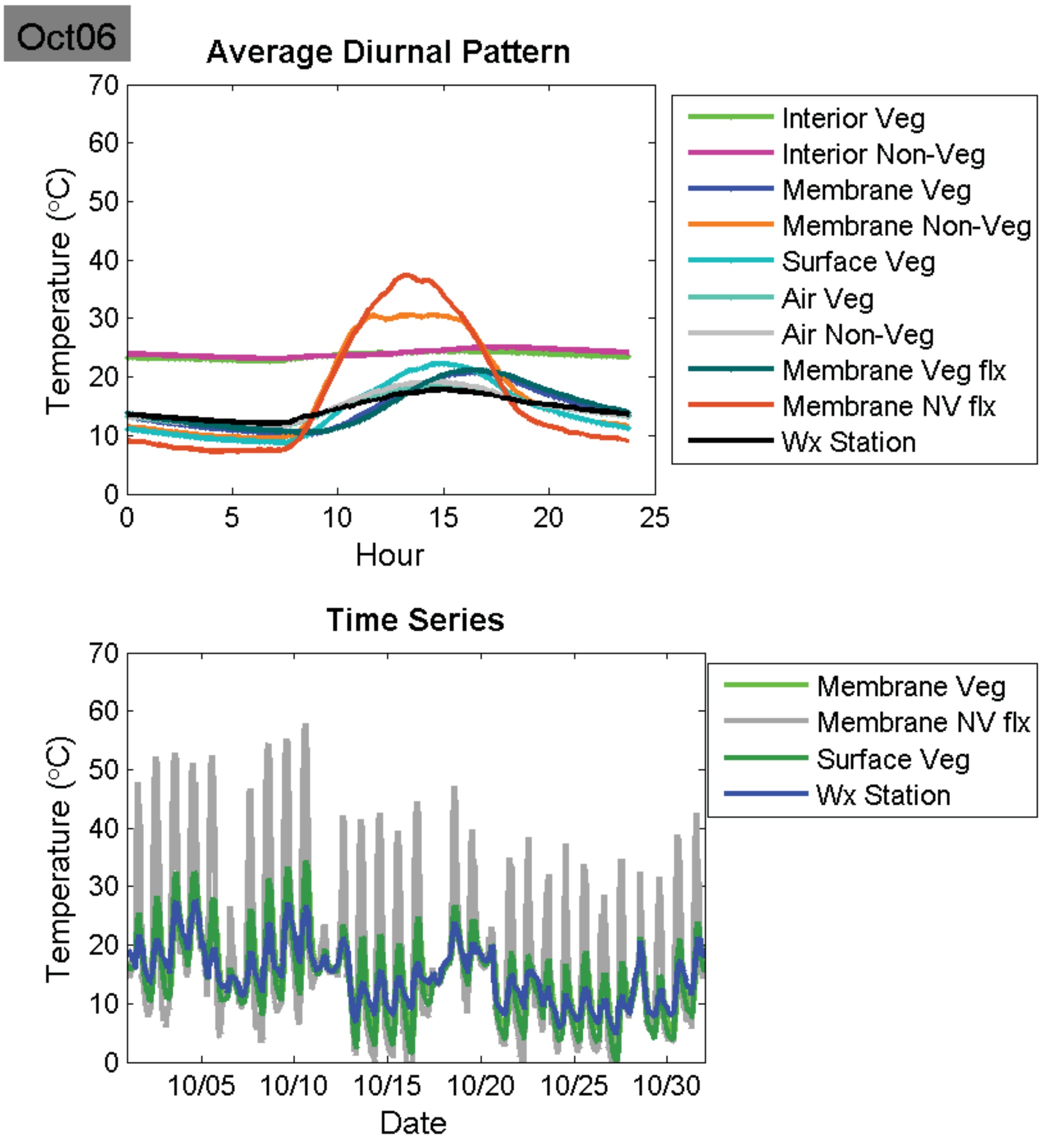

Figure 21: October 2006 Average diurnal temperatures (top) and monthly average temperatures.

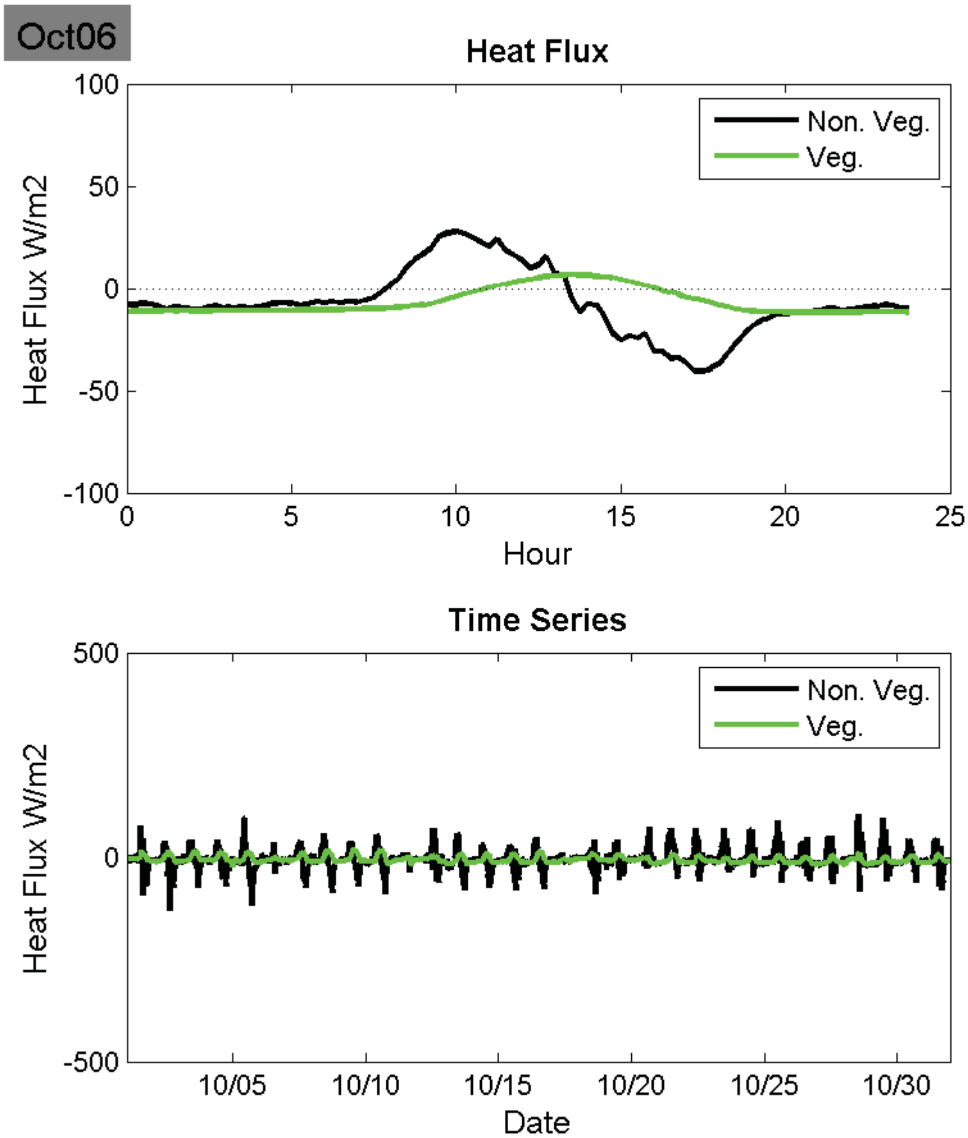

Figure 22: October 2006 Average diurnal heat flux through a green and non-green roof (top) and monthly daily heat flux.

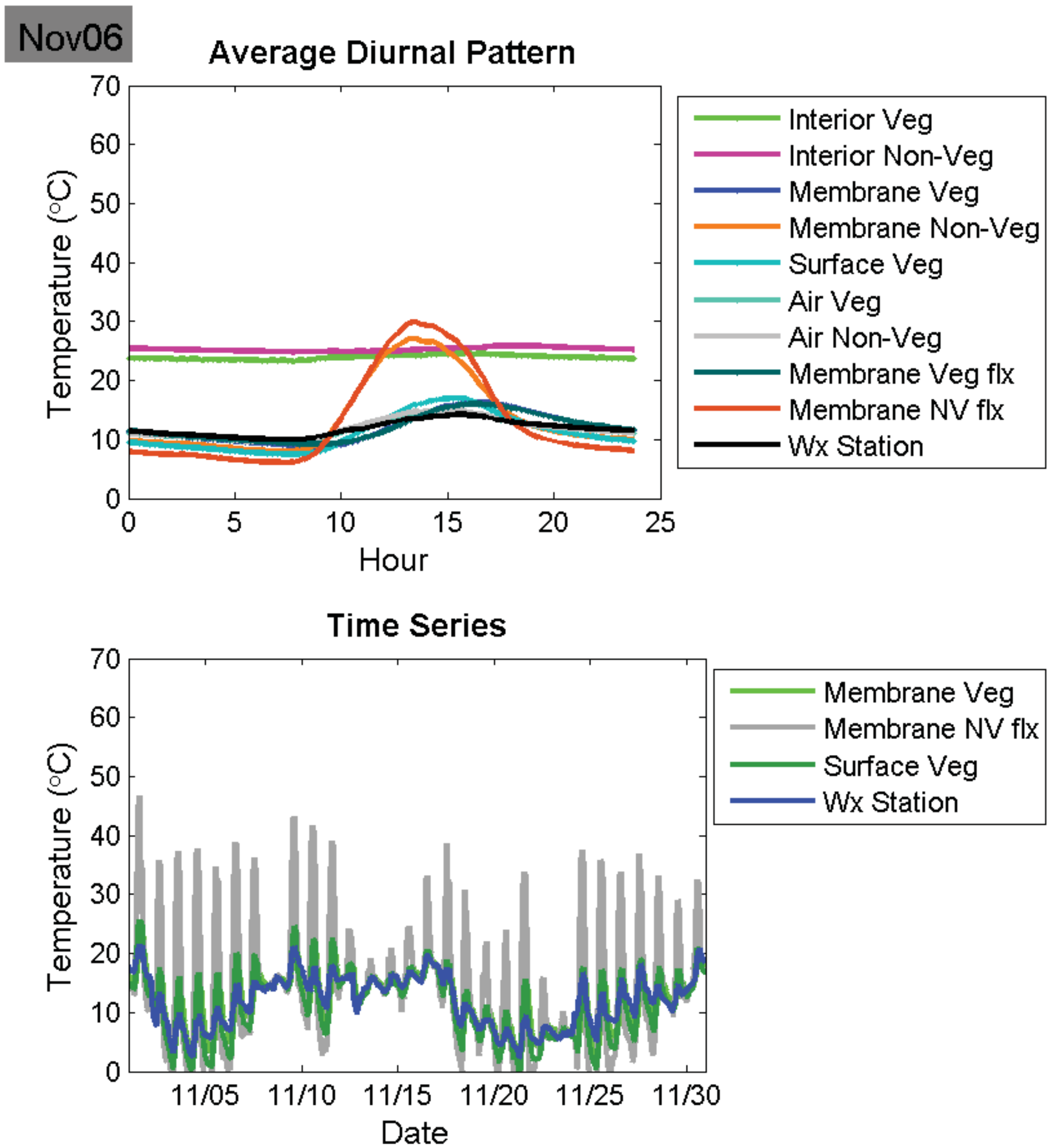

Figure 23: November 2006 Average diurnal temperatures (top) and monthly average temperatures.

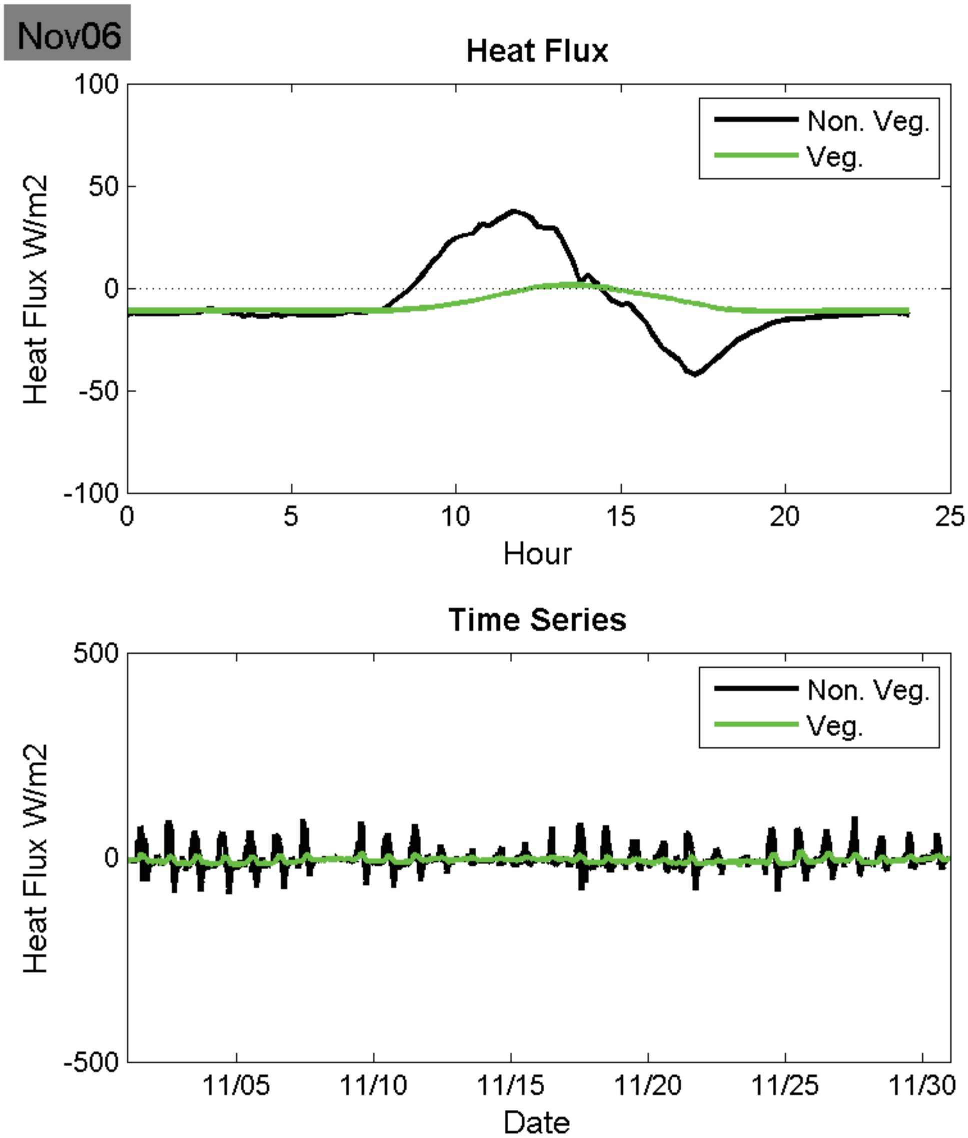

Figure 24: November 2006 Average diurnal heat flux through a green and non-green roof (top) and monthly daily heat flux.

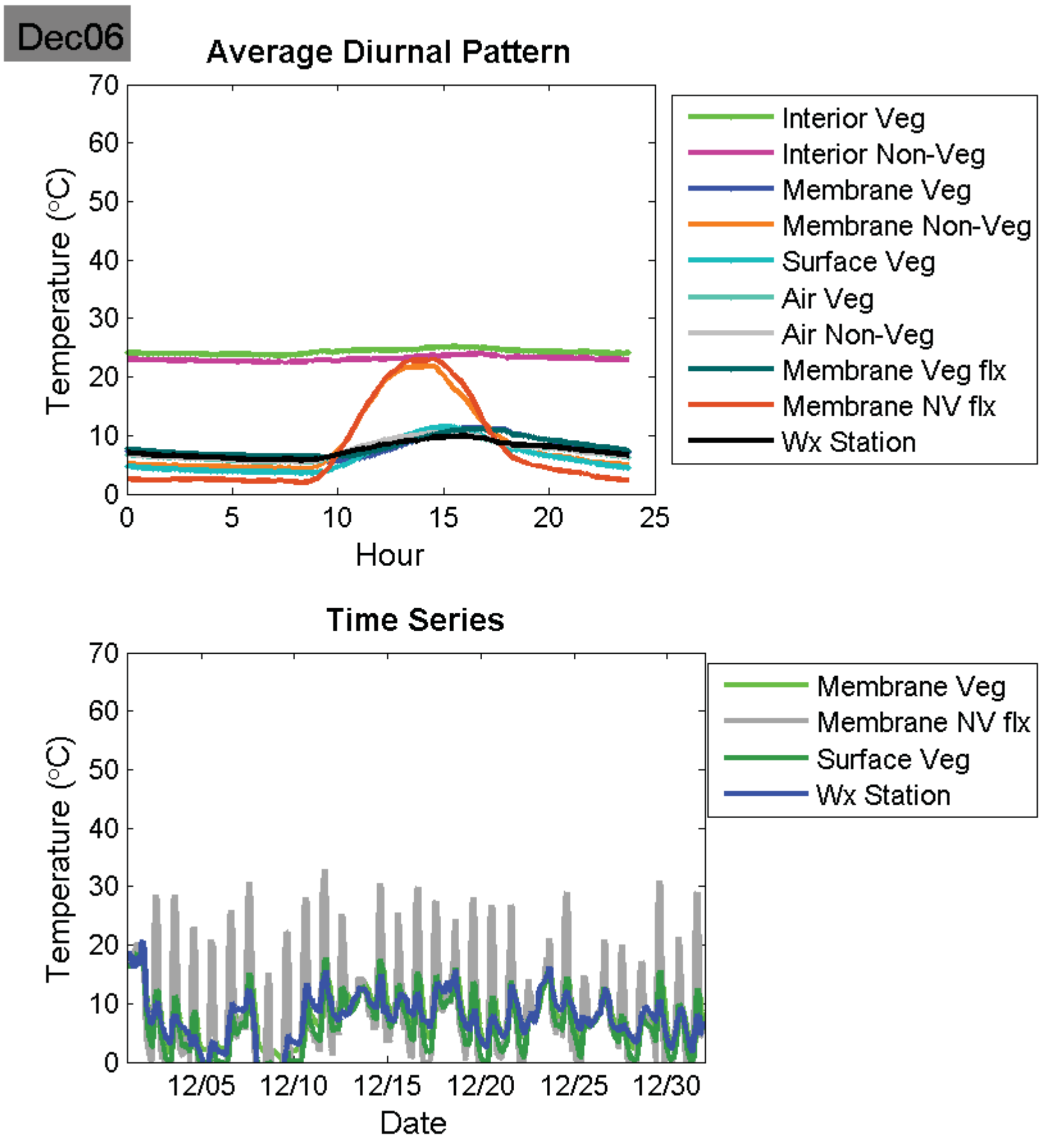

Figure 25: December 2006 Average diurnal temperatures (top) and monthly average temperatures.

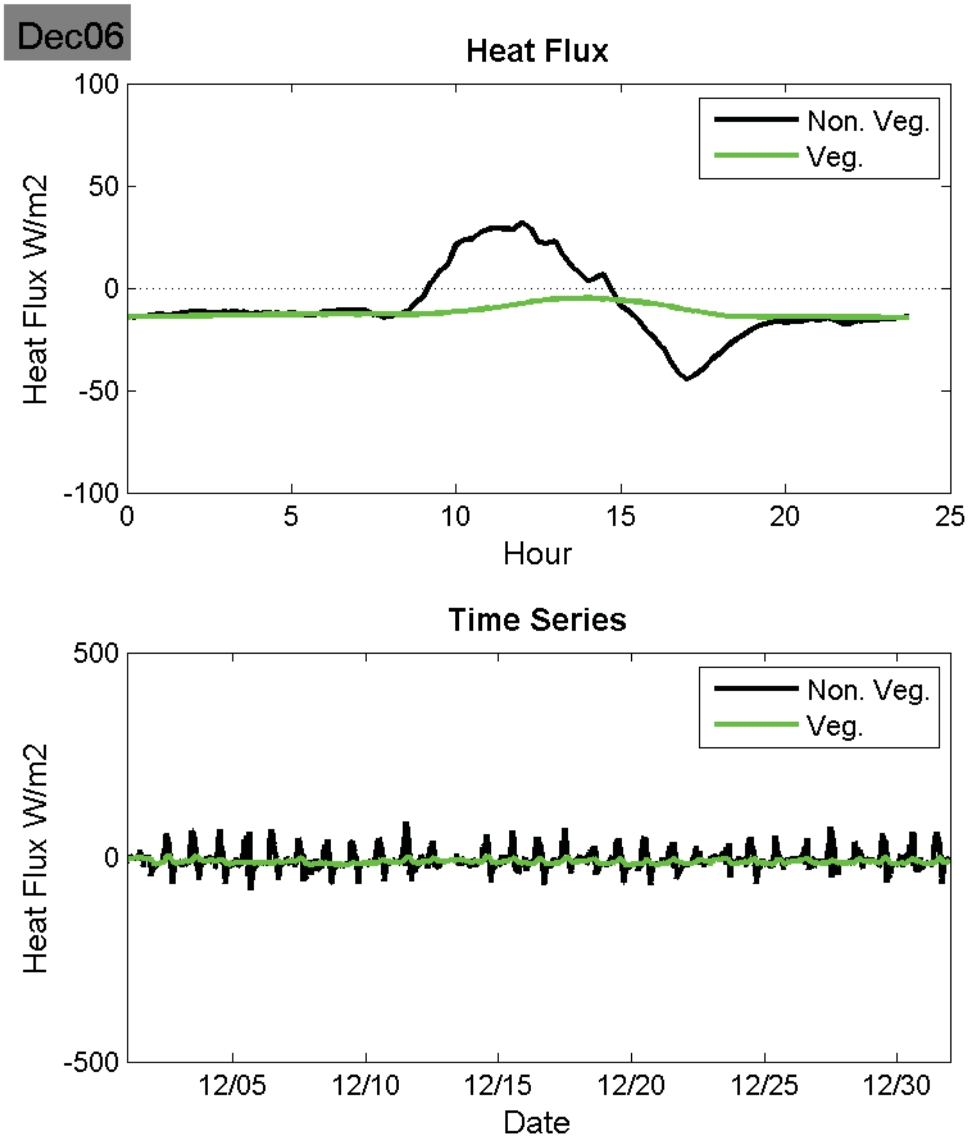

Figure 26: December 2006 Average diurnal heat flux through a green and non-green roof (top) and monthly daily heat flux.

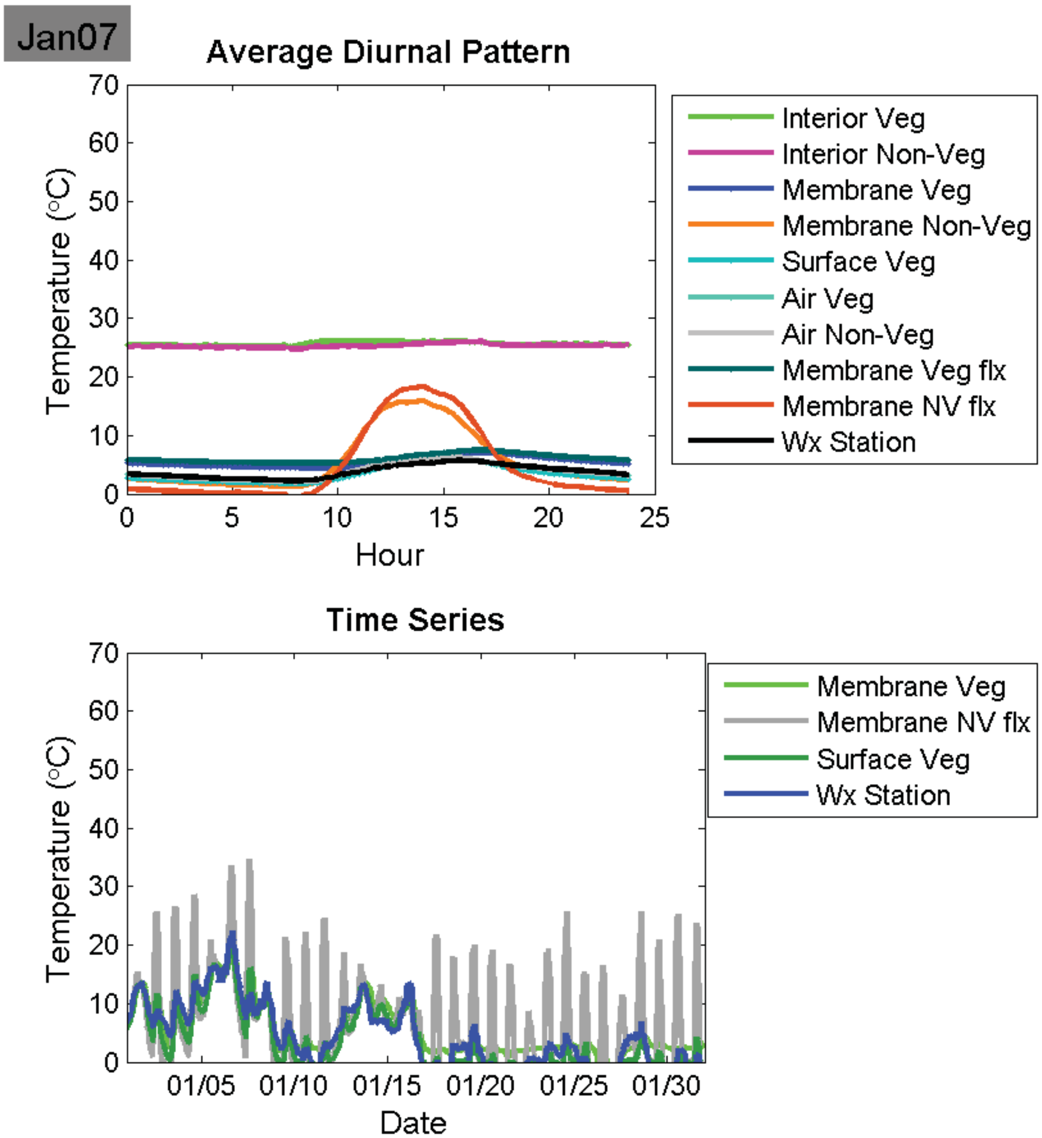

Figure 27: January 2007 Average diurnal temperatures (top) and monthly average temperatures.

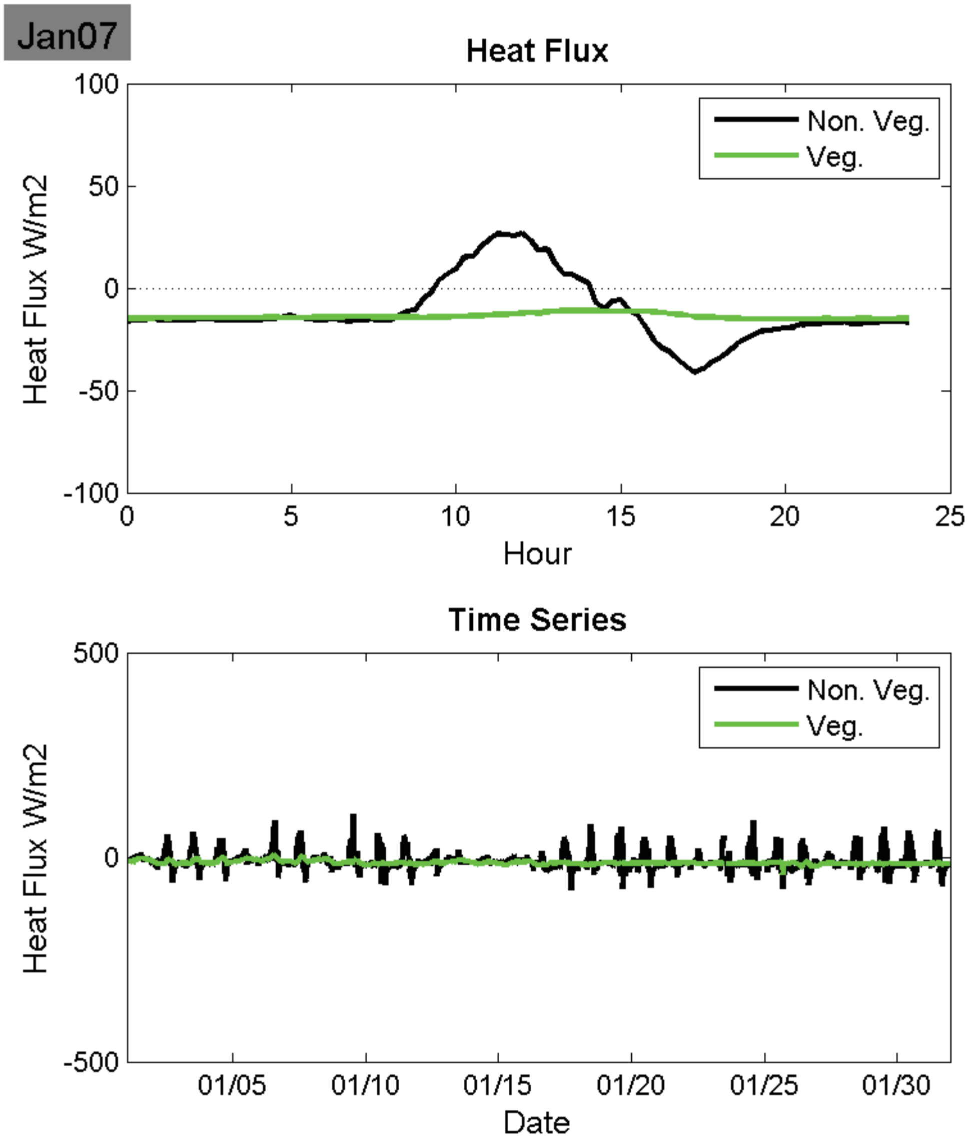

Figure 28: January 2007 Average diurnal heat flux through a green and non-green roof (top) and monthly daily heat flux.

