Green Roof Design for the University of Iowa IIHR Building

PROJECT REPORT

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Introduction & Objectives:

The debate is over; human beings have to this point had an adverse effect on the stability of Earth. Many human practices and processes utilized to sustain the current standard of living have proven to be unsustainable. In light of this fact, the green revolution is gaining momentum throughout the world. Substitutes are being developed and proposed for many practices including the cars people drive, methods for energy generation, and the design of the buildings we work and live within. Among the many novel ideas and practices emerging is the use of green roofs on building tops. A green roof is essentially a roof with a living system of plants on the top. The practice is well established in Europe, in part due to European policy as well as the financial benefits realized when implementing a green roof. However, in the United States, green roof technology has been slow to catch on. The market is minimal and more information needs to be relayed to people in order to stimulate the green roof market in the United States. The green roof team is hoping that some of the questions concerning green roofs can be answered and some of the benefits of green roofs can be displayed by retrofitting a green roof to the Maxwell Stanley Hydraulics Laboratory (IIHR) here on the University of Iowa campus. The information presented in the following paper will provide the objectives of the retrofit, a site description, and the methodology used in designing the green roof. In addition, the cost benefits from the addition of the green roof will be presented, followed by a discussion of results and conclusions reached with some recommendations.

Retrofitting a green roof to the IIHR would provide many benefits to the building. For the purposes of our project, the green roof would accomplish the following objectives:

1) Reduce the water run-off from the roof of the IIHR to the Iowa River.

2) Reduce the energy used by the IIHR facility.

3) Increase the longevity of the roof of the building

4) Eliminate the roof leak problem which the IIHR currently has due to standing water.

5) Provide a site for taking measurements and researching the effects of green roofs on buildings.

6) Lead, by example, the University of Iowa and the community of Iowa City to the practices of sustainability.

Meeting the above objectives would benefit both the University of Iowa and the community of Iowa City.

Site Description:

The IIHR is located at the corner of Burlington ST. and Riverside DR. on the Iowa River. The building began as a small cubicle in 1919. A photo of the original structure is provided in figure 1.

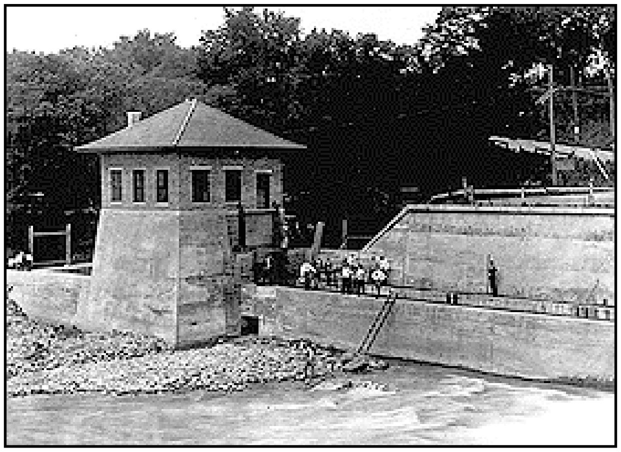

Figure 1: Photo of the original IIHR in 1919.

Figure 1 depicts the IIHR as it appeared in 1919; this laboratory provided a site of research for the University of Iowa's first hydraulics courses. As the hydraulics department expanded, so did the IIHR. In 1928, a larger structure was constructed and in 1932, two additional segments were added to the portion built in 1928. A photo of the IIHR facility in the 1940's in shown in figure 2.

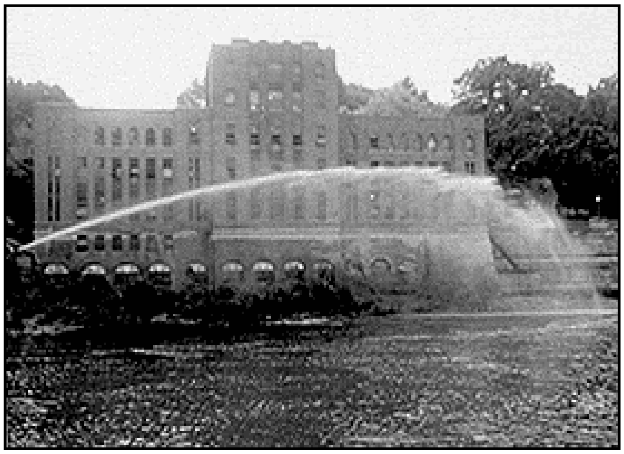

Figure 2: Photo of IIHR in the 1940's.

Figure 2 is a photograph of the IIHR in the 1940's, after the reconstruction of 1928 and 1932. In the photo, tests are being conducted on fire-fighting nozzles for the U.S. Coast Guard. The building today is similar to the three section building which stood in 1932, although, the facility has undergone many renovations since 1932. In fact, the floor plan of the three main sections of the building is the same today as it was in 1932. Figure 3 is an AutoCAD diagram of the IIHR floor plan.

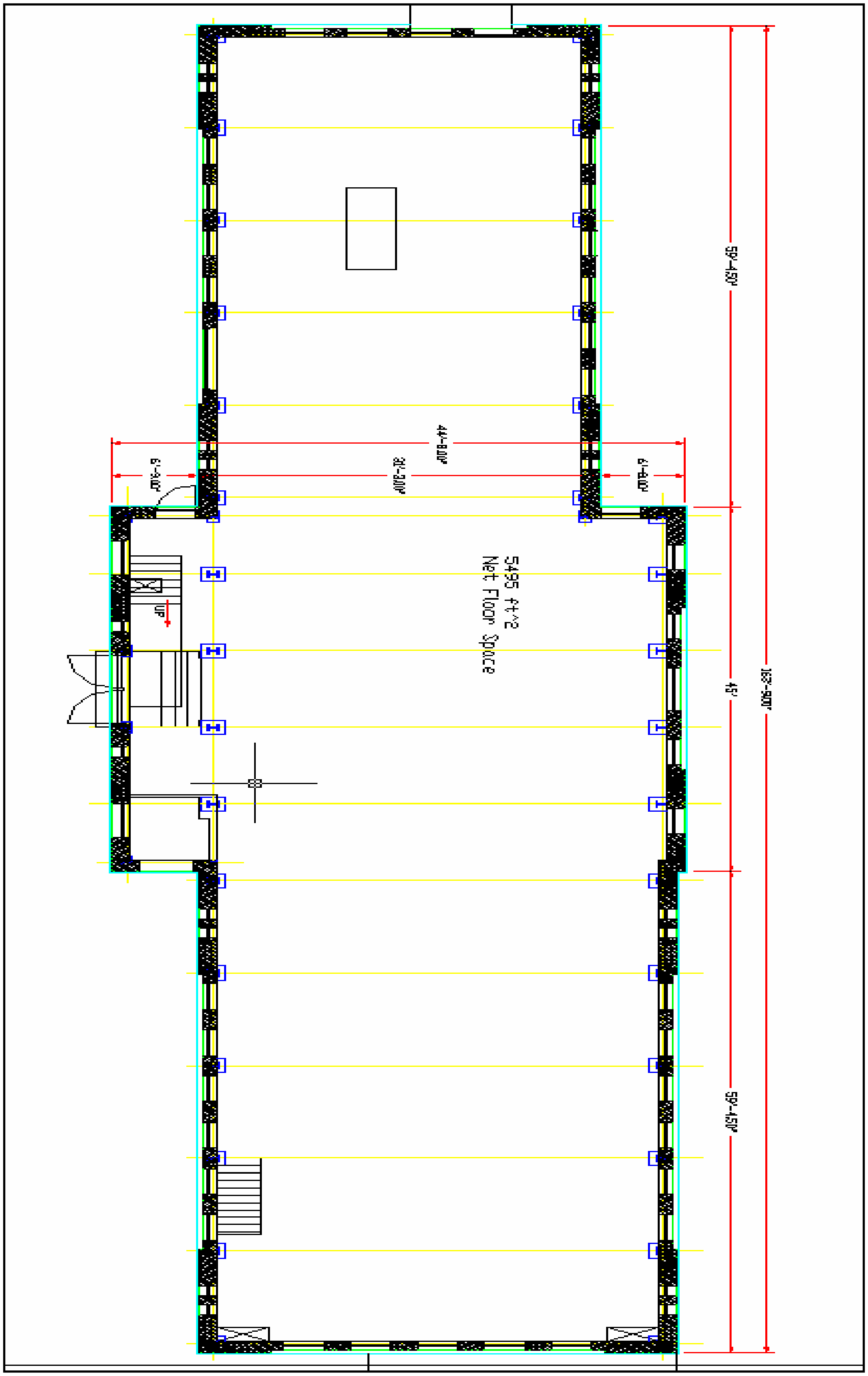

Figure 3: An AutoCAD diagram of the IIHR floor plan.

Figure 3 is an AutoCAD diagram of the IIHR floor plan and gives the dimensions of the three portions which comprise the entire IIHR. For the purposes of this project, it was determined that the best candidates for the retrofit were the North third of the building and the South third of the building. Both of these sections have easy access from the middle, penthouse, section of the facility and both the North and South roof have substantial surface area, resulting in a larger impact from the addition of the green roof.

