Quality Assurance Project Plan

Temperature Profiles of a Modular Green Roof as Compared to a Conventional Gravel Ballast Roof for the Heat Island Objective in the 2007 Region 8 U.S. EPA RARE Project, entitled: "Characterization of Green Roof Performance Parameters in the High Elevation, Semi-arid, Temperate Colorado Front Range Region."

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QA ID No.

QA Review Distribution Date

Title: Temperature Profiles and Select Weather Parameters of a Modular Green Roof As Compared To Conventional Gravel Ballast Roof in Denver Colorado

BACKGROUND

Green, living, vegetated, or eco roofs, all terms referring to a class of roof that supports the growth of plants with growing media and in some instances with extra load-bearing capacity, are gaining in popularity throughout the world because of purported favorable environmental and economic attributes. In a quest to shrink its ecological footprint, the EPA, along with other Federal Departments and Agencies, currently is engaged in promoting greater energy efficiency, resource conservation, and carbon emissions reductions through, among other initiatives, designing, constructing, operating, and maintaining high-performance buildings ([1]U.S. Environmental Protection Agency). A green roof is a feature of many high-performance buildings, one of which is the new Region 8 office building at 1595 Wynkoop Street in Lower Downtown Denver, CO.

Green roofs reportedly offer a host of positive attributes relative to conventional roofs that help improve water and air quality in urban settings, in addition to improving urban aesthetics. Particularly germane to this study is a growing body of literature indicating that green roof designs have a cooling effect on urban environments as compared with conventional roof designs ([2]U.S. Environmental Protection Agency). Various authors report that green roofs in combination with urban forestry can significantly mitigate urban heat island effects and provide relief to urban populations especially during heat waves, which are forecasted to increase due to global climate change (Akbari et al., 1999; Banting et al., 2005). In several urban areas, mortality rates from heat waves are forecasted to increase (Knowlton et al., 2004) and measures such as expanding green roof technologies and urban forestry programs to cool urban environments will help protect vulnerable populations (Rosenzweig et al., 2006). There is also at least one report indicating a strong correlation between urban heat islands and air quality standards exceedances in tropospheric ozone concentration (Stone, 2005**)**. High tropospheric ozone concentrations significantly contribute to respiratory ailments in vulnerable populations, are expected to increase in frequency and severity, and are forecasted to increase morbidity and mortality in urban areas (Knowlton et al., 2004). Yet uncertainties remain high over the feasibility, economic viability, and magnitude of environmental benefits realized due to a paucity of rigorous scientific investigations of green roofs, especially in our high plains ecoregion as compared to other low elevation and more humid regions. Information on green roofs in this region is anecdotal or merely speculative, unless what has been reported in low elevation, humid regions also applies to the high plains region. This Project will provide defensible scientific data that informs each one of these uncertainties.

Being the first of its kind within this region, the advent of the Denver EPA green roof offers the unique opportunity to see how green roofs perform and to begin to quantify the environmental results and economic benefits one derives from this emerging building technology. This overall Project addresses three study Objectives: 1. Biological Performance, 2. Stormwater, and 3. Heat Island. This QAPP specifically addresses the Heat Island study, which will use weather station instrumentation to collect temperature profile data on the green roof and the chosen control roof, sited about 50 meters away at 1536 Wynkoop Street. In addition, data on precipitation, solar irradiation, and relative wind speed and direction will be collected from the green roof and relative humidity will be collected from both roofs. Data from this study will be used for all three study Objectives in this Project, and will provide insights into differences in the interaction of visible and infrared radiation with the green roof and the control gravel ballast roof.

Weather station instrumentation were provided with in-kind contributions from the Colorado State University's Department of Horticulture and Landscape Architecture (CSU) and from Region 8 EPA as well as purchased with the RARE funds provided by EPA's Office of Research and Development (ORD) to CSU through a cooperative agreement. All instrumentation were obtained from Campbell Scientific Supply or are compatible with Campbell Scientific instrumentation.

The study design will allow us to collect temperature data without compromising the integrity of the roof envelope of either building. This means that all temperature data is collected from a point extending from the waterproof roof membrane and skyward along a vertical axis at locations on each roof that more or less typifies that roof. Measurement locations include at the roof waterproof membrane surface, at both the gravel-air interface for the control roof and the growth medium-air interface for the green roof, and at a vertical distance of one foot (ca. 0.31 meter) from the waterproof membrane of the control and green roof. Infrared temperature sensor (infrared radiometer) measurements of emitted infrared radiation will be taken from the gravel surface and the plant crowns on the control and green roof, respectively.

SECTION 1.0 PROJECT DESCTIPTION, OBJECTIVES, AND ORGANIZATION

1.1 Purpose of Study

This study is designed to generally provide key weather data for all three Objectives of the Project and, specific to Objective 3 - Heat Island Objective, to quantify temperature profiles of the green roof relative to the conventional roof. From these data, we will extrapolate information regarding the relative magnitude to which these two kinds of roofs might contribute to urban heat island effects and the relative magnitude to which the temperature profile reacts to diurnal and seasonal solar intensity fluctuation. Because of the far-reaching scope of the Project - with a three-prong emphasis on biological performance (Objective 1), stormwater mitigation (Objective 2), and heat island mitigation - resources are optimized for all three Objectives. A holistic approach to this study has been implemented, as opposed to a highly detailed study to quantify a building's thermal input into an urban setting and heat flux through roof envelopes, as are frequent in published literature (Kosareo and Ries, 2006; Valasco, 2006; Takebayashi and Moriyama, 2007). Modifications and additions to this initial experimental design that optimize data collection and observations on temperature flux across the roof envelope will be added to this QAPP as more resources become available.

Weather condition data from the green roof and the control roof augment the biological performance studies, which are designed to qualitatively and quantitatively characterize performance of plant species in our unique high plains ecoregion. Most species studied are new to green roof applications and most are native to our region, which presents climactic conditions that especially on roof surfaces with limited growth media are challenging for plant growth and survival. Weather data is also crucial to stormwater mitigation studies designed to quantify stormwater runoff discharge volumes and temporal shifts in peak flows originating on the green roof and the control roof. Our rain gage with snowfall adapter will provide continuous, real-time precipitation volume-verses-time data within the proximate area. These data are essential for accounting of runoff volumes and flow attenuation for each of the two roof types in the study.

Experimental designs will provide essential information for all three Objectives described in the RARE Proposal and also provide limited data that could yield important insights into the efficacy of green roofs in reducing building energy usage. We will attempt to quantify heat flux through roof envelopes on a theoretical basis according to the Second Law of Thermodynamics and principals of heat transfer through matter by conduction, convection, and radiation. However, critical studies of this type necessitate temperature sensor placement at levels within the roof envelope to obtain an adequate temperature profile across the roof envelope and to incorporate additional sensors to measure evaporation, soil moisture, and net radiation from both upper and lower roof surfaces (Takebayashi and Moriyama, 2007; Valasco, 2006). This type of sensor placement compromises the roof envelope and we do not have the capacity to incorporate this degree of complexity into our studies at this time. Both buildings in the Project are owned and operated by private entities, from which we need permission to gain access to certain spaces and to impart structural modifications. We intend to seek permission to place a temperature sensor in each building on the inside surface of the ceiling below where temperature sensors are placed on the outer surface of the roof. Logistical problems such as intruding into a tenant’s workspace and/or gaining access to the ceiling are of concern to us and to the building management. We plan to address these concerns with building managers in the near future.