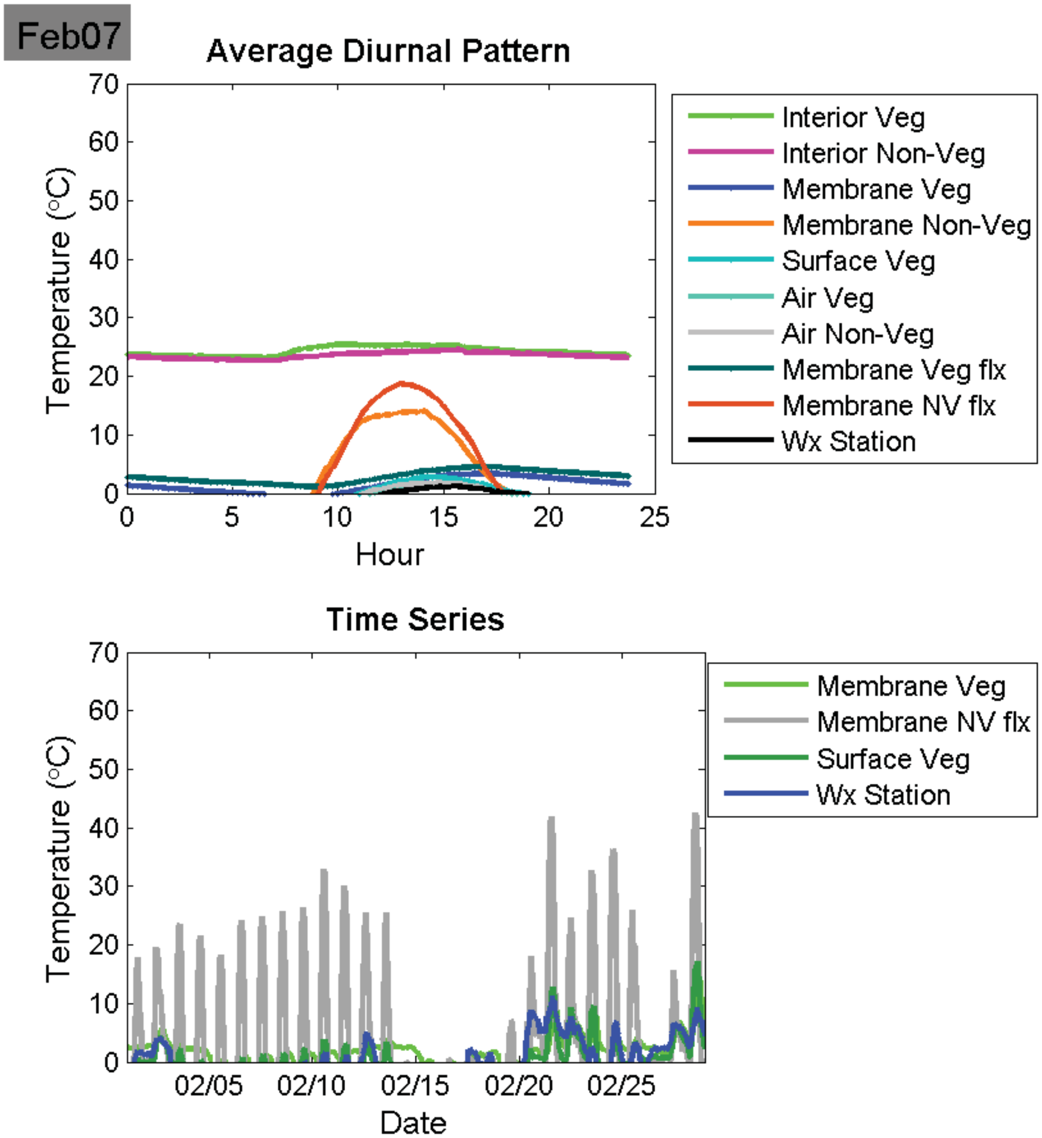

Figure 29: February 2007 Average diurnal temperatures (top) and monthly average temperatures.

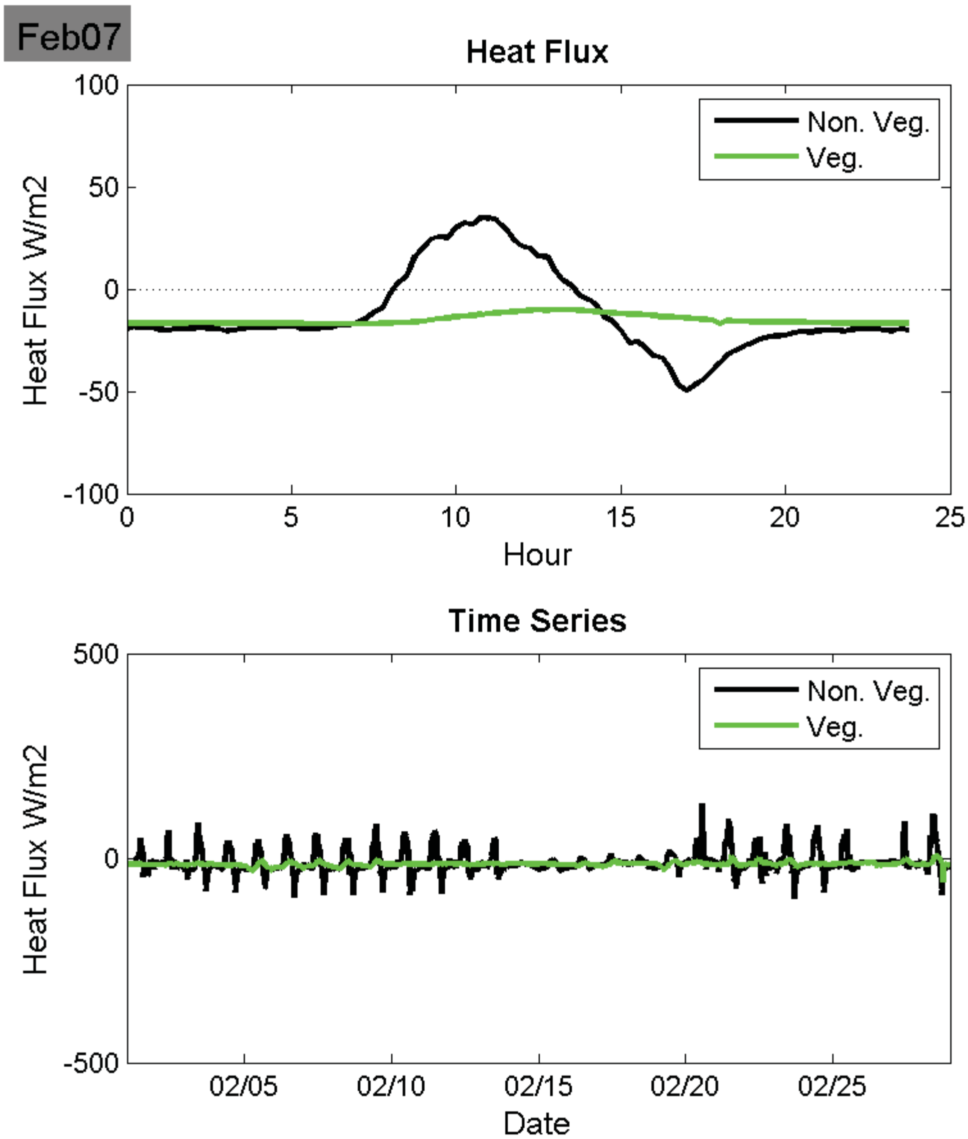

Figure 30: February 2007 Average diurnal heat flux through a green and non-green roof (top) and monthly daily heat flux.

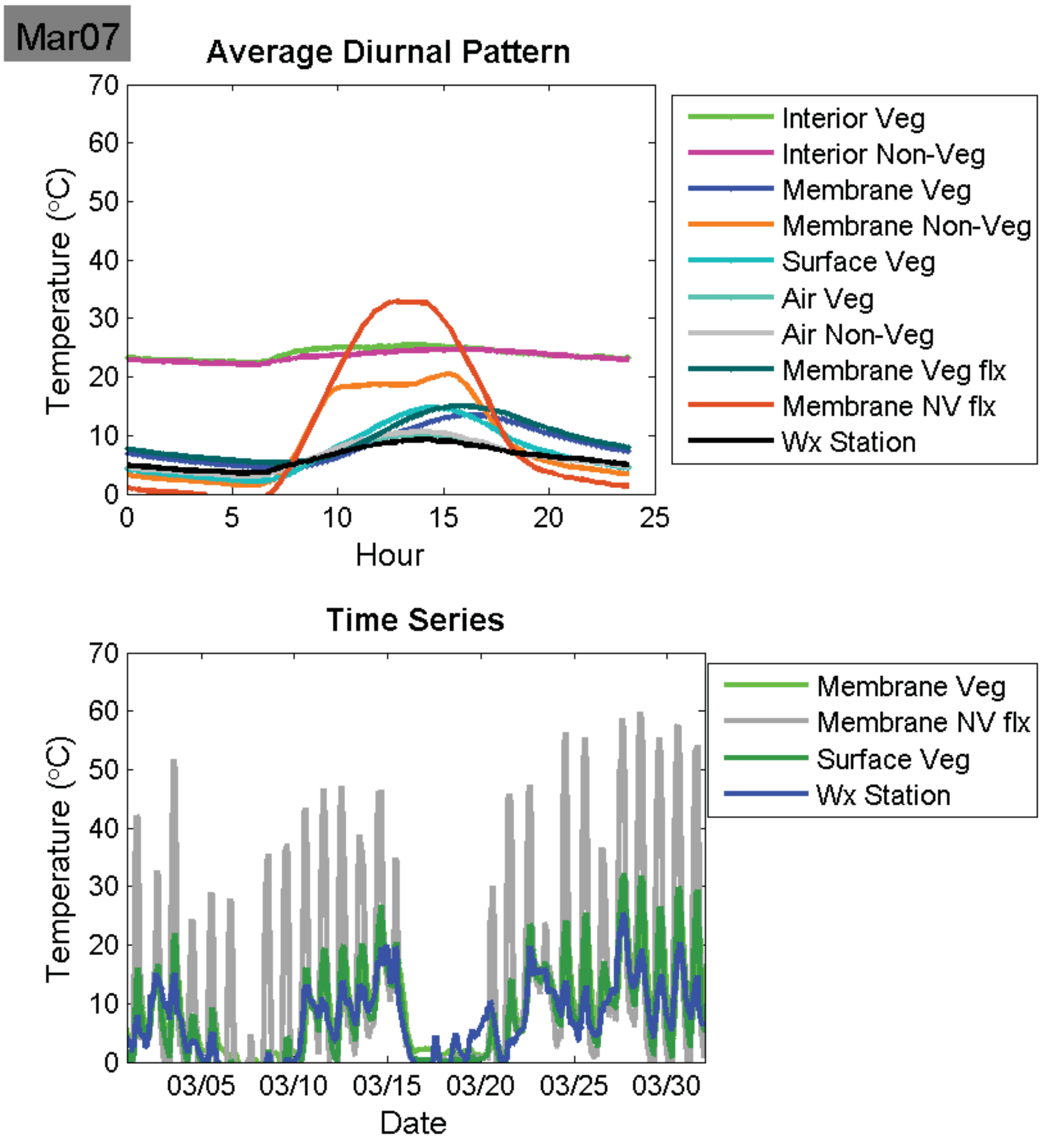

Figure 31: March 2007 Average diurnal temperatures (top) and monthly average temperatures.

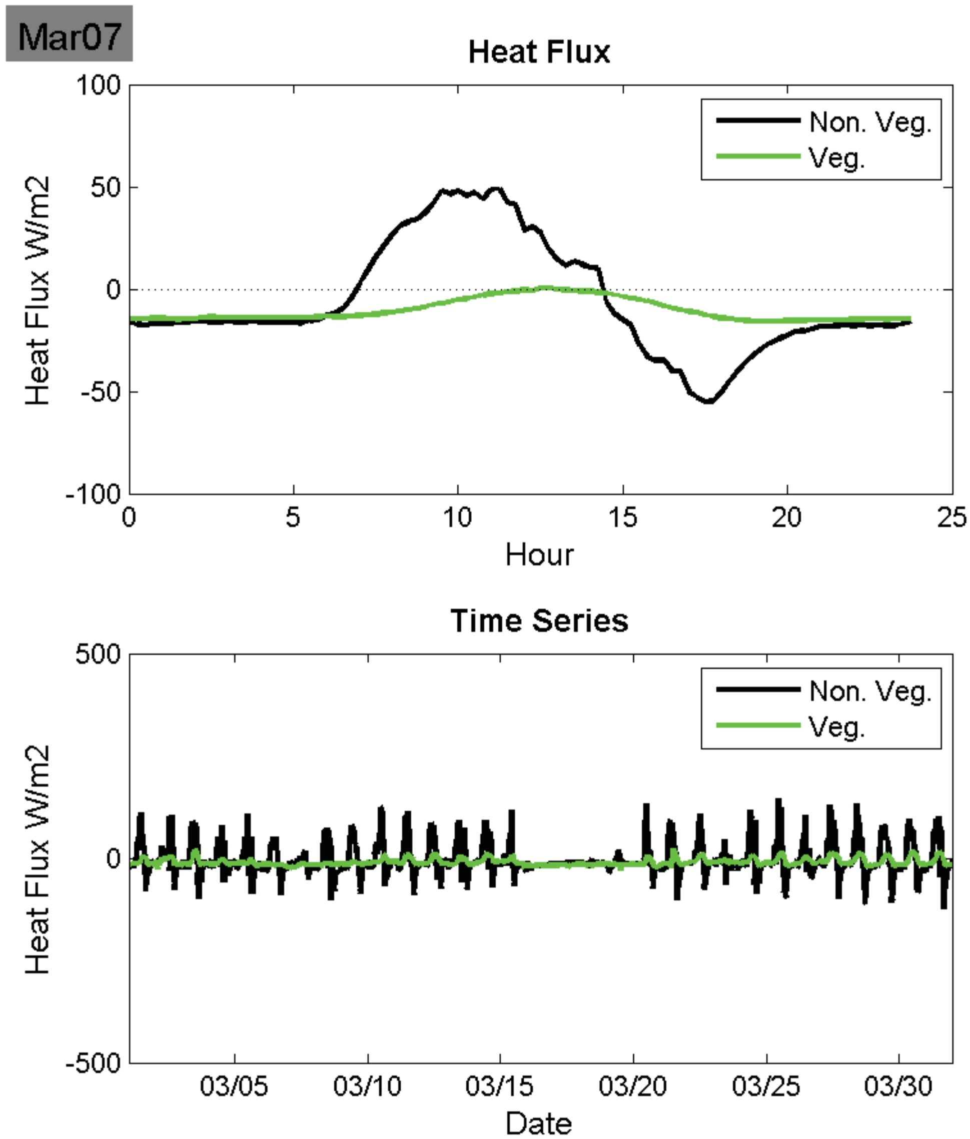

Figure 32: March 2007 Average diurnal heat flux through a green and non-green roof (top) and monthly daily heat flux.

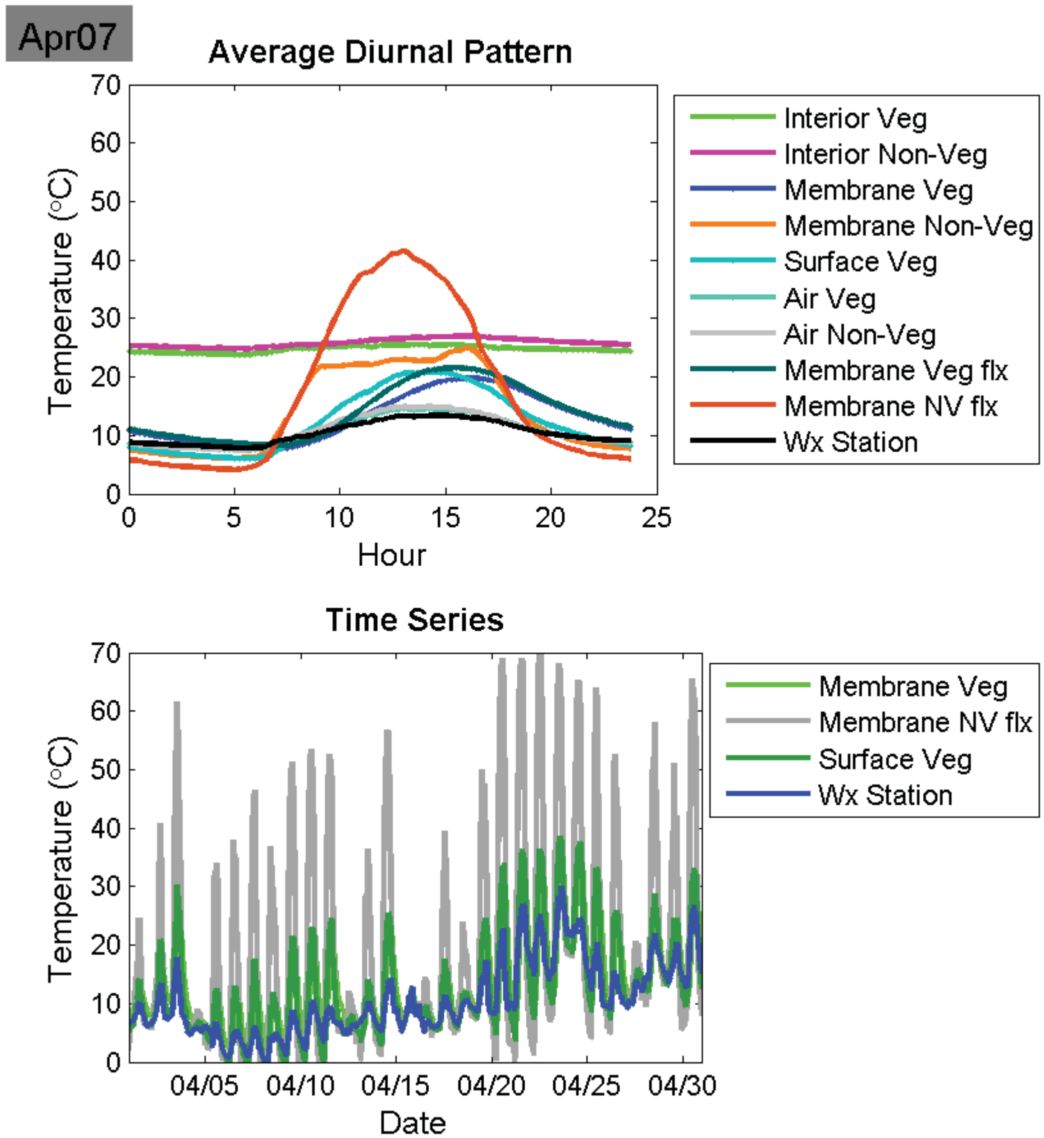

Figure 33: April 2007 Average diurnal temperatures (top) and monthly average temperatures.

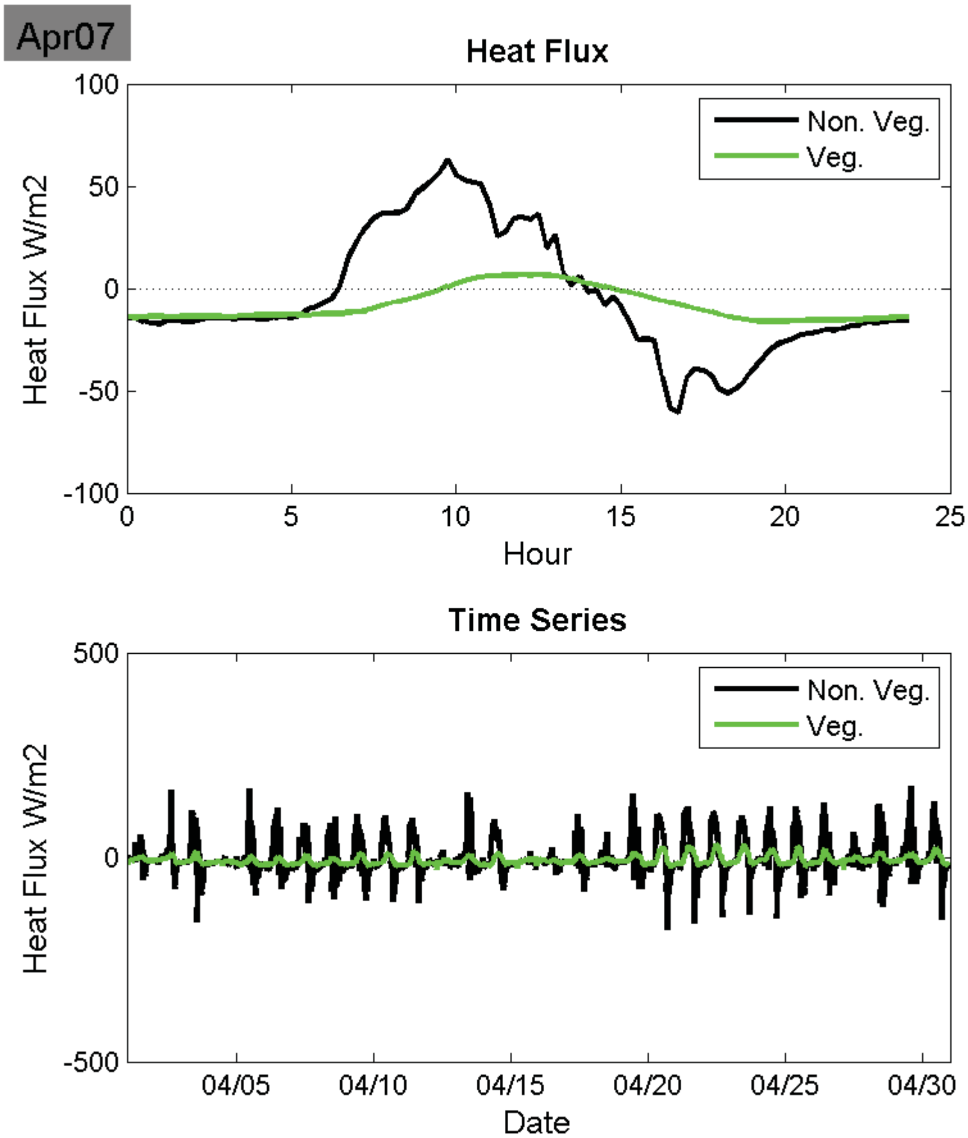

Figure 34: April 2007 Average diurnal heat flux through a green and non-green roof (top) and monthly daily heat flux.

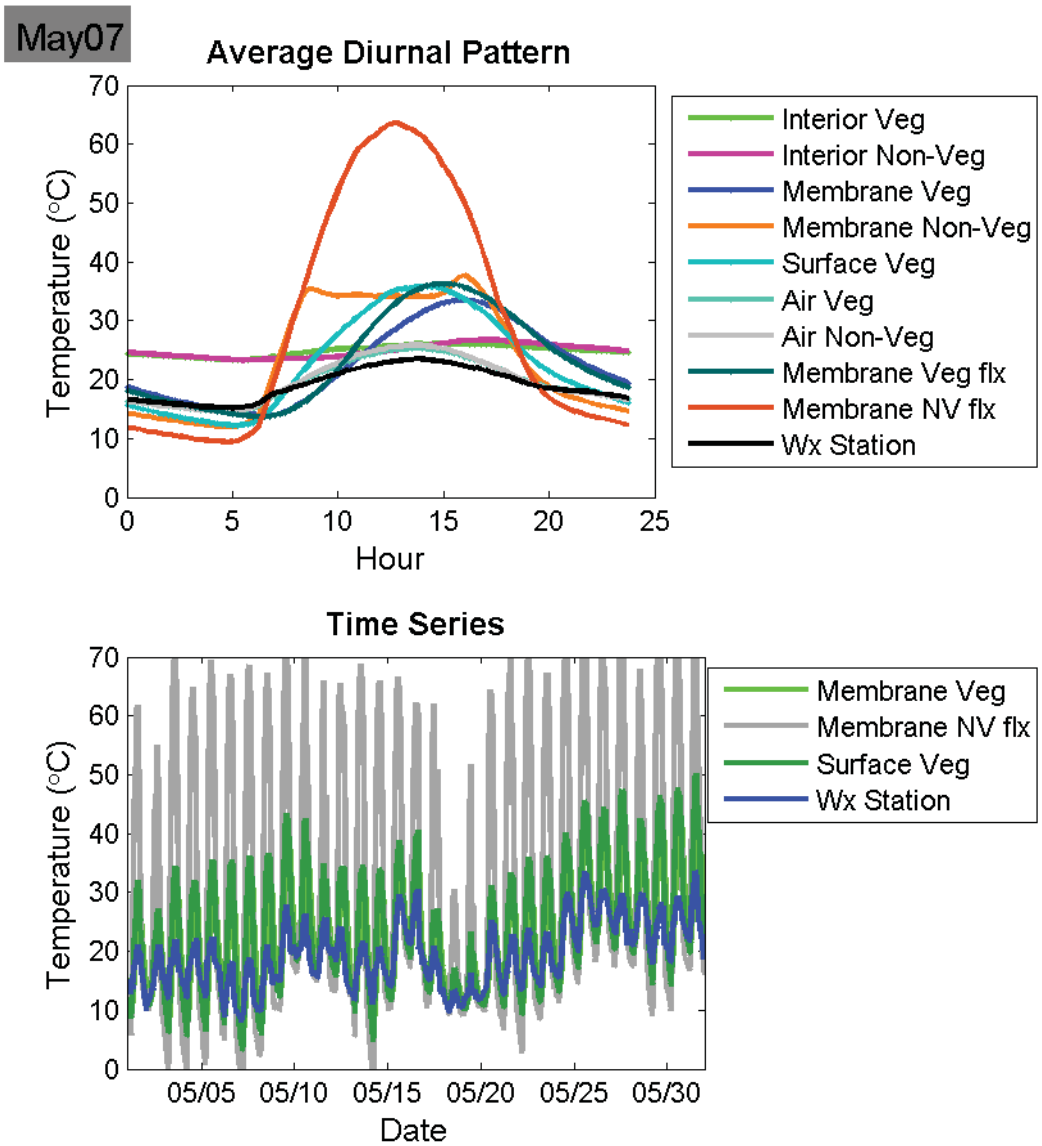

Figure 35: May 2007 Average diurnal temperatures (top) and monthly average temperatures.

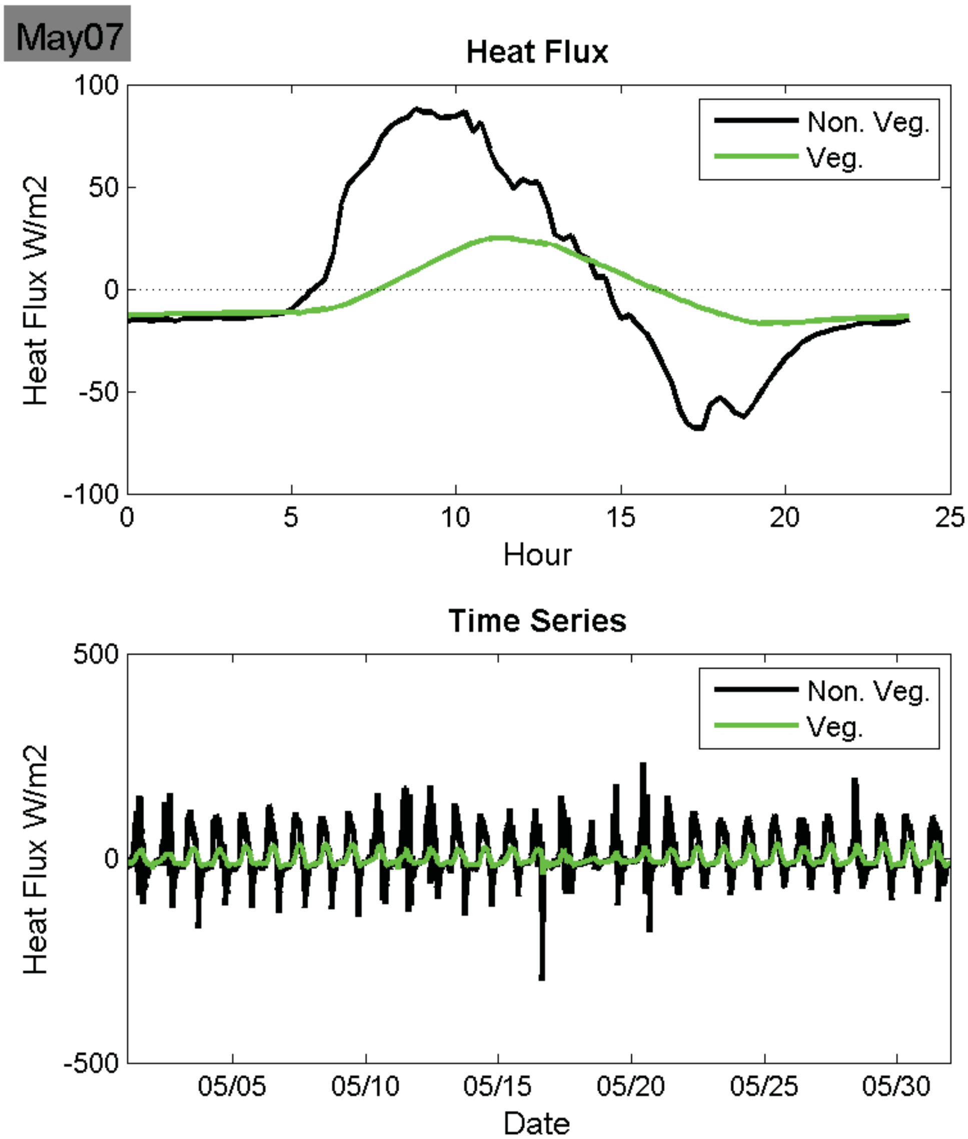

Figure 36: May 2007 Average diurnal heat flux through a green and non-green roof (top) and monthly daily heat flux.