The North and South roof both have problems with standing water. The sections have a low point on the East side of the building and this low point results in standing water after rains or melting snow. After some time, the standing water begins to leak into the IIHR building, disrupting and inconveniencing the individuals located in the hydraulics lab. Photographs of the South and North roofs are displayed in Figures 4 and 5 respectively.

Figure 4: Photo of the South roof of IIHR.

Figure 5: Photo of the North roof of IIHR.

Figure 4 is a photo of the South roof on top of the IIHR. The photo indicates the areas of standing water on the East side of the roof (Left side of the photo on this page) by the discolored strip. The South roof has dimensions of 38 ft by 59 ft or 2242 ft^2. Figure 5 is a similar photo of the North, and again, the areas of standing water are indicated by the discolored strip in the photograph. However, in the case of figure 5, the East portion of the roof is the right side of the figure. The North roof of IIHR has dimensions of 32 ft by 59 ft or 1888 ft^2. The large surface area, ease of accessibility and mild topography of both the South and North roof make them excellent candidates the retrofit of a green roof. In addition, the middle section or penthouse is two floors higher than the South and North roofs. Thus, water from the penthouse can be captured and used as needed for irrigating the green roof. With candidate sites selected, researched was conducted to determine the best site and best green roof design for that site. The details of this research process are discussed in the methodology section.

Methodology:

Feasibility:

The initial step to take when attempting a retrofit such as this is to determine the feasibility of the project. Certain information concerning the structure is needed to determine if the structure can support a retrofit to the roof. The most important bit of information needed is the load bearing capacity of the building. To obtain this information, University professionals were contacted and many discussions were held, in addition to the review of many blue prints and documents related to the IIHR. Difficulties were encountered while trying to determine the load bearing of both the South and the North roofs of the IIHR. Thus, the team decided it was best to move forward with designing the green roof. To minimize the effect of the retrofit, the team decided to design the lightest green roof possible. As the team moved on, much data was gathered and analyzed concerning the water runoff mitigation the green roof would provide.

Water Budget:

The purpose of doing a water budget on the green roof is to predict the behavior of the roof during rainfall events. A water budget will measure the amount of rainfall that can be stored in the growing substrate and taken up by the plants. It will also measure the amount of rainfall runoff that is produced once the storage capacity of the green roof is reached. A water budget can also predict how the green roof performs during different rainfall events. These are all important things to know because the benefits of the green roof, in terms of runoff reduction, can be quantified. For design purposes, it is necessary to know the peak runoff from the green roof so a proper drainage system can be chosen. Considering all of these things, a water budget was prepared for the IIHR green roof in order to quantify the stormwater management benefits and analyze the performance of the roof during different storm events.

The method used to prepare the water budget was a simple mass balance. The first step in a mass balance approach is to define a control volume. The control volume for our analysis consists of all the layers in the green roof design (drainage layer, water retention layer, growing media, plants) spread out over the entire area of the North roof. A simplified version of the control volume is shown in **Error! Reference source not found.**. The green roof is represented as a bucket. Q represents runoff, P represents precipitation, and E represents evapotranspiration.

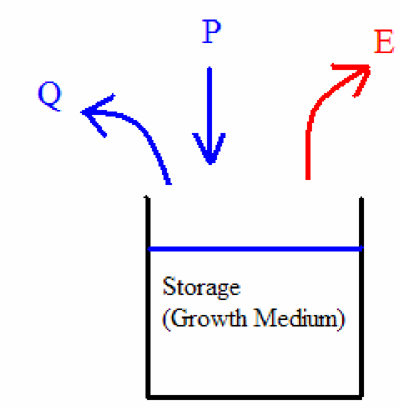

Figure 6: Control volume used for the water budget.

Using the principles of a mass balance leads to the development of equation (1):

$$\Delta S = P - E - Q \qquad (1)$$

Δ S = change in storage (in.)

P = Precipitation (in.)

E = Evaporation (in.)

Q = Runoff (in.)

Equation (1) was applied to the control volume for analysis of the IIHR green roof water budget.

Precipitation and evaporation data for Iowa City were provided by Professor Allen Bradley. The data was from the National Weather Service and included hourly precipitation data, daily precipitation data, and daily potential evaporation for Iowa City. The data covered over 30 years, from the early-1950's to 1982. For the water budget analysis, the period from 1962-1982 was chosen. A 20-year period was chosen as a balance between too much data, yet still being comprehensive. The final variable in the mass balance equation is the storage, S. The storage capacity of the Xero Flor system was provided to us, and is shown in **Error! Reference source not found.**

Table 1: Storage capacity of Xero Flor system.

Storage Capacity		
Water Retention Fabric (1.5 cm)	2 mm	0.079 in
2.5 cm Media	5 mm	0.197 in
4.0 cm Media	8 mm	0.315 in

A few assumptions needed to be made in order to use this approach and make data analysis simpler. The first assumption is that runoff only occurs once the "bucket" is full. This means that when it rains, there is no direct runoff while the green roof still has some storage capacity. In reality, this does not occur since not all rainfall is absorbed into the ground even if the soil is not saturated. The second assumption is that the time period used for analysis (1962-1982) is adequate to describe current weather trends. This may not be the case, but any differences are probably small and will not change the results that much. A final assumption is that the present roof on the IIHR is impermeable and has no storage capacity, i.e. 100% of rainfall goes to runoff. This is a fairly good assumption.

The final step in the water budget methodology was to determine how to analyze the substantial amount of data we were provided with. First, we wanted to look exclusively at rainfall events. Therefore, we limited our water budget analysis to the months of April through October. Second, we wanted to see how the green roof performs on a monthly basis, as well as how it performs in certain rainfall events. We divided the analysis up into 20-year monthly averages of runoff, and runoff from light, medium, and heavy rainfall events.

Roof Design:

After doing research on-line, at the library, and consulting with professionals in the field of green roofs, it was found that there is an abundance of reliable information on the internet for learning more about the products available in the line of green roofing. The website www.greenroofs.com is a very good general site for becoming familiar with the range of products available. Specifically, the link from this website called "Greenroofs 101" was consulted to gain a greater understanding on the variety of greenroof types and methods. Information such as commonly asked questions, concepts, advantages, components, how-to's, industry support, information sources, and plant types can all be found at this site. In addition, it was found that many universities across the United States have endeavored to construct their own green roofs; information and papers describing the purpose and success of their green roof projects can be referenced from the greenroofs.com website.

The design team knew that the City of Coralville, Iowa has an existing facility available for community events, called the North Park Pavilion, which has a green roof. This facility can be viewed easily from Interstate 80, in Coralville, on the north side of I-80. When the City of Coralville was contacted about this facility, direction was pointed to Neumann Monson Architects as the designers for the roof.

Consultation was made with Neumann Monson Architects to gain their recommendations for green roof design criteria. Design criteria, or the areas of design that the green roof design would be contingent upon included the following:

- Capacity of the bearing structure
- Waterproofing membrane
- drainage
- soil media

- plants
- irrigation/storage of water

Part of the curriculum for Sustainable Systems (course number: 53:107), is a series of lectures by professionals in varying fields of engineering and planning who are trying to make the world more sustainable. One of the guest speakers was Jim Patchett, founder and president of the Conservation Design Forum in Elmhurst, Illinois. Patchett is bold initiator of green roof design and was very insightful regarding recommendations for the IIHR green roof idea. Although one of the main challenges during preliminary design was a low weight capacity of the roof, Patchett said “this is not a problem, you can install a green roof on 10 lbs/ft^2 capacity structure”. Other documents regarding extensive and intensive and pre-cultivated roof design were also forwarded to the design team from Patchett. These documents were used to make the final recommendation as to which green roof products to use for the IIHR roof.

Cost Benefit:

The basic cost savings from having a green roof stem from its abilities to be able to add an extra layer of insulation to the top of the roof and reflect a greater amount of the sun’s away from the roof. To determine how these benefits will affect the heating and cooling costs of the building will depend on the amount of heat transfer through the roof.

The heat transfer through the roof depends on several different forces. They are: conduction, convention, and radiant heat from the sun, air, clouds, and roof itself. Figure 7 is a description of how the different types of heat transfer have affects on the amount of heat that enters or leaves the building.