1.2 The process, site, facility, apparatus, and/or environmental system

The experimental and control roofs are on multi-story buildings in the Denver, CO, city limits. The green roof is on three levels of 1595 Wynkoop Street. The site of the weather station is on the ninth floor (lowest) green roof level, where biological performance, Objective 1, studies are conducted. The control roof is slightly above the 6^{th} floor level of the Alliance Center Building at 1536 Wynkoop Street (from the 6^{th} floor within the building, one ascends four stair steps to exit onto the conventional gravel ballast roof). The weather station on the green roof is 2 to 3 meters from the 10^{th} floor penthouse wall at the south and east section of the building. The weather station on the control roof is sited on the west portion of the building 2 to 3 meters from the edge of the roof. Both weather stations are sited such that they are exposed to daylight for all daylight hours, except that the control roof experiences limited shading in the early mornings and late evenings. We believe both sites are adequate and will not interfere with the collection of data that are representative of each type of roof.

A schematic of the green roof and the control roof weather stations is provided in Figure 1:

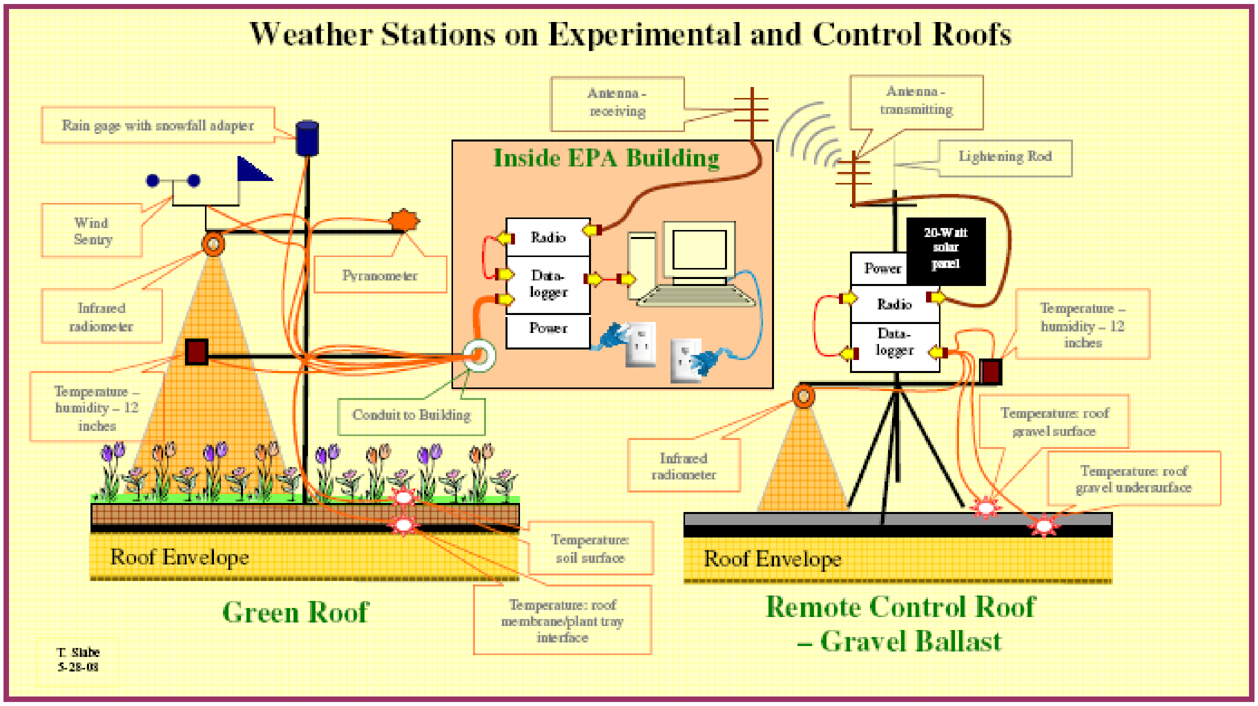

Figure 1 schematic of weather stations on green roof and control roof.

Communication is established between the two weather station dataloggers with RF 401 spread spectrum radios from Campbell Scientific. This allows for greater flexibility for quality control actions such as power supply checks and at-will data checks.

A list of key weather station components is provided:

Items to purchase for the Green Roof Studies for the weather station. (T.S. 070926).								
Sensors: sensors EPA provided are indicated in itallics.								
Type-name	**model #**	**price**	**experi-mental roof**	**control roof**	**required excessories**	**added price**	**subtotal**	**notes**
1. Temp. and humidity sensor	*CS500*	*N/A*		*one each*	*Radiation shield, model # 41303-5A*	*N/A*	*0*	*This part is retired at by the vender.*
2. Temp. and humidity sensor	HMP45C	551	one each		Radiation shield, model #41003-5. Requires 20-25 foot cable.	yes - approx. $100.00	651	CSU obtained/purchased. This part replaces CS500 temp. and humidity sensor (retired).
3. Temp. sensors - 6 each - thermocouples for beneath soil and soil surface	Type T and Type E thermocouples	N/A	two each of Type T and two each of Type E	two each of Type T	Two Type E are 20-25 foot cable and Type T are 10'.			CSU obtained/purchased.
4. Infrared radiometer	IRR-P	705	one each	one each	CM220 or CM230 mounts. One for green roof requires 20-25 ft cable.	20	1450	Measure IR emitted from vegetation (crown) on green roof and gravel on control roof.
5. Silicon pyranometer - solar radiation sensor	*LI200X*	*N/A*	*one each*			*N/A*	*0*	
6. Wind sentry set	*03001-L*	*N/A*	*one each*		*N/A*	*N/A*	*0*	
7. Rain gage - tipping bucket by Texas Ele.	TE525WS-L	388.24	one each		Cables	N/A	388.24	CSU obtained/purchased. This is for Objective 2, Stormwater Management, and also useful for Objectives 1 and 3.
8. Snowfall conversion adaptor	CS705	460	one each		Antifreeze, # 10869	83	543	CSU obtained/purchased. This is for Objective 2, Stormwater Management.
						total	**3032.24**	
Telemetry: recommended.								
900 MHz Spread Spectrum Radio - 2 each	RF401	440	one each	one each	Yes - to be determined.		880	CSU obtained/purchased.
9-dBd antenna - 2 each	14201	165	two each	one each	Yes - to be determined.		330	CSU obtained/purchased.
Cable - 2 each	COAXRPSMA-L	41.76	one each	one each	Yes - to be determined.		83.52	CSU obtained/purchased.
Cable	COAXNTN-L	84.8	one each	one each			170	CSU obtained/purchased.
Antenna surge protector kit	14462	115	one each	one each			230	CSU obtained/purchased.
						total	**$1,693.52**	
Preliminary cost estimate without solar panel, new battery, enclosure, etc. (refer below) is							**$4,725.76**	
Solar panel	Donated by Air Program, OPRA, Ken Distler and Michael Copeland.							
Battery	To be determined. R8 Laboratory provided one battery that Ken Distler tested and found to retain charge.							
One each CR 1000 Campbell Scientific datalogger provided by CSU and R8 EPA.								
Station mounting on the experimental roof will be completed under contract by the EPA infrastructure program according to submitted plans.								
Tripod for the control roof is provided by the R8 Laboratory.								
Weather resistent enclosure for the green roof is provided by the R8 Laboratory and for the control roof is provided by CSU.								
Note that all prices are taken from 2007 U.S. Price List for Campbell Scientific. Prices are subject to change. Also, some required accessories, e.g., mounts and cables, may not be included in this summary estimate. Therefore this price estimate no doubt is low.								

Table 1: essential weather station components.