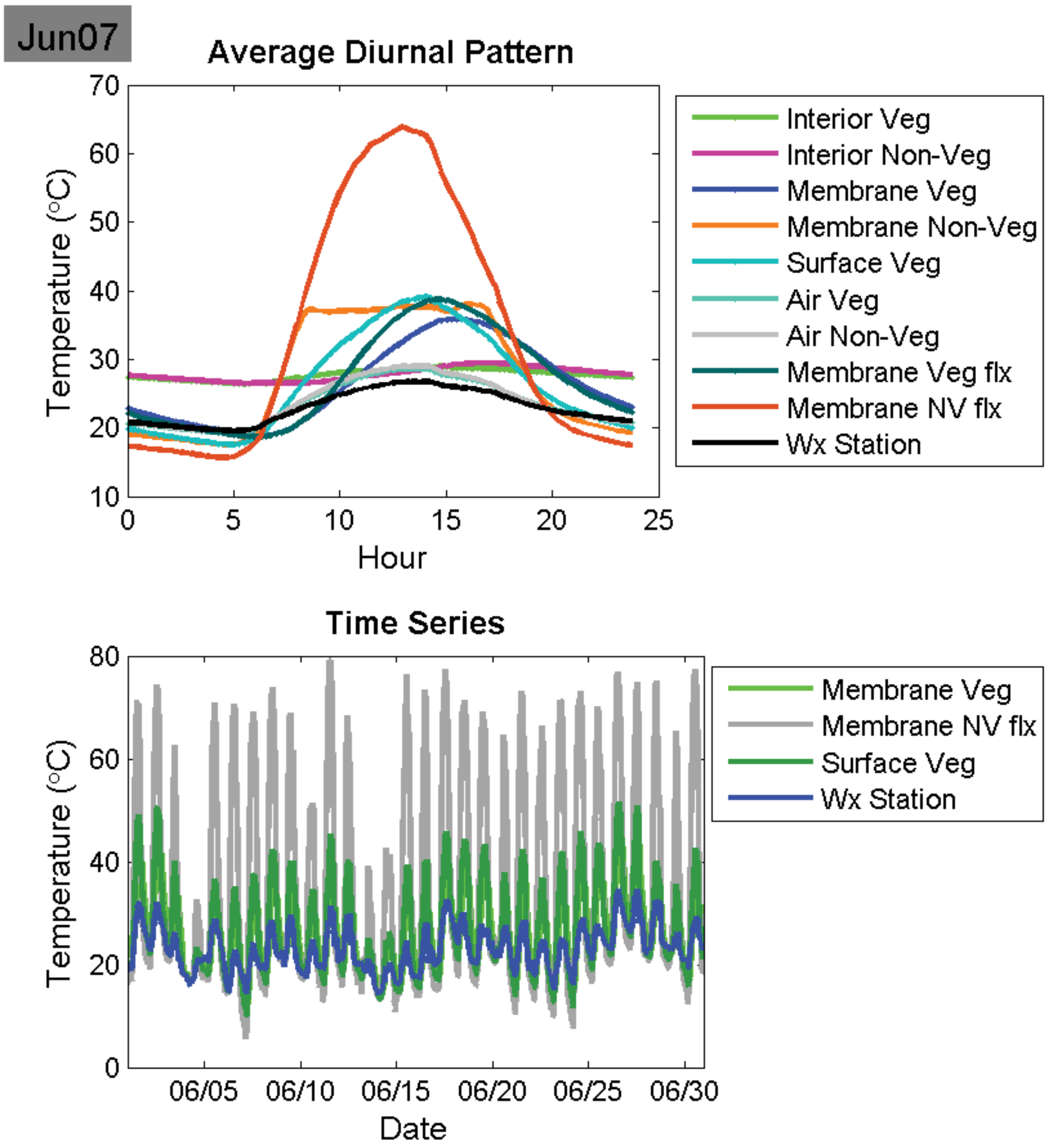

Figure 37: June 2007 Average diurnal temperatures (top) and monthly average temperatures.

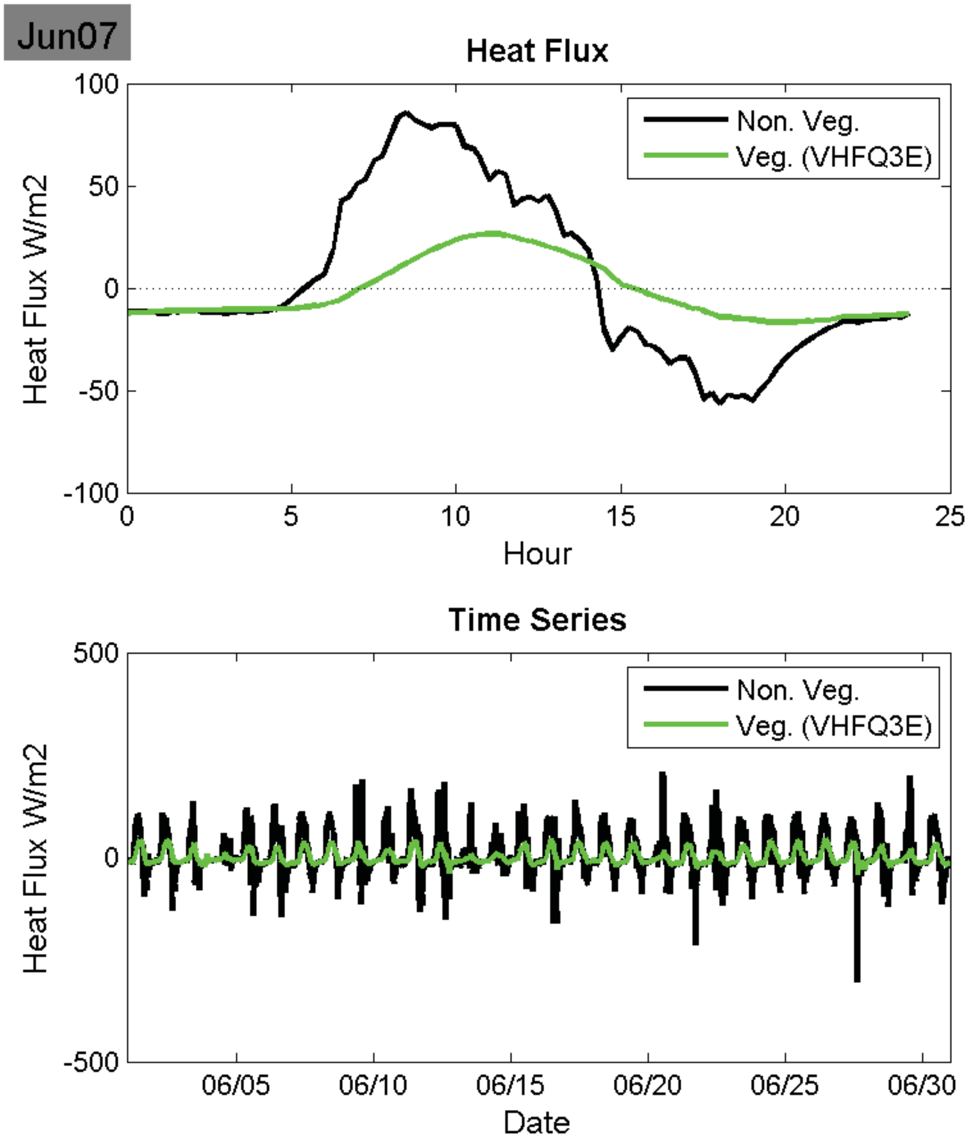

Figure 38: June 2007 Average diurnal heat flux through a green and non-green roof (top) and monthly daily heat flux.

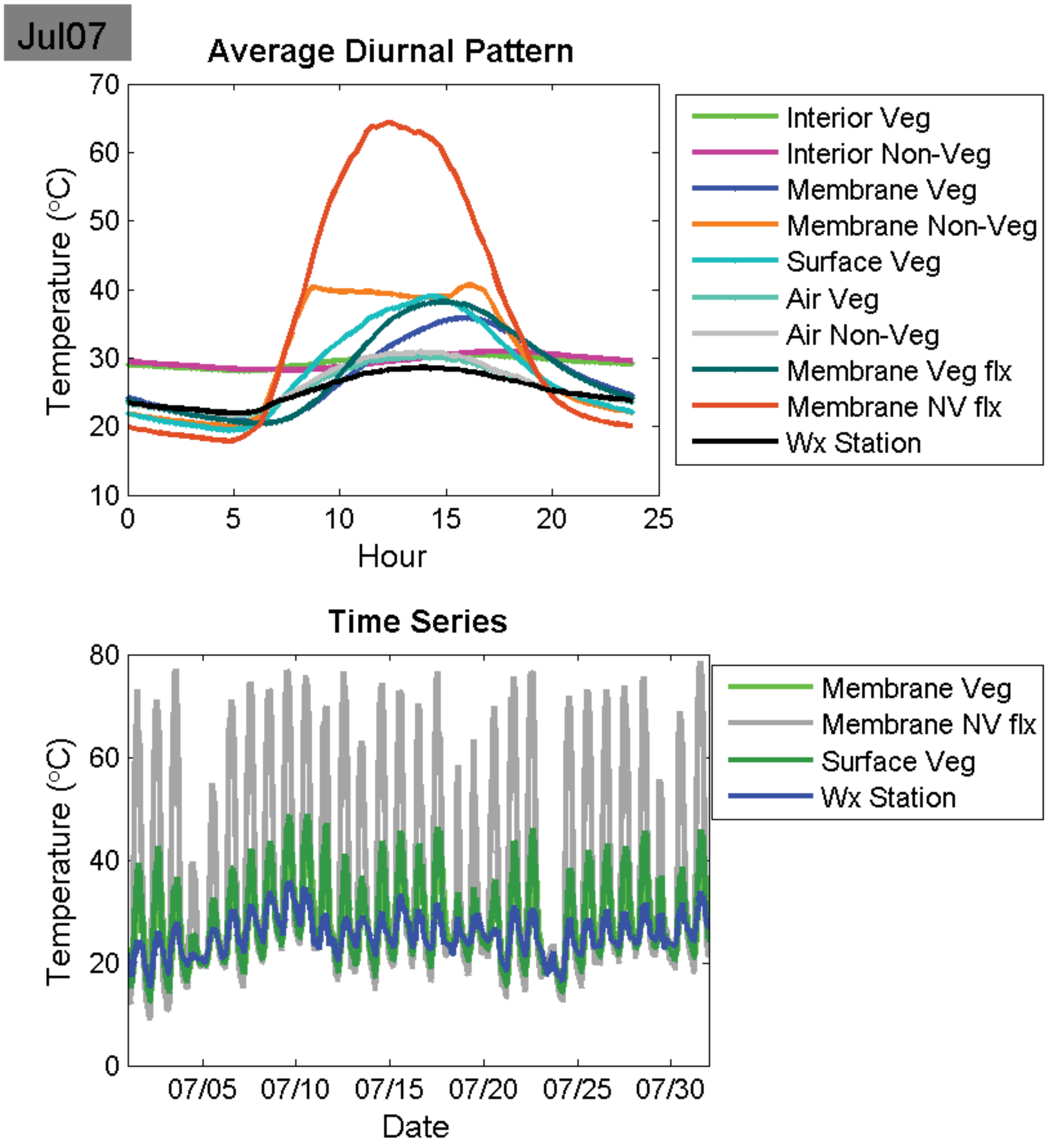

Figure 39: July 2007 Average diurnal temperatures (top) and monthly average temperatures.

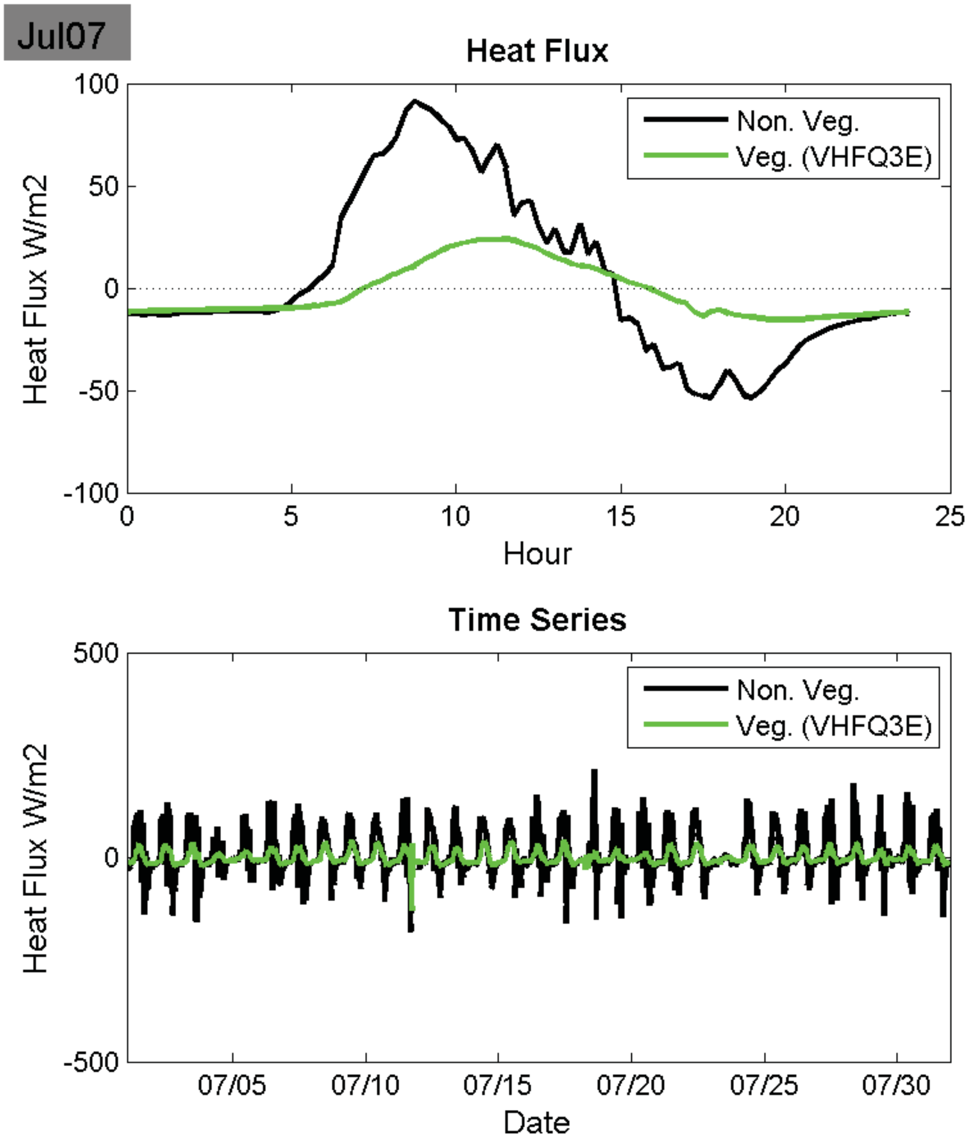

Figure 40: July 2007 Average diurnal heat flux through a green and non-green roof (top) and monthly daily heat flux.

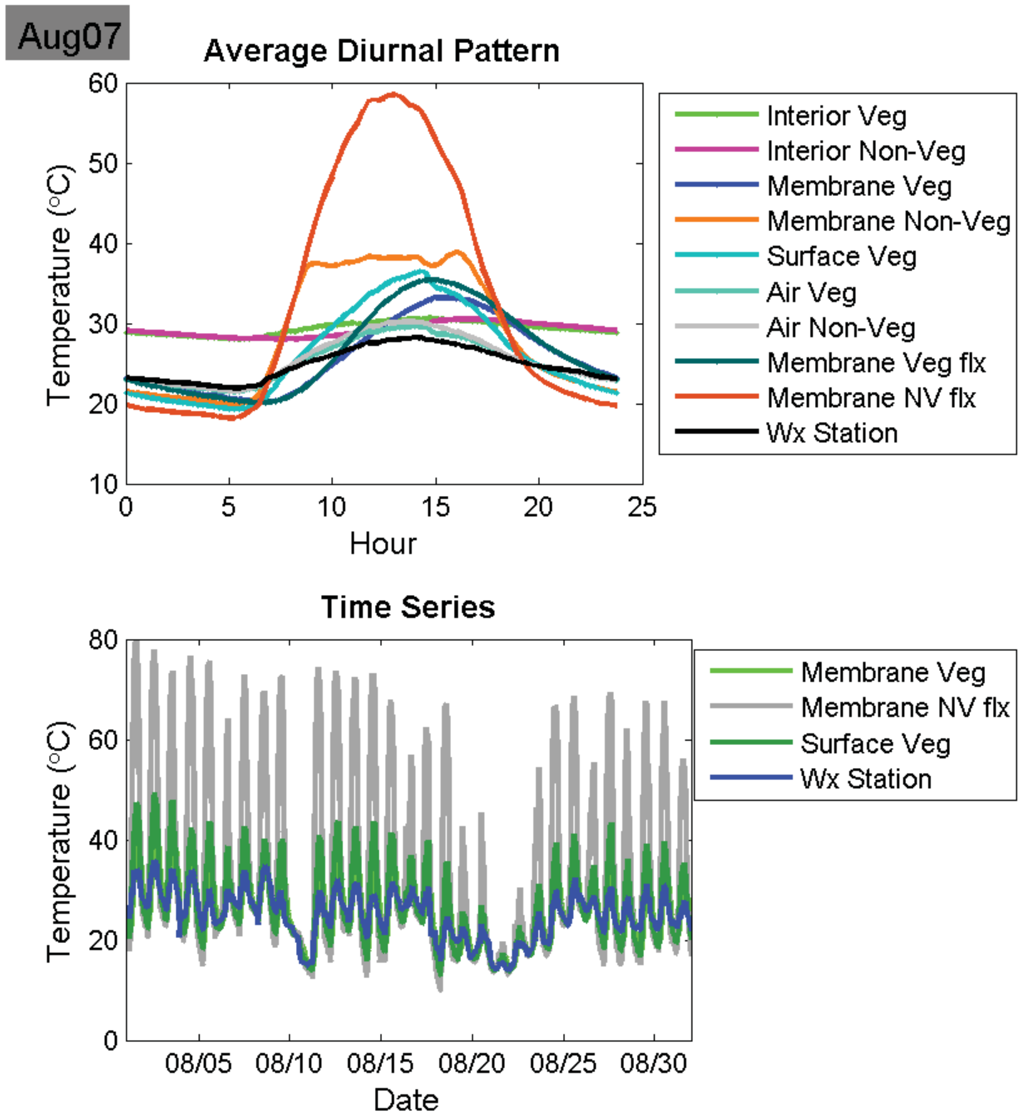

Figure 41: August 2007 Average diurnal temperatures (top) and monthly average temperatures.

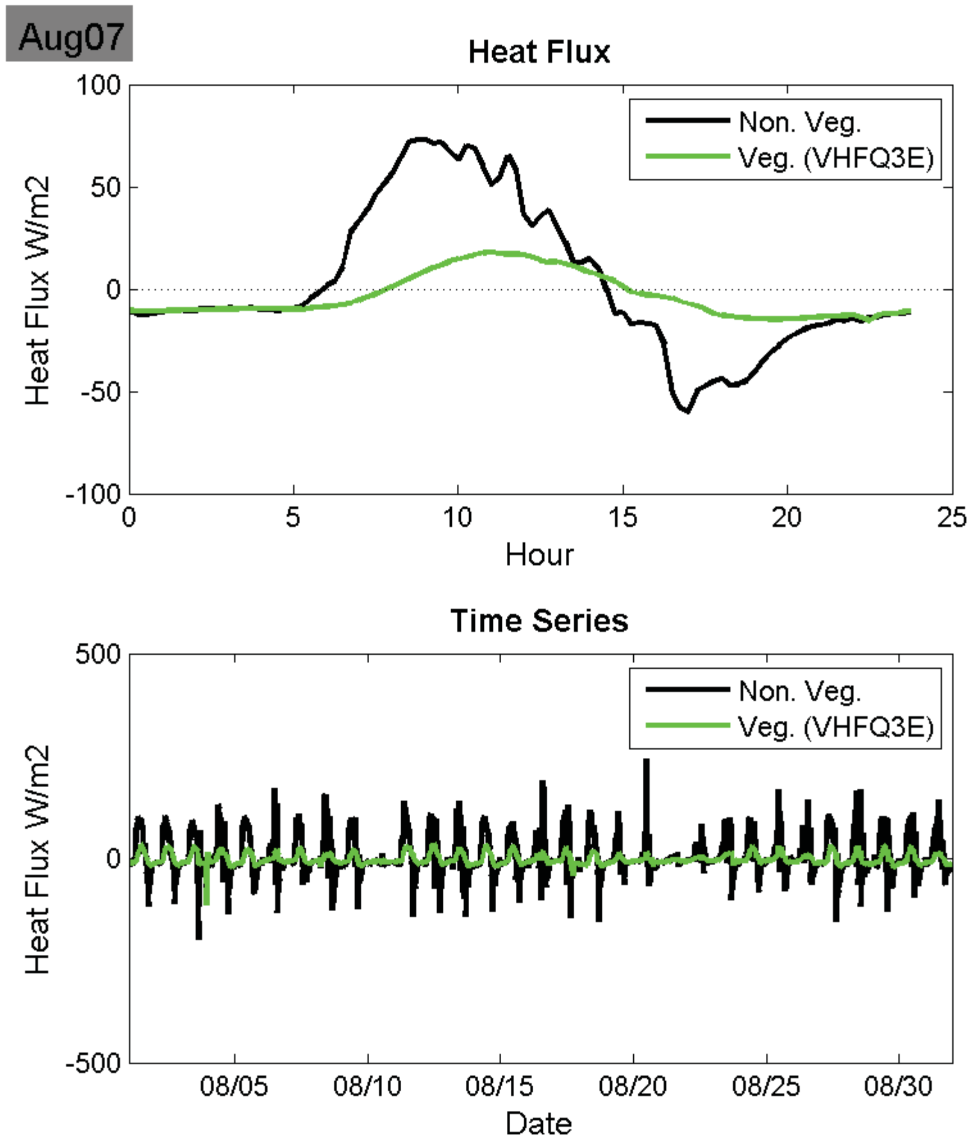

Figure 42: August 2007 Average diurnal heat flux through a green and non-green roof (top) and monthly daily heat flux.

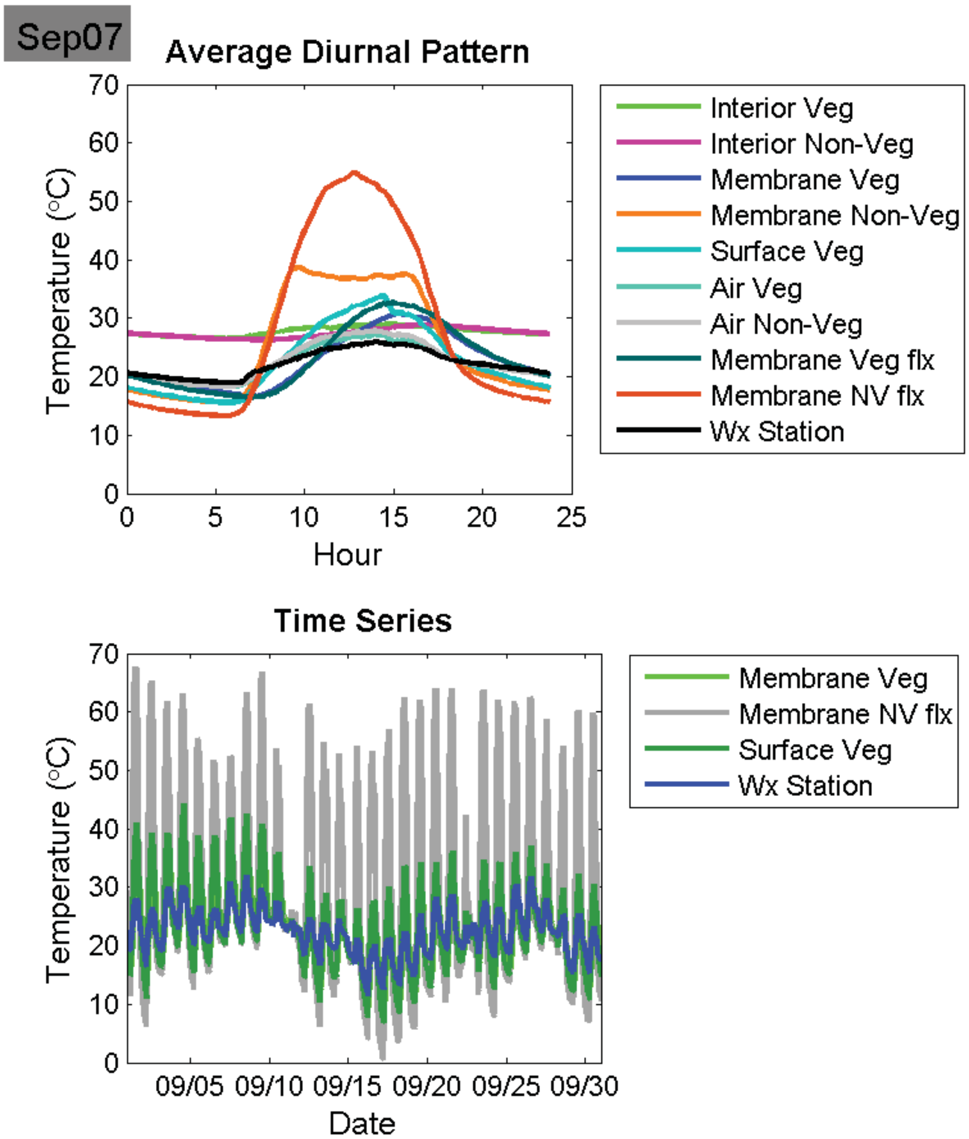

Figure 43: September 2007 Average diurnal temperatures (top) and monthly average temperatures.

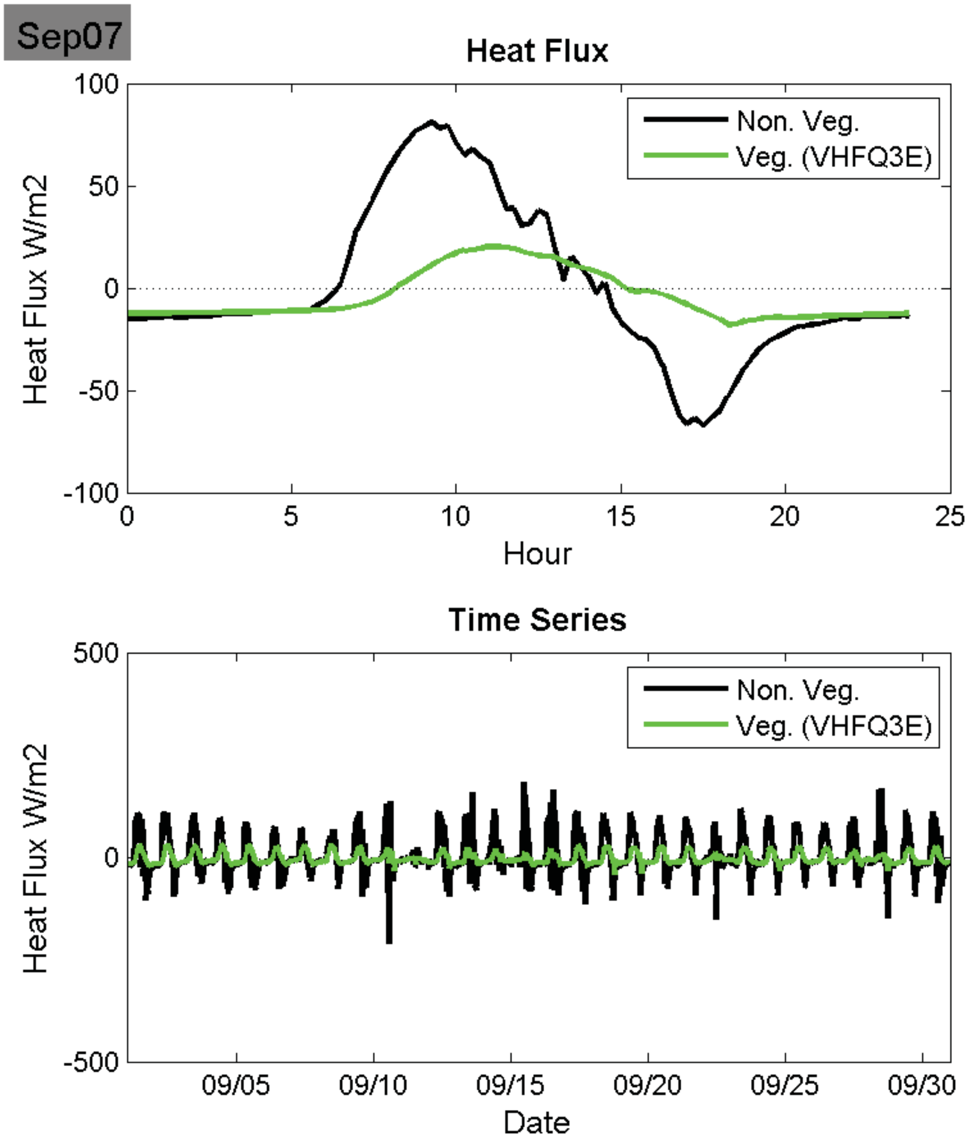

Figure 44: September 2007 Average diurnal heat flux through a green and non-green roof (top) and monthly daily heat flux.

6. STORMWATER RUNOFF AND RETENTION

6.1 Background

Development has led to large areas of impervious surfaces such as parking lots and building roofs. Runoff from these areas is causing problems for many urban and suburban communities. Not only are total wet weather flows increased, but peak flow rates are also increased. Rooftop greening has been suggested as a method to reduce these impacts by reducing the impervious surface within a developed zone (Scholz, 2001). The stormwater benefits offered by green roofs include not only direct retention of a portion of the rainfall, but also delaying the runoff peak and decreasing the peak rate of runoff from the site (PACD 1998; Carter & Rasmussen, 2006; Denardo et al., 2005; Jarrett et al., 2006). Annual reductions of runoff of 38 to 54% and 38 to 45% have been reported for 3 in.-thick roof media (Miller, 1998) and 40% retention of the 2-yr storm for 2.5 in. media (Scholz, 2001), the 2–yr storm being a primary metric for stormwater conveyance design. Many other studies have demonstrated similar stormwater retention and detention results (Berghage et al., 2008; Denardo et al., 2005; Rowe et al., 2003). However, large-scale in-situ studies are limited and green roof data specific to the New York City region is needed. This project reports on stormwater runoff and retention on the Gratz building green roof in New York City.