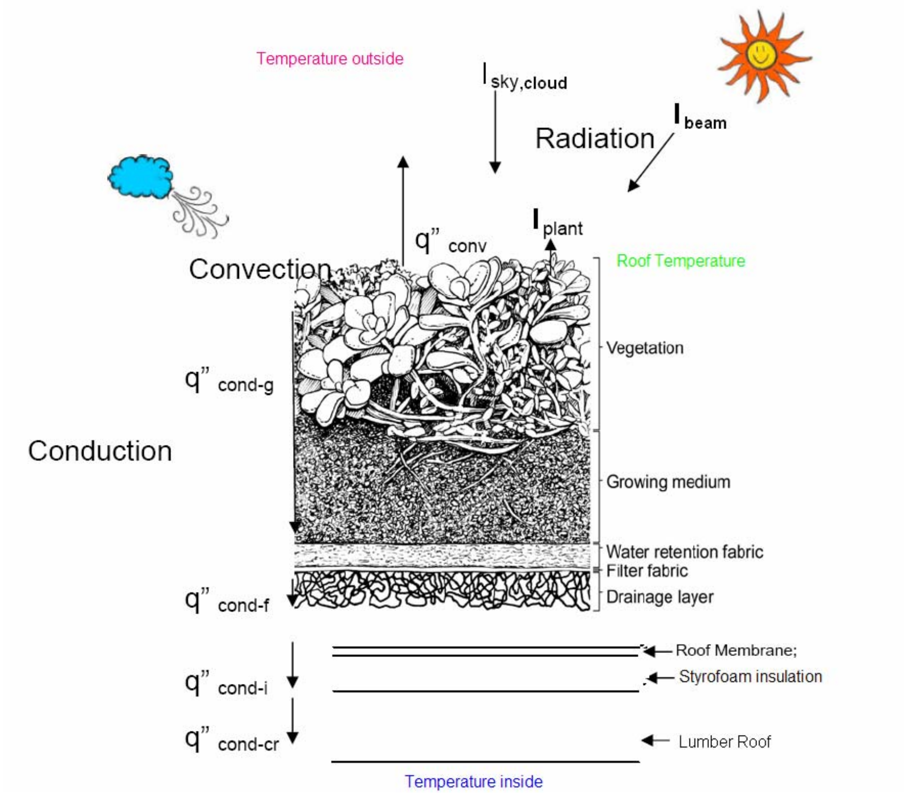

Figure 7: Heat transfer modes through a green roof[i]

Where I_x are the heat fluxes attributed to radiation and q's are the heat fluxes related to conduction and convection. Radiant energy is the major contributor to heat flux in the summer and can come from two main areas: beam solar irradiance (I_b) and diffuse solar irradiance (I_{sky}, I_{clouds})[ii]. The amount of beam solar irradiance that actually enters the building from the sun is dependent on how reflective is the roof's surface and time of day. Therefore, the less energy the roof reflects the greater the fraction of energy the roof will absorb (α). Radiant energy emitted from the clouds and skies are dependent on the weather conditions and are usually constant[ii]. Total radiant heat transfer into the building and reflected from the building can be characterized by Equation 2.

$$q_{rad} = A\alpha(I_B + I_A + I_D) - \varepsilon\sigma A(T_{roof}^4 - T_{outside}^4) \qquad (2)$$

Where q_{rad} is the radiant heat, A is the area, α is the absorptivity, σ is the Boltzmann's constant, ε is the emissivity, and T's are the temperatures of the roof and the ambient air. Since the sky radiation is in approximately the same spectral region as surface emission, we can conclude Equation 3[i].

$$\alpha \cong \varepsilon \tag{3}$$

Heat transfer for convection is primarily caused by wind current. It is also dependant on the difference between the temperature of the roof and the temperature outside as well as the heat transfer coefficient for convection. This coefficient can be correlated to the magnitude of wind speed. Equations 4 and 5 correspond to the convection heat flux and convection coefficient.

$$q_{conv,gr} = hA(T_{ouside} - T_{roof}) \tag{4}$$

$$h = 5.7 + 3.8v_w \tag{5}$$

Where q_{conv} is the convective heat, h is the convection coefficient, and v_w is the wind speed in m/s.

Conduction through each layer of both the conventional and green roofs are dependant on their thermal conductivities (k) and thickness (x). Thermal conductivities can be found in literature for each component[iii] and grouped together is form an overall conduction heat transfer coefficient (U). Equation 6 and 7 describe conductive heat transfer and its overall coefficient, respectively.

$$q_{cond} = UA(T_{roof} - T_{inside}) \tag{6}$$

$$\frac{1}{U} = \frac{x_1}{k_1} + \frac{x_2}{k_2} + \frac{x_3}{k_3} \ldots \tag{7}$$

Then final step is to combine all the heat transfers for the overall heat transfer (Equation 8).

$$Q_{total} = q_{rad} + q_{cond} + q_{conv} \tag{8}$$

This equation is orientated so the when Q is positive heat is entering the building and when Q is negative heat is leaving the building. The cost analysis portion is derived from determining how much it will cost to counteract the heat loss or gain.

Data Collection:

As previously stated, the three major areas of heat transfer are radiant, convection, and conduction where pertinent information is needed for each of them. This information comes from external factors (weather conditions) and internal factors (properties of the conventional and green roofs) and can be found in Appendix A. In an ideal situation there would be hourly external data about the ambient air temperature, amount of sunlight, cloud cover, soil temperature, wind speed at the roof height, temperature of the conventional roof, and the temperature of plants. It should be apparent that all of this information is unavailable on an hourly basis, but there is a source such as the National Climatic Data Center[iv] (NCDC) that has daily, monthly, and yearly averages for the surrounding Iowa area. What is important is that the total heat transfer and costs analysis be computed over the entire year. The radiant beam energy flux and ambient air temperature are collected on monthly averages. The wind speed, indoor air temperature, and cloud/sky radiation were based upon a yearly average.

The internal data about the conventional and green roofs are inherent properties and do not vary over the course of a year. These values are the absorptivity, emissivity, thermal conductivities, and layer thicknesses and can be found in literature[i,iii,v].

Existing cost data for air conditioning and heating was collected from Facilities Management at the university and can be found in Appendix B.

Assumptions

The large piece of missing information is that of the surface temperature of both the conventional and green roofs. Heat transfer studies have concluded that the maximum temperature change from ambient air for a black roof with full sun and no wind is about 50°C (90°F)[vi]. Using similar techniques, with compensation for absorptivity, a green roof's maximum temperature increase is about 16°C (61°F). The temperature change from ambient is calculated using the heat transfer equation provided by Cool Roofing Database modified for the change in each month's radiant energy and each roof's absorptivity. This value is then halved for a conservative estimate of actual temperature change. This will result in a lower, more conservative, cost savings.

Another major assumption is the wind speed. The data for the wind speed in the Iowa area from the NCDC is taken at 50m, where the building stands at about 25m. This data was linearly interpolated for 25m. The final heat transfer assumption is that heat can only move through the roof and the rest of the walls are adiabatic. This is, of course, a poor assumption because heat will enter and exit through such things as windows and external walls.

The only cost analysis assumption is that the air-conditioning and heat units are 100% efficient. That is, if the air-conditioning needed to remove 1000 kW-h from the building, it would not use any more electricity to do so. The same concept was used for cases of heating.

Calculations

Heat Transfer

The radiant beam energy was calculated by letting only a fraction of the maximum possible energy through with respect to the month percent of possible daily sunlight[iv] and average daily hours of sunlight. The roof temperature was determined by the ambient air temperature change as stated in the assumptions. The overall heat transfer coefficient for the conduction term was determined from the existing roofs layers and a sample green roof from Eumorfopoulou[iii]. The green roof used in this study was similar to that of the proposed roof and was used because of the lack of knowledge about the thermal conductivities of the proposed roof. From here equations for the radiant, convective, and conduction transfers were calculated and totaled.

Cost Analysis

The cost savings is calculated based on the energy differences in heating and air-conditioning between the existing roof and a green roof. In the summer the cost of electricity is \$0.063/kW-h and in the winter the cost of steam is \$10.78/MMBtu. These two dollar amounts can translate directly into cost savings.

The financial devices used to analyze the cost savings versus capital cost are the simple payback and internal rate of return (IRR). The IRR will include the depreciation over the life of the roof, increase in electricity costs and maintenance costs. The life of the green roof is expected to last a minimum of 40 years where as a conventional roof is replaced every 20 years. This unique bonus of a green roof is not included in the cost benefits of a green roof but is an important feature to be noted.

Results & Discussion:

Water Budget:

Urban stormwater management is an important aspect of achieving sustainability. Rapid runoff from roofs and other impervious surfaces can exacerbate flooding, increase erosion, and result in combined sewer overflows that could discharge raw sewage into our waterways (Van Woert, et.al, 2005). Green roofs are growing in popularity because they have proven to be an effective tool to manage stormwater in a sustainable way. Our main purpose of preparing a water budget was to quantify the amount of runoff that is reduced as a result of installing the green roof. This section presents the results from our water budget- the monthly results and the individual rainfall results. Three scenarios were analyzed: the present roof, the green roof with 2.5 cm of growing media, and the green roof with 4.0 cm of growing media.

20 Year Monthly Averages:

As described in the Methodology section, part of the water budget was to analyze performance of the green roof on a monthly basis. The results are shown in Figure 8 and Figure 9. Percent Retention is defined as the percentage of total monthly rainfall that is prevented from going to runoff. These figures reveal some key points. First, as expected, the 4.0 cm growing media retains more rainfall than the 2.5 cm media. Second, the green roof achieves the most reduction in runoff during the spring and fall. This is because the green roof performs best in light to medium rainfall events, which typically occur in the spring and fall. It is encouraging to see that the green roof will result in at least 50% reduction in runoff each month throughout the course of the year.