1.3 Objectives

The specific objective is to obtain accurate temperature, relative humidity, solar radiation intensity, precipitation, and wind speed and direction data for all three objectives of the Project and, specific to Objective 3, to ascertain from the data as much as possible how the green roof design differs relative to a conventional roof design in response to ambient climactic conditions in our high plains ecoregion. Especially during daily peak temperature periods during summer, conventional roofs because of their design and materials reportedly are much warmer than green roofs ([2]U.S. EPA**)**, which is supported by our preliminary observations. During the growing season, green roof planting media and plants store water, which as it evaporates exerts a net cooling effect. Plant crowns also shade the substratum from direct sunlight and absorb some visible light wavelengths for photosynthesis and photorespiration and reflect other visible wavelengths back into the atmosphere. By contrast, conventional roof materials are known to absorb a large amount of the incident solar radiation, which consists mainly of the visible wavelengths. When the portion of the visible spectrum is absorbed in materials, such as high-emissivity and low albeto roofing materials that generally comprise conventional roofs, those visible wavelengths are converted to infrared radiation, or heat, and re-emitted back into the atmosphere. Thus conventional roofs are thought to contribute more to urban heat islands than do green roofs. In addition, if an outer roof surface temperature is extremely high, there is a corresponding temperature increase in the interior of the building, depending upon roof's resistance to heat flow, or R-Factor. In many instances, during warm months a building must remove this excess heat with air conditioners, which themselves are a significant source of waste heat that enters urban settings and contributes the urban heat islands (Banting et al., 2005). The extra mass on green roofs contributed by the growth media and plant materials might provide measurable resistance to heat flow through the roof envelope from the interior to exterior during cold months, and thus reduce heating requirements in buildings with green roofs relative to conventional roofs, all other factors such as envelope thickness and level of insulation being equal. Characterizing temperature profiles of the roof surfaces will provide insights into the relative contributions of each kind of roof to urban heat island effects and into building energy usage.

The overall objective is to ascertain through these studies whether or not green roofs are feasible in our region and to obtain information on whether or not green roofs are economically viable over a building's life cycle. Since this is the first extensive green roof installation of its kind in this region, we plan to inform others of its strengths and weaknesses as they relate specifically to our high plains ecoregion.

1.4 Project Organization and Responsibilities

Name	Affiliation and Responsibility	Telephone
Thomas O'Connor	EPA Office of Research and Development (ORD), Project Officer	732-321-6723
Patti Tyler	Region 8 EPA, Office of the Regional Administrator, Region 8 Project Co-lead/Manager	303-312-6081
Joni Teter	Region 8 EPA, Office of Technical and Management Services, Region 8 Project Co-lead/Manager	303-312-6553
Thomas Slabe	Region 8 EPA Regional Laboratory, Region 8 Technical Lead for Objective 3 of the Project, Planning, Experimental Design, Data collection, Data Validation, Data Reduction, Data Analysis, Report Preparation and Quality Assurance	303-312-7797
Gregory Davis	Region 8 EPA Office of Partnerships and Regulatory Assistance, Waste Water Unit,	303-312-6314

	Region 8; Technical Lead for Objective 2 of the Project, Planning, Experimental Design, Data collection, Data Validation, Data Reduction, Data Analysis, Report Preparation and Quality Assurance	
Dr. James Klett	Colorado State University Department of Horticulture and Landscape Architecture; Project Principal Investigator	970-491-7179
Jennifer Bousellot	Colorado State University Department of Horticulture and Landscape Architecture, Ph.D. Student and Research Assistant; Technical Lead for Objective 1 of the Project, Planning, Experimental Design, Data collection, Data Validation, Data Reduction, Data Analysis, Report Preparation and Quality Assurance	303-908-3538
Carolyn Esposito	EPA ORD, QA Officer	732-906-6895

Table 2 Project Staff and Responsibilities

Project Task Activities	Date
Initial Quality Assurance Plan Development/Approval	10/15/2008
Revision of QAPP	10/24/2008
Programming of Dataloggers	Completed
Calibration of instrumentation	Completed
Preliminary Results Analysis	Completed
Begin official data collection	10/15/2008
End data collection	TBD*
Write initial report	1/1/2009

Table 3 Preliminary Project Schedule

SECTION 2.0 EXPERIMENTAL APPROACH

2.1 All known or preestablished test conditions and variables shall be provided in the QAPP.

At the time of writing this draft the weather station instrumentation have been installed and are effectively in operation. Initially, several practical hurdles related to installations on roof surfaces had to be overcome, in addition to ramping up regional capacity for the intended experimental approach. In a comment on the first draft, the Project Officer Thomas O’Connor wrote “Play with the equipment and determine the capabilities of the equipment, then submit the QAPP.” Therefore this QAPP describes an experimental approach that has for almost two months been tested, appears to be working, troubleshooting is largely complete, and maintenance and calibration procedures are essentially developed.

Several changes have been made during the past few months during the set-up phase, largely due to potential hazards related to roof installations. Because of electrical grounding, support structure, antenna placement, power supply, and several other issues, the install and troubleshooting was a challenge. Gaining access to the remote weather station on the control building roof can at times be time-consuming, depending upon the availability of building management staff.

Components for the weather station were assembled from disparate localities and they were from various vintages. In addition, because of the uniqueness of rooftop installation of instrumentation, additional supplies were procured and custom designs were implemented. We therefore had to improvise, update software, and attend to safety and quality control considerations, which prolonged weather station installations. One example is electrical grounding of instrumentation with proper earth grounds. This added over $2,000 to installation costs. In addition to safety concerns of short circuits and lightening, static discharges are a major concern from a data quality control perspective. We are confident that grounding is properly implemented and the installations are safe and functional.

For our experimental approach, we modified the experimental design of Columbia University's Climate Impact Group (CIG) research station experimental design to fit within our budget and capabilities. Compared with the CIG's design depicted in Figure 2, below, we have eliminated two temperature sensors on our green roof and modified the location of one temperature sensor on our control roof (Table 4). Because the buildings in our study are not owned be the U.S. EPA, we had no say with regard to placing sensors through the roof envelope. In the future, we plan to work with building owners to place thermocouples at location on the interior surface of the roof and this QAPP will be updated accordingly.

Table 4 compares CIG's design with our current design of placement of temperature sensors:

Roof Type	CIG	R8EPA
Green	6-12 inches above roof deck	12 inches above roof deck
Green	Height of vegetation	Vegetation crowns
Green	Top of growing medium	Top of growing medium
Green	Bottom of growing medium	None
Green	Waterproof membrane	Beneath GreenGrid® plant trays in contact at waterproof membrane level
Green	Ceiling within building	None
Control	6-12 inches above roof deck	12 inches above roof deck
Control	None	Top of gravel ballast
Control	Waterproof membrane	Waterproof membrane
Control	Ceiling within building	None

Table 4 Comparison of CIG temperature sensor placement with R8EPA green roof and control roof temperature sensor placement, and modification thereof.

Currently we are using Type E and Type T thermocouples to measure temperatures of surfaces (soil, waterproof membrane, gravel, beneath plant trays), temperature and relative humidity probes to measure ambient temperatures (12 inches above roof deck), and precision infrared temperature sensors to measure the vegetation crowns and gravel surface. Gravel surface temperature readings are measured with both the Type T thermocouple and the infrared temperature sensor (infrared radiometer).

Figure 2 from CIG depicts the placement of temperature sensors in their design with red dots in the lower left. Our green roof system differs from CIG's in that the R8EPA's is a GreenGrid® system that incorporates modular 2 foot by 4 foot by 4 inch plant trays. Trays are not indicated in Figure 2 or in CIG's description of their experimental design.