6.2 Data and Methods

Runoff from green and non-green roof quadrants on the Gratz building was monitored from October, 2006 through September, 2007. Details of the roof and the installation and locations of the runoff sensors are provided in *Section 3.1 Experimental Setup* of this report. Runoff data for green roof sections were collected for the entire period. Runoff data from the non-green roof and the vegetated Quad II were not collected from October 2006 through March 2007 due to system failure. Data from the tipping bucket rain gage installed on the site weather station were not available from November, 2006 through June, 2007, since the tipping bucket was removed for the winter months. Data for precipitation during this period were obtained from the NOAA NWS Central Park weather station, which is less than 10 miles from the Gratz Building in Long Island City and showed good agreement with the site precipitation data when available. Weather station precipitation data or Central Park precipitation data and runoff data from the green and non-green roof sections were used to calculate the percent retention for each rainfall event. Moisture probe data were compared to storm event data. Data were evaluated, summarized and analyzed using Excel.

6.3 Results and Discussion

6.3.1 Precipitation Summary

A total of 64 runoff or precipitation events were recorded during the monitoring period (Table 3, Table 4). Table 2 presents the rain event and runoff information for the vegetated roof sections, for the period of 10/1/06-9/30/07. Runoff results are averages for vegetated quadrant II and III from mid-March 2007 onward and refer to Quad III sensor prior to this date, due to Quad III sensor failure. Runoff data for the conventional quadrant is presented in Table 3 and has a limited duration (mid-March 2007 to Sept 2007). Of the rainfall events, 57 events had complete data sets for green roof runoff. These 57 events were used to determine monthly and seasonal summaries (Table 5, Table 6). The largest event during the monitoring period occurred on April 15, 2007. Total precipitation measured at the Central Park weather station was 8.4". Runoff from the green roof in this event totaled 10,427 gallons, which is just over 6" of runoff. The non-green control roof sections had 6.4" of runoff for the same event. There were several other large rain events captured during the monitoring period. Events in excess of 3" also included 3.62" on 11/8/06 and 3.88" on 6/3/07. Total measured precipitation during the period was 60.8" including events measured at Central Park and on site. Total precipitation in events used for monthly and seasonal summaries was 56.4" (Table 5). The total precipitation for events less than 3" used in summary data was 40.4". The total measured precipitation of 60.8" for the twelve months from October 2006 through September 2007 is higher than the average annual precipitation for New York City (49.8").

6.3.2 Green Roof Runoff and Retention

The Gratz green roof retained 38.6% of the total precipitation for measured events (Table 5). This retention resulted in a total of 37,200 gallons not running off into the storm water system for each section of monitored green roof. Monthly stormwater retention by the green roof ranged from 72% total retention in May, 2007 to 17% retention in January, 2007. Green roof retention for larger events was frequently less than 10% (*Figure 45, Figure 46*). Green roof retention was 100% for many smaller events. For example; in June, 2007 there were seven events where there was 100% retention. In contrast, retention from non-green roof sections was mostly between 10 and 30% except for small events where the non-green roof frequently retained in excess of 50% of the precipitation (Table 4). This is similar to many other reports (i.e. Denardo, et al. 2005) of stormwater on green and non-green roofs where a significant proportion of small events are retained by non-vegetated roofs but in storms larger than 0.25" most of the precipitation runs off.

Runoff from the green roof was greatest in the winter (79%) and least in the summer (55%) (Table 6), with intermediate values in the spring and fall. The greatest total retention occurred in the wettest month, April 2007 even though that month also had the greatest runoff (*Figure 47*). Summer months had greater total retention, while winter months had much lower total retention (*Figure 47*). Extreme events contribute significantly to the total runoff observed from the Gratz roof. If the precipitation events in excess of 3" are removed from the analysis, total annual retention by the green roof was 43%, with 51% in the summer, 47% in the spring, 39% in the fall, and 21% in the winter. Monthly retention rates range from 100% in June to 17% in January without events in excess of 3" (Table 7, Table 8). These values are similar to those reported for other green roofs where most studies suggest 40-60% annual retention.

The amount of runoff and retention was also influenced by the event frequency. Frequent precipitation events occupy the growing media's water holding capacity, causing more of the subsequent rain events to leave the roof as runoff (*Figure 45*). In this regard, the roof acts as a sponge with a limited water storage capacity. When the sponge is full of water, runoff occurs. When the sponge is dry, water is retained. The total potential for water retention is a function of the depth of the media and the moisture holding capacity of the media. The average water holding capacity for commercial green roof media is about 35-45% by volume, meaning that a 3.5-4" roof can retain between 1.5 and 2". Since the roof is seldom completely dry and the media retains some hard to release matric water, the capacity of a relatively dry roof is usually about 1". This is what we see with the Gratz roof, which retained for example just over 1" of rain on 8/21/07 (Table 3). Retention as a percentage of precipitation was greatest in the warmer months and less in the winter (*Figure 48*).

6.3.3 Soil Moisture and Runoff

Soil moisture, as indicated by the soil moisture probes and runoff, was well correlated in this study (Table 3). Precipitation events that produced runoff had soil moisture in excess of 30-40%, at the end of the event, while those that produced no runoff had soil moisture less than 20%. Events where the green roof retained water generally had lower soil moisture levels at the start of the rain event (Table 3).

The successful use of soil moisture probes in this study is an interesting and potentially important contribution to the monitoring of green roof effectiveness. Because the media on a roof is typically very different from that in a field soil with very high drainage and large particles, it is difficult to achieve good soil-probe contact and the effectiveness of soil moisture probes and their potential utility has thus been questioned. In this study, the moisture probes worked fairly consistently; and in fact provided data when other measurement systems on the site failed. Monthly charts of soil moisture and runoff rate confirm this relationship between roof moisture and runoff and can provide interesting insights into the function of the roof. In October, 2006 for example, soil moisture reached 45% with this peak corresponding to the highest rate of observed runoff (*Figure 49*). Other rain events that resulted in soil moisture in excess of 35% also resulted in runoff. The rain event early in the month that increased soil moisture to 25% (10/2/2006) did not result in runoff. It is interesting how quickly soil moisture drops from the peak during a rain event to 15-20%. This general pattern can be seen in other monthly charts of soil moisture and runoff (*Figure 34-44*).

Several other interesting patterns can be seen in evaluating these figures. There are several periods in the cold season, November 2006 through February 2007, where the probes go to zero either intermittently or for an extended period. These periods do not correspond to low temperatures or any other parameters measured in this study. There are a number of changes in winter soil moisture that do not correspond to measured runoff and may be the result of snow melt. It might be expected that small snow events would not result in runoff. In wet periods with frequent rains like the end of March, 2007 (*Figure 54*) the moisture probes suggest that the media remains quite wet as would be expected for periods with limited evapotranspiration. In contrast, the summer soil moisture approaches pre-storm levels in as little as five days. This result agrees with reported evapotranspiration from green roof plants (Berghage et al 2007).

6.3.4 Individual and Typical Storm Events

Perhaps the most interesting event recorded in this study was the extreme event in mid April resulting in over 6" of runoff from over 8" of rain. This event demonstrates the function of a green roof under extreme conditions. As has been reported in other studies, the first portion of the storm event is retained by the roof (*Figure 61*). Once the roof reaches field moisture capacity, additional rain results in runoff similar to that from a non-green control roof. Although any moisture in excess of field capacity eventually runs off the roof, the green roof reduces peak flows similar to a detention basin. The peak flow off of the conventional roof was nearly 20 gal/min. In contrast, the peak flow from the green roof was 14 gal/min. The green roof briefly stores water and slows down the flow as the runoff is forced to travel through the media. This has been reported in previous studies, however many of those were based on small test roofs or small measurement modules on larger roofs. In this case, the result is confirmed on a larger scale. The runoff from the green roof begins after the conventional roof and ends after the conventional roof runoff ceases, the peaks are dampened, and the overall runoff volume is less (72% of rainfall compared to 75%). It is also interesting to observe the dampening of the two small runoff peaks by the green roof late in this storm. In this case, the green roof continued to greatly attenuate runoff peaks even though the roof was clearly saturated.

A more typical large rainfall event, 1.4" on 7/5/07, is shown in *Figure 62*. Runoff follows the typical pattern where the first part of the storm is retained and runoff peaks are attenuated with runoff occurring for an extended period after the precipitation ceased. It is also interesting to note that the attenuation of the first large peaks in this storm is greater than observed in the later peak. This is frequently observed for green roof runoff, where runoff from the roof may begin before full field capacity moisture retention is reached in heavy rains. This is a function of the green roof media, which has a high percentage of large particles to allow rapid drainage of excess moisture. In a heavy rain, moisture is flowing though the media even while it is being absorbed by the media.

A typical summer rain for the Northeast U.S. is shown in *Figure 63* for the Gratz building (6/27/07). In this event, less than half an inch of rain fell. There was no runoff from the green roof, while nearly all the precipitation from the conventional roof was measured as runoff.

6.4 Conclusions

The Gratz green roof effectively reduced the amount of stormwater runoff contributed to the city stormwater drainage system by about 40%, or over 74,400 gallons from the two monitored sections during the period studied. The roof was most effective in the summer and least effective in the winter. The roof was most effective at retaining typical small summer rains of less than 1", frequently retaining 100% of these events. Winter precipitation retention was limited by the lack of evaporation and evapotranspiration as indicated by relatively high soil moisture during this period. In extreme events, the roof retained water up to the field capacity of the media (approximately 1.5") followed by runoff similar to that from the non-green control roof section. Even when saturated, the green roof affected peak flows and held gravitational water in macropores. It resulted in lower peak flows and runoff that continued for a period after the storm event had ended. The soil moisture probes functioned well and could be used in conjunction with a rain gage to evaluate the effectiveness of a green roof that is not equipped with a runoff measurement system.

Table 3: Gratz rain event summary for vegetated roof sections, Oct 2006-Sept 2007

Date	Total Rain (in)	Vegetated Roof					
		% retained	% runoff	Total retained (gal)	Total runoff (gal)	Soil moisture (% start)	Soil moisture (% end)
10/1/2006	0.41	100	0	701	0	6	20
10/4/2006	0.69	51	49	606	547	9	25
10/11/2006	1.57	20	80	526	2159	9	28
10/18/2006	1.04	30	70	533	1246	12	27
10/19/2006	0.4	65	35	442	242	14	27
10/27/2006	1.92	18	82	592	2691	8	28
10/31/2006	0.63	100	0	1077	0	11	11
11/2/2006	0.26*						
11/8/2006	3.62*	31	69	1915	4267	31	30
11/12/2006	0.3*						
11/13/2006	0.5*	54	46	458	397	1	1
11/17/2006	0.73*	49	51	608	641	38	34
11/23/2006	1.92*	18	82	602	2683	41	37
12/1/2006	0.23*	34	66	133	261	34	35
12/13/2006	0.21*					35	
12/22/2006	1.25*	25	75	528	1610	6	59
12/25/2006	0.45*	13	87	97	673	59	49
1/1/2007	1.52*	29	71	753	1847	57	48
1/8/2007	1.42*	4	96	103	2325	61	47
1/13/2007	1.63*						
1/18/2007	0.19*						
2/2/2007	0.23*						
2/13/2007	0.97*						
2/20/2007	0.11*	0	100	0	188	36	32
2/21/2007	*				606	32	29
2/22/2007	0.21*	68	32	244	115	31	30
2/27/2007	*				141	41	32
3/2/2007	2.55*	11	89	486	3875	45	40
3/16/2007	*	90	10	3662*	4070	11	35
3/18/2007	*				15	38	39
3/19/2007	*				2107	23	32
3/23/2007	0.09*	100	0	154	0	17	32
4/1/2007	0.05*	100	0	85	0	7	9
4/2/2007	0.06*	100	0	102	0	10	17
4/4/2007	0.85*	35	65	510	943	11	35
4/12/2007	1.38*	15	85	362	1998	8	35
4/15/2007	8.41*	28	72	3955	10427	13	38
4/16/2007	0.1*	100	0	171	0	34	38
4/25/2007	0.14*	100	0	239	0	5	9

4/27/2007	2.04*	33	67	1136	2352	9	40
5/1/2007	0.42*	65	35	470	248	10	36
5/11/2007	0.17*	100	0	290	0	4	20
5/12/2007	0.18*	100	0	308	0	11	19
5/17/2007	0.83*	57	43	815	604	7	33
5/19/2007	0.2*	100	0	342	0	17	33
6/3/2007	3.88*	28	72	1865	4770	2	36
		100	0	564	0	6	18

(Table continued)

Date	Total Rain (in)	Vegetated Roof					
		% retained	% runoff	Total retained (gal)	Total runoff (gal)	Soil moisture (% start)	Soil moisture (% end)
6/16/2007	0.04*	100	0	68	0	7	8
6/19/2007	0.43*	100	0	734	0	4	9
6/20/2007	0.085*	100	0	144	0	9	11
6/21/2007	0.18*	100	0	307	0	7	10
6/27/2007	0.14	100	0	239	0	3	5
6/27/2007	0.42	100	0	709	0	5	24
7/5/2007	1.31	35	65	774	1466	9	32
7/5/2007	0.12	100	0	204	0	23	32
7/11/2007	1.01	53	47	909	818	4	31
7/18/2007	2.04	45	55	1555	1933	5	35
8/3/2007	0.56	83	17	798	159	6	34
8/8/2007	2.92	50	50	2482	2512	11	35
8/10/2007	0.99	30	70	513	1180	17	38
8/17/2007	0.25	100	0	426	0	7	20
8/19/2007	0.10	100	0	169	0	15	25
8/21/2007	1.37	8	92	191	2152	30	34
9/10/2007	0.26	100	0	445	0	8	19
9/11/2007	0.85	21	79	306	1148	28	39
9/15/2007	0.09	100	0	154	0	30	35
9/22/2007	0.33	52	48	292	272	24	40
9/28/2007	0.2	100	0	342	0	30	35

* In rain column indicates rain data obtained from Central Park rather than on site.
** In rain column indicates no rain data for the runoff event.
* In retention (gal) column indicates that the amount of rain calculated as retained likely exceeded the capacity of the roof to store water.

Table 4: Gratz rain event summary for non-green roof sections; Data from 3/16/07-9/30/07

Date	Total Rain (in)	Non-vegetated		
		% Runoff	Total runoff (gal)	Peak runoff rate (gpm)
3/16/2007	**		408	2.8
3/18/2007	**		68	0.7
3/19/2007	**		2064	7.7
3/23/2007	0.09*	66	154	1.2
4/1/2007	0.05*	59	51	1.5
4/2/2007	0.06*	213	220	6.3
4/4/2007	0.85*	90	1310	15.4
4/12/2007	1.38*	104	2472	16.2
4/15/2007	8.41*	75	10853	20.2
4/16/2007	0.1*	56	96	1
4/25/2007	0.14*	68	164	3.2
4/27/2007	2.04*	67	2353	18.2
5/1/2007	0.42*	100*	790	9.8
5/11/2007	0.17*	94	275	17.7
5/12/2007	0.18*	78	240	4.1
5/17/2007	0.83*	84	1195	18.5
5/19/2007	0.2*	34	129	2.0
6/3/2007	3.88*	76	5079	17.6
6/12/2007	0.33*	61	221	17
6/16/2007	0.04*	100	69	4.9
6/19/2007	0.43*	30	219	5.3
6/20/2007	0.085*	43	63	2.6
6/21/2007	0.18*	45	140	8.8
6/27/2007	0.14	68	163	15,2
6/27/2007	0.42	88	628	15.4
7/5/2007	1.31	73	1637	17.7
7/5/2007	0.12	85	176	4.8
7/11/2007	1.01	46	791	20.9
7/18/2007	2.04	44	1527	20.8
8/3/2007	0.56	64	344	20.1
8/8/2007	2.92	35	1742	21.2
8/10/2007	0.99	91	1553	11.3
8/17/2007	0.25	62	264	16.1
8/19/2007	0.10	73	125	1.4
8/21/2007	1.37	91	2147	11.3
9/10/2007	0.26	45	201	16.9
9/11/2007	0.85	55	789	18.5
9/15/2007	0.09	70	107	2.4
9/22/2007	0.33	81	456	16.1
9/28/2007	0.2	37	125	14.98

* in rain column indicates data obtained from Central Park
** in rain column indicates no rain data for the runoff event
* in % runoff column indicates no data collected

Table 5: Monthly summary of runoff from the Gratz green roof

	Rain (in)	Retention (in)	Runoff (in)	Retention %	Runoff %
October, 2006	6.7	2.6	4.0	39.3%	60.5%
November, 2006	6.8	2.1	4.7	30.9%	69.0%
December, 2007	1.9	0.4	1.5	23.0%	77.1%
January, 2007	2.9	0.5	2.4	17.0%	83.0%
February, 2007	0.3	0.1	0.2	44.6%	55.4%
March, 2007	5.0	2.5	2.5	50.1%	49.9%
April, 2007	13.0	3.8	9.2	29.4%	70.5%
May, 2007	1.8	1.3	0.5	72.3%	27.7%
June, 2007	5.5	2.7	2.8	49.2%	50.7%
July, 2007	4.5	2.0	2.5	44.9%	55.0%
August, 2007	6.2	2.7	3.6	43.3%	58.1%
September, 2007	1.7	0.9	0.8	52.0%	48.0%
Total	**56.4**	**21.8**	**34.7**	**38.6%**	**61.5%**

Table 6: Seasonal summary of runoff and retention from the Gratz green roof

	Rain (in)	Retention (in)	Runoff (in)	Retention %	Runoff %
Summer	16.2	7.4	8.9	45.7%	54.7%
Fall	15.2	5.6	9.5	37.0%	62.8%
Winter	5.2	1.1	4.1	20.9%	79.1%
Spring	19.9	7.7	12.5	38.6%	62.9%

Table 7: Monthly summary of runoff and retention on the Gratz green roof with extreme events removed (all events >3" removed)

	Rain (in)	Retention (in)	Runoff (in)	Retention %	Runoff %
October, 2006	6.7	2.6	4.0	39.3%	60.5%
November, 2006	3.2	1.0	2.2	31.0%	69.1%
December, 2007	1.9	0.4	1.5	23.0%	77.1%
January, 2007	2.9	0.5	2.4	17.0%	83.0%
February, 2007	0.3	0.1	0.2	44.6%	55.4%
March, 2007	5.0	2.5	2.5	50.1%	49.9%
April, 2007	4.6	1.5	3.1	33.0%	67.0%
May, 2007	1.8	1.3	0.5	72.3%	27.7%
June, 2007	1.6	1.6	0.0	99.5%	0.0%
July, 2007	4.5	2.0	2.5	44.9%	55.0%
August, 2007	6.2	2.7	3.6	43.3%	58.1%
September, 2007	1.7	0.9	0.8	52.0%	48.0%
Total	**40.5**	**17.2**	**23.3**	**42.6%**	**57.6%**

Table 8: Seasonal summary of runoff and retention from the Gratz green roof with all events in excess of 3" removed.

	Rain (in)	Retention (in)	Runoff (in)	Retention %	Runoff %
Summer	12.3	6.3	6.1	51.3%	49.3%
Fall	11.5	4.5	7.0	38.9%	60.9%
Winter	5.2	1.1	4.1	20.9%	79.1%
Spring	11.4	5.3	3.6	46.7%	31.4%

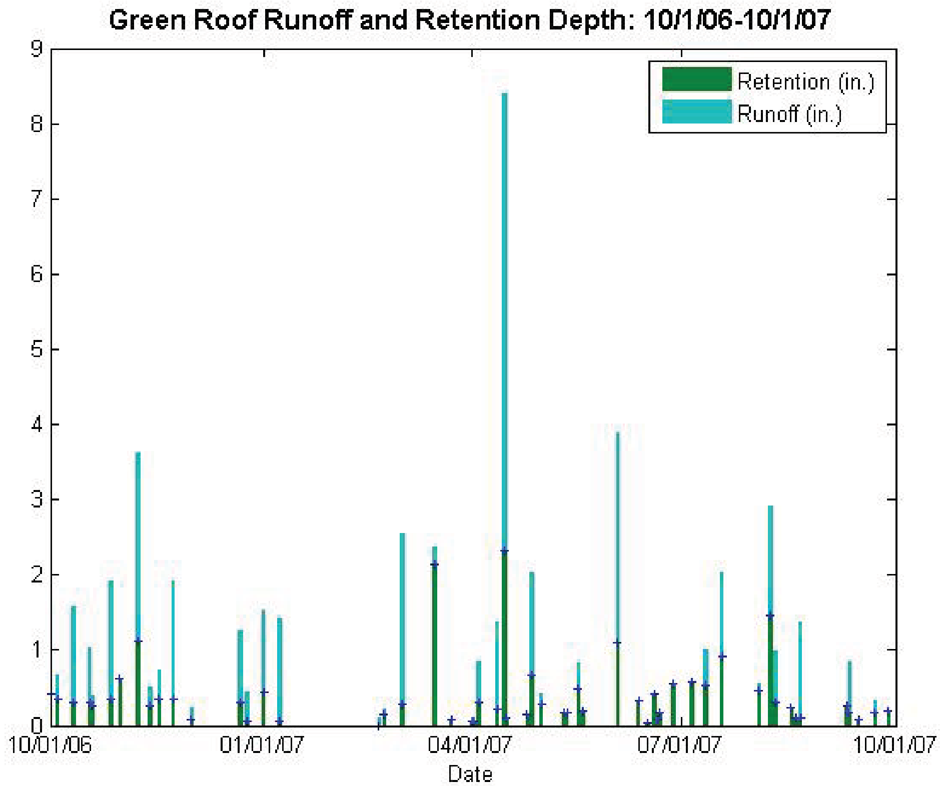

Figure 45: Runoff and retention of measured precipitation events by the Gratz green roof in New York City. The total bar height (Runoff + Retention) is equal to the measured precipitation.

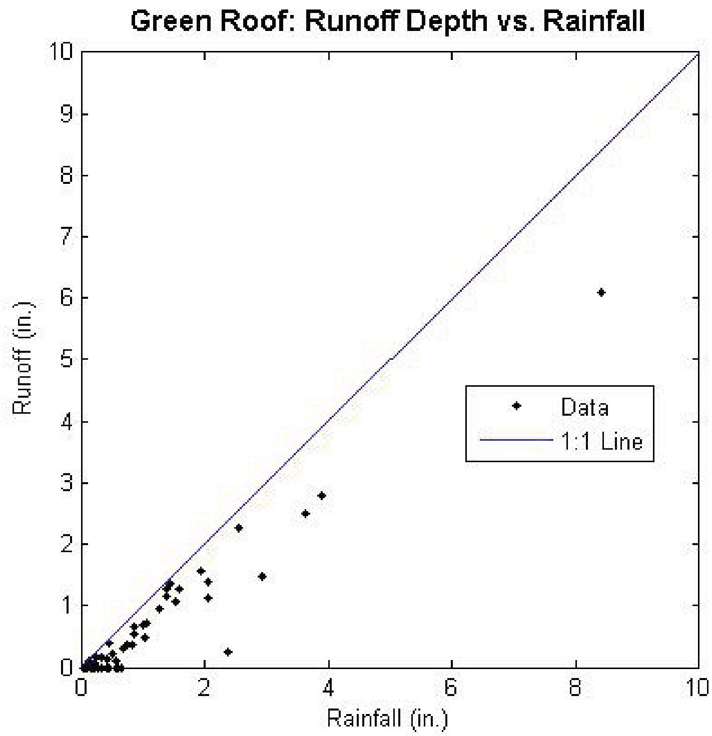

Figure 46: Scatter plot of green roof runoff versus precipitation for rainfall events from 10/1/06 to 10/1/07.

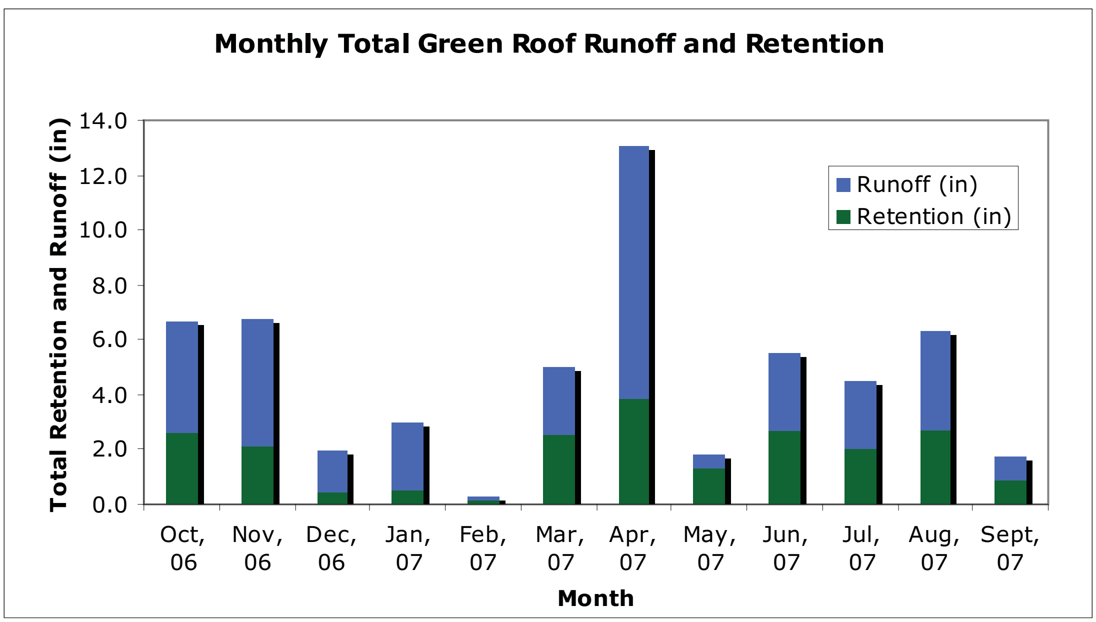

Figure 47: Monthly runoff and retention of stormwater by the Gratz green roof in New York City. Total bar (Runoff + Retention) height is equal to the total precipitation for events measured during each month.

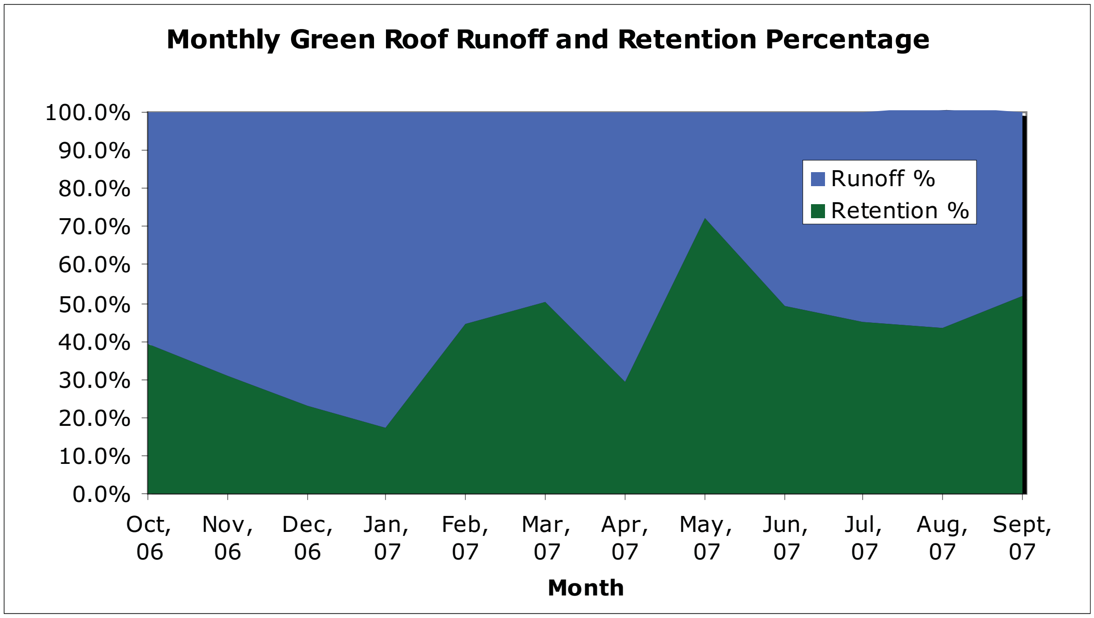

Figure 48: Stormwater runoff and retention as a percentage of the total precipitation of measured events for each month.

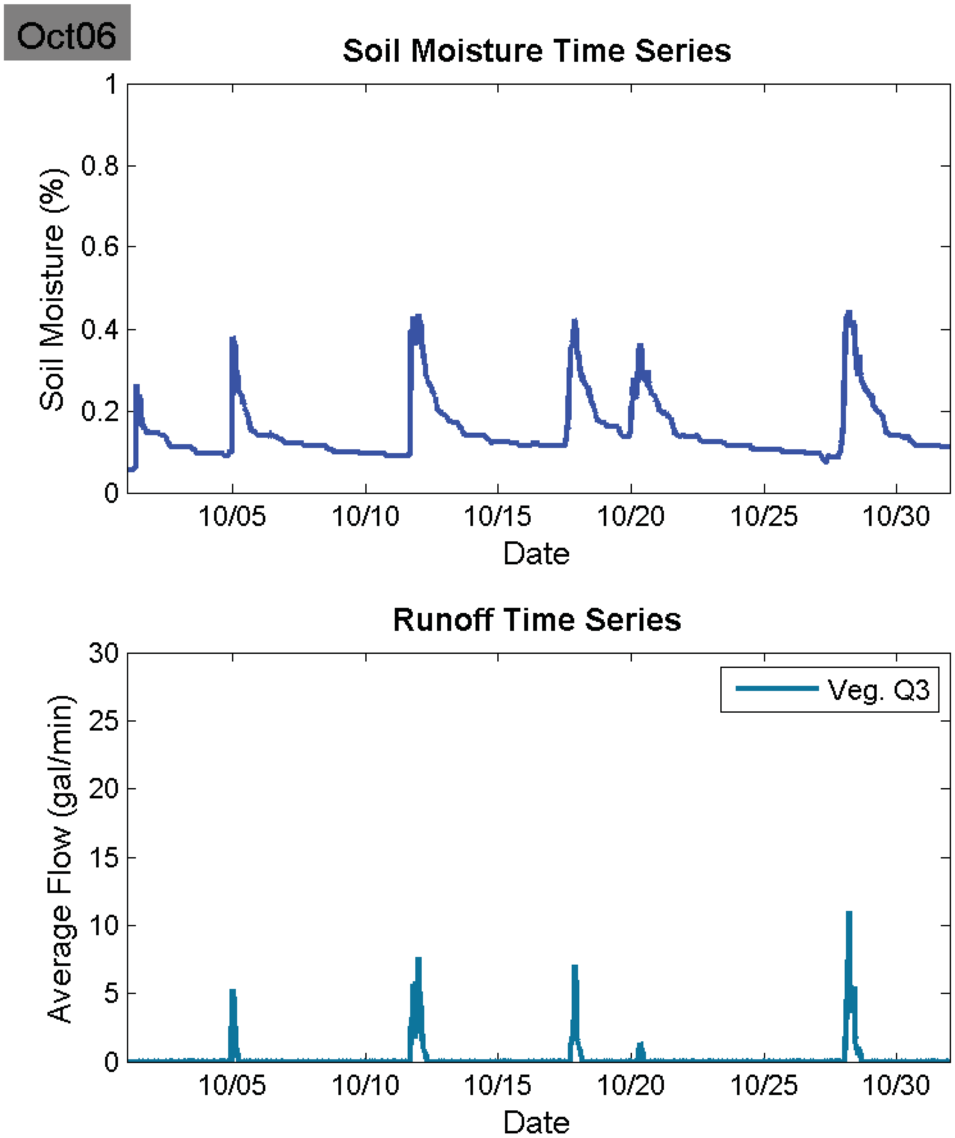

Figure 49: October 2006 Soil moisture (%) and Veg. Q3 runoff (gal/min).