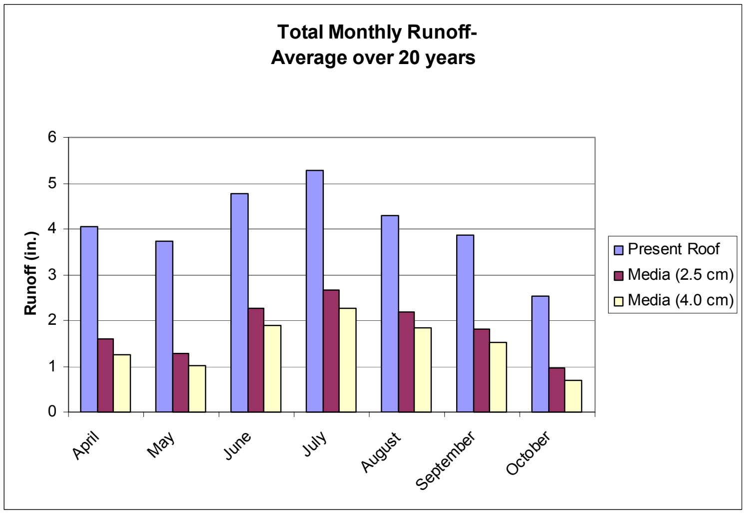

Figure 8: Average Total Monthly Runoff (1962-1982)

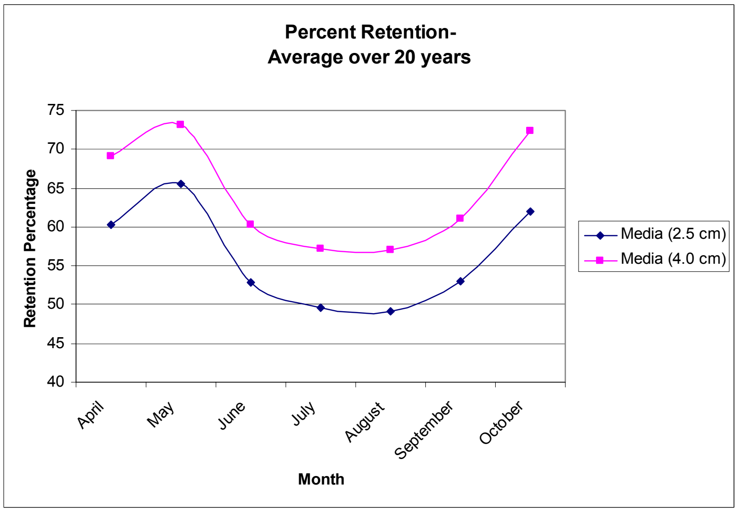

Figure 9: Average Percent Retention of Rainfall (1962-1982)

Individual Rainfall Events:

Rainfall events were classified as follows: light (0.35 in. or less over a 24 hr period), medium (0.35-1.00 inches over a 24 hr. period), and heavy (greater than 1 in. over a 24 hr period). Rainfall events were selected randomly from the 20 year study period. Over the 20 years, between the months of April and October, it rained on 1,447 days. 55% of the events were light rainfall events, 33% were medium, and 12% were heavy. A summary of each event is given in **Table 2: Summary of light, medium, and heavy rainfall events.**

Table 2: Summary of light, medium, and heavy rainfall events.

	Light		Medium		Heavy	
	2.5 cm	4.0 cm	2.5 cm	4.0 cm	2.5 cm	4.0 cm
Retention (%)	53	67	68	79	16	20
Delay in Runoff (hr)	40	42	28	43	1	5
Total Rainfall (in.)	0.74		1.12		3.11	
Storm Duration (hr)	50		60		22	
Date	March 19,29,21 - 1977		May 4,5,6 - 1982		July 17,18 - 1982	

Light Rainfall Event:

A cumulative runoff hydrograph and a runoff hydrograph are shown in Figure 10: Cumulative runoff hydrograph for light rain event. and Figure 11: Runoff hydrograph for light rain event. respectively. These hydrographs show that total runoff is reduced, runoff rate is reduced, and runoff is delayed from the onset of precipitation.

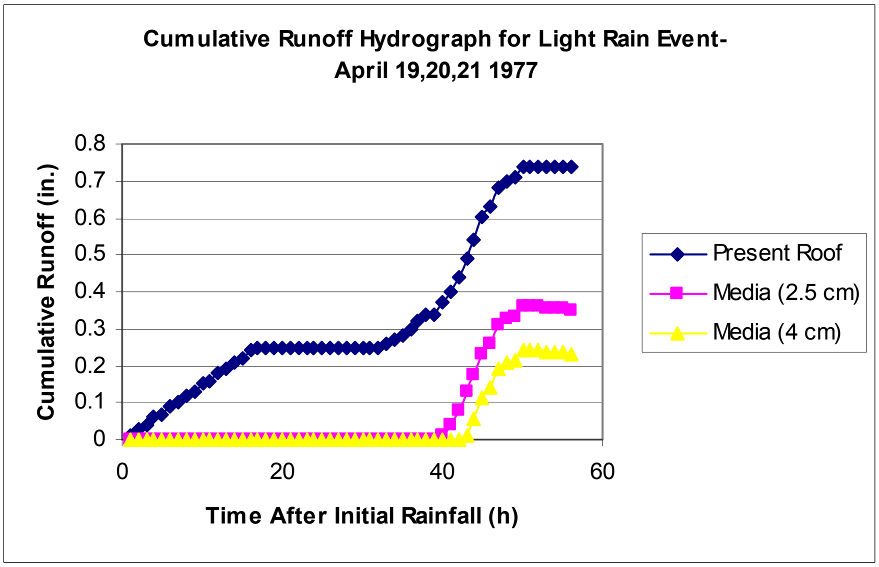

Figure 10: Cumulative runoff hydrograph for light rain event.

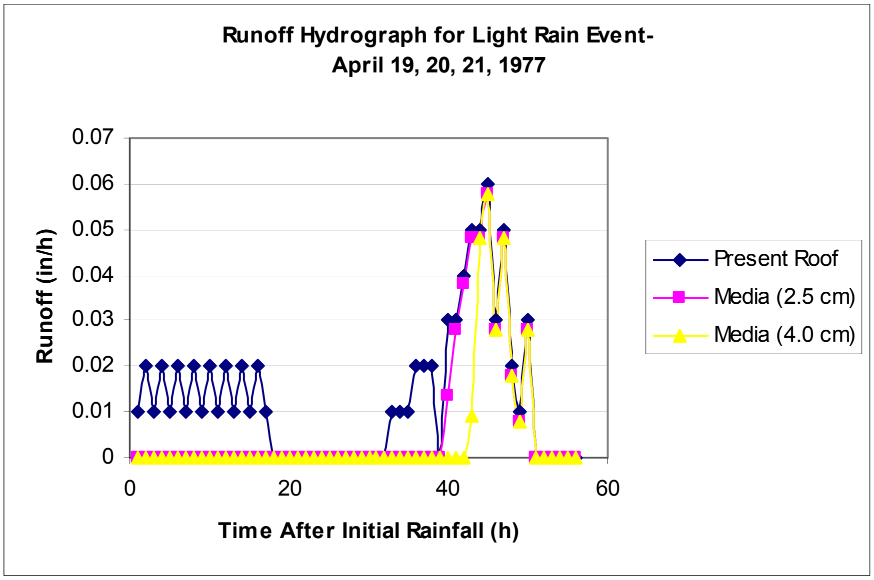

Figure 11: Runoff hydrograph for light rain event.

Medium Rainfall Event:

A cumulative runoff hydrograph and a runoff hydrograph are given in Figure 12: Cumulative runoff hydrograph for medium rain event. and Figure 13: Runoff hydrograph for medium rain event. respectively, for a medium rainfall event. These graphs show that the green roof performs best in an intermittent, medium rainfall event.

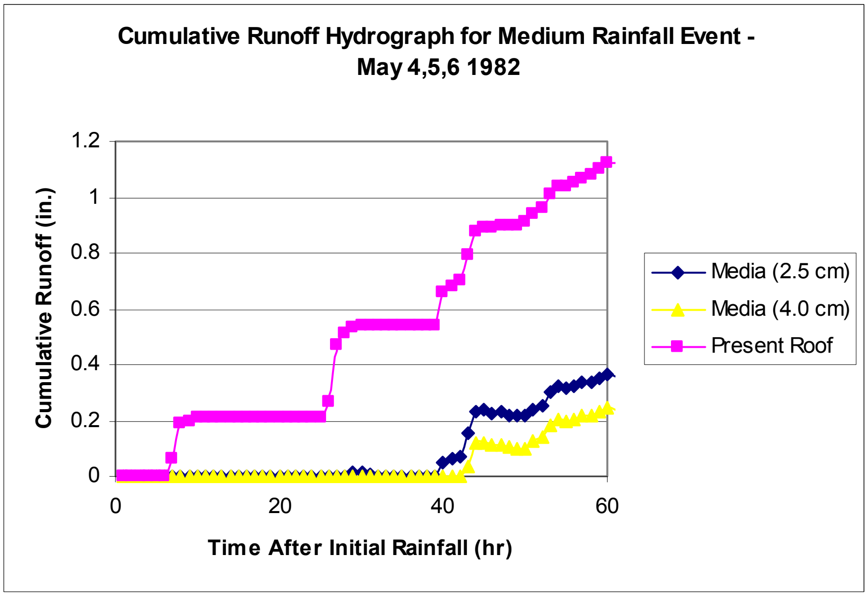

Figure 12: Cumulative runoff hydrograph for medium rain event.