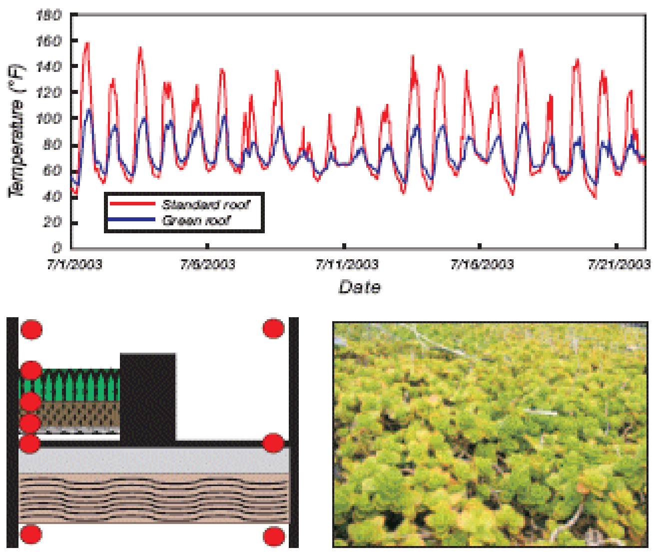

Figure 2 Example of an experimental design used as a model, with modification, for our experimental design for roof temperature data collection.
From: Center for Climate Systems Research
Climate Impacts Group
Columbia University
Armstrong Hall
2880 Broadway
New York, NY 10025
Research Station
http://ccsr.columbia.edu/cig/greenroofs/index.html
http://ccsr.columbia.edu/cig/greenroofs/Green_Roof_Research_Station.pdf

Graphics produced from temperature data taken July 24, 2008 as one typical summer day show that the chosen experimental design will effectively resolve differences in temperatures between the different roof layers and between the green roof and the control roof. Figure 3 below shows a wide range in temperature difference between the green roof membrane (GR-mem; temperature high at approximately 83ºF; beneath the plant trays) and the control roof membrane (CR-mem; temperature high at approximately 144ºF; beneath gravel ballast.) Interestingly, time verses temperature data of the gravel surface measured with the infrared radiometer (CR-IRR) and the Type T thermocouple (CR-GS) are almost in lock-step in Figure 3. These data show as one might expect that the temperatures (given in degrees Fahrenheit) of the green roof membrane beneath the plant trays are cooler at midday than the ambient temperatures (GR-AT and CR-AT) taken at one foot above roof deck, while temperatures of all other surfaces are warmer than the ambient temperatures. In addition, between 4:20 PM and 4:25 PM we received 0.04 inch of rain, which produced an abrupt increase in relative humidity and drop in all recorded temperatures on both roofs. Redundancy in temperature measurements contributes to quality assurance goals of the Studies.

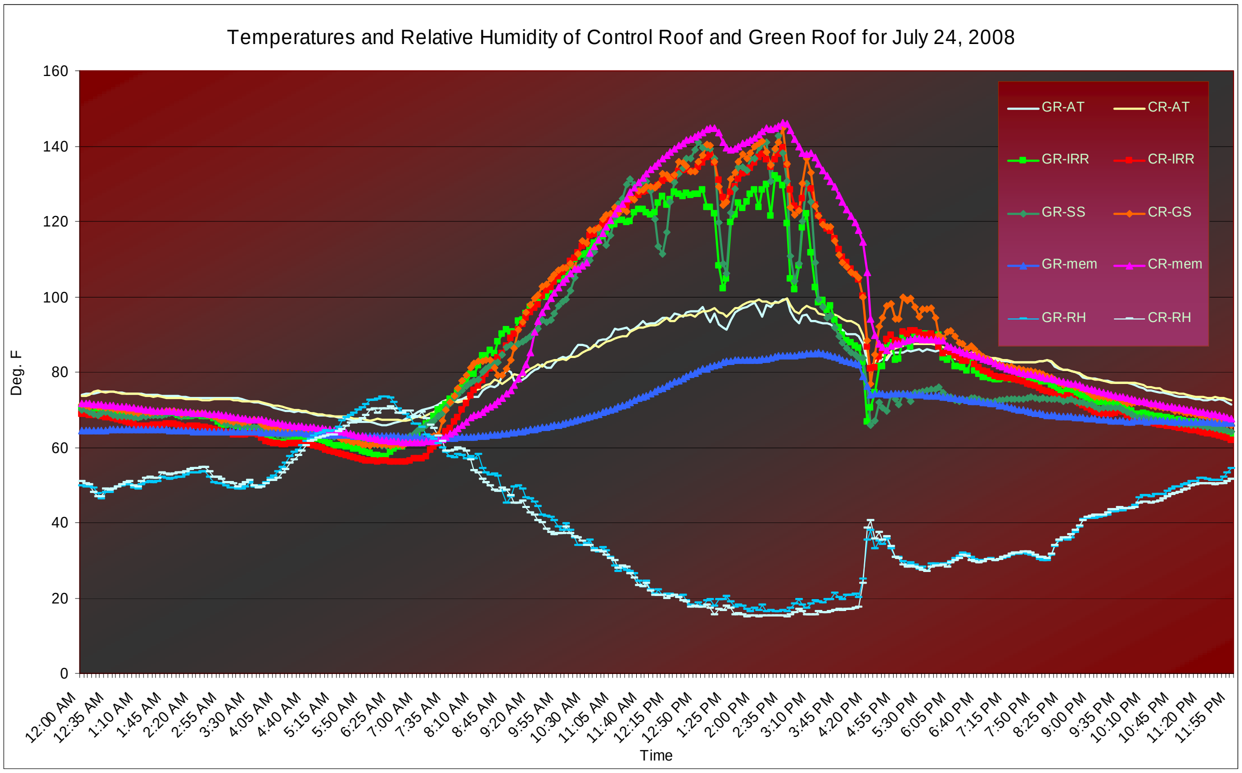

Figure 3 Graph of temperatures for July 24, 2008.

Regarding wind speed and direction and precipitation measurements, the anemometer and wind vane and rain gage are located at the biological performance experimental site. The purpose of this instrumentation is to obtain data on the conditions at the site, relative to the prevailing conditions in the general area. This instrumentation is near the 10th floor penthouse outer wall, which will cause wind turbulence and will impart an effect on precipitation, wind speed, and wind direction. We are not interested in the weather conditions, per see, as much as gauging the relative conditions at the site where biological performance testing is being conducted. The same may be stated for solar radiation measurements with the pyranometer, except that the solar radiation intensity measurements are expected to be comparable at any site in the proximate area that does not receive shade throughout a portion of the day. The pyranometer is exposed to direct sunlight throughout the entire day and this site is considered typical for the proximate area, including the green roof and the control roof.

Thus far our experimental design appears to be working well. Early data indicates that the instruments are taking accurate measurements. Further monitoring, calibration, and data analysis are needed at the moment to determine accuracy, in a strict statistical sense. For example, we calibrate the precipitation gage on nearly a weekly basis and are obtaining precise calibrations of 57 tips per pint of water, indicating rainfall amount of 0.57 inch. However, for the month of August we recorded 2.19 inches of precipitation at our site, yet 4.03 inches were recorded at Denver International Airport. We therefore must reconcile why the discrepancy exists between rainfall amount over the ca. 20 miles between Downtown Denver and Denver international Airport.

2.2 All measurements (i.e., analytical [chemical, microbiological, assays, etc.], physical, and process) shall be identified for each sample type or process, and project-specific target analytes shall be listed and classified as critical or noncritical in the QAPP.

Both CR1000 dataloggers are programmed to take a recording from each sensor every 30 seconds. Single 30 second recordings (10 recordings) from each sensor are averaged for each 5-minute interval and that average is recorded by the CR1000s.