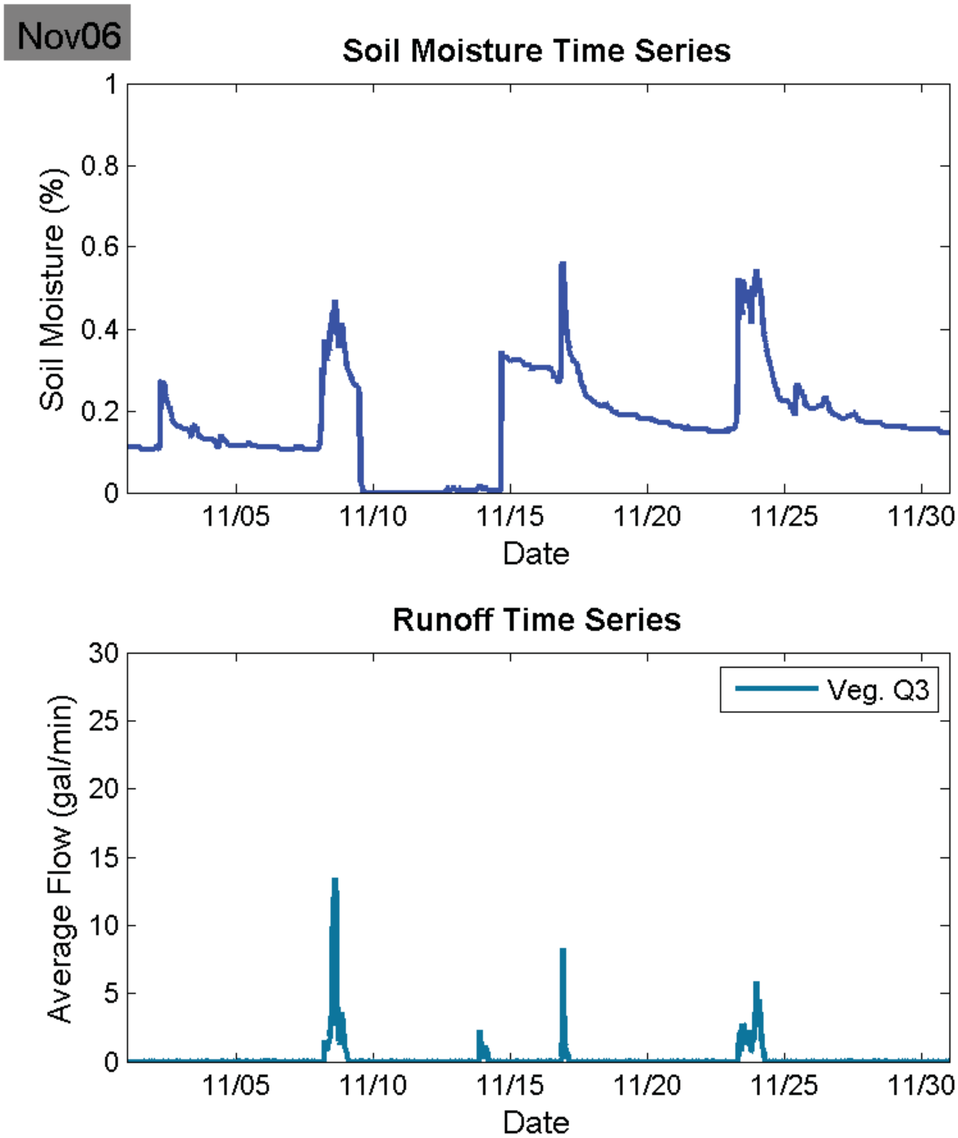

Figure 50: November 2006 Soil moisture (%) and Veg. Q3 runoff (gal/min).

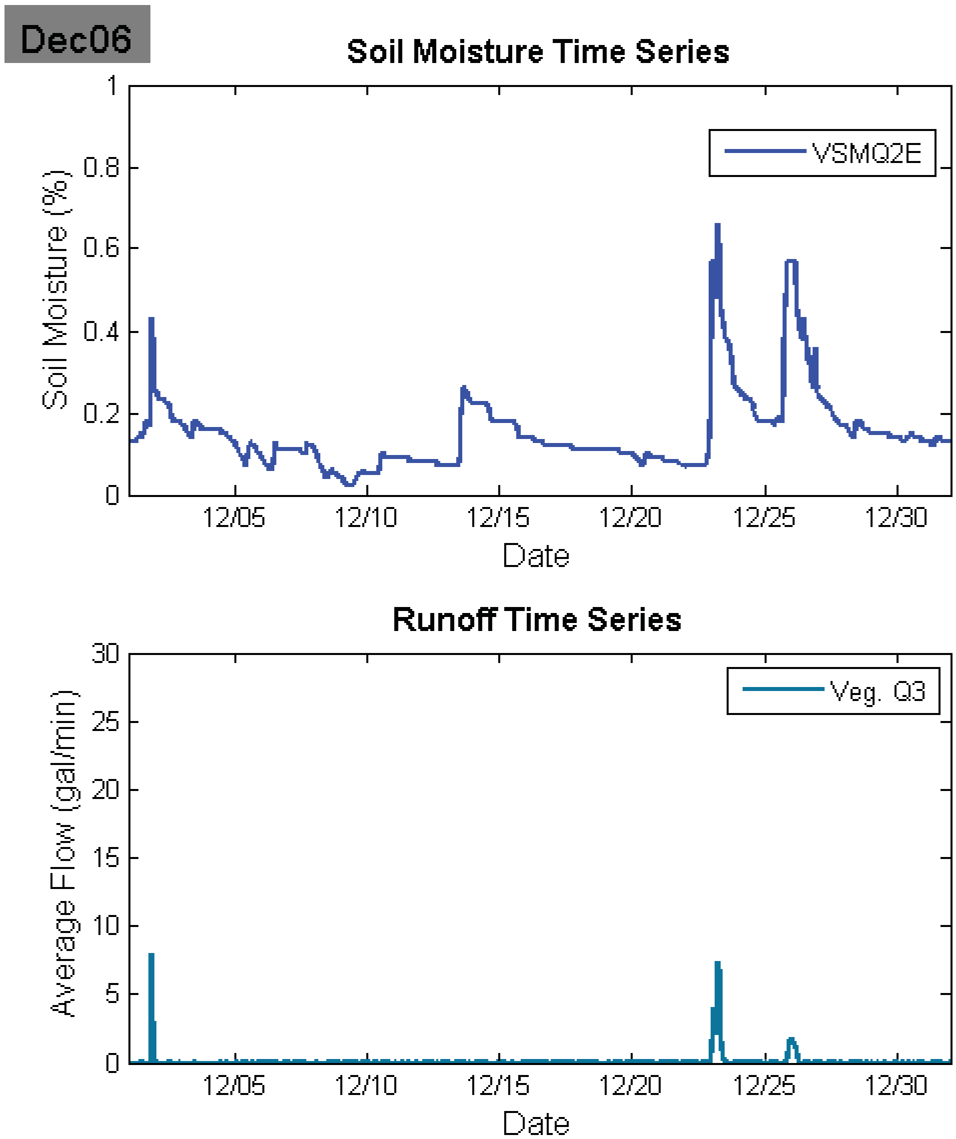

Figure 51: December 2006 Soil moisture (%) and Veg. Q3 runoff (gal/min). The quadrant III soil moisture (VSMQ3E) probe malfunctioned in this month, so in place of an average, only the quadrant II soil moisture (VSMQ2E) is shown.

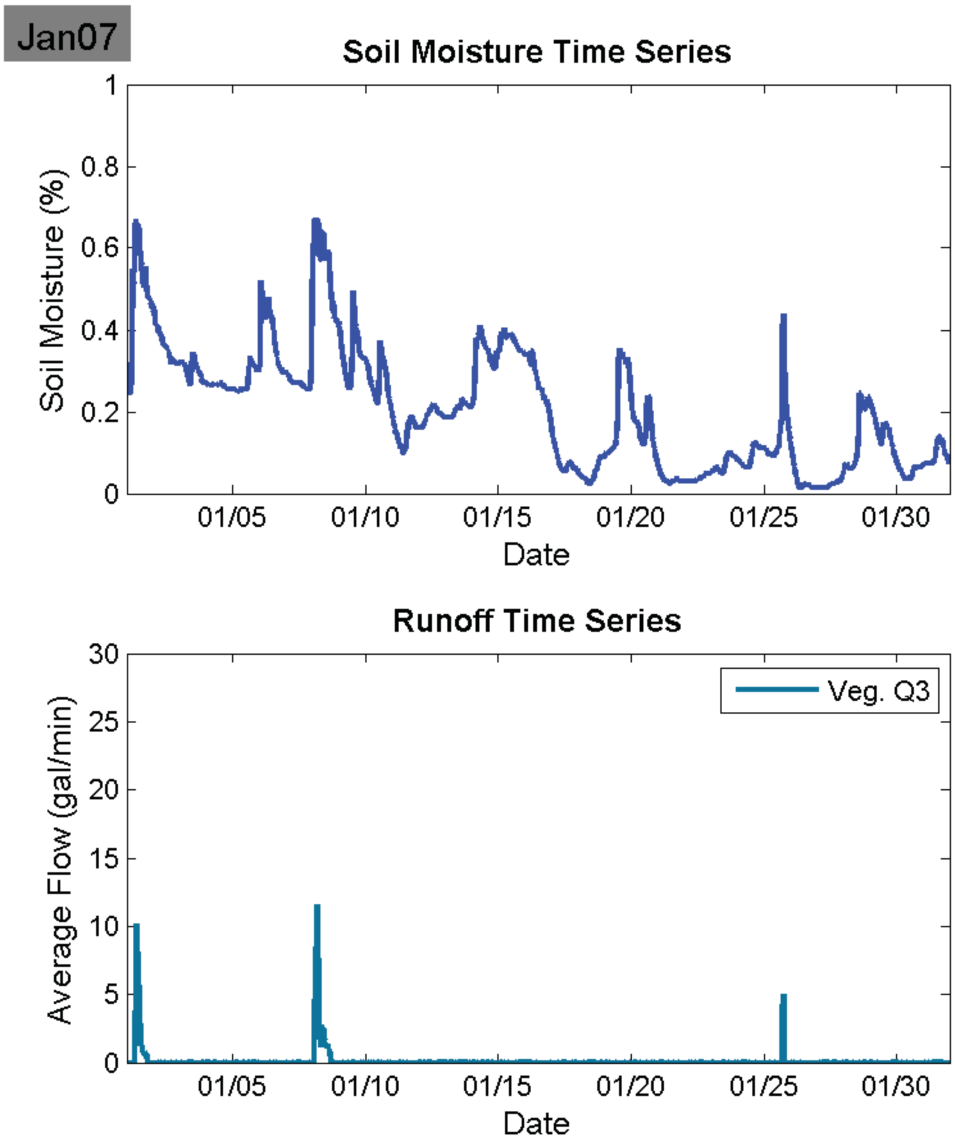

Figure 52: January 2007 Soil moisture (%) and Veg. Q3 runoff (gal/min).

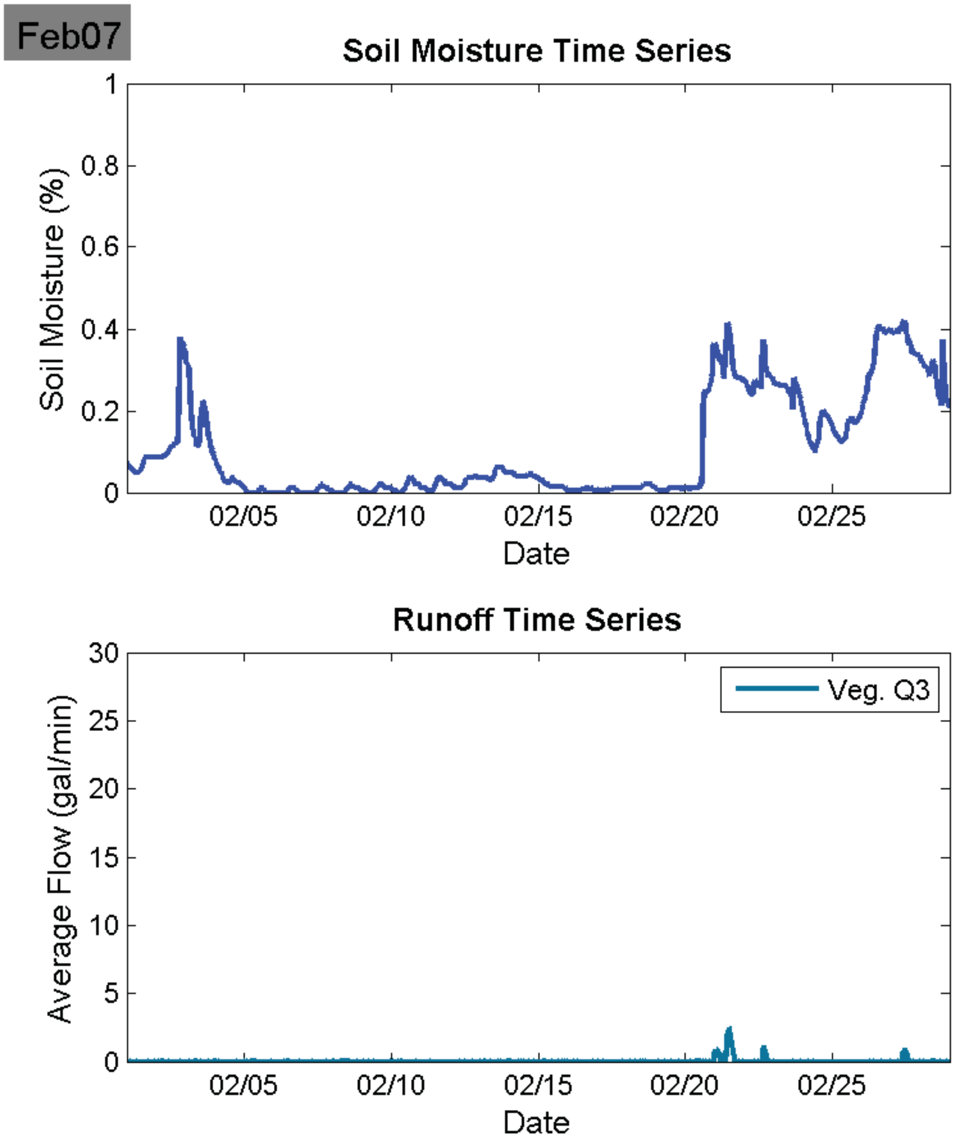

Figure 53: February 2007 Soil moisture (%) and Veg. Q3 runoff (gal/min).

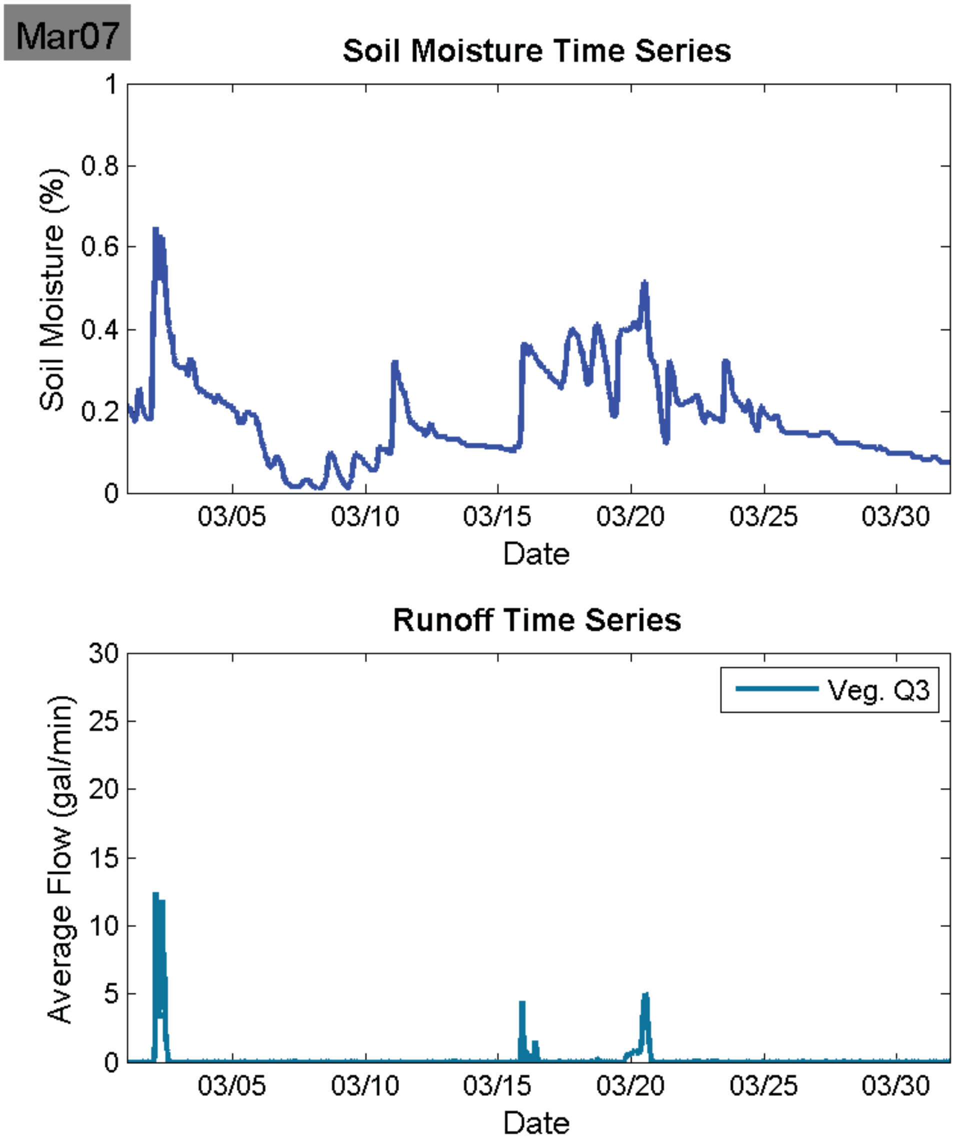

Figure 54: March 2007 Soil moisture (%) and Veg. Q3 runoff (gal/min).

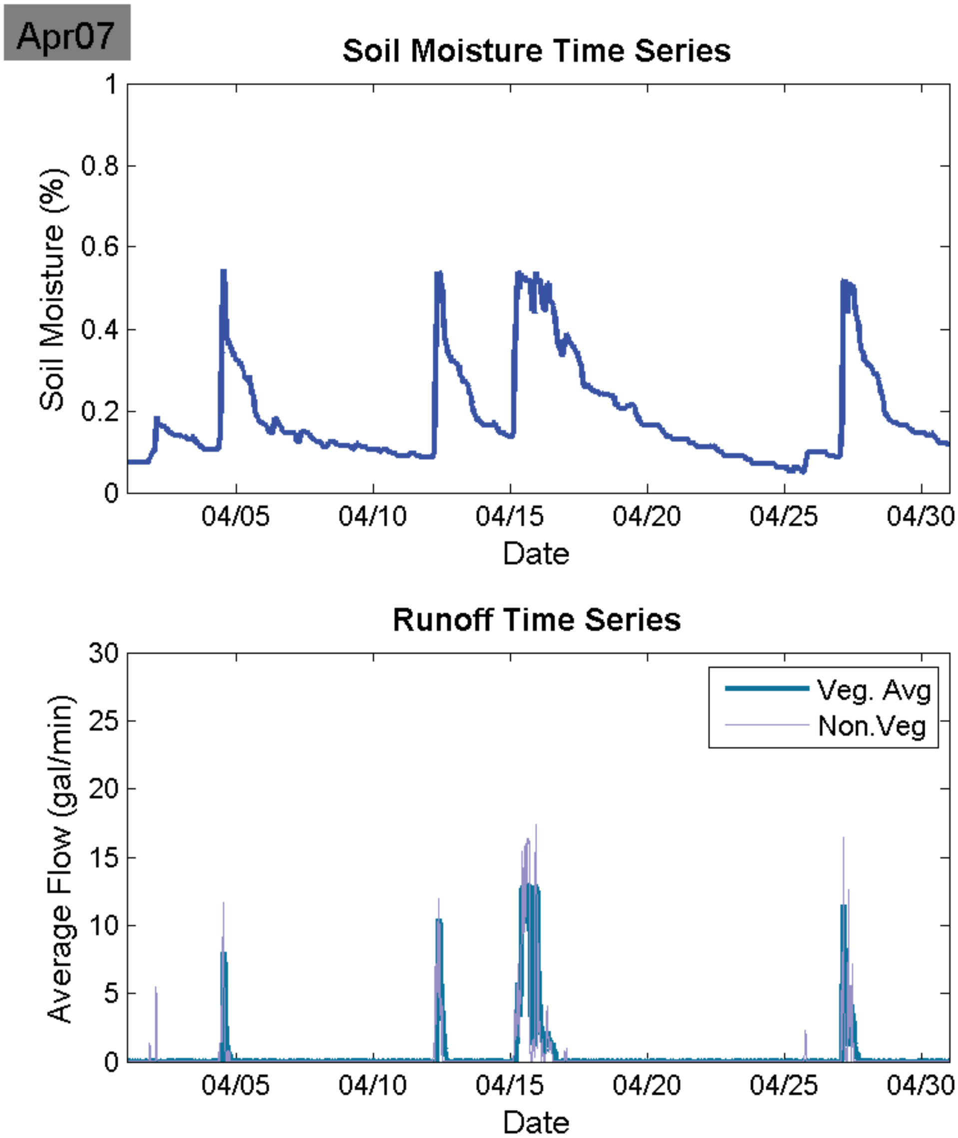

Figure 55: April 2007 Soil moisture (%) and Veg. Avg. runoff (gal/min).

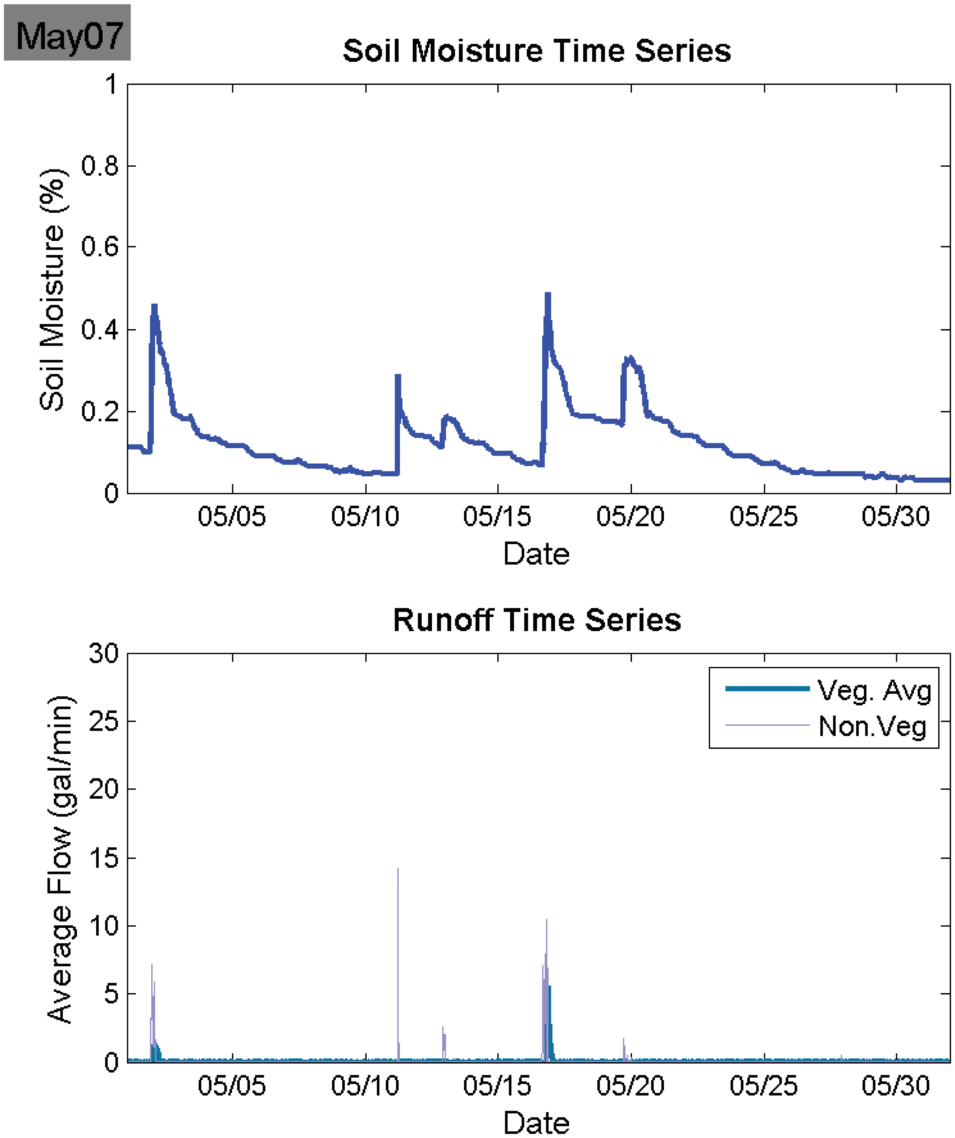

Figure 56: May 2007 Soil moisture (%) and Veg. Avg. runoff (gal/min).

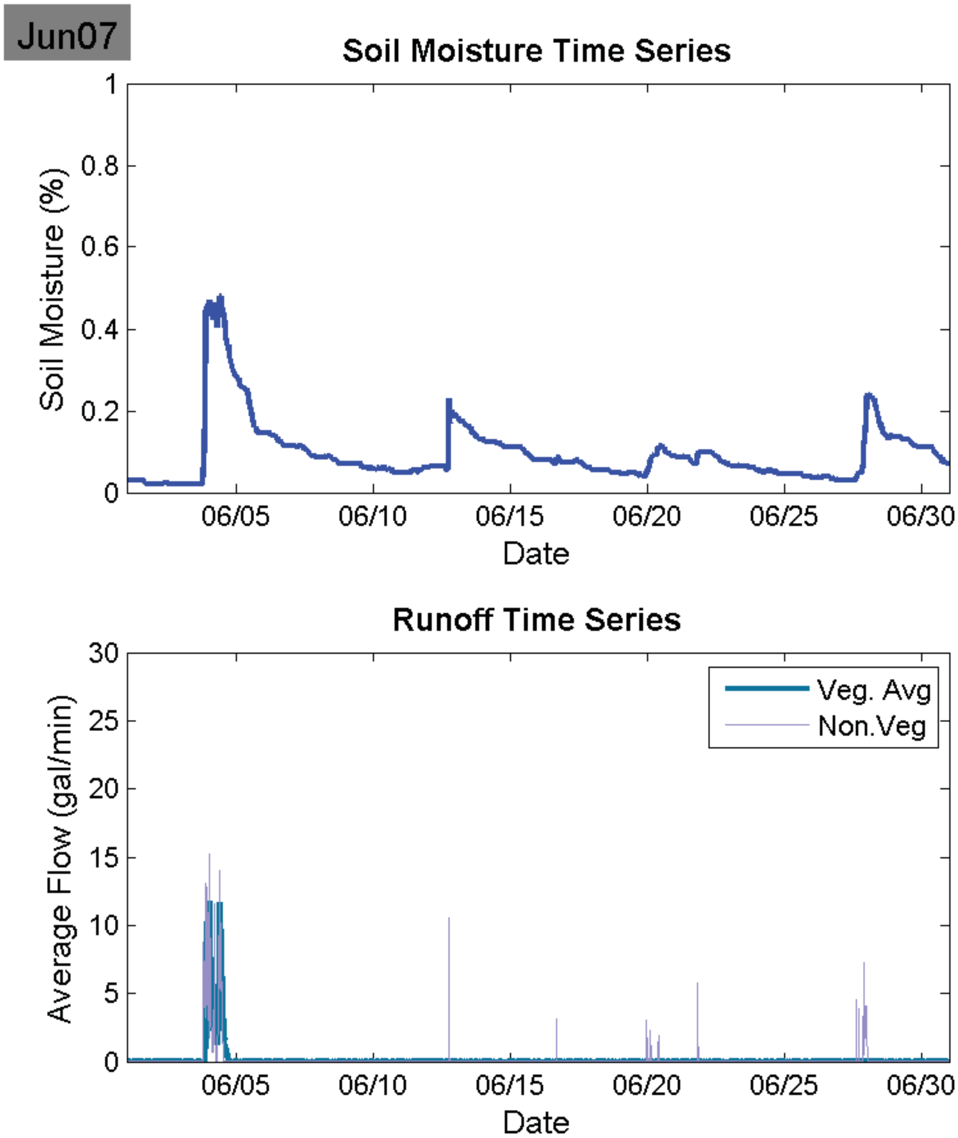

Figure 57: June 2007 Soil moisture (%) and Veg. Avg. runoff (gal/min).