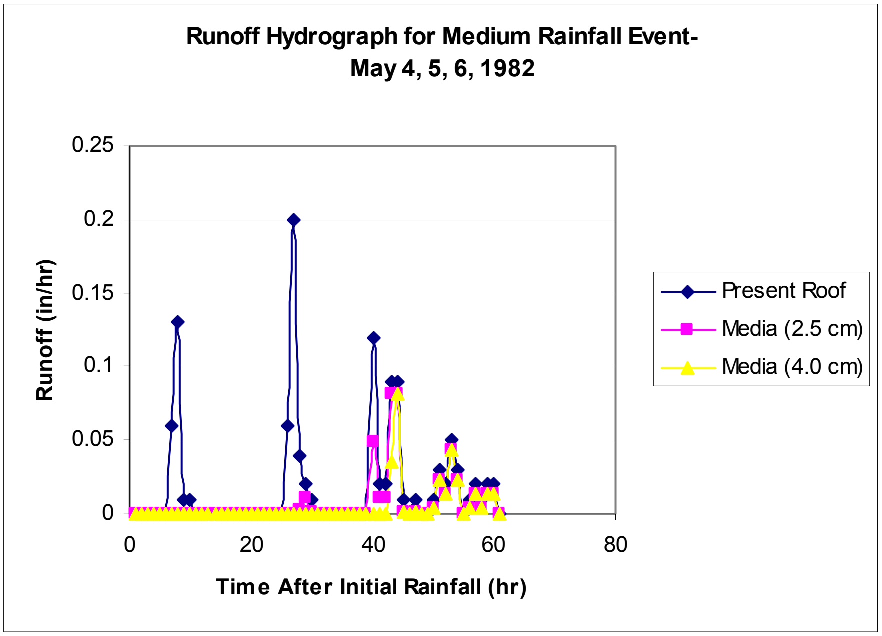

Figure 13: Runoff hydrograph for medium rain event.

Heavy Rainfall Event:

Based on the results from our water budget, the green roof will perform the worst in heavy rain events. Thankfully, these events only occur about 12% of the time when it rains. A cumulative runoff hydrograph and a runoff hydrograph are given in Figure 14: Cumulative runoff hydrograph for heavy rain event. and Figure 15: Runoff hydrograph for heavy rain event. respectively.

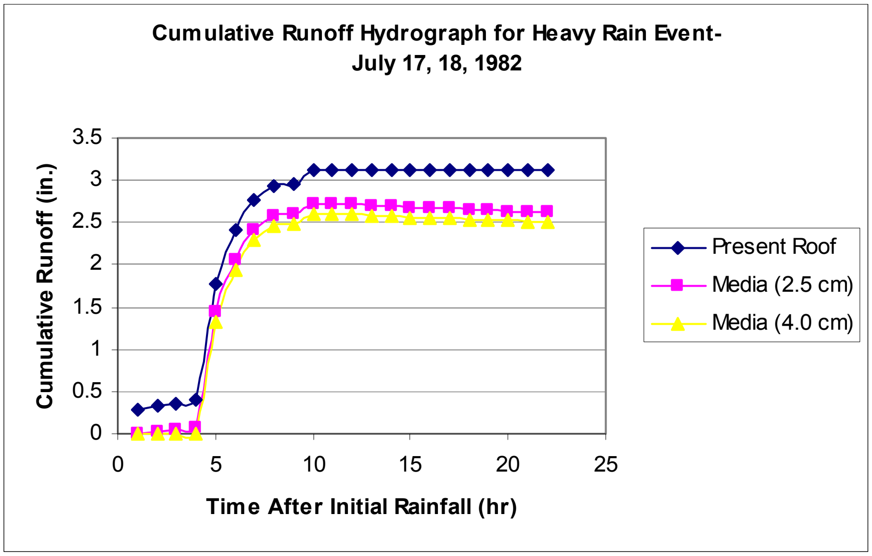

Figure 14: Cumulative runoff hydrograph for heavy rain event.

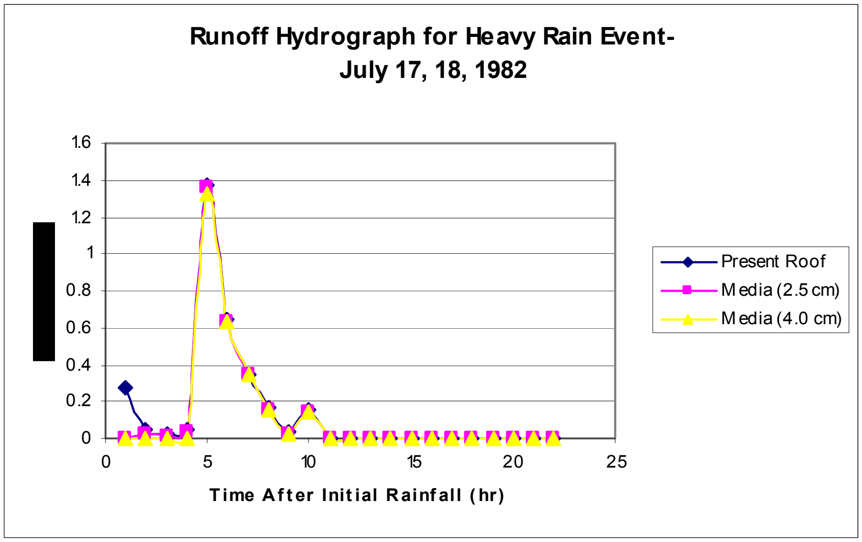

Figure 15: Runoff hydrograph for heavy rain event.

Water Quality:

Current green roof research shows that green roofs improve water quality of stormwater runoff. This is another benefit that will come from building the IIHR green roof. Several published papers on water quality benefits of green roof research were consulted. One study showed that green roofs have the ability to filter numerous contaminants from rainwater that has flowed across the roof surface (Dramstad et al., 1996). Another study showed that pollutants can be taken up and degraded by the plants or bound in the growing substrate of green roofs (Johnston and Newton, 1996). We don't just want to take their word for it- we want to do research of our own on the IIHR green roof. Studying water quality of the runoff from the IIHR green roof would be a great partnership with the College of Engineering. Improved water quality is another aspect of the overall sustainability of green roofs.

Plant Survivability:

Sedum plant species are currently the preferred green roof plant for a shallow green roof system in a Midwest climate because of their ability to withstand extended drought conditions. In addition, plant selections for a shallow green roof system must be cold tolerant and have a high growth index to provide quick coverage of the roof. The Sedum species has been shown to have all of these properties. The National Research Council's Institute for Research in Construction conducted a plant survivability study. After several extensive frosts, all Sedum species survived (Boivin and Liu 2001). Another study conducted at Michigan State University showed that various species of Sedum survived 28 days of drought. The studied suggested that this is about the maximum period of drought. They recommended water being applied at least once every 28 days during drought conditions (Van Woert et al, 2005). It is anticipated that the green roof plants on the IIHR green roof will have no major problems surviving in the Iowa City climate.

Heat Transfer:

Inputs to the heat transfer analysis common to both the conventional and green roof can be seen by Table 3. Inputs particular to each type of roof is described in Table 4. The important feature to note here is the difference in absorptivities.

Table 3: Common variables and their values.

Variable	Value	Unit
T_{inside}	22.3	^{o}C
I_b	900	W/m^2
$I_{d,a}$	200	W/m^2
v_w	2	m/s
h	5.7	W/m^2 K
σ	5.67E-08	$W/m^2 K^4$
A	167	m^2

Table 4: Absorptivity and overall heat transfer coefficient for each type of roof.

Roof	α	U (W/m^2 K)
Conventional	0.9	0.476
Green	0.3	0.413

Table 5 contains values obtained from NCDC and applied to total radiant beam energy.

Table 5: Percent of possible sunlight and daily hours of sunlight.

Mo.	% of Possible Sunlight	Hours of Sunlight
Jan	0.36	0.4
Feb	0.46	0.5
Mar	0.64	0.6
Apr	0.73	0.7
May	0.72	0.8
Jun	0.79	0.9
Jul	0.85	0.9
Aug	0.85	0.9
Sep	0.75	0.9
Oct	0.57	0.7

Nov	0.54	0.6
Dec	0.43	0.5

Table 6: Calculation of overall heat transfer coefficient for conduction.