Measurement	Procedure
1. Temperature of green roof beneath plant trays (at waterproof membrane level)	Type T thermocouple, 105T
**2. Temperature of green roof beneath plant trays (at waterproof membrane level)	Type E thermocouple, 105E
3. Temperature of control roof beneath gravel (at waterproof membrane level)	Type T thermocouple, 105T
4. Temperature of green roof at growth media-air interface	Type T thermocouple, 105T
**5. Temperature of green roof at growth media-air interface	Type E thermocouple, 105E
6. Temperature of control roof at gravel-air interface	Type T thermocouple, 105T
7. Temperature of control roof at gravel-air interface	Infrared radiometer, IRR-P
8. Temperature of green roof at plant crown surface	Infrared radiometer, IRR-P
9. Air/ambient green roof temperature and relative humidity at 1-foot above roof deck	Temperature and relative humidity probe, CS500
10. Air/ambient control roof temperature and relative humidity at 1-foot above roof deck	Temperature and relative humidity probe, HMP45C
11. Rainfall on green roof	Tipping bucket rain gage, TE525WS, 8 inch collector
12. Snowfall on green roof	Precipitation adapter, CS705
13. Solar irradiation on green roof	Pyranometer, LI200X
14. Wind speed on green roof	Young wind sentry anemometer, 03101 R.M.
15. Wind direction on green roof	Young wind sentry vane, 03301 R.M.

Table 5 Measurements and Procedures

**Type E thermocouples with lengthened cables were added to the experimental design on August 7, 2008 at 13:30 in order to extend out to a site more representative of the green roof. This was necessitated due to a change in design concerning the support structure for the weather station (use of a tripod was disapproved by the building management and we therefore developed a customized support structure design). We found that Type E thermocouples and Type T thermocouple can serve as controls for one another.

We feel that all of these measurements are critical to the success of the project, due to its far-reaching nature of addressing biological performance, stormwater, and heat island.

2.3 Sampling or monitoring points for all measurements

Information is provided in Figure 1 of placement of sensors. Figures of the control roof and green roof weather stations are provided:

Figure 4 (left) Weather station on control roof, looking down from green roof in an east, north-east direction.
Figure 5 (right) Weather station on green roof, looking more-or-less in the westerly direction.

2.4 Frequency of sampling/monitoring

We are recording data continuously, with 30 second measurements averaged over 5 minutes per data point for each sensor. The CR1000 dataloggers have been storing in their circular memory devices for the green roof and the control roof one month of data and close to two months of data, respectively. Nevertheless, we download all data on a weekly basis. Data downloads are executed from within our instrument room on the 9th floor of the EPA office building. A transmitting-receiving antenna for the RF401 spread spectrum radio on the green roof has been installed at the 10th floor level of the EPA building within direct line-of-sight of the antenna for the control roof radio. Download is extremely easy now that the troubleshooting issues are resolved. In the future, we plan to program the dataloggers to provide continuous, or nearly continuous, automatic downloads and, if approved by the R8 Information Technology Program, to network these data to provide data access to the Region and perhaps beyond. Discussions with the Campbell Scientific applications engineers indicate that this is not difficult to accomplish. We first need to "drop" a network connection feed to the location in our instrument room where our computer is located.

2.5 Evaluating project objectives (i.e., data analysis), including formulas, units, definitions of terms, and statistical analysis, if applicable, shall be included in the QAPP.

Graphics like or similar to that presented above in Figure 3 will be produced with all collected data for analysis and for presentations.

Temperature and relative humidity comparisons between the green roof and the control roof – surface temperature fluctuation and overall surface temperatures are generally lower on the green roof than on the control roof during the warm season, mid June through mid September. Temperature maximums at the waterproof membrane level on the control roof are substantially greater than that of the green roof (beneath plant trays) and at least during the growing season should be easily resolved at the 99 percent confidence interval. Overall, there will be significantly lower temperatures at all levels on the green roof as compared with the control roof. We will evaluate daily temperature maximums, daily temperature minimums, yearly average temperatures, and other parameters that will provide a clear understanding of the differences between the two disparate roof installations. During the cold months, the temperature differences between the two types of roofs will diminish. Standard statistical methods will be employed and statistically significant differences will be established when at least the 95 percent confidence level is exceeded. Emphasis in data analysis will be placed in the growing season period. However, we will collect data throughout the year and analyze all of the data. Data from the various kinds of sensors, including the two types of thermocouples, two models of temperature probes, and infrared temperature sensors will be compared with one another for quality assurance checks. Temperature and relative humidity data collected at one foot above roof deck on the two roofs seems to remain reasonably comparable between the two roofs and therefore are reasonable internal checks for data quality.

Solar irradiation – green roof installations exist around the world. They are more frequent in regions with greater cloud cover than is characteristic of the high plains ecoregion. Solar radiation data is indispensable to our overall project to show that solar input in our region, in particular during the growing season, is substantially higher than that of localities where green roof applications are generally found, such as, for example, Germany; Toronto, Ontario, Canada; New York City, USA; and Tokyo, Japan. These locations are all much lower in elevation and more humid than the high plains, with a concomitant reduced intensity of solar radiation from lower elevation, cloud cover, and haze. Consequently, to accurately describe the conditions that typify our region, we will benefit from data collected at the precise location of our study. In addition, anecdotal observations on our green roof suggest that at least some of the plant species benefit from shadows cast by photovoltaic panels installed upon our roof. By collecting baseline data on solar irradiation, we may find these data very useful in future studies that may focus on optimal growing conditions for disparate plant species or on minimizing irrigation requirements. High solar irradiation can cause reversible and irreversible damage to photosynthetic apparatus, induces high rates of photorespiration to counteract the damaging effects of excess sunlight, and on hot days contributes to excessive wilting. Anecdotally at least, it appears as though partial shading of roof plants in our region is beneficial to plant growth and survival and that the integration of solar panels into green roof designs can improve roof performance while providing a platform for this renewable energy technology.

Precipitation – precipitation in the high plains region is highly variable over time and space. It will be valuable to collect precipitation data on site to compare with regional weather information. These data will also be essential for quality checks for the stormwater objective and for characterizing growing conditions on the roof for the biological performance objective. In addition, these data, as with solar radiation data, will allow us to accurately compare the climate in our region with other regions where most green roof research is conducted.

SECTION 3.0 SAMPLING PROCEDURES

3.1 Establishing steady state conditions

Steady state conditions for climate are determined over extremely long time periods. We wish to just obtain a snapshot over the duration of the project. Weather conditions especially in our high plains region are quite variable. However, this is a temperate climate with distinct seasons characterized by weather extremes. Drought, high solar irradiation, heat waves, blizzards, and high winds are not uncommon. We wish to chronicle weather conditions by taking accurate measurements to demonstrate that the high elevation, semi-arid, temperate climate is markedly different from localities where most green roof research is conducted and to test the degree to which results from other regions with disparate climates can be applied to our region.

3.2 Each sampling/monitoring procedure to be used shall be described in detail or referenced in the QAPP.

Samples will not be collected during these studies. Monitoring procedures are explained in detail above. Essentially, as per the chosen experimental design, the instrumentation does the monitoring following installation. Investigators monitor the instrumentation to insure that it is operating correctly and properly calibrated according to manufacturers suggested procedures and frequencies. A summary of Campbell Scientific recommended troubleshooting, maintenance, and calibration procedures is given in Table 6.