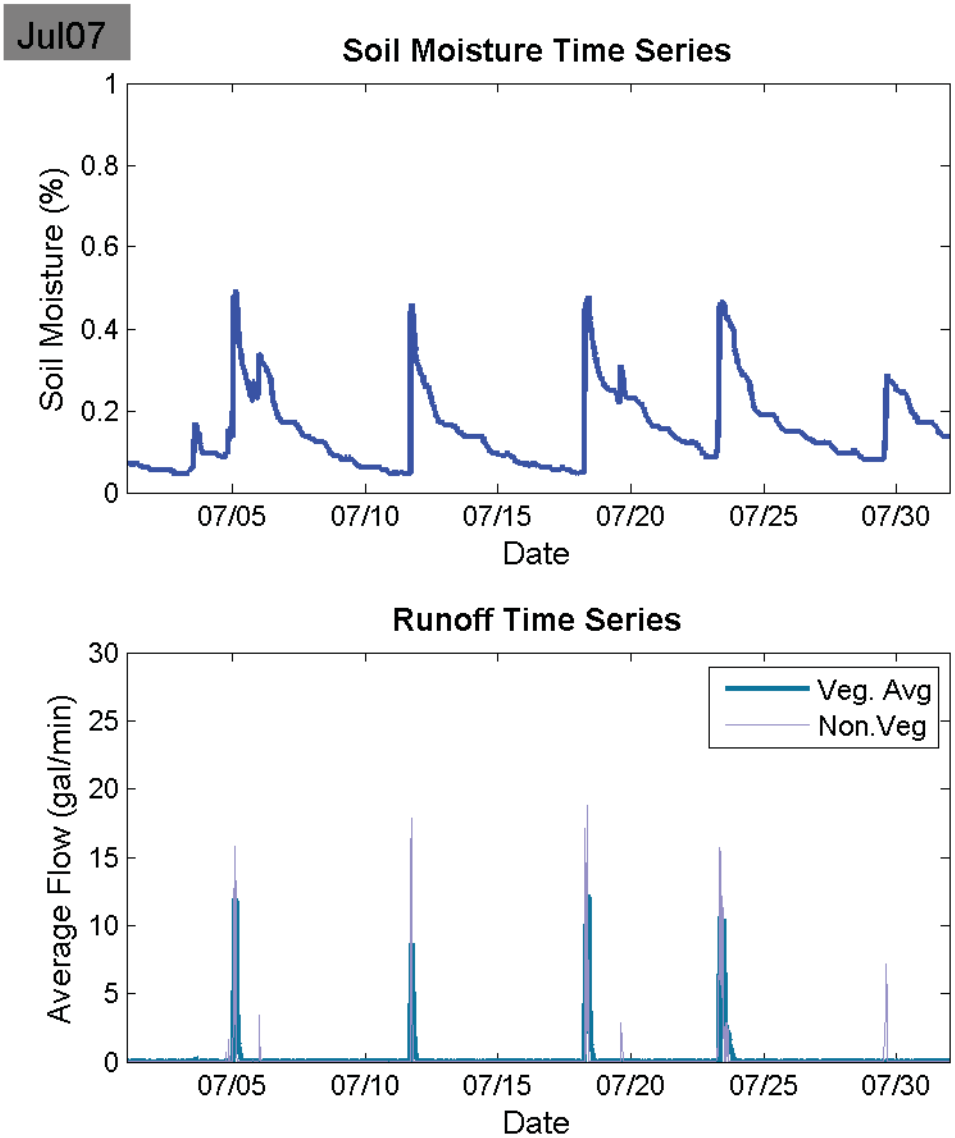

Figure 58: July 2007 Soil moisture (%) and Veg. Avg. runoff (gal/min).

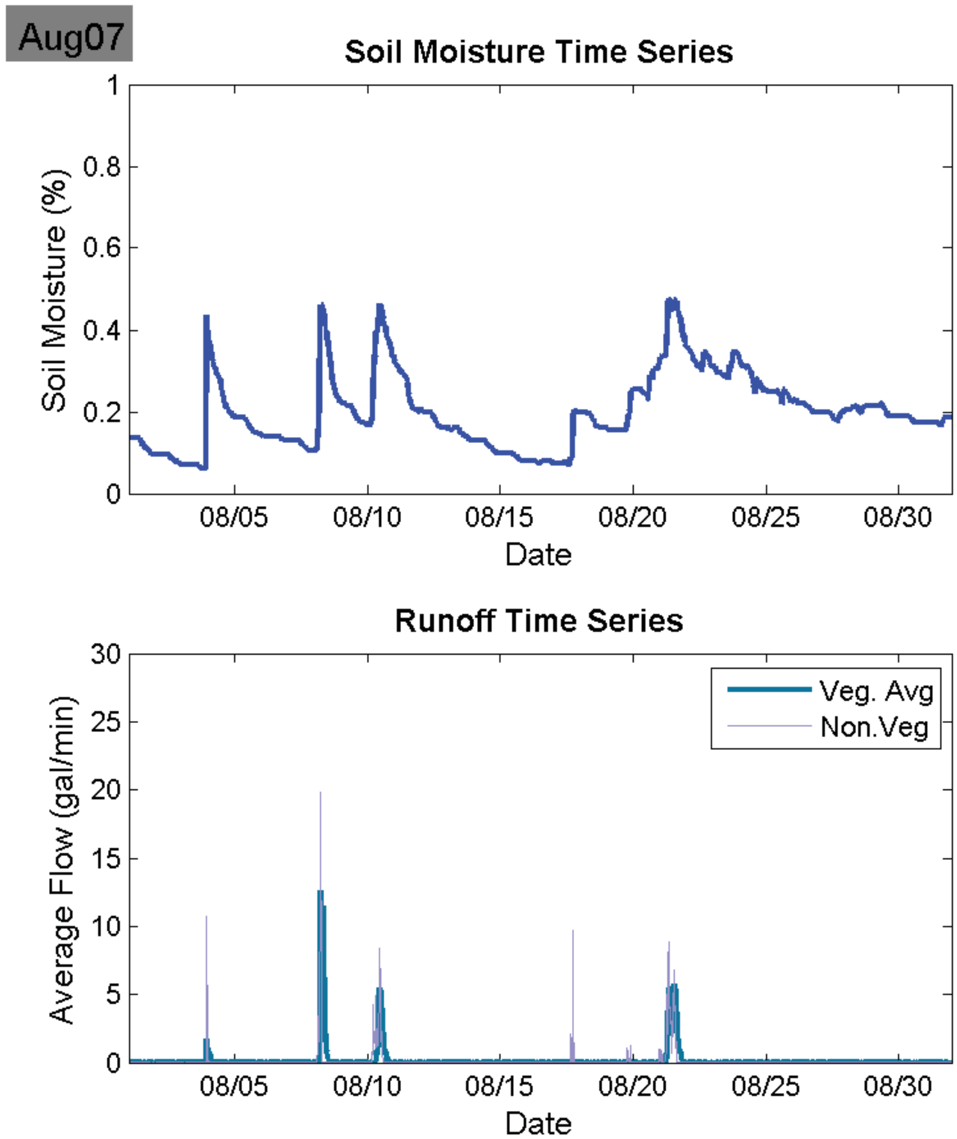

Figure 59: August 2007 Soil moisture (%) and Veg. Avg. runoff (gal/min).

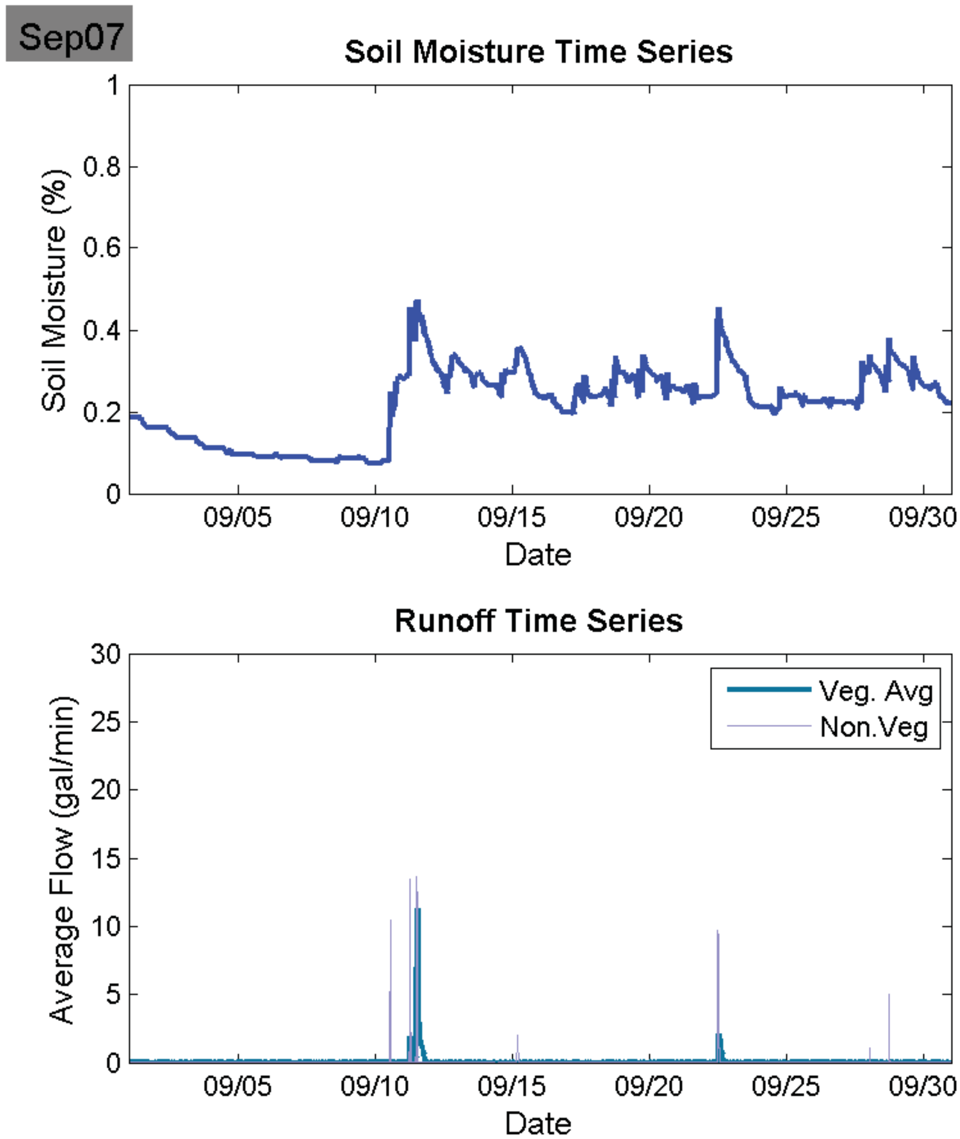

Figure 60: September 2007 Soil moisture (%) and Veg. Avg. runoff (gal/min).

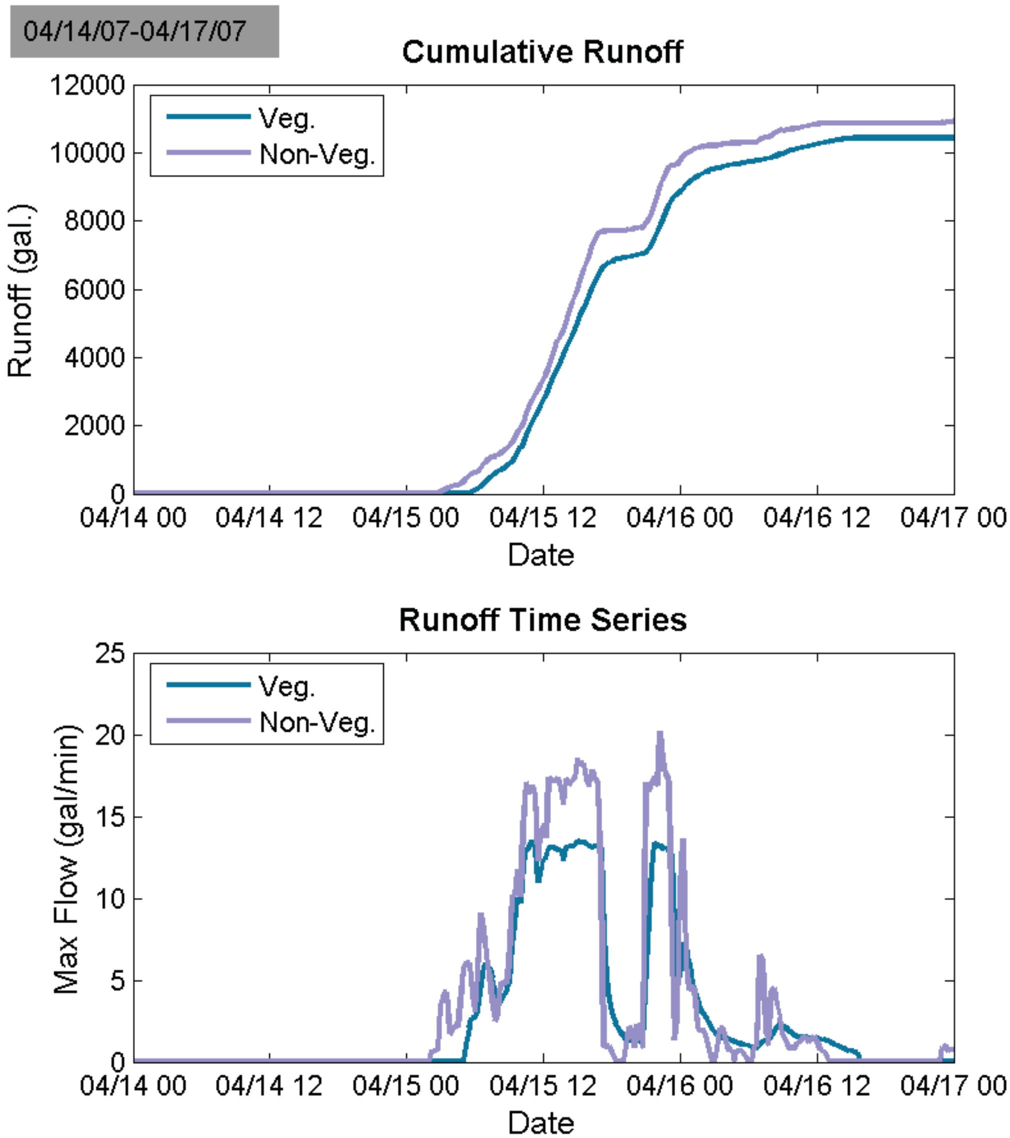

Figure 61: Runoff from Gratz vegetated and non-vegetated control roofs. Total precipitation in excess of 8”.

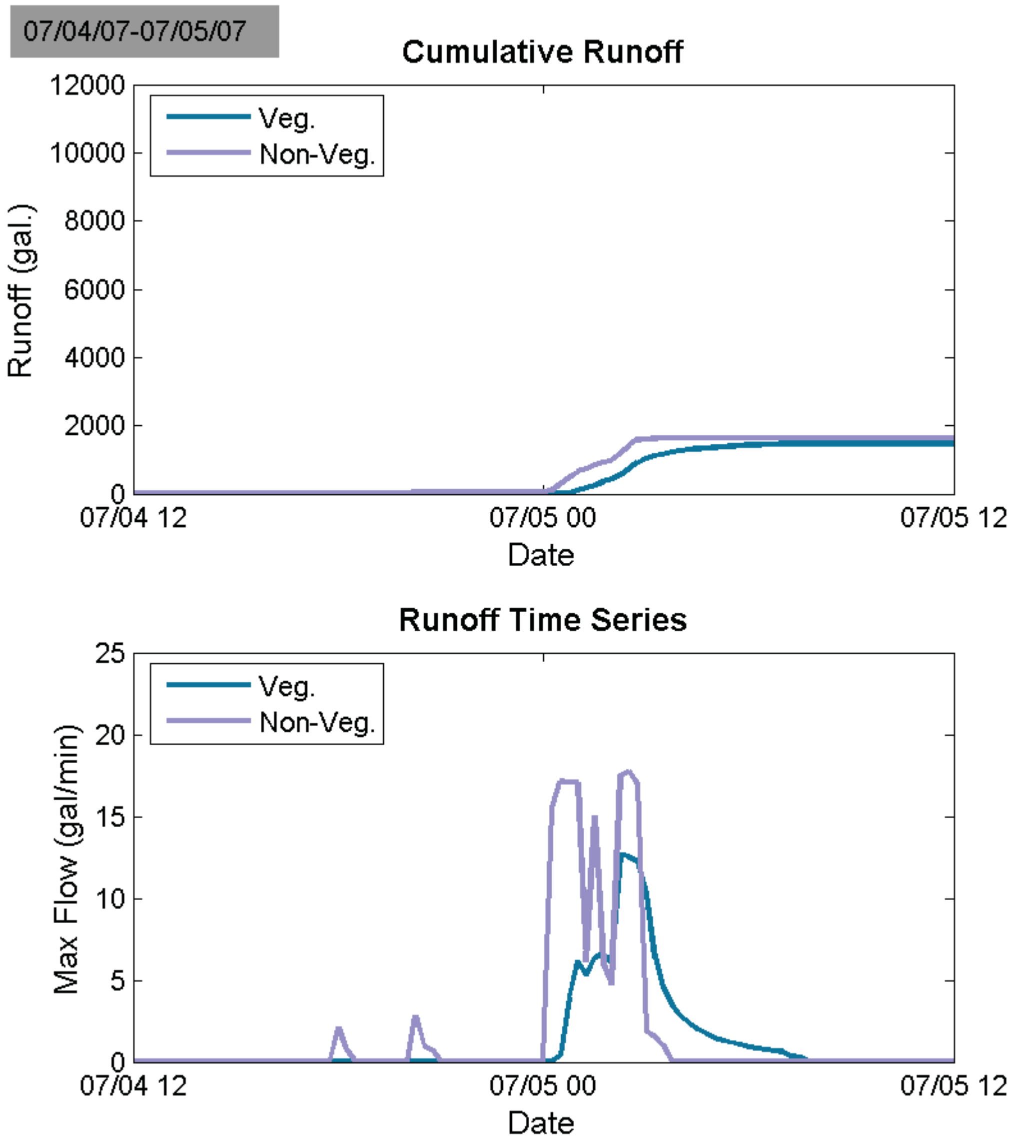

Figure 62: Runoff from vegetated and non-vegetated control roofs for a 1.4" summer rain.

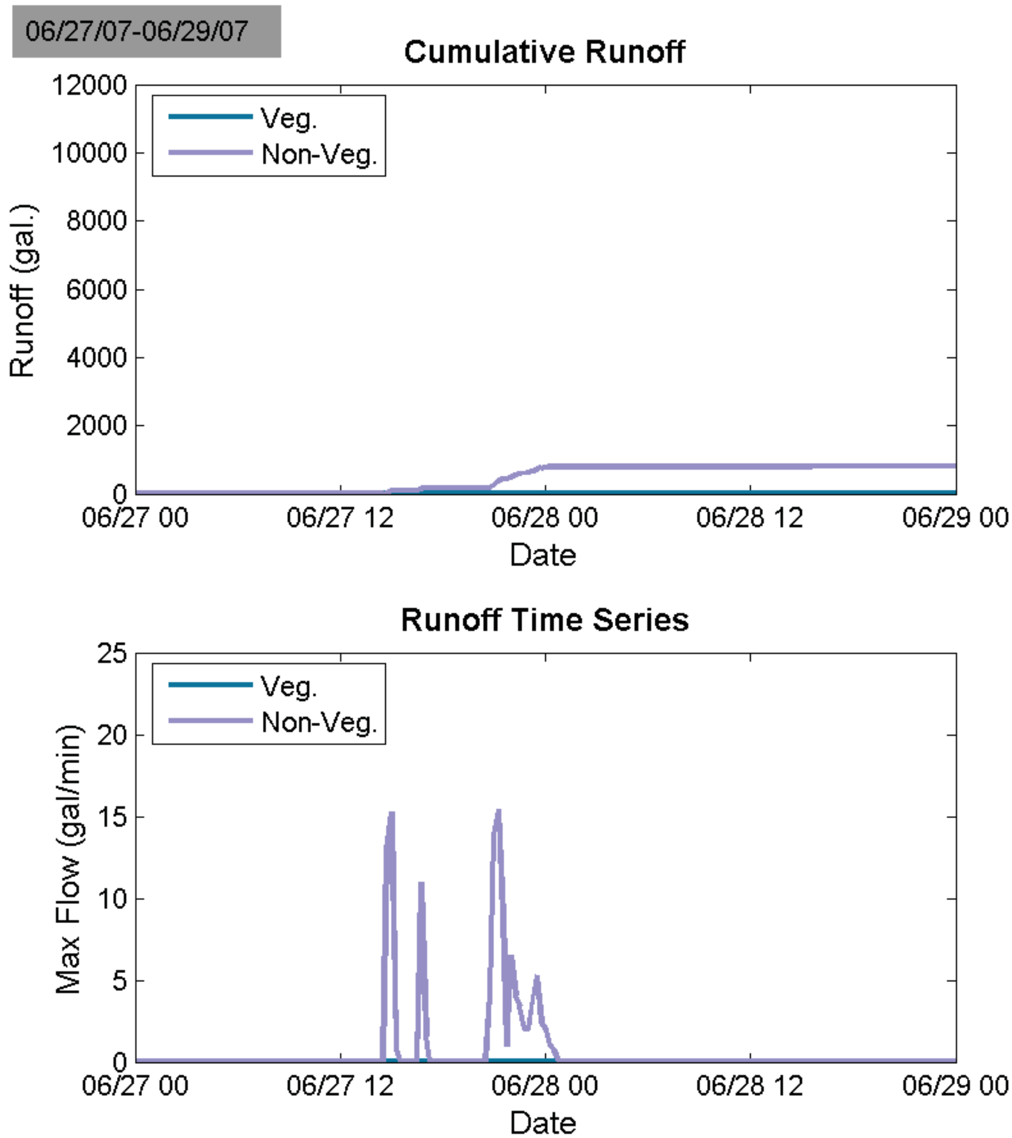

Figure 63: Runoff from control and vegetated roof sections for a typical summer rain of under ½ inch (~10 mm).

7. WATER QUALITY ANALYSIS OF RUNOFF

Water sample analysis was conducted at the Gratz Industry and Silvercup Studios Green Roof Research Station. The purpose of the analysis was to study the water filtration potentials of a vegetated roof compared to a conventional roof for two study sites. The parameters were chosen from the New York City Drinking Water Quality Tests and Environmental Protection Agency's (EPA) National Primary Drinking Water Standards. This analysis will also factor what impacts green roof runoff can have on a gray water system, a synergistic green technology.

The analytical results demonstrate how green roofs can improve the quality of storm water and have no damaging impacts to a gray water system. There was a significant reduction of heavy metals in the green roof runoff compared to conventional roof runoff. For example, lead levels dropped from 166µg/L to 14.2µg/L in green roofs. The same effect was observed for Zinc, with levels dropping from 199µg/L to 63µg/L in green roof runoff. These outcomes show that green roofs are successful in heavy metal filtration.

The results from green roof runoff samples also indicate reduced levels of other damaging agents to water quality. Green roofs reduce organic material in water, thereby lowering the levels of biological oxygen demand. As a result of metal filtration in a green roof, the chemical oxygen demand is also reduced: vegetated roof- 8.83mg/L, conventional roof- 43mg/L. Coliform analysis was inconclusive, but indicated that the presence of pigeons feeding on the green roof could be a factor as could the lower runoff volume.

7.1 Research Design

A total of eight samples were collected, four of green roof runoff, three of conventional roof runoff, and one of precipitation. Each sample was roughly 2.7 L. Three samples were collected at the Gratz research site and five from the Silvercup research station. Analysis was extended to include the Silvercup site in order to increase reproducibility and capitalize upon the individual roof platforms and runoff access afforded at this location. Silvercup Studios (42-22 22nd Street) is another green roof monitoring research station in the Long Island City, New York area by the Queensboro Bridge. However, the research station is comprised of raised green roof and conventional roof platforms as opposed to the in-situ design at Gratz. Each green roof platform has two 4' x 4' GreenTech modules with 3" to 4" of growing medium and sedum vegetation with partial coverage. The conventional roof platforms are silver painted EPDM.

At the Silvercup research station, five samples were collected from: precipitation, two green roof 4'x8' platforms, and two conventional 4'x8' roof platforms. Water was collected from 6 p.m. Tuesday 9/5/06 to 8 a.m. Wednesday 9/6/06, during which there was approximately 1 cm of rainfall. There were showers during the morning preceding the collection and a major rain event occurred on Saturday 9/2/06. Runoff samples were collected at the gutter downspouts of the elevated platforms and the precipitation sample was drawn from a large plastic container, which was placed at the site during the collection period. A preliminary coliform analysis was run for samples collected 8/29/06.

At Gratz Industries (13-06 Queens Plaza South) where the roof is separated by knee wall into quadrants, two samples were collected from the green roof 2,500 sq ft quadrants, and one sample from the conventional quadrant. Water was drawn from a reservoir of the storm water drain for each monitored quadrant in the morning of Wednesday 9/6/06.

Water samples were collected for analysis of the following:

1) Heavy Metals:
    a. Cadmium – a heavy metal often seen in urban runoff
    b. Copper - Runoff from rooftops has shown increase in copper concentration. Different roofing material can reduce concentrations.
    c. Iron - Heavy metal, water quality concern, also can stain porcelain.
    d. Lead - Runoff from rooftops has shown increase in lead concentration. Different roofing material can reduce concentrations.
    e. Zinc - Runoff from rooftops due to roofing material (galvanized steel) has shown increase in concentration.
2) Hardness- Measurement of minerals in water
    a. Total Hardness
    b. Calcium
    c. Magnesium
3) Nitrogen - Nitrates have been found in rainfall; creates conditions harmful to aquatic life.
    a. Total Organic Nitrogen
    b. Ammonia
    c. Nitrate
    d. Nitrite
4) Conductivity - Standard water quality measurement (ability of water to carry an electrical current).
5) Phosphorus - Depletes oxygen in water and leads to anaerobic conditions that are harmful to aquatic life.
    a. Total Phosphorus
    b. Phosphorus, Ortho
6) pH - Acidity or alkalinity; incident precipitation can be acidic
7) Total Suspended Solids - Sediment in water; also known as turbidity.
8) Coliform - Used to indicate whether other harmful bacteria may be present
    a. Total Coliform

b. Fecal Coliform

9) Biological Oxygen Demand - Indicative of organic matter, standard for storm water runoff.

10) Chemical Oxygen Demand - Indicative of organic matter, standard for storm water runoff

Online References

http://pubs.acs.org/cgi-bin/abstract.cgi/esthag/1999/33/i10/abs/es980922q.html

http://www.epa.gov/safewater/mcl.html#d_dbps

http://www.nyc.gov/html/dep/pdf/wsstat02data.pdf#search=%22nyc%20water%20quality%20testing%22

Environmental Laboratory Services (North Syracuse, NY 315.458.8033) performed the analysis for all parameters except for Total and Fecal Coliform, which was completed by EMSL Analytic, Inc. (New York, NY 212.290.0051).

7.2 Results

7.2.1 Water Quality Test #1 - Gratz

Date Collected: Sept 6, 2006

Date Submitted: Sept 6, 2006

Reported: Sept 11, 2006

Tech: C. Garcia, E. Bradley, G. Loosvelt

Collection Period: September 5, 2006 (overnight, rain event lasted till September 6, 3 a.m.)

Sample collected: 9:00 a.m. – 11:30 a.m.

Site: Gratz

Collection points: 2 vegetated quadrants: FM1, FM2

1 conventional quadrant: FM 3

Water Quality Test: Metals; Cadmium, Copper, Lead, Zinc, Iron

Note: One of the location points, Gratz FM 1 (vegetated quadrant), did not give quality results. This is due to amount of sediment and residue that could have collected in the drainage pipe. Therefore, results from Gratz FM1 are erroneous and will not be used.

units	**test**	Vegetated	Conventional
UG/L	Cd	<5.00	<5.00
UG/L	Cu	76.6	102
UG/L	Pb	14.2	166
UG/L	Zn	63.2	199

UG/L	Fe	<25.0	<25.0

The results show that vegetated roofs have a lower content of metals compared to conventional roofs. Metals are filtered out and are trapped within the vegetated roofs, therefore reducing the content in water runoff. Also, flow meter tubing is made of copper and could be contributing to the high values of copper seen in the samples.

Water Quality Test: Hardness, Calcium, Magnesium

units	**test**	Vegetated	Conventional
MG/L	Ca	29	6.96
MG/L	Mg	3.05	<1.0
MG/L as CaCO3	Total Hardness	85-mod. hard	17-Soft

The results show vegetated roofs to have a higher hardness level of water compared to conventional roofs. This could result in content of calcium and magnesium in the growing medium and rock aggregates.

Water Quality Test: Biochemical Oxygen Demand

Units	**test**	Vegetated	Conventional
MG/L as CL2	BOD	<2	3

Biochemical oxygen demand results were lower in a vegetated roof. This test determines how many milligrams of oxygen are consumed in a liter of water. It is related to the concentration of organic material in water. Any number less than 5mg/L indicates moderately clean water. The lower BOD content in a vegetated roof might indicate that the vegetation is filtering and retaining organic materials.

Water Quality Test: Chlorine Screen Total, residual

units	**test**	Vegetated	Conventional
MG/L as CL3	Chlorine screen, total residual	<0.1	<0.1

Water treatment facilities use chlorine to treat water. Treated water contains low counts of chlorine residue. The overall results show very low traces of chlorine in both Gratz and Silvercup data.