Conventional

U (W/m2K) =	**0.476**

Material	**Thickness (m)**	**k (W/mK)**	**x/k**
Lumber	0.0508	0.13	0.390769
Styrofoam	0.0508	0.03	1.693333
Rubber	0.003175	0.188	0.016888
		R	2.100991

Green Roof

U (W/m2K) =	**0.413**

Material	**Thickness (m)**	**k (W/mK)**	**x/k**
Lumber	0.0508	0.13	0.390769
Styrofoam	0.0508	0.03	1.693333
Rubber	0.003175	0.188	0.016888
Soil	0.0762	1.16	0.06569
Water Barrier	0.0005	0.186	0.002688
Drainage	0.1	0.5	0.2
Plant Cover	0.05	1	0.05
		R	2.419369

shows the calculation of the overall heat transfer coefficient for the determination of the amount of conduction energy into the building. The existing Styrofoam layer in the conventional roof accounts for the majority of the total insulation.

This concludes that the addition of a green roof does not add significant additional thermal insulation.

Table 6: Calculation of overall heat transfer coefficient for conduction.

Conventional

U (W/m2K) =	0.476

Material	Thickness (m)	k (W/mK)	x/k
Lumber	0.0508	0.13	0.390769
Styrofoam	0.0508	0.03	1.693333
Rubber	0.003175	0.188	0.016888
		R	2.100991

Green Roof

U (W/m2K) =	0.413

Material	Thickness (m)	k (W/mK)	x/k
Lumber	0.0508	0.13	0.390769
Styrofoam	0.0508	0.03	1.693333
Rubber	0.003175	0.188	0.016888
Soil	0.0762	1.16	0.06569
Water Barrier	0.0005	0.186	0.002688
Drainage	0.1	0.5	0.2
Plant Cover	0.05	1	0.05
		R	2.419369

The Microsoft Excel file used for the energy balance calculations can be found in Appendix C. Preliminary results show that the majority of the heat transfer into the building is caused by radiation and that the majority of the heat loss from the roof is caused by convection. Figure 16: Contribution of each energy source in a conventional roof. and Figure 17: Contribution of each energy source in a green roof. explain how each of the three modes of heat transfer affects each type of roof throughout the year.

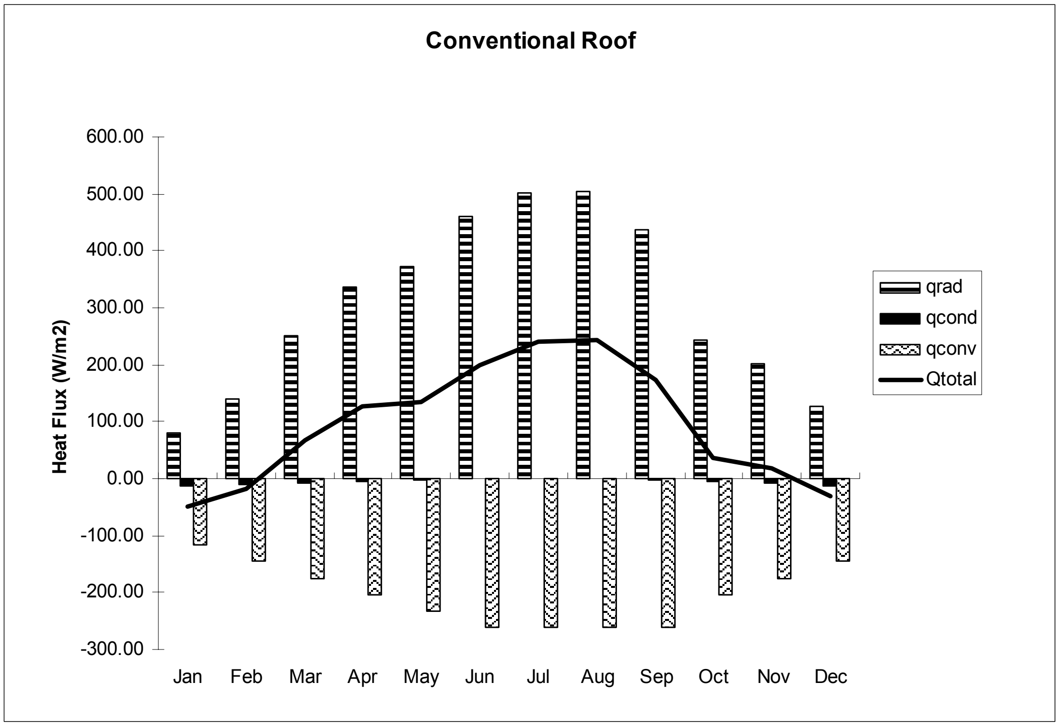

Figure 16: Contribution of each energy source in a conventional roof.

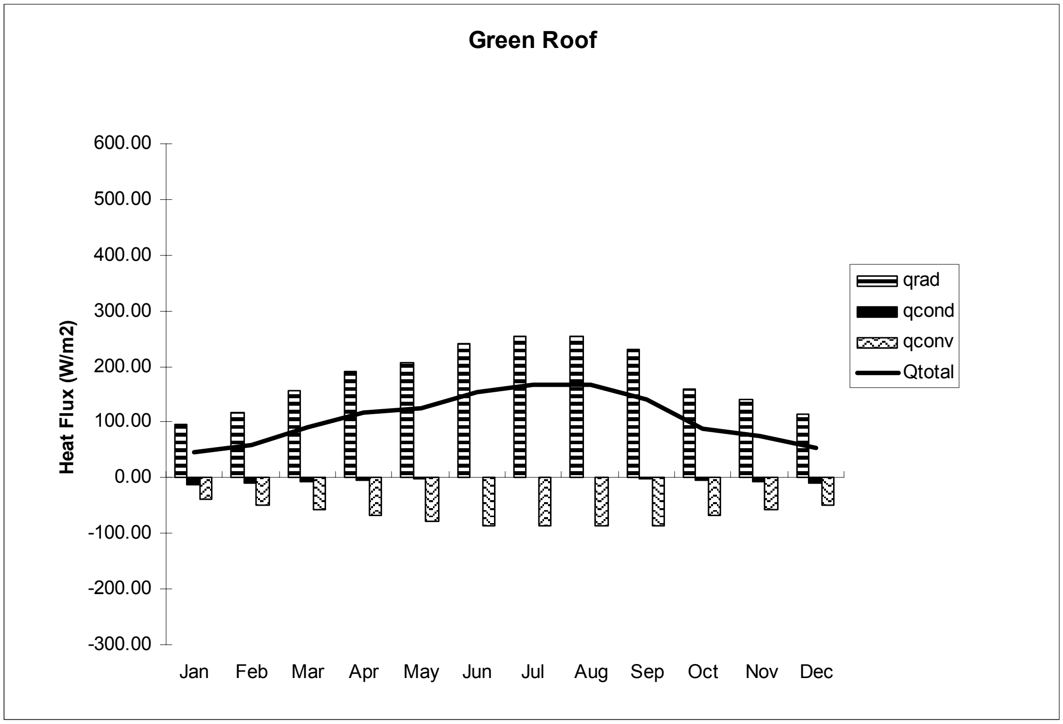

Figure 17: Contribution of each energy source in a green roof.

What these figures show is that the conduction term has little to no effect on the heat transfer, thus confirming that the extra insulation provided by the green can be considered negligible. Figure 16: Contribution of each energy source in a conventional roof. does an excellent job describing the flow of heat into the building in the summer time and flow of heat out of the building in the winter. The green roof (**Error! Reference source not found.**16) exemplifies the same heat inflow in the summer, but maintains this inflow throughout the winter. In reality this would not be the case, steam would still be needed to heat the building, and this most likely is a cause of the external wall adiabatic assumption. Heat will still be leaving through other areas of the building.

The total heat transfer for each type of roof throughout the year can be seen by **Error! Reference source not found.**17.