Component	Troubleshooting	Maintenance/Calibration
TE525WS-L Tipping bucket rain gage	1. Check that the sensor is wired to the Pulse Channel specified by the pulse count instruction. 2. Verify that the Configuration Code (Switch Closure), and Multiplier and Offset parameters for the Pulse Count instruction are correct for the datalogger type. 3. Disconnect the sensor from the datalogger and use an ohm meter to do a continuity check of the switch. The resistance measured at the terminal block on the inside of the bucket between the plack and white leads should vary from infinite (switch open) when the bucket is tipped, to less than an ohm when the bucket is balanced.	Following calibration, check is advised every 12 months. Routinely check for and remove foreign material. Field Calibration Check: 1. Secure a metal can that will hold at least one quart of water. 2. Punch a very small hole in the bottom of the can. 3. Place the can in the top funnel of the rain gage and pour 16 fluid ounces (1 pint) of water into the can. 4. If it takes less than 45 minutes for this water to run out, the hole in the can is too large. 5. The following number of tips should occur: TE525WS – 57+-2. 6. Adjusting screws are located on the bottom adjacent to the large center drain hole. Adjust both screws the same number of turns. Rotation clockwise increases the number of tips per 16 oz of water; counter clockwise rotation decreases the number of tips per 16 oz of water. One half turn of both screws causes a 2% to 3% change. 7. Check and re-level the rain gage lid.
CS705 Precipitation Adapter		During site visits, verify the slot in the top of the overflow tube is free of ice or debris and remove any debris from the catch orifice. If the slot in the overflow tube becomes plugged, the overflow tube may create a siphon and draw down the antifreeze level. The PGE solution becomes more dilute as precipitation is captured and mixed. Initially, the CS705 is charged with at pure antifreeze mixture giving it a 10:0 antifreeze:water ration. The ratio increases to 1:1 with the equivalent of six inches of liquid, 1:2 with eight inches, and 1:3 with nine inches. The 1:1 solution becomes slushy at a temperature of about -35 degrees C, the 1:2 at -20C ,and the 1:3 at -10C. Ratios greater than 1:3 are not recommended. Refer to Fig. 5-1 in Manual to determine the amount of remaining antifreeze based on precipitation (water equivalent) recorded.
IRR-P Precision Infrared Temperature Sensor		As with any optical sensor, it is important to keep the lens and view clean. Otherwise the sensor will be measuring the temperature of the obstruction instead of the surface of interest. Clean the lens gently with moistened cotton swab. Distilled water

		or alcohol works well for most dust/dirt. Salt deposits dissolve better in a weak acid solution (about 0.1 molar sol.)
LI200X Pyranometer	Symptom:-9999 or radiation values around 0 1. Check that the sensor is wired to the Differential channel specified by the measurement instruction. 2. Verify that the Range code is correct for the datalogger type. 3. Disconnect the sensor leads fro the datalogger and use a DVM to check the voltage between the red (+) and the black (-) wires. The voltage should be 1-5 mV for 0 to 1000 Wm-2 radiation. Mo voltage indicates a problem with the photodiode, cable, or the variable shunt resistor. Symptom: Incorrect solar radiation 1. Make sure the top surface of the sensor head is clean, and that the sensor is properly leveled. 2. Verify that the Range code, multiplier and offset parameters are correct for the desired engineering units and datalogger type.	On a regular basis level of the pyranometer should be checked. Any dust or debris on the sensor head should be removed. The debris can be removed with a blast of compressed air or with a soft bristle, camel hair brush. check the that the grain hole next to the surface of the sensor is free of debris. CAUTION Handle the sensor carefully when cleaning. Be careful not to scratch the surface of the sensor. Recalibrate the LI@))X every two years. Obtain an RMA number before returning the LI200X to Campbell Scientific, Inc. for recalibration. Calibration LI200X pyranometers output a current that is proportional to the incoming solar radiation. Each LI200X has a unique calibration factor. A variable shunt resistor in the cable converts the current to the voltage measured by the datalogger. Campbell Scientific sets the shunt resistor so that the pyranometer outputs 5 mV kWM2. The resistor value if found using Ohms low. The resistance is found by dividing the desired output voltage by the calibrated current output. For example, a pyranometer with a calibration of 92 uA kW^{-1} m^2, will have the resistor set to: 54.35 ohms = 5 mV $kW^{-1}$$\cdot$$m^2$/0.092 mA kW^{-1} m^2.
CS500 Temp. and Relative Humidity Sensor (the one on the green roof)		Probe requires minimal maintenance. Check monthly to make sure the radiation shield is free from debris. The white screen at the tip of the probe should also be checked for contaminants. When near bodies of salt water, requires additional maintenance. The filter can be rinsed gently in distilled water. If necessary, the chip can be removed and rinsed as well. Do not scratch the chip while cleaning. The offset and gain on the CS500 electronics can not be adjusted as part of a recalibration. Replace the chip as needed.
HMP45C Temp. and Relative Humidity Sensor (the one on the control roof)	Symptom: -9999, NAN, -40 deg C, or 0% relative humidity 1. Check that the sensor is wired to the correct excitation and analog input channels as specified by the measurement instructions. 2. Verify the Range code is correct for the datalogger type. 3. Verify the red power wire is correctly wired to the 12V, Switched 12V, or SW12V module. The terminal the wire is connected to will depend on the datalogger program. Connect the red wire to a 12V terminal to constantly power the sensor for troubleshooting purposes. With the red wire connected to the 12V, a voltmeter can be used to check the output voltage for temperature and relative humidity on the yellow and blue wires respectively (temperature deg C = mV* 0.1 – 40.0; relative humidity % = mV * 0.1). Symptom: Incorrect temperature or relative humidity 1. Verify the multiplier and offset parameters are correct for the desired units (Table 5-1).	Requires minimal maintenance. Check monthly to make sure the radiation shield is free from debris. The black screen at the end of the sensor should also be checked for contaminates. Extra maintenance required if used near salt water bodies. The filter can be rinsed gently in distilled water. If necessary, the chip can be removed and rinsed as well. Do not scratch the chip while cleaning. If located near corrosive chemicals including gasses the sensor life expectance can be shortened. Refer to manual.
Type T and E thermocouples		Check proper placement frequently.
03101Wind Sentry anemometer and 03301 Wind Sentry vane	Wind direction – symptom: -9999 or no change in direction. 1. Check that the sensor is wired to the Excitation and the Single-Ended channel specified by the measurement instruction. 2. Verify that the excitation voltage and range code are correct for the datalogger type. 3. Disconnect the sensor from the datalogger and use an ohm meter to check the potentiometer. Resistance should be about 10K ohms between	Wind Sentry if fully calibrated before shipment and should require no adjustments. For calibration methods, refer to Instruction Manual for 03001 R.M. Young Wind Sentry Set.Call Campbell Scientific for replacement of parts. Maintenance calls for monthly visual/audio inspection of anemometer at low wind speeds. Verify that the cup assembly and wind vane rotate freely. Inspect the sensor for physical damage. Replace the anemometer bearings when they become noisy, or the wind speed threshold increases above an acceptable level. The condition fo the bearings can be checked with a paper clip as described in the R.M Young manual.

	the black and white wires. The resistance between either the plack/red or white/red wires should vary from 1K to 11K depending on vane position Resistance when the vane is in the 5 detree dead band should be about 1M ohm. Wind speed – symptom: no wind speed. 1. Check that the sensor is wored to the Pulse channel specified by the Pulse count instruction. 2. Disconnect the sensor fro the datalogger and use an ohm meter to check the coil. The resistance between the white and black wires should be a nominal 1350 ohms. Infinite resistance inticates an open coil; low resistance indicates a shorted coil. 3. Verify that the Configuration Codes, and Multiplier and Offset parameters for the Pulse Count instruction oar correct for the datalogger type. Wind speed – symptom: wind speed down not change. 1. For the dattloggers that are programmed with Edlog, the input location for the wind speed is not updated if the datalogger is getting "Program Table Overruns". Increase the execution interval (scan rate) to prevent overruns.	The potentiometer has a life expectancy of fifty million revolutions. As it becomes worn, the element can produce noisy signals or become non-linear. Replace the potentiometer when the noise or non-linearity becomes unacceptable.

Table 6 Campbell Scientific recommended troubleshooting, maintenance, and calibration procedures.

3.3 Sampling/monitoring procedures shall be appropriate for the matrix/analyte being tested.

Type T and Type E thermocouples typically measure soil temperatures. All other sensors are installed according to manufacturer/supplier recommendations.

3.4 If sampling/monitoring equipment is used to collect critical measurement data (i.e., used to calculate the final concentration of a critical parameter), the QAPP shall describe how the sampling equipment is calibrated.