Water Quality Test: Total Suspended Solids

units	test	Vegetated	Conventional
MG/L	Solids, total suspended	10	54

Results show suspended solids to be high in a conventional roof. Compared to a vegetated roof, conventional roof surfaces collect debris, and during a rain event are washed away, unfiltered, into the drainage system. Vegetated roofs filter storm water before entering the drainage system and therefore, reduce amounts of suspended solids in water.

Water Quality Test: Phosphate, Ortho

units	test	Vegetated	Conventional
MG/L	phosphate, ortho	0.36	0.08

Conventional roof and precipitation results show low amounts of orthophosphate. Orthophosphate, or phosphoric acid, is used in water treatment plants to treat water. It forms a protective coating inside pipes to prevent lead from leaching into water. The growing medium in vegetated roofs can also contribute to traces of orthophosphate in runoff water.

Water Quality Test: Phosphate, Total

units	test	Vegetated	Conventional
MG/L	phosphorus, total	0.42	0.24

Results of phosphate are higher in a vegetated roof. This difference can be attributed from growing medium. Phosphorus is a nutrient essential for plant growth. The amounts in the water runoff of both roofs were significantly low.

Water Quality Test: Total Organic Nitrogen, Nitrate, Nitrite, Ammonia

units	**test**	Vegetated	Conventional
MG/L	nitrite	<0.20	<0.20
MG/L	ammonia nitrogen	<1.0	<1.0
MG/L	nitrate	<0.20	<0.20
MG/L	total organic nitrogen	<1.0	1

Results show nitrogen to be low in vegetated roofs. Nitrogen is naturally found in rainfall and the results show traces in the precipitation and conventional roofs. The organic nitrogen is absorbed by plants as it is an essential nutrient. This is why runoff water, after it has traveled through a vegetated roof, will show lower amounts of total nitrogen.

Ammonium nitrogen is found in fertilizer and soil. This compound is converted to nitrate in soil, which is essential for plant growth. Nitrate, as well as nitrite, is also naturally found in the air and soil. The results should show lower traces of these compounds in water runoff from a vegetated roof.

Water Quality Test: pH, Hydrogen ion (pH)- overage

units	**test**	Vegetated	Conventional
	pH screen	7.3	7.3
S.U.	Hydrogen ion (ph)- overaged	7.47	6.77

The pH levels show precipitation to have been acidic. Normal precipitation levels of pH average 5.6 to 4.5. In the Northeast, the 2005 average level of acid precipitation has been recorded at 4.2-5. Vegetated roofs act as a good buffer for acid rain. Results show the pH levels neutral in vegetated roof runoff.

The amount of hydrogen ions determines the alkalinity or acidity of water. The higher the hydrogen ion content, the more acidic it is. It is measured in pH standard units. The hydrogen ion test is a good reference in checking against the results of the pH levels.

Water Quality Analysis: Conductivity

units	**test**	Vegetated	Conventional
UMHOS/CM	Conductance	196	60

Conductance was much higher in vegetated roofs. The range that determines the quality to be good is 150 to 500 umhos/cm. This standard test is also related to the total dissolved solids (TDS.) With high levels of TDS come high levels of conductance. TDS affects the aesthetics of water making it cloudy and can interfere with disinfectants used to improve water quality at treatment plants. Other contributors to higher conductivity are high concentrations of calcium and magnesium in the vegetated roof.

Water Quality Test: Coliform

units	**test**	Vegetated	Conventional
CFU/100ml	Fecal Coliform	TNTC	TNTC
CFU/100ml	Total Coliform	Confluent growth	TNTC

Results show high amounts (TNTC – too numerous to count) of fecal and total coliform in both vegetated and conventional roofs. The drainage system at Gratz allows for a greater amount of water to be collected. This may be the reason the coliform counts are high. The high content of fecal coliform could be attributed to the same reasons observed at Silvercup: pigeons.

Water Quality Test: Chemical Oxygen Demand

units	**test**	Vegetated	Conventional
MG/L	COD	8.83	43.4

Chemical oxygen demand determines the content of oxidizable organic and inorganic matter in water. Part of COD includes oxidation of metals. Since metals were filtered from water runoff through the vegetated roof, the levels of COD are low.

7.2.2 Preliminary Water Quality Test: Coliform Only - Silvercup

Date Collected: 8/29/06; Submitted: 8/29/06 5:00p.m.; Reported: 9/1/06

Silvercup Green Roof Research Station

Tech: E.Bradley and C. Garcia

Collection Period: 8/29/06 2:30 p.m. - 4:00 p.m., WX: intermittent light showers.

Collection Points: Green roof platforms: GR7, GR10

Conventional roof platforms: CR11, CR12

Notes: Rain in morning. Higher rates of runoff from vegetated platforms than from conventional roof is due to large portion of rain occurring hours earlier. Green roofs will detain precipitation and then release it over a longer period of time than conventional roofs for which there is little lag in runoff and where the runoff peak is sharper and higher. One hour after a rain event, all precipitation on a conventional roof will have runoff, but a green roof could be still slowly releasing water. Overall, there was a limited amount of runoff so a complete set of tests could not be run.

Coliform Testing: Membrane Filtration Technique		
	Total Coliform	Fecal Coliform
Sample	**CFU/100ml**	**CFU/100ml**
GR7	332	335
GR10	TNTC	168
CR11	29	-
CFU=colony forming unit		
TNTC=too numerous to count		

Preliminary results from Silvercup Research Station show higher levels of total coliform for green roof runoff than for conventional roof runoff.

This difference could be attributed to fecal matter from pigeons which have been observed on the Silvercup green roofs. Also, first flush from the conventional and vegetated roof were not tested. Potentially the first runoff from a conventional roof (which would include any particulates or waste deposited on the roof surface) would have higher CFU values. Also we should investigate the difference in runoff volume between vegetated and conventional surfaces to see how both coliform concentration and overall total compares (green roofs can detain significant portions of rainfall, reducing runoff volumes).

__7.2.3 Water Quality Test #2 - Silvercup__

Date Collected: September 6, 2006

Date Submitted: September 6, 2006

Reported: September 11, 2006

Tech: C. Garcia, E. Bradley, G. Loosvelt

Collection Period: September 5, 2006 (overnight, rain event lasted till Sept 6, 3 a.m.)

Sample collected: 9:00 a.m. – 11:30 a.m.

Site: Silvercup

Notes: No rain. Containers were placed underneath each platform drain to capture water runoff from overnight rain events. Previous attempt, August 29, 2006, there was not enough runoff to run complete set of tests. During this event, there was plenty of runoff captured in containers to run test on all parameters.

Water Quality Test: Coliform

	Total Coliform	Fecal Coliform
Sample	CFU/100ml	CFU/100ml
GR7	24	<1
GR10	<1	<1
CR11	2	<1
CR12	<1	2
PRECIP	2	<1

Results show low levels of fecal coliform for green roof and conventional roof runoff. First flush from conventional roof and green roof was not tested.

Comparison to previous Coliform Test

Date: 08/31/2006	Total Coliform	Fecal Coliform
Sample	CFU/100ml	CFU/100ml
GR7	332	335
GR10	TNTC w/ coliform	168
CR11	29	-------------

In comparing data from August 29 to data collected September 5, the content of both fecal and total coliform was much higher in the August samples. The water collected in September may not have been mixed well enough before pouring into a sample bottle. Since the runoff water was collected, over a long period of time, into a deep container, the higher content of coliform could have been at the bottom half of the collected water. It may be a possibility that there could have been a higher coliform count in samples taken during the first flush.

Water Quality Test: Metals; Cadmium, Copper, Lead, Zinc, Iron

units	**test**	Vegetated	Vegetated	Conventional	Conventional
UG/L	Cd	<5.0	<5.00	<5.00	<5.00
UG/L	Cu	138	162	9.17	7.01
UG/L	Pb	<5.0	<5.00	6.14	<5.00
UG/L	Zn	12.1	29.7	82.1	77.1
UG/L	Fe	28.5	37.3	158	51.0

The results show that vegetated roofs have a lower content of metals compared to conventional roofs. Metals are filtered out and trapped within the vegetated roofs, therefore reducing the metal content in water runoff.

Water Quality Test: Hardness, Calcium, Magnesium

units	**test**	Vegetated	Vegetated	Conventional	Conventional
MG/L	Ca	36.8	36.2	2.77	2.48
MG/L	Mg	5.18	7.17	<1.00	<1.00
MG/L as CaCO3	Total Hardness	113-Mod. Hard	120-mod. Hard	7-soft	6-soft

The results show vegetated roofs to have a higher hardness level compared to conventional roofs. This could result in content of calcium and magnesium in the growing medium and rock aggregates used.

Water Quality Test: Biochemical Oxygen Demand

units	**test**	Vegetated	Vegetated	Conventional	Conventional
MG/L as CL2	BOD	<2	<2	3	3

Biochemical oxygen demand results were lower in vegetated roof. This test determines how many milligrams of oxygen are consumed in a liter of water in five days. It is related to the concentration of organic material in water. Any number less than 5mg/L indicates moderately clean water.

Water Quality Test: Chlorine Screen Total, Residual

**See Gratz Data*

Water Quality Test: Total Suspended Solids

units	**test**	Vegetated	Vegetated	Conventional	Conventional
MG/L	Solids, total suspended	<4	<4	16	4

Vegetated roof shows lower levels in TSS. Difference is due to conventional roof surfaces collecting debris, and during a rain event the debris is washed away, unfiltered, into the drainage system. Vegetated roofs filter storm water before entering the drainage system, and therefore reduce the amount of suspended solids in water.

Water Quality Test: Total Organic Nitrogen, Nitrite, Nitrate, Ammonia Nitrogen

units	**test**	Vegetated	Vegetated	Conventional	Conventional
MG/L	total organic nitrogen	1	1.1	1.1	1.2
MG/L	nitrite	<0.20	<0.20	<0.20	<0.20
MG/L	ammonia nitrogen	<1.0	<1.0	1.0	<1.0
MG/L	nitrate	0.28	0.46	0.78	0.74

Results show total nitrogen to be the same in both vegetated and conventional roofs. Nitrogen is naturally found in rainfall and the results show traces in the precipitation and conventional roof. The organic nitrogen is absorbed by plants as it is an essential nutrient. Nitrogen content in rain water and soil is naturally low. Normally, runoff that filters through vegetated roofs shows low traces of nitrogen compared to conventional roofs.

Ammonium nitrogen is found in fertilizer and soil. This compound is converted to nitrate in soil, which is essential for plant growth. Nitrate, as well as nitrite, is also naturally found in the air and soil. The results should show lower traces of these compounds in runoff water from a vegetated roof.

Water Quality Test: Chemical Oxygen Demand

units	test	Vegetated	Vegetated	Conventional	Conventional
MG/L	COD	38.1	43.7	21.9	21.3

Chemical oxygen demand determines the content of oxidizable organic and inorganic matter in water. Normally, COD would be lower in vegetated roof water runoff. The data indicates high levels of copper and iron along with calcium and magnesium that can have a combined affect of higher COD levels.

Water Quality Test: pH, Hydrogen ion (pH)- overage

test	Vegetated	Vegetated	Conventional	Conventional
pH screen	7.8	7.8	5.2	5.2
Hydrogen ion (pH)-overage S.U.	7.64	7.74	4.84	3.93

The pH levels show precipitation to have been acidic. Normal precipitation levels of pH average 5.6 to 4.5. In the Northeast, the 2005 average level of acid precipitation has been recorded at 4.2-5. Vegetated roofs act as a good buffer for acid rain. Results show the pH levels neutral in vegetated roof runoff.

The amount of hydrogen ions determines the alkalinity or acidity of water. The higher the hydrogen ion content, the more acidic it is. It is measured in the standard units of pH. The hydrogen ion test is a good reference in checking against the results of the pH levels.

Water Quality Test: Conductance

units	test	Vegetated	Vegetated	Conventional	Conventional
UMHOS/CM	Conductance	227	238	28	29

Conductance was much higher in vegetated roofs. The range that determines the quality to be good is 150 to 500 umhos/cm. This standard test is also related to the total dissolved solids (TDS.) With high levels of TDS come high levels of conductance. TDS affects the aesthetics of water, making it cloudy, and can interfere with disinfectants used to improve water quality at treatment plants.

Water Quality Test: Phosphate Total, Orthophosphate

units	**test**	Vegetated	Vegetated	Conventional	Conventional
MG/L	phosphate, ortho	0.12	0.21	<0.05	<0.05
MG/L	phosphorus, total	0.18	0.23	<0.05	<0.05

Conventional roof and precipitation results show low amounts of orthophosphate. Orthophosphate, or phosphoric acid, is used in water treatment plants to improve the quality of water. It forms a protective coating inside pipes to prevent lead from leaching into water. The growing medium in vegetated roofs can also contribute to traces of orthophosphate in runoff water.

Results of total phosphate are higher in a vegetated roof. This difference can be attributed from growing medium. Phosphorus is a nutrient essential for plant growth.

7.3 Conclusions

The water quality analysis of both green roof research stations demonstrated that storm water quality improves as it travels through a vegetated area. Green roofs act as a filter trapping suspended solids, organic material, and heavy metals. When comparing green and conventional roof results, heavy metals were significantly reduced in all parameters tested. As a result from heavy metal filtering, chemical oxygen demand levels were also reduced.

Since organic material is captured in a green roof, the results showed low levels of biological oxygen demand. Suspended solids were also filtered out, lowering the amount of total suspended solids in runoff.

Green roofs will increase the hardness level because of the calcium and magnesium content in the growing medium but will not have any significant affects to the water quality. Green roofs will also have a higher content of phosphate. The phosphate is derived from the growing medium.

Green roofs naturally absorb nitrogen content. Since there was not much nitrogen in the storm water, the total nitrogen as well as nitrate, nitrite and ammonia levels were insignificant. There were some amounts of nitrate detected in the precipitation, and results showed nitrate levels reduced in green roof runoff.

Coliform analysis was inconclusive. Gratz results show contents of total and fecal coliform too numerous to count. The preliminary results at Silvercup showed very high levels of total and fecal coliform as well, but during the secondary testing the results were low.

7.4 Discussion

Something to consider is the type of pipes used in an irrigation and drainage system. The copper tubing used at Gratz could have contributed to the high levels of copper in the analysis. Analysis still shows green roofs reducing the copper amount in water runoff. Other heavy metals tested were also reduced in green roofs.

Coliform levels were high due to fecal matter from pigeons. Pigeons have been observed at Gratz green roof and Silvercup green roof. Concentration of coliform was probably high in water that collected in each of the three (3) drainage pipes. It is assumed that water from the first flush, containing high levels of coliform, was still in the pipes.

Green roofs capture organic material, which lowers the biological oxygen demand (BOD). The lower the levels of BOD in water, the better the quality. The levels were well below the standard drinking water levels and would have no impact on gray water systems. The calcium and magnesium in a green roof's growing medium increases water's hardness level. The water was moderately hard but will have low impacts on its quality since it is below the average hardness of water: 122 ppm.

Green roofs do need phosphate as a nutrient as well as nitrogen. There will be traces of these elements in water runoff, but it will have minimal impacts in terms of runoff water quality. Small levels of orthophosphate were detected in the analysis. Orthophosphate is used in water treatment plants to improve water quality. It forms a protective coating inside pipes to prevent lead from leaching so it may become beneficial to a buildings plumbing system.

8. ASSESSMENT OF MONITORING ELEMENTS AND FUTURE WORK

This project was a successful demonstration of a complex and intensive monitoring approach, which provided in situ data on the thermal and stormwater management performance of a green roof. While the standard green roof research design consists of small-scale simulation roof platforms, the Gratz green roof project incorporated comprehensive monitoring of 2,500 sq. ft. quadrants. The placement of the weather station in the center of the roof was optimal, as it provided ambient conditions for comparison and was not impacted by structures that could cause deviations of the background signal by way of turbulence or shading. Attachment to the knee-wall provided a stable base, and the possibility of damaging the roof and inducing leaks was thereby minimized. Full establishment of the vegetation should be a key consideration in any green roof research study and we found that as survivability was an issue at the start of this project, ideally monitoring would be administered over a longer duration. This is also true given the variability in climate, for which an extended period of record could support confidence intervals for potential green roof benefits over different conditions.

The stormwater monitoring system was integrated into the building runoff piping in such a way that the high volume flow produced by the large roof catchment area could be measured, but blockage concerns were minimized due to the overflow piping. Drainpipe and sedimentation trap cleanup was necessary and is highly recommended for similar research projects, especially in the nascent stage, when the growing medium has not yet completely settled. Although issues have been reported in some green roof studies in terms of lack of meaningful data from soil moisture probes due to the high porosity and air space of the growing media; we found the performance of the Gratz probes (CS616s) to be satisfactory and to return meaningful data, which greatly complemented our stormwater analysis.

In terms of thermal monitoring, this research project employed over forty thermocouples at multiple levels throughout the roofing array; which was an intensive process, but yielded results with high reproducibility. There were issues with the thermocouples placed at the membrane level presumably due to the high temperatures at this location; however, the thermocouples that were part of the heat flux sensors were a useful proxy. In future work, higher grade thermocouples should be employed at the membrane level, especially if black roofing is used, due to the extreme temperature fluctuations. Radiation shields for the near-surface ambient thermocouples was a necessary investment, as otherwise these sensors would have recorded erroneously high values. The tripod design for the shield installation proved successful and is recommended over suspension from a PVC infrasture, as the tripod system provided a sturdy base for the shield with minimal impact on the thermal environment and was cost-efficient. In order to better assess the impact on indoor temperatures, we suggest that an increased number of temperature probes be used or a thermal camera be employed, as the number of heat sources in the Gratz building, and inconsistent conditions, made analysis difficult.

We also suggest that an Ethernet modem (such as Campbell-Scientific's NL100) be used to remotely collect data from green roof research stations, when Internet access is available. The telephone modem that was used at the site proved to be highly inconsistent and unreliable. For future green roof research projects, given an Ethernet modem and the ability to download the data in near real-time, we envision that there are tremendous opportunities to leverage the data for pedagogical impact and community outreach. Additionally, a Web camera could be a very substantial addition to a green roof research program as it could be used to monitor the establishment of the green roof vegetation and phenology as well as provide a means to generate further interest in and awareness of green roofs.

9. CONSTRUCTION EXPERIENCE & COSTS

Green Roof technology consists of a series of lightweight layers placed upon each other. Each layer serves a specific purpose necessary for the effective functioning of a green roof system. These layers are designed to insulate, waterproof, prevent downward root penetration, direct the flow and storage of excess water and a growing medium (soil) for plant growth.

Critical in the design of a green roof system on an existing structure is a structural analysis of the roof to calculate the allowable additional load. Design criteria required to satisfy the monitoring requirements included: dividing the roof into four quadrants each with its own drainage piping, installation of the monitoring equipment and weather station, and clogged roof drains. Architectural challenges involved the installation of a metal grid and modification in the green roof system.

Roof Capacity Analysis: Gratz Industries is a one-story steel frame structure with non-load bearing brick and concrete block façade walls. Concrete block piers fireproof and encase steel columns supporting a roof system of steel girders, beams and purlins. Probes through the roof were taken to determine its composition. This investigation revealed roof deck is composed of 3" deep gypsum plank spaced at 2'-9" o. c. Incorporating assumptions for live and dead loads on the existing roof the base load was calculated at 55 lbs per square footing without the green roof system. In analyzing the allowable increase capacity of the roof basically four members must be considered; the girders, the filler beams, the spandrels and the purlins. The new loads calculated were added to the existing live and dead loads, resulting in additional allowable loads between 10psf to 30psf.

Design & Construction: For monitoring purposes Earth Pledge required the roof divided into four (4) Quadrants of approximately 2,500 square feet each. Three of the four quads were to be monitored employing the following arrangement: Two (2) quads were vegetated and instrumented with arrays of thermocouples (heat sensors). One quad was similarly instrumented but left unvegetated, with just the manufacturer's conventional roof membrane, to serve as the control quad. The fourth was quad just vegetated and not instrumented.

The arrays were vertically installed as follows:

- At the ceiling inside the building
- On top of the roof water proof membrane
- On top of the growing medium (soil)
- In the ambient air 6' above the vegetation or the convention roof.

The division was accomplished by constructing 2'-0" high light gauge steel knee walls bisecting the roof in an east-west and north-south direction. The application of tapered rigid insulation established pitch toward newly installed, roof drains and leaders centrally located in each quad. Three (3) of the leaders were fitted with flow meters to monitor flow rates of storm water runoff from each quadrant. To avoid the persistent clogging of the drains and flow meter from runoff of the growing medium it was necessary to place a wire basket / screen around the roof drain, which required periodically cleaning along with the flow meter.

With the insulation in place, the green roof system was ready for installation. The components of a green roof system can be purchased under warranty from a single manufacturer to include: the water proof membrane, root barrier, drainage layer, and growing medium. Soprema, the manufacturer used on this project offered a five (5) & ten (10) year labor and material warranty, but accepted no responsibility for performance of any vegetation. The water proof membrane consisted of two (2) layers of a heat welded 180 SBS bitumen base and cap sheet. Plumbing and electrical roof penetration required for the monitoring wring and irrigation system were installed in waterproofed pitch pockets. Interior ceiling and top of membrane thermocouples were installed and low voltage wiring run to the as yet to be installed weather station atop the intersection of the two knee walls.

Installation of Sopradrain, a high compressive strength poly core covered with a filter fabric used to restrict movement of the soil, doubles as a drainage layer and root barrier. An allowable load of 10 psf equates to approximately 2 inches of growing medium (an engineered soil composed of organic matter (X%) and expanded shale(Y%).The greater percentage of organic matter the heavier the medium. Gratz uses a 20%/80% mixture weighting in at approximately 5lbs per board foot (12"x12"x1"). Due to the shallow two-inch growing medium in the 10 psf areas Balmori Associates, the landscape architect and the Soprema Representative recommended installing "AquaMat Jardin" a proprietary capillary mat designed for water retention, essentially a diaper. The mat was donated by Soprema and Dan Stubbolo, the contractor, graciously provided the labor free of charge.

Prior to installation of the growing medium Earth Pledge located and wired the membrane thermocouples. The growing medium and plants (sediums) were installed by the landscape contractor, Greener by Design. Given the different allowable loads, depth of the growing medium varied, making grading of the roof a challenge. The medium also contained an unacceptable amount of deleterious material. The landscape contractor spent several days cleaning the medium of this material and removing pieces larger than 3/8" in diameter. In order to prevent the growing medium from migrating toward the roof drains, a 5'-0" x 5'-0" aluminum planting grid (Perma-lok) was placed. The labor to install the planting grid was donated by Gratz Industries as well as the labor to install the perimeter fence. Concurrent with placing the grid, Earth Pledge (EP) and its consultants installed the weather station (refer EP monitoring report for instrumentation) and the thermocouples atop the growing medium.

Installation of the plants (in the form of "plugs") occurred in July 2006, but due to miscommunication in scheduling, half were delivered before the growing medium was in place. The weather was unusually hot and dry, and as a result several of the "plugs" were "burned." Subsequent to replacement of the burnt plugs, the plants were planted in groups of 15 to 20 plugs per grid.

An unanticipated consequence resulting from installation of the aluminum planting grid was that the grid rested on top of the AquaMat Jardin, restricting the flow of water to the roof drains. As a result, pools of water collected inside of the grids, saturating the plant roots. To resolve the condition, 4x4 blocks were place beneath the intersecting grid corners to raise the field off the Mat and allow the water to drain.

Contruction challenges included:

- Increase in construction costs (see below)
- Post-bid design change to include the AquaMat Jardin.
- Division of the roof into four quadrants
- Installation four separate roof drainage systems.
- Installation and coordination of the thermocouples: four devices / array with fou arrays / quadrant.
- Keeping the growing medium from clogging the flow meters.
- Installation of the planting grid.
- Coordination of Contractor and various other sources of labor seriously impacted job efficiency

Summary of Gratz Construction Costs

Summary of Cost	Schedule of Values	Cost per Square Foot
General Conditions	$58,200	$5.82/SF
Carpentry	$29,100	$2.91/SF
Roof Membrane & Insulation	$122,220	$12.22/SF
Plumbing	$32,010	$3.20/SF
Perimeter Fence	$2,500	$0.25/SF
Aquamat	$3,750	$0.50/SF
Green Roof System (7,500 s.f.)	$49,470	$6.60/SF
Total	$297,250	$31.50/SF

The original project budget allocated $200,000 for installation of the 10,000 SF green roof. The contract for construction was signed for a total of $291,000 dollars. The project team applied for and received a $50,000 grant from the Rockefeller Brothers foundation. Another $5,000 was donated by the Donald Gratz Memorial Fund, and NYSERDA increased its contribution to close the deficit.

A green roof system consists of several components. Building from the roof deck up, these are rigid insulation to provide the pitch to roof drains, a water proof roof membrane, a root barrier, a drainage layer, the growing medium (soil) and the plants. As conceived the project anticipated repair of the existing roof membrane allocating approximately $20,000. However, no green roof manufacturer would warranty its product over an existing roof membrane. Installation of the new roof membrane cost $122,220.

Additional costs not anticipated within the scope of the original budget can be attributed to requirements of the monitoring program as follows:

- Carpentry: Installation of low knee walls to divide the roof into four quadrants, and installation of a new scuttle hatch and roof ladder ($29,100).
- Plumbing: Provide roof drainage system at the four (4) separate quadrants ($29,000).
- Installation of a 5 x 5 metal grid and new perimeter fence (labor and materials donated).

Note: General Conditions typically refer to job site overhead costs which include mobilization and breaking down, site protection, temporary facilities like construction toilets, insurance etc..

Key finding: Costs of the aquamat, ($3,750), “green roof system” ($49,470), irrigation system ($3,000 est.) and a prorate share of the general conditions for the green roof($13,700) was only 23% of the total construction cost. This suggests installation of green roofs should be considered at the time a new roof membrane is being installed.

10. PUBLIC OUTREACH

The Pratt Center for Community Development, EarthPledge, Balmori, and Gratz Industries all conducted outreach to share the experience and results of the Gratz Green Roof. The project received media coverage in the Queens Ledger and the Downtown Express. It was presented on the Web sites of the Pratt Center, EarthPledge, and Balmori. It was included in PowerPoint presentations made to more than a dozens groups around New York and beyond. We made or sent presentations to the local elected officials (including the City Council, Queens Borough President, and City of New York).

11. SUMMARY

This report presents the design, implementation, and analysis for the Gratz Green Roof Research Station (13-06 Queens Plaza South, Long Island City, NY). A truly innovative project, it features one of the largest green roof stormwater monitoring systems and has demonstrated the utility of soil moisture probes for green roof research. This project encompasses both thermal and stormwater analysis and provides valuable data on green roof performance in New York City. As local climate plays an important role in terms of green roof efficacy and impact, this dataset is particularly useful for green roof cost benefit analysis specific to the region.

The Gratz Green Roof Research Station consists of a 10,000 ft^2 roof that has been divided into three vegetated quadrants (two monitored) and one monitored conventional-roof quadrant with a black tar surface. A weather station is installed at the center of the roof. Thermal data is collected with thermocouples positioned inside the building, at the waterproofing membrane, the top of the growing medium, and 6" above the roof surface. This is supplemented by heat flux sensors placed at the membrane. Hydrological instrumentation includes three flow meters positioned to measure the runoff for the two vegetated and the one conventional quadrant. Additionally, soil moisture probes and the weather station rain gage provide relevant data.

Issues affected the conventional roof membrane thermocouples at high temperatures, but the heat flux sensor temperature measurement was found to be a suitable proxy. Built up accumulations in the flow meter piping (see plumbing *ANNEX I - INSTALLATION PICTURES*) resulted in compromised data for the vegetated quadrant II sensor and conventional quadrant until March 2007. However, the vegetated quadrant III sensor was fully functioning for the entire monitoring duration.

The thermal data illustrates the pronounced modulating effect that the green roof has on the membrane temperatures. Also monthly total heat flux was negative throughout the year (building loss) for the green roof, while it was positive for the summer for the conventional roof (gain). The diurnal heat flux signal is significantly attenuated for the green roof, which could decrease the conditioning requirements for the building and is of particular note because of summer electrical load peaks. The green roof retained 40% of annual precipitation and is expected to perform even better following the full establishment of the vegetation. Additionally, runoff peaks were delayed and attenuated. Runoff water quality results indicated a decrease in heavy metal concentration for the green roof, a higher hardness and phosphorus level, and a lowered biological oxygen demand and total suspended solids.

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GRATZ RESEARCH TEAM

Leslie Hoffman, Greg Loosvelt (Earth Pledge) and research team (Engela Sthapit and Eliza Bradley) were responsible for overseeing the instrumentation, scientific monitoring and experimental design of the Gratz Industries Green Roof Research Project.

Earth Pledge sub-contractors:

Christopher Wark (Shade Consulting) conducted heat transfer analysis for Gratz Industries building.

Dr. Robert Berghage (Pennsylvania State University Green Roof Research Center) advised on the installation and monitoring of the project and data analysis.

David Gilmore and David Adams (Climatronics Corporation) responsible for installing the weather station and installing/programming the datalogger.

William Riley (Pratt Institute Center for Community and Environmental Development) was responsible for the project management. Pratt Center is also the architect of records and project architects.