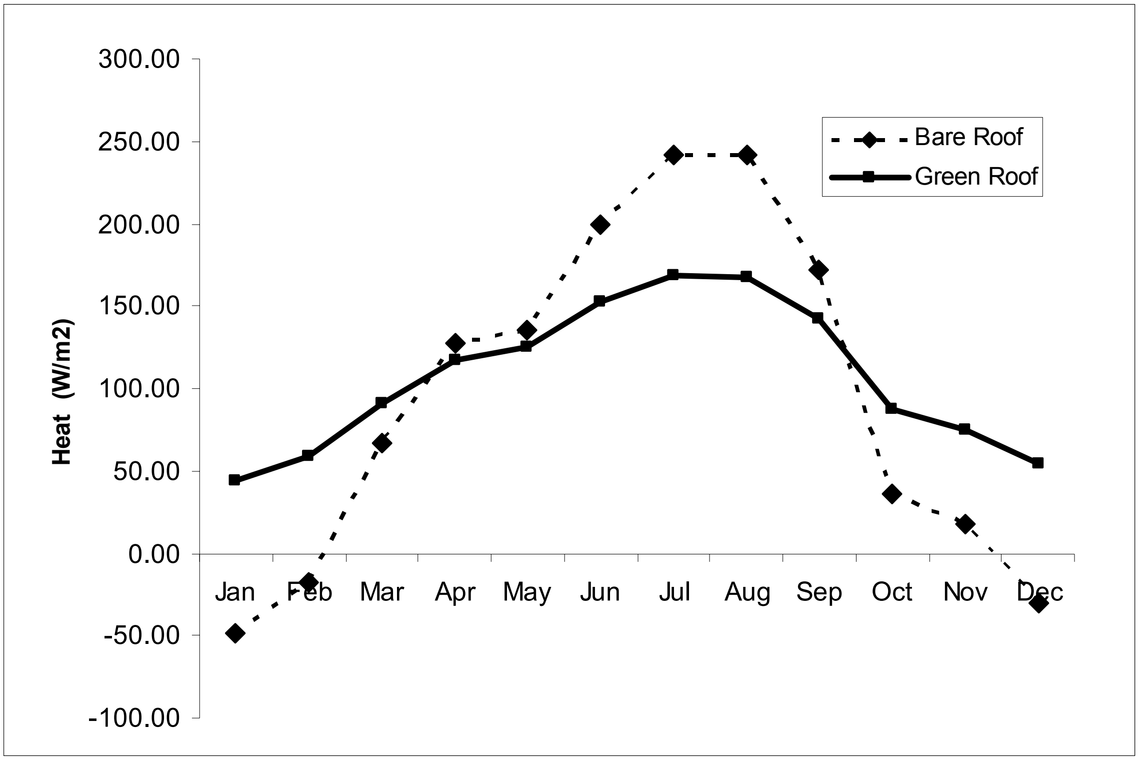

Figure 18: Total heat transfer comparison.

Figure 18: Total heat transfer comparison. shows how the green roof reduces the energy inflow in the summer and retains heat in the winter. The reduction in heat inflow of the green roof in the summer is largely in part due to the decreased absorptivity value. The decreased absorptivity also reduces the amount of radiant heat loss from the roof (see Equation 2).

Cost Analysis

Based upon a total capital investment of $21,000 there would be a simple payback of six years and an internal rate of return of 16% to place a green roof on the north section. The monthly cost savings with the implementation of a green roof for heating and air-conditioning is shown by Figure 19: Monthly savings from a green roof..

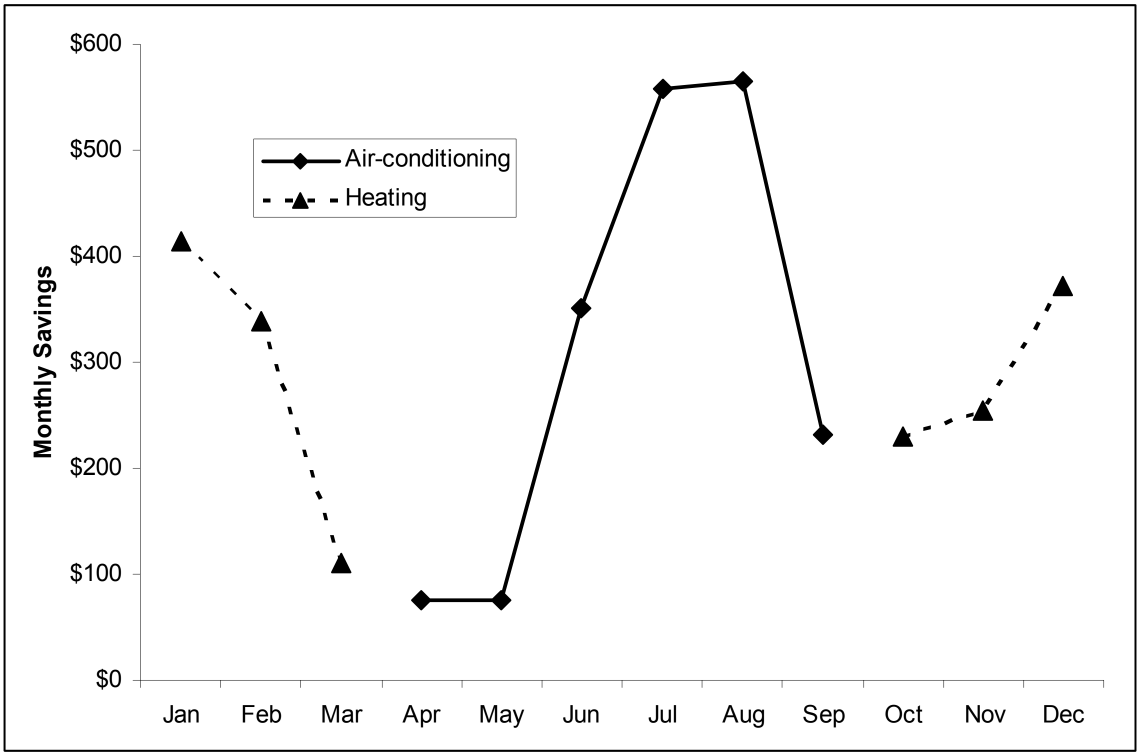

Figure 19: Monthly savings from a green roof.

These savings were derived from the cost per kilo-watt of electricity and million BTU of steam assuming 100% efficiency of the units used for heating and cooling. The largest savings are those from the air-conditioning in July and August. Figure 20: Annual air-conditioning, heating, and total savings. displays the annual savings from air-conditioning, heating, and total savings.

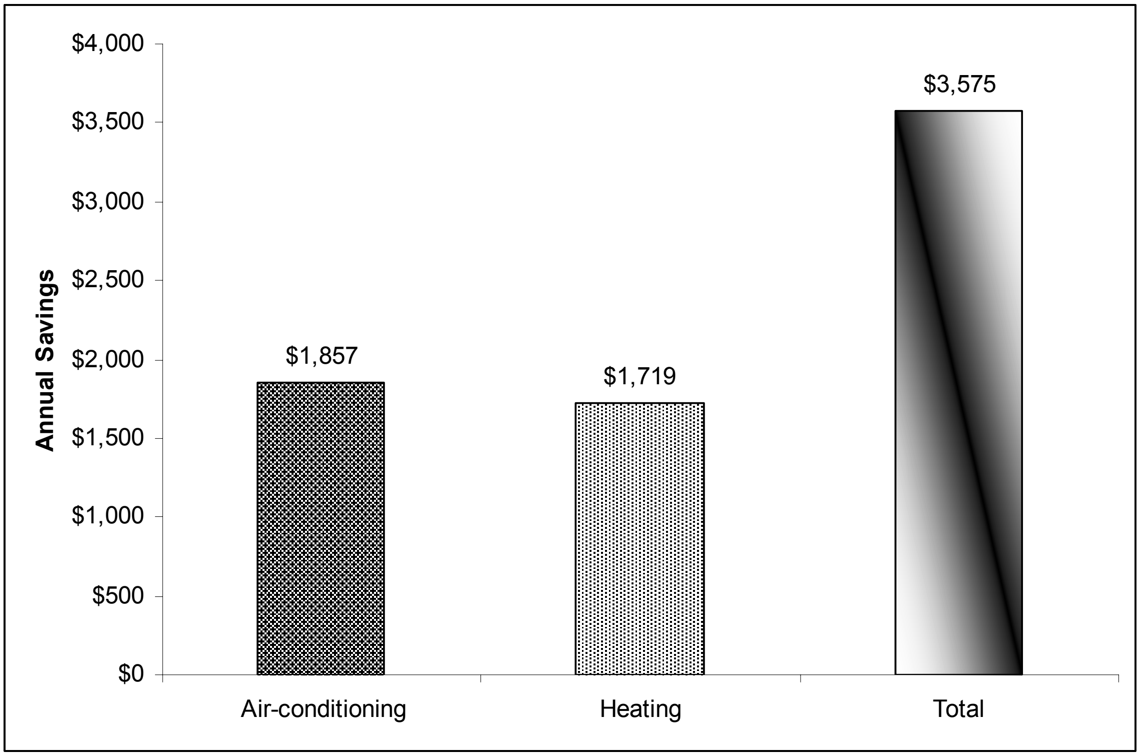

Figure 20: Annual air-conditioning, heating, and total savings.

The internal rate of return of 16% accounts for the depreciation of the roof assuming a 40 year life, a $300 annual maintenance to fertilize and water in case of extended drought, and increase cost of electricity. The detailed calculation can be found in Appendix D.

The total annual savings of $3,575 does not, however, account for the savings other external protection provided by a green roof. The greatest being that it can extend the life of the conventional roof two to three times. In the winter plants can also undergo 'root respiration' which can stop the soil from freezing.[iii] Finally, in general, a green roof reduces daily[i] and seasonal fluctuations in heat transfer.