Refer to Table 6 above.

3.5 Cross-contamination

Not applicable.

3.6 Representativeness

The several types of temperature sensors together with relative humidity sensor, precipitation gage, and pyranometer will be in continuous operation. Data from all sensors will be compared with one another. With some temperature sensors the data should be comparable, such as those measuring ambient temperatures and the Type T thermocouple and infrared radiometer on the control roof that both measure the temperature of the outer gravel surface. The relative humidity sensor data should be comparable. Collectively and in combination with instrumentation from the Region 8 laboratory such as calibrated thermometers, we will ensure that the data are representative of roof weather conditions and that sensors are taking accurate measurements. For one week per year we will obtain a NIST certified pyranometer from the CSU Climate laboratory to change out with our pyranometer to ensure data we obtain from our pyranometer are representative/accurate.

3.7 A list of sample quantities to be collected, and the sample amount required for each analysis, including QC sample analysis, shall be specified in the QAPP.

The TE525WS tipping bucket rain gauges require a minimum of 0.01 inch of rainfall for the tipping bucket to record data. The maximum cumulative rainfall data is independent of the tipping bucket mechanism and is a function of the programmable CR1000 datalogger. Accuracy of ±1% can be maintained for rain intensities of 1 inch per hour.

3.8 *Containers used for sample collection*

Not applicable

3.9 Sample preservation methods

Not applicable.

3.10 Holding time requirements

Not applicable.

SECTION 4.0 TESTING AND MEASUREMENT PROTOCOLS

4.1 Each measurement method to be used shall be described in detail or referenced in the QAPP. Modifications to EPA-approved or to similarly validated methods shall be specified.

Manufacturer's recommendations were modified at least for the site recommendations for the Young Wind Sentry anemometer and vane and for the precipitation gage. For accurate weather measurements one must site this instrumentation in open areas away from buildings, trees, and any like vertical structures. We are not as concerned about regional weather as we are about the precise conditions on the portion of roof surface of interest, where the biological performance tests are being completed and where a portion of roof surface is typical of that roof. With regard to placement of other sensors, that was covered above in the section on experimental design.

4.2 Methods shall be appropriate for the matrix/analyte being tested.

Not applicable.

4.3 For unproven methods, the QAPP shall provide evidence that the proposed method is capable of achieving the desired performance.

Not applicable.

4.4 For measurements which require a calibrated system, the QAPP shall include specific calibration procedures, and the procedures for verifying both initial and continuing calibrations (including *frequency and acceptance criteria, and corrective actions to be performed if acceptance criteria are not met).*

All equipment is factory calibrated. Troubleshooting, maintenance, and calibration recommendations from the manufacturer/supplier are provided in Table 6.

The precipitation gage will be calibrated at least once per month as described using one pint of water being equal to 0.57 inches plus or minus 1%. The pyranometer will be changed out with a NIST certified calibrated pyranometer from CSU for one week and then reinstalled. Data will be compared to ensure that the pyranometer is recording accurately.

All manufacturers/suppliers recommendations will be followed.

SECTION 5.0 QA/QC CHECKS

5.1 At a minimum, the QAPP shall include quantitative acceptance criteria for QA objectives associated with accuracy, precision, and detection limits for critical measurements (as applicable), for each matrix.

Monitoring of instrumentation will include all recommended maintenance and calibration procedures provided in manufacturer/supplier instruction manuals and in Table 6. Dates, times, power supply voltage, and data will be monitored in between prescribed inspections of instrumentation. Results will be compared with regional weather data and with measurements obtained with properly calibrated laboratory instruments, such as NIST certified pyranometers and thermometers. Inspections and calibrations will be recorded.

5.2 Any additional project-specific QA objectives shall be presented in the QAPP, including acceptance criteria.

Not applicable.

5.3 The specific procedures used to assess all identified QA objectives shall be fully described in the QAPP.

Data will be collected and assessed in a timely fashion to ensure proper performance of sensors, power supplies, and accompanying instrumentation.

5.4 The QAPP shall list and define all other QC checks and/or procedures (e.g., blanks, surrogates, controls, etc.) used for the project.

The equipment will be checked and calibrated according to manufacturer specifications.

5.5 For each specified QC check or procedure, required frequencies, associated acceptance criteria, and corrective actions to be performed if acceptance criteria are not met shall be included in the QAPP.

<u>Thermocouples</u> – data collected with Type T and Type E thermocouples will be compared. The green roof has both thermocouple models located beneath the plant trays and at the soil-air interface. Data from the different thermocouples at the same levels should be comparable. On the control roof one Type T

thermocouple and the infrared temperature sensor measure gravel surface temperature. Data from the thermocouple and the infrared temperature sensor should be comparable. We plan to install two new Type E thermocouples on the control roof in corresponding levels of the existing Type T thermocouples. Data from the two new Type E thermocouples should closely correspond with data from the Type T thermocouples. There are no recommended calibration and maintenance procedures given in the manufacturers/suppliers literature.

Temperature and relative humidity probes – these measure ambient temperatures and relative humidity at two locations, one on the green roof and one on the control roof, at one foot above the roof deck. Data from these sensors should closely correspond with one another. Recommend to inspect monthly.

Infrared temperature sensors – we anticipate that data from peak temperature periods show lower temperatures on the green roof as compared to that from the control roof. During nighttime hours, temperature differences between the two surfaces should decrease considerably, approaching zero difference, as shown in Figure 3. Data from the control roof should closely correspond with data from the Type T thermocouple on the control roof that like the infrared sensor measures the gravel surface temperature. Will check and clean at least monthly.

Pyranometer – check and clean on a regular basis and send to manufacturer for recalibration every two years.

Rain gage – following initial calibration, it is recommended to check and calibrate annually. We conduct field and calibration checks/tests on a monthly basis.

Wind sentry – monthly audio and visual inspections.

SECTION 6.0 DATA REPORTING, DATA REDUCTION, AND DATA VALIDATION

6.1 The reporting requirements (e.g., units, reporting method [e.g., wet or dry]) for each measurement and matrix shall be identified in the QAPP.

Thermocouples – degrees centigrade
Temperature and humidity probes – degrees centigrade and relative humidity percent
Infrared temperature sensors – degrees centigrade of sensor housing and target temperature (targeted surface area)
Pyranometer – average flux density in killoWatt/square meter (kW/m^2), daily total flux density in mega-Joules/square meter (MJ/m^2)
Rain gage – number of tips (0.01 inch per tip)
Wind sentry – wind speed in Meters/second (M/s) and direction in degrees (0 – 360)

The dataloggers record dates and times.

6.2 Data reduction procedures specific to the project shall be described, including calculations and equations.

The dataloggers produce *.dat files that will be downloaded to our computer and archived on various storage devices. The *.dat files are converted to excel files for analysis and further data processing. Equations are embedded in the CR1000 datalogger programs, included below:

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1. Control CR1000 program:

```
'CR1000
'Created by Short Cut (2.5)

'Declare Variables and Units
Public Batt_Volt
Public AirTC
Public RH
Public SBTemp
Public TmV
Public TargTemp
Public PTemp_C
Public Temp_C(2)
Dim Tsqr1
Dim Tsqr2
Dim SBTempK
Dim m
Dim b
Dim TargTempK

'Declare Constants fot IRR-P 1520.
Const mC2=78557.1
Const mC1=8.67820e+006
Const mC0=1.50080e+009
Const bC2=26056.6
Const bC1=-892966
Const bC0=-4.90018e+006

Units Batt_Volt=Volts
Units AirTC=Deg C
Units RH=%
Units PTemp_C=Deg C
Units Temp_C=Deg C

'Define Data Tables
DataTable(Table1,True,-1)
	DataInterval(0,5,Min,10)
	Average(1,Batt_Volt,FP2,False)
	Average(1,AirTC,FP2,False)
	Average(1,RH,FP2,False)
	Average(1,SBtemp,FP2,False)
	Average(1,TmV,FP2,False)
	Average(1,TargTemp,FP2,False)
	Average(1,Temp_C(1),FP2,False)
	Average(1,Temp_C(2),FP2,False)
EndTable

'Main Program
BeginProg
	Scan(30,Sec,1,0)
		'Default Datalogger Battery Voltage measurement Batt_Volt:
		Battery(Batt_Volt)
		'HMP45C (6-wire) Temperature & Relative Humidity Sensor measurements AirTC and RH:
		VoltSE(AirTC,1,mV2500,1,0,0,_60Hz,0.1,-40.0)
		VoltSE(RH,1,mV2500,2,0,0,_60Hz,0.1,0)
		If RH>100 And RH<108 Then RH=100
		'Wiring Panel Temperature measurement PTemp_C:
		PanelTemp(PTemp_C,_60Hz)
		'Instruction to measure the sensor body temperature:
		Therm109(SBTemp,1,5,1,0,_60Hz,1.0,0)
		'Instruction to measure the mV output of the thermopile:
		VoltDiff(TmV,1,mV2_5,2,True,0,_60Hz,1.0,0)
		'Calculation of m (slope) and b (intercept) coefficients for target temp calc:
		m=mC2*SBTemp*SBTemp+mC1*SBTemp+mC0
		b=bC2*SBTemp*SBTemp+bC1*SBTemp+bC0
		'Target temp calc based on calc'd m & b coefficients:
		SBTempK=SBTemp+273.15
		Tsqr1=SBTempK*SBTempK*SBTempK*SBTempK+m*TmV+b
```

```
		Tsqr2=SQR(Tsqr1)
		TargTempK=SQR(Tsqr2)
		TargTemp=TargTempK-273.15
		'Type T (copper-constantan) Thermocouple measurements Temp_C(1):
		TCDiff(Temp_C(1),2,mV2_5C,4,TypeT,PTemp_C,True,0,_60Hz,1,0)
		'Call Data Tables and Store Data
		CallTable(Table1)
	NextScan
EndProg
```

2. Green roof CR1000 program:

```
'CR1000
'Created by Short Cut (2.5)

'Declare Variables and Units
Public Batt_Volt
Public GR_Temp
Public Mmbrne_Temp
Public AirTC
Public RH
Public SlrkW
Public SlrMJ
Public WS_ms
Public WindDir
Public SBTemp
Public TmV
Public TargTemp
Public PTemp_C
Public Temp_C(2)
Public Rain_mm
Dim Tsqr1
Dim Tsqr2
Dim SBTempK
Dim m
Dim b
Dim TargTempK

'Declare Constants fot IRR-P 1520.
Const mC2=84476.4
Const mC1=9.30294e+006
Const mC0=1.45445e+009
Const bC2=25519.1
Const bC1=-841067
Const bC0=-8.98137e+006

Units Batt_Volt=Volts
Units AirTC=Deg C
Units RH=%
Units SlrkW=kW/m²
Units SlrMJ=MJ/m²
Units WS_ms=meters/second
Units WindDir=Degrees
Units PTemp_C=Deg C
Units Temp_C=Deg C
Units Rain_mm=mm

'Define Data Tables
DataTable(Table1,True,-1)
	DataInterval(0,5,Min,10)
	Average(1,Batt_Volt,FP2,False)
	Average (1,GR_Temp,FP2,False)
	Average (1,Mmbrne_Temp,FP2,False)
	Average(1,AirTC,FP2,False)
	Average(1,RH,FP2,False)
	Average(1,SlrkW,FP2,False)
	Totalize(1,SlrMJ,IEEE4,False)
	Average(1,WS_ms,FP2,False)
```

```
        Average(1,WindDir,FP2,False)
        Average(1,SBtemp,FP2,False)
        Average(1,TmV,FP2,False)
        Average(1,TargTemp,FP2,False)
        Average(1,Temp_C(1),FP2,False)
        Average(1,Temp_C(2),FP2,False)
        Totalize(1,Rain_mm,FP2,False)
EndTable

'Main Program
BeginProg
        Scan(30,Sec,1,0)
                'Default Datalogger Battery Voltage measurement Batt_Volt:
                Battery(Batt_Volt)

                'Measure temp from Type E thermocouples
                TCDiff (GR_Temp,1,mV2_5C,7,TypeE,PTemp_C,True ,0,250,1.0,0)
                TCDiff (Mmbrne_Temp,1,mV2_5C,8,TypeE,PTemp_C,True ,0,250,1.0,0)

                'HMP50 Temperature & Relative Humidity Sensor measurements AirTC and RH:
                VoltSE(AirTC,1,mV2500,1,0,0,_60Hz,0.1,-40.0)
                VoltSE(RH,1,mV2500,2,0,0,_60Hz,0.1,0)
                If (RH>100) And (RH<108) Then RH=100
                'LI200X Pyranometer measurements SlrMJ and SlrkW:
                VoltDiff(SlrkW,1,mV7_5,2,True,0,_60Hz,1,0)
                If SlrkW<0 Then SlrkW=0
                SlrMJ=SlrkW*0.001
                SlrkW=SlrkW*0.2
                '03001 Wind Speed & Direction Sensor measurements WS_ms and WindDir:
                PulseCount(WS_ms,1,1,1,1,0.75,0.2)
                If WS_ms<0.21 Then WS_ms=0
                BrHalf(WindDir,1,mV2500,5,1,1,2500,True,0,_60Hz,355,0)
                If WindDir>=360 Then WindDir=0
                'Wiring Panel Temperature measurement PTemp_C:
                PanelTemp(PTemp_C,_60Hz)
                'Instruction to measure the sensor body temperature:
                Therm109(SBTemp,1,6,2,0,_60Hz,1.0,0)
                'Instruction to measure the mV output of the thermopile:
                VoltDiff(TmV,1,mV2_5,4,True,0,_60Hz,1.0,0)
                'Calculation of m (slope) and b (intercept) coefficients for target temp calc:
                m=mC2*SBTemp*SBTemp+mC1*SBTemp+mC0
                b=bC2*SBTemp*SBTemp+bC1*SBTemp+bC0
                'Target temp calc based on calc'd m & b coefficients:
                SBTempK=SBTemp+273.15
                Tsqr1=SBTempK*SBTempK*SBTempK*SBTempK+m*TmV+b
                Tsqr2=SQR(Tsqr1)
                TargTempK=SQR(Tsqr2)
                TargTemp=TargTempK-273.15
                'Type T (copper-constantan) Thermocouple measurements Temp_C(1):
                TCDiff(Temp_C(1),2,mV2_5C,5,TypeT,PTemp_C,True,0,_60Hz,1,0)
                'TE525/TE525WS Rain Gauge measurement Rain_in:
                PulseCount(Rain_mm,1,2,2,0,0.01,0)
                'Call Data Tables and Store Data
                CallTable(Table1)
        NextScan
EndProg
```

6.3 The data validation procedures used to ensure the reporting of accurate project data to internal and external clients shall be described.

3/18/2011
Dates and times for all dataloggers coincide with each other, with official U.S. Time, and with local weather as observed by field personnel and reported by the National Oceanic Atmospheric Administration National Weather Service Denver/Boulder Weather Forecast Office.

6.4 Expected product document

Internal report, conference papers, outreach material, and journal article submissions.

SECTION 7.0 ASSESSMENTS

Not Applicable

SECTION 8.0 REFERENCES

[1]U.S. Environmental Protection Agency. Federal Leadership in High Performance and Sustainable Buildings Memorandum of Understanding, April 2006, http://www.epa.gov/greeningepa/documents/sustainable_mou_508.pdf.

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