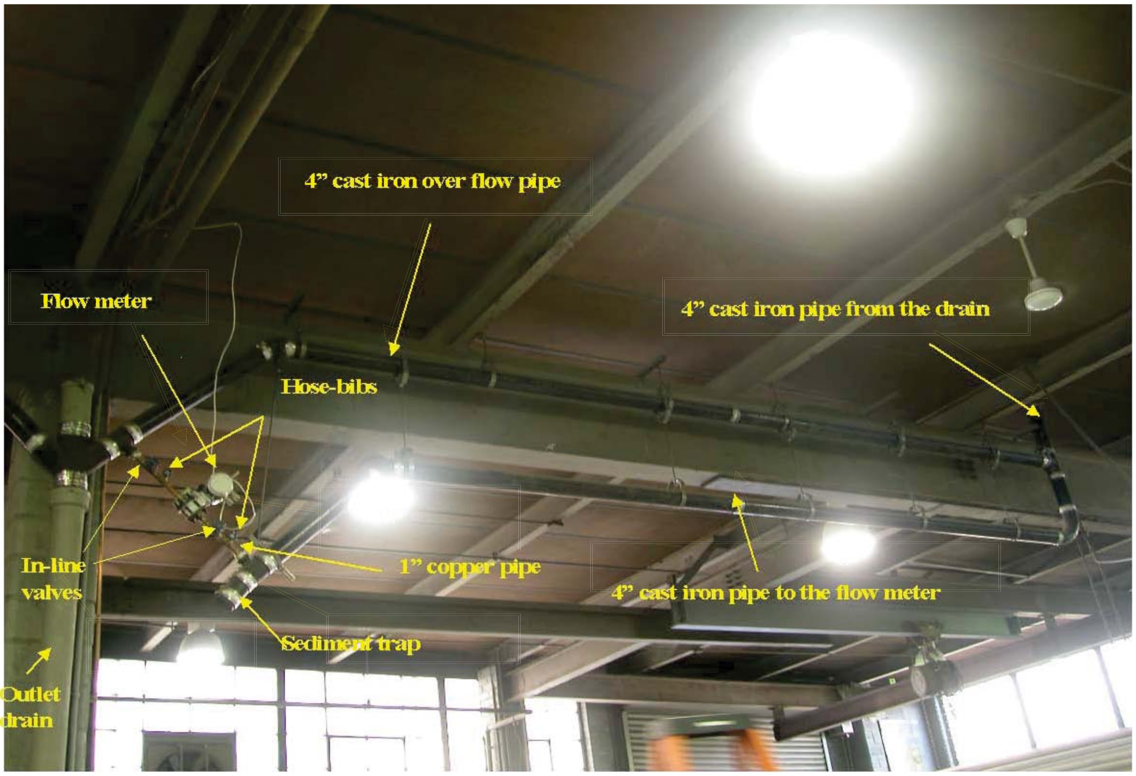
Dan Stubollo (Allied Construction) the contractor for roofing, plumbing and electrical works on the Gratz project.

Balmori Associates were responsible for landscape design.

Richard Heller (Greener by Design) was responsible for placing soil substrate and planting.

David Rosencrans (Gratz Industries) is the chief person at the Gratz Industries.

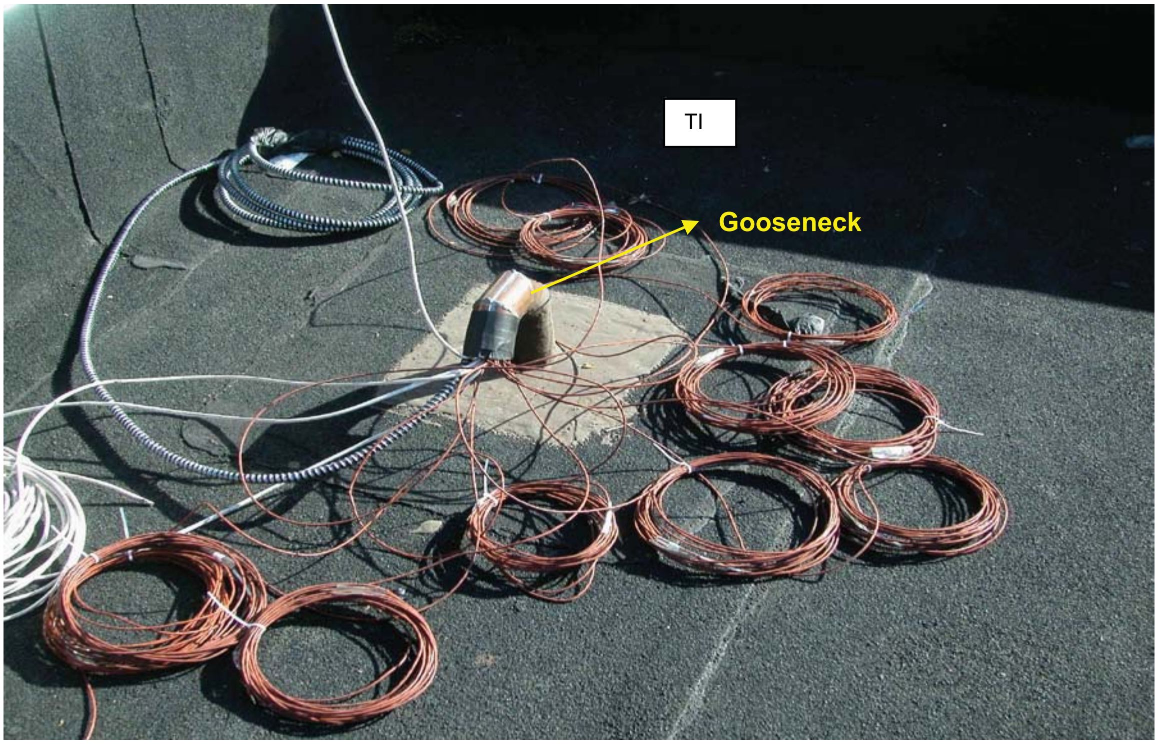
ANNEX I - INSTALLATION PICTURES



Flow meter installation at Gratz Industries

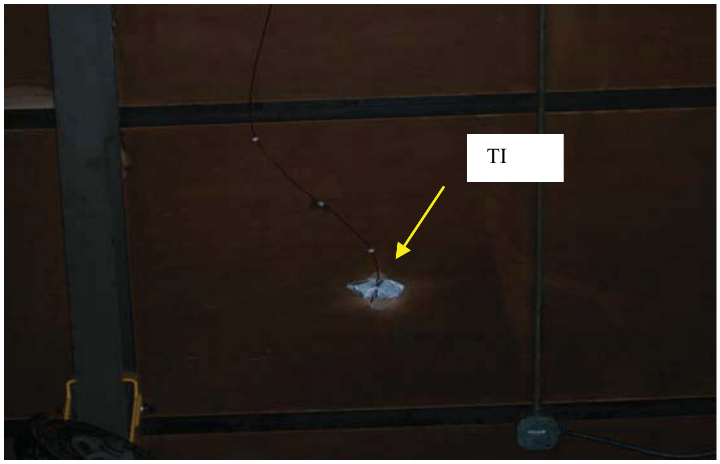
Four experimental quadrants at Gratz Industries before and after green roof installation

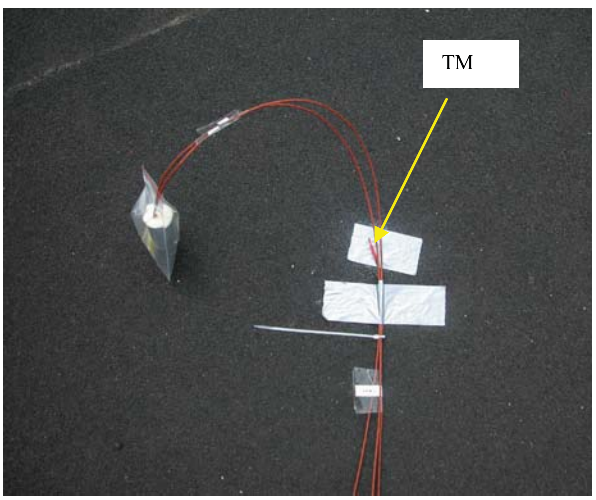
Thermocouple wires, flow meter wires, power cable and telepho ed out of the gooseneck from the building at Quad I

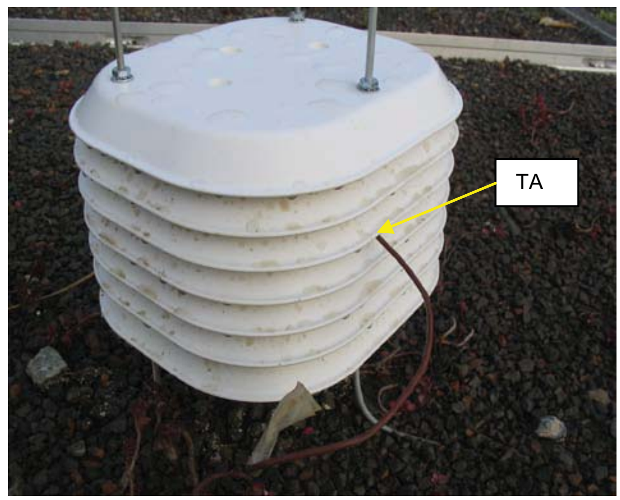


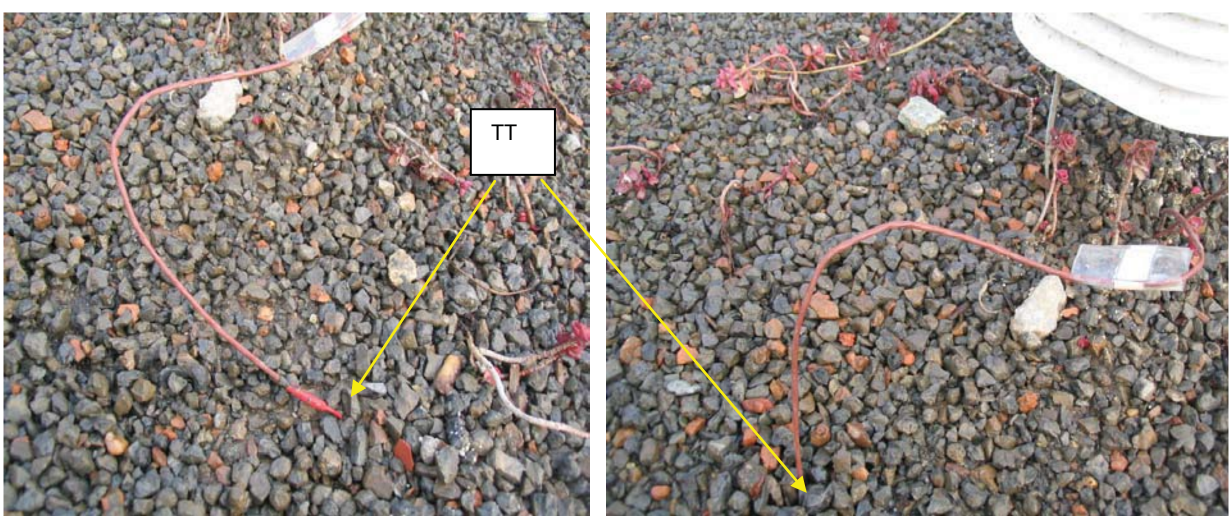
Installation of sensors at the rooftop of Gratz Industries building

Installation of TI, TM, TT and TA Thermocouples. TI is at the ceiling inside the building. TA is covered by radiation shield.



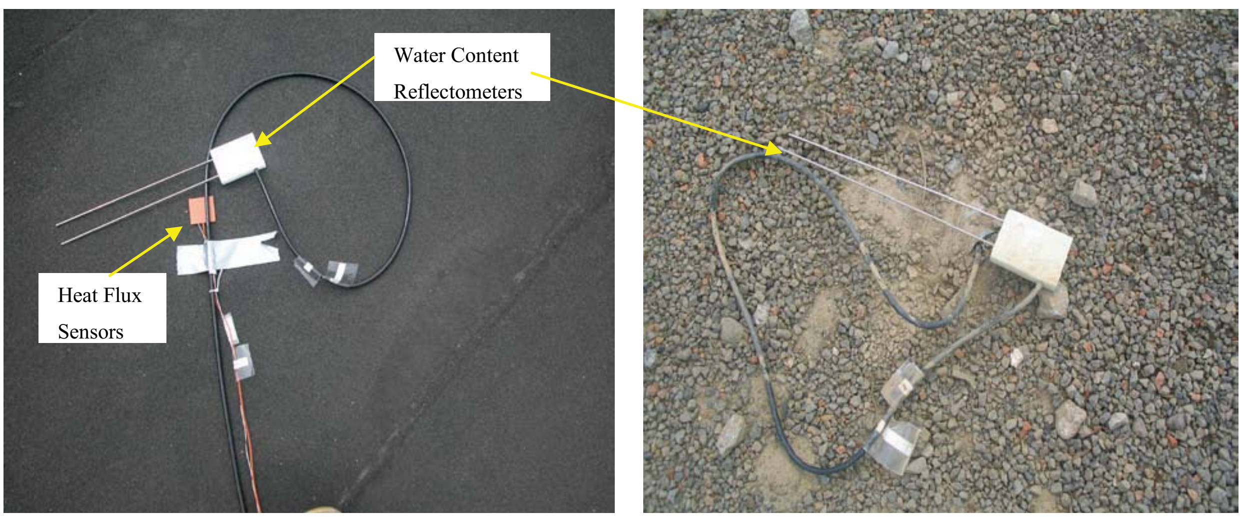






Radiation shield set-up

Installation of Heat Flow Sensor and Water Content Reflectometer



Weather Station installed on three knee walls facing east

Indoor building space under Quadrant II

Indoor building space under Quadrant IV

Indoor building space under Quadrant III (not available)

Drainpipe and sedimentation trap cleanup operation

ANNEX II - LIST OF INSTRUMENTS AND SENSORS

Description	Model	QTY
Note: The equipments are from Campbell Scientific unless noted otherwise		
Sensors		
Water Content Reflectometer (soil moisture sensors)	CS616-L	2
	length each (avg ft)=65	2
	Total	
Thermocouple sensors	105T_L	41
Thermocouple cables	20 AWG (ft)	1790
	20 AWG (ft)	1634
Heat Flow Sensors (Concept Engineering)	F-005-4-T-L (ft)	3
Flow meters	ABB 10D1475W (mini-mag)	3
	(10D1475WN09PD29AC11C1111E1)	
Communication		
Modem	COM210	1
Cable (included; connects with datalogger)	SC12	
Current Shunt TIM Module (100 ohm, connect flow meter to mux)	CURS-100	3
Datalogger	CR1000	1
Multiplexer	AM25T	2
Cable (multiplexer to datalogger)	MUXPOWER_L (2 ft) cable	1
	MUXSIGNAL _L (2 ft) cable	1
	MUXPOWER_L (5 ft) cable	1
	MUXSIGNAL _L (5 ft) cable	1
mounting / enclosure		
10' Alum. tripod (includes grounding kit)	CM110	1
16/18" enclosure (two conduits and a mounting bracket)	ENC 16/18-DC-LB	1
12/14" enclosure (two conduits)	ENC 12/14-DC	1
Enclosure Mount Hanger kit	P/N 17813	2
4' sensor cross arm mount (includes with CM210 mounting kit)	CM204	1
6-Plate gill radiation shield for ambient thermocouples	*Davis Instruments* (P/N 07714)	11
power supply		
12V power supply with charging regulator and rechargable battery 18V 1.2A wall charger, 6 ft	PS100-US	1
Weather Station Sensors		
Anemometer (wind speed & direction)	*Climatronics* Wind Mark III (includes mounting kit)	1
Cable	3pr 18AWG cable	1
Temperature & RH Probe	HMP50-L-GM	1
	L-6 ft cable	1
	GM-41303 -5A Gill Shield	1
Pyranometer (solar radiation)	LI200X-L-LB-SM	1
	L-11 ft cable	1
	LB-LI2003S Leveling Base	1
	SM-CM225 Solar Stand (sensor stand)	1
Precipitation (Rain Guage)	Climatronics 360	1
Software	LoggerNet	1

ANNEX III – GRATZ PLANTING LIST AND PLANTING PLAN

PLANT SCHEDULE

SEDUMS

key	quantity	Botanical Name	Common Name	size	spacing	Number of plants per 24 sf unit
Sc	1140	Sedum cauticola 'Lidakense'	Stonecrop	Plugs	6"	96
Ob	1062	Orostachys boehmeri	Fish mouth Stonecrop	Plugs	6"	96
Sre	672	Sedum reflexum	Spruce stonecrop	Plugs	6"	96
Sra	1577	Sedum rupestre Angelina	Stonecrop	Plugs	8"	54
Sw	1125	Sedum spurium 'White Form'	Stonecrop White Form	Plugs	6"	96
Sar	1050	Sedum 'Rose Carpet' *	Stonecrop Rose Carpet	Plugs	5"	140
St	1192	Sedum floriferum	Weihenstephaner Gold	Plugs	8"	54
Dn	1212	Delosperma nubigenum	Yellow Ice Plant	Plugs	8"	54
Ssa	1228	Sedum acre 'Aureum'	Sedum Golden Acre	Plugs	8"	54
Sse	576	Sedum sexangulare	Tasteless Stonecrop	Plugs	6"	96
Ssi	1237	Sedum sieboldii	Stonecrop	Plugs	6"	96
Ss	1533	Sedum spurium fuldaglut	Stonecrop fireglow	Plugs	6"	96
Sh	1440	Sedum hybridum 'Immergrunchen'	Stonecrop Immergrunchen	Plugs	6"	96
Sba	1243	Sedum 'Bertram Anderson'	Stonecrop Bertram Anderson	Plugs	8"	54
Ssp	1105	Sedum spurium 'John Creech'	John Creech Stonecrop	Plugs	8"	54
Ssv	1099	Sedum spurium 'Voodoo'	Stonecrop Voodoo	Plugs	8"	54
Ssw	1484	Sedum spurium Roseum	Stonecrop	Plugs	6"	96

* Sedum 'Bertram Anderson' acceptable substitute for S. 'Rose Carpet' - substitute entire units only, distribute substituted units evenly

** Sedum telethium 'Autumn Fire' acceptable substitute for S. sieboldii - substitute entire units only, distribute substituted units evenly

NOTES

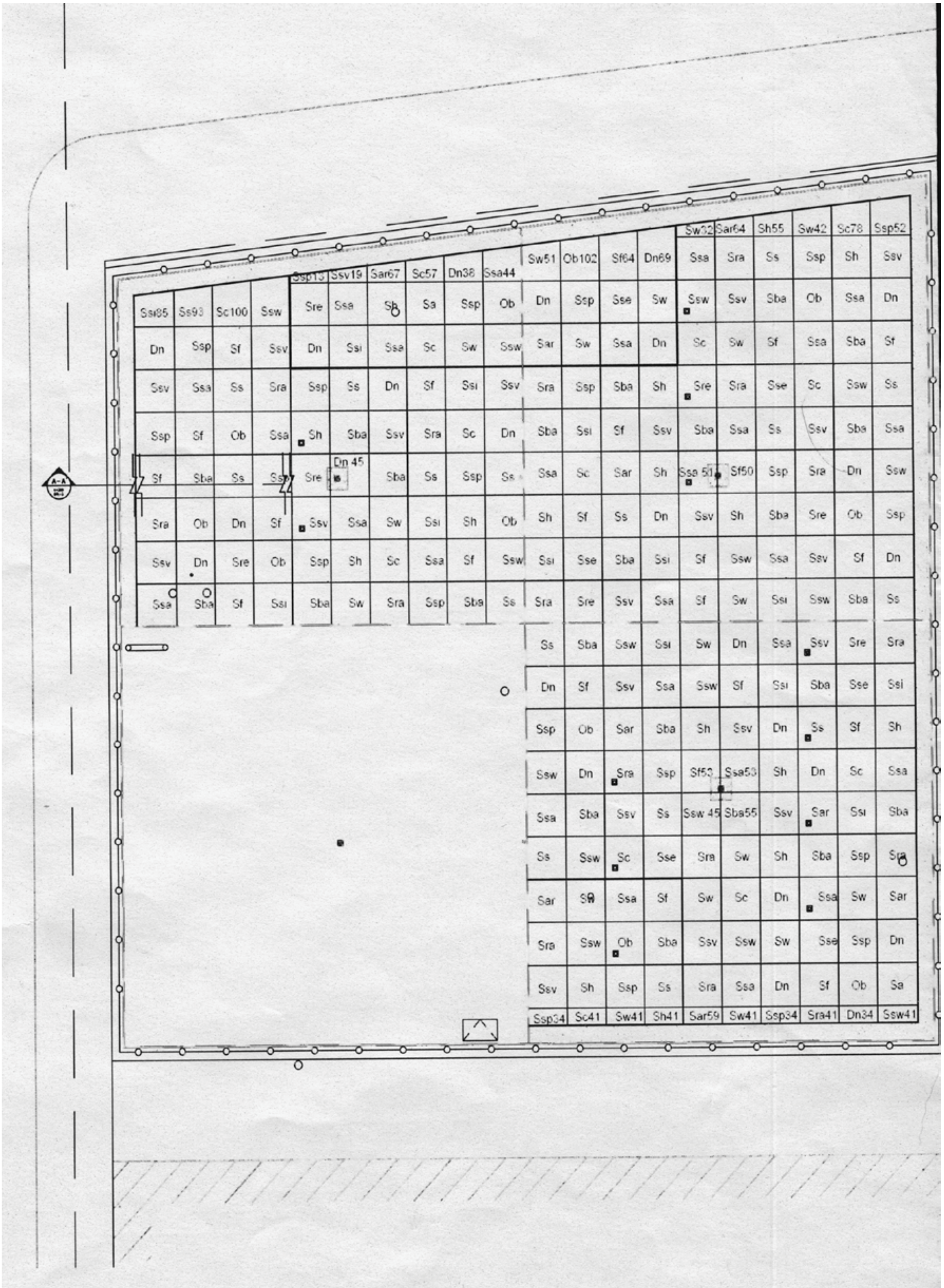
1. All plant materials are subject to the project landscape architect's approval before purchase.
2. The project landscape architect shall approve the layout of the grid structure as shown in the landscape architect's drawings prior to planting. The contractor shall give the landscape architect or equal one week in advance notice.
3. The landscape contractor supply all plant materials in quantities sufficient for intensified sedum plantings for coverage within one growing season.
4. The landscape contractor shall verify all sedum quantities and notify the landscape architect or equal of any discrepancies.
5. The landscape contractor shall give a warranty on the plant materials for a period of two years.
6. The landscape contractor shall set all plants and stakes plumb unless otherwise specified.
7. The landscape contractor shall provide green roof soil substrate as per the contract specifications.
8. All plants shall be watered throughly twice during the first 24-hour period after planting. All plants shall then be watered weekly or more often, if necessary, during the first growing season.
9. The contractor shall lay a wind protection blanket overtop of the plantings during the first growing season to prevent plugs from becoming uprooted by the wind.
10. The landscape contractor shall refer to the plant list for seasonal requirements and other restrictions related to the time of planting.
11. All plant materials shall conform to the guidelines established by the current American Standard for Nursery Stock, published by the American Association of Nurserymen or equivalent.
12. The contractor shall locate and verify the existence of all utilities prior to starting work.

6	06/26/06	Plant Revisions
5	03/29/06	Plant Revisions
4	02/16/06	Plant Revisions
3	11/01/05	Plant Revisions
2	08/25/05	Plant Revisions
1	07/19/04	100%DD

PLANTING PLAN

L-102

06-16-06
1/16"=1'-0"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Ssv Sh Ssp Ss Sra Ssa Dn Sf Ob Sa
Ssp34 Sc41 Sw41 Sh41 Sar59 Sw41 Ssp34 Sra41 Dn34 Ssw41
A-A

ANNEX IV - ACRONYMS FOR SENSORS AND EQUIPMENTS AT SPECIFIC LOCATIONS AND THEIR UNIT OF MEASUREMENT

Acronyms

		Acronym	Description
Thermocouples	INSIDE -- Ceiling Placement	**VTIQ2A**	Vegetated Temperature Inside the building at Quadrant 2 and location A (deg. C)
		VTIQ2B	Vegetated Temperature Inside the building at Quadrant 2 and location B (deg. C)
		VTIQ2C	Vegetated Temperature Inside the building at Quadrant 2 and location C (deg. C)
		VTIQ2D	Vegetated Temperature Inside the building at Quadrant 2 and location D (deg. C)
		VTIQ3A	Vegetated Temperature Inside the building at Quadrant 3 and location A (deg. C)
		VTIQ3B	Vegetated Temperature Inside the building at Quadrant 3 and location B (deg. C)
		VTIQ3C	Vegetated Temperature Inside the building at Quadrant 3 and location C (deg. C)
		VTIQ3D	Vegetated Temperature Inside the building at Quadrant 3 and location D (deg. C)
		CTIQ4A	Conventional Temperature Inside the building at Quadrant 4 and location A (deg. C)
		CTIQ4C	Conventional Temperature Inside the building at Quadrant 4 and location C (deg. C)
		CTIQ4D	Conventional Temperature Inside the building at Quadrant 4 and location D (deg. C)
	OUTSIDE -- Membrane	**VTMQ2A**	Vegetated Temperature at the roof Membrane at Quadrant 2 and location A (deg. C)
		VTMQ2B	Vegetated Temperature at the roof Membrane at Quadrant 2 and location B (deg. C)
		VTMQ2C	Vegetated Temperature at the roof Membrane at Quadrant 2 and location C (deg. C)
		VTMQ2D	Vegetated Temperature at the roof Membrane at Quadrant 2 and location D (deg. C)
		VTMQ3A	Vegetated Temperature at the roof Membrane at Quadrant 3 and location A (deg. C)

Acronym for thermocouples

6 characters

Char 1: Veg or Conv (V or C)
Char 2-3: Vertical location (TI, TM, TT, or TA)
Char 4-5: Quadrant (Q2, Q3, Q4)
Char 6: Horizontal Location (A, B, C, D, E)

Quadrants

UNMONITORED Q1 (vegetated)

Q2 (vegetated)

Q3 (vegetated)
Q4 (conventional)

vegetated (array of 4 thermocouples)

0: TI=At Ceiling Inside Building

1: TM=At Roof Membrane

	VTMQ3B	Vegetated Temperature at the roof Membrane at Quadrant 3 and location B (deg. C)	(Below Drainage Layer)
		Vegetated Temperature at the roof Membrane at Quadrant 3 and location C (deg. C)	2: TT=Top of substrate, plant level
		Vegetated Temperature at the roof Membrane at Quadrant 3 and location D (deg. C)	3: TA=Ambient, 6"
		Conventional Temperature at the roof Membrane at Quadrant 4 and location A (deg. C)	
		Conventional Temperature at the roof Membrane at Quadrant 4 and location C (deg. C)	*conventional (array of 3 thermocouples)*
		Conventional Temperature at the roof Membrane at Quadrant 4 and location D (deg. C)	0: TI=At Ceiling Inside Building
Top of Soil		Vegetated Temperature on Top of the soil at Quadrant 2 and location A (deg. C)	1: TM=At roof membrane
		Vegetated Temperature on Top of the soil at Quadrant 2 and location B (deg. C)	2: TA=Ambient, 6"
		Vegetated Temperature on Top of the soil at Quadrant 2 and location C (deg. C)	
		Vegetated Temperature on Top of the soil at Quadrant 2 and location D (deg. C)	
		Vegetated Temperature on Top of the soil at Quadrant 3 and location A (deg. C)	
		Vegetated Temperature on Top of the soil at Quadrant 3 and location B (deg. C)	
		Vegetated Temperature on Top of the soil at Quadrant 3 and location C (deg. C)	
		Vegetated Temperature on Top of the soil at Quadrant 3and location D (deg. C)	

		Vegetated Temperature in Ambient air at Quadrant 2 and location A (deg. C)
		Vegetated Temperature in Ambient air at Quadrant 2 and location B (deg. C)
		Vegetated Temperature in Ambient air at Quadrant 2 and location C (deg. C)
		Vegetated Temperature in Ambient air at Quadrant 2 and location D (deg. C)
		Vegetated Temperature in Ambient air at Quadrant 3 and location A (deg. C)
		Vegetated Temperature in Ambient air at Quadrant 3 and location B (deg. C)
		Vegetated Temperature in Ambient air at Quadrant 3 and location C (deg. C)
		Vegetated Temperature in Ambient air at Quadrant 3 and location D (deg. C)
		Conventional Temperature in Ambient air at Quadrant 4 and location A (deg. C)
		Conventional Temperature in Ambient air at Quadrant 4 and location C (deg. C)
		Conventional Temperature in Ambient air at Quadrant 4 and location D (deg. C)
		Vegetated Heat Flow at Quadrant 2 and location E, at roof membrane (W/m^2)
		Vegetated Heat Flow at Quadrant 3 and location E, at roof membrane (W/m^2)
		Conventional Heat Flow at Quadrant 4 and location E, at roof membrane (W/m^2)
		Vegetated Temperature (from heat flux sensor) at Quadrant 2 and location E (deg. C)
		Vegetated Temperature (from heat flux sensor) at Quadrant 3 and location E (deg. C)
		Conventional Temperature (from heat flux sensor) at Quadrant 4 and location E (deg. C)
		Vegetated Soil Moisture at Quadrant 2 and location E (%)
		Vegetated Soil Moisture at Quadrant 3 and location E (%)
		Vegetated Flow meter Total at Quadrant 2 (Gal/15mins)
		Vegetated Flow meter Total at Quadrant 3 (Gal/15mins)

Acronym for heat flux sensors (with and without temperature) and water content reflectometers

Char 1: Veg or Conv (V or C)

Char 2-3: Sensor (HF, HT, SM)

Char 4-5: Quadrant (Q2, Q3, Q4)

Char 6: Horizontal Location (E)

Acronym for flow meter

Char 1: Veg or Conv (V or

			C) Char 2-4: Sensor (FMT, FMF) Char 5-6: Quadrant (Q2, Q3, Q4)
		Conventional Flow meter Total at Quadrant 4 (Gal/15mins)	
		Vegetated Flow meter Average Flow at Quadrant 2 (Gal/min)	
		Vegetated Flow meter Average Flow at Quadrant 3 (Gal/min)	
		Conventional Flow meter Average Flow at Quadrant 4 (Gal/min)	
		Vegetated Flow meter Max Flow at Quadrant 2 (Gal/min)	
		Vegetated Flow meter Max Flow at Quadrant 3 (Gal/min)	
		Conventional Flow meter Max Flow at Quadrant 4 (Gal/min)	
	PRECIP	WX station Tipping Bucket (mm/15 min)	
	WSPAVG	Wind Speed Average (m/s)	
	WSPMAX	Wind Speed Max (m/s)	
	WDIRDG	Wind Direction (Degrees)	
	WDIRSD	Wind Direction Standard Deviation (unit less)	
	SOLRKW	Kilowatts per meter squared (kW/m^2)	
	SOLRMJ	Mega Joules per meter squared (MJ/m^2)	
	TMPCWX	Wx Station Temperature (deg. C)	
	RHWXST	Relative Humidity (%)	

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