Feasibility:

After consulting University professionals: Darian De Jong, Ann Rosenthal, Gary Nagle, Don Grimm & Michael Nottingham, a value for the load bearing of the South roof was located on a blue print of the facility. The South roof has a load bearing of 50 lbs/ft^2. However, the specifications also indicate that an additional load bearing of 41 lbs/ft^2 must be available for rain and snow load. This required weight capacity eliminates the South roof as a possible candidate for the retrofit because the green roof will weigh more than 9 lbs/ft^2. Thus, the team began looking into the North roof and after many conversations and reviewing many documents and blue prints associated with IIHR, no load bearing capacity could be determined. One blue print did list the following the load bearing capacities for the north portion of the building:

1st floor load bearing = 400 lbs/ft^2
2nd floor load bearing = 300 lbs/ft^2
3rd floor load bearing = 200 lbs/ft^2
Roof load bearing = ??? lbs/ft^2

By linear extrapolation one might deduce that the roof is capable of supporting 100 lbs/ft^2. However, in light of the possible consequences, the team decided it was too dangerous to make such an assumption. Further efforts could be made to determine the load bearing of the North roof, such as, reviewing documents associated with the IIHR which were created before 1928. Documents created before 1928 may contain specifications pertaining to the original design of the building, such as the roofs load bearing capacity. A final option is to have a certified engineer calculate the load bearing of the North roof from the structural information provided by the blue prints of the IIHR.

Conclusions & Recommendations:

Many university campuses across the United States feature green roofs due to the added educational value, garden-like improvement, storm water runoff reduction, insulation value and added longevity of the roof-top surface. In this report it has been shown that a green roof at the IIHR facility would create a more sustainable system with these improvements made. The University's IIHR facility is an ideal location for a green roof due to existing support from the College of Engineering staff and existing roof structure properties. Although the University of Iowa is located in an agricultural and environmentally aware community, there are no green roofs featured on campus. Therefore, this project would enhance the campus, reduce runoff, reduce costs for the University, and would provide yet another sustainable quality for the University to advertise.

As discussed in the methodology and results and discussion sections of this report, a variety of resources were consulted to determine what type of green roof would best suit the IIHR roof. After considering both extensive and intensive green roof systems, an extensive green roof system was recommended. Specifically, a light weight extensive system would be the ideal application for the IIHR. Because the exact weight bearing capacity of the roof-top still remains officially unknown, a light weight system is preferred. A light weight extensive system has an overall depth equal to 2-3" with a wet weight range of 9-15 lbs/ft^2.

Green roofs require specific soil (growth) media and planting materials for development and growth. Green roof experts recommend using a 75% organic material to 25% organic material ratio for the growing media. This ratio provides enough inorganic media to aid in resisting media compaction over time. It should be noted that for the Coralville, North Ridge Pavillion, this ratio was used. Specifically, the Pavillion used a mix of angular sand, expanded slate, and peat moss to make-up the inorganic fraction of growing media (Neumann Monson). The growth media and plants should be compatible with one another. It is generally recommended that plants native to Iowa City be identified and incorporated into a design, if they can be grown in the type of growth media specified above.

Because the success of a green roof design is very contingent on the soil, plants, and climate, it was the endeavor of the IIHR green roof design team to find the best green roof products for this application. After considering factors such as installation, and maintenance of the green roof, it was determined that a pre-cultivated system would suit our project. A pre-cultivated green roof is a field cultivated vegetation mat consisting mostly of sedum species grown within a two-ply fabric carrier.

Xero Flor America, LLC, a provider of green roof supplies, carries the leading pre-cultivated green roof mat system in the United States. A standard pre-cultivated green roof system manufactured by Xero Flor is the lightest weight system on the market. The minimal saturated weight required for this product is ideal for the IIHR. The Ford Motor Company Rouge Complex in Dearborn, Michigan, and Michigan State University both feature green roof systems by Xero Flor. Research at the Ford Company roof was done by Xero Flor which demonstrated that due to the thin design, the system is naturally weed-resistant. The Xero Flor system is grown at ground level and rolled up in sections and set on pallets for delivery to a project. The sections can easily be rolled/laid out at the roof site, thereby creating a less work in trying to establish the vegetation directly at the site.

A profile view of the pre-cultivated Sedum blend *lightweight* green roof system is shown in Figure 21: Recommended pre-cultivated green roof system..

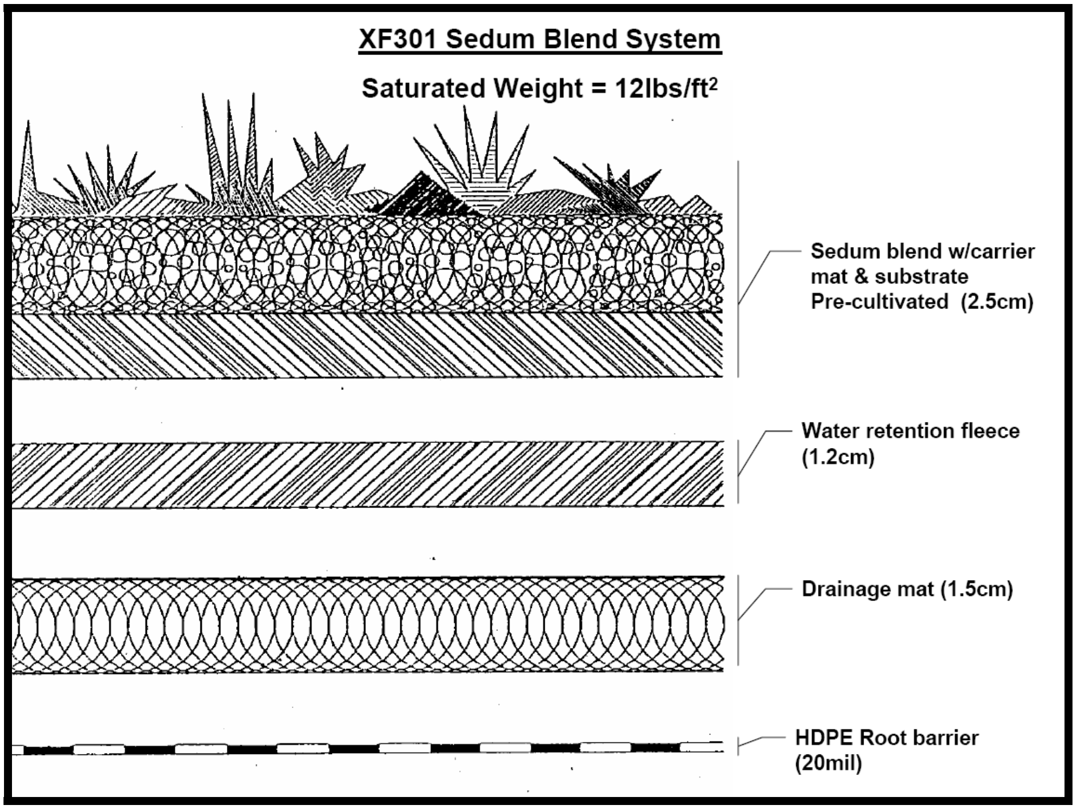

Figure 21: Recommended pre-cultivated green roof system.

The 4-part vegetation mat is part of the Xero Flor's patented technology developed in Germany over 30 years ago (Xero Flor). As shown in Figure 21: Recommended pre-cultivated green roof system., each layer has certain function. The bottom layer, a 20 mm thick root barrier sheet, and the second bottom layer, the drainage mat, are both laid in place individually. The third layer is 1.2 cm thick and acts as a water retention media, to conserve moisture between rainfall events. The top layer, consists of a pre-cultivated vegetation mat with an additional section of water-retention fleece attached to the back.

Installation

The IIHR roof has an existing typical roof – rubber coating. This existing coating provides the underlay necessary for the pre-cultivated roof system. To ensure that the roof is free of all debris, a sweep and inspection of the roof should be performed. Once, the inspection is completed, the root barrier can be loose laid. The A minimum of 10 inch overlap should be done when laying the root barrier layer. Next, the drainage layer can be rolled out. The drainage layer features a geotextile fabric and nylon entanglement fabric. When rolling out the drainage layer the geotextile fabric side should be facing up. Next, the water retention fleece layer should be rolled out, either side facing up. Adjacent pieces of the drainage layer and the water retention layer should be offset by half the length of the roll.

Finally, the pre-cultivated mat can be laid. The mat is supplied to the site either in rolls or in flat sheets and with a minimum of 70% vegetation coverage. Each full piece of the cultivated mat should be offset from the adjacent piece by half its length. Xero Flor recommends that upon complete installation, that it may be necessary to redistribute or supplement the substrate to ensure even coverage across the carrier mat.

Xero Flor specifies that a minimum of 24 inches must be maintained from the vegetation and the edge of the roof and a minimum of 18 inches must be maintained from all roof drains and vents. Therefore, it will be necessary for the drainage layer to laid out across the entire roof (leaving cut-outs for drains), however, the top, vegetation layer will not be laid in these above specified areas. Instead, it is recommended that gravel be placed in the open spaces on top of the drainage layer. After installation of the green roof, it is recommended that an organic fertilizer, such as Milorganite 6-2-0 at approximately 12 to 15 lbs/ 1000 ft^2, using a rotary spreader be applied for the first two weeks. Then, it is recommended that the fertilizer be used once per year at the beginning of spring (early April for our location).

An outlet or a means to supply water to the roof is required. Sufficient water must be supplied to the green roof for the first 1-2 years of the roof. This will ensure adequate plant health and growth during the establishment phase. After considering possible watering alternatives, the recommended and most cost effective system would be to conserve water from the top penthouse of the IIHR facility in a cistern shown in Figure 22: Water capture cistern for irrigation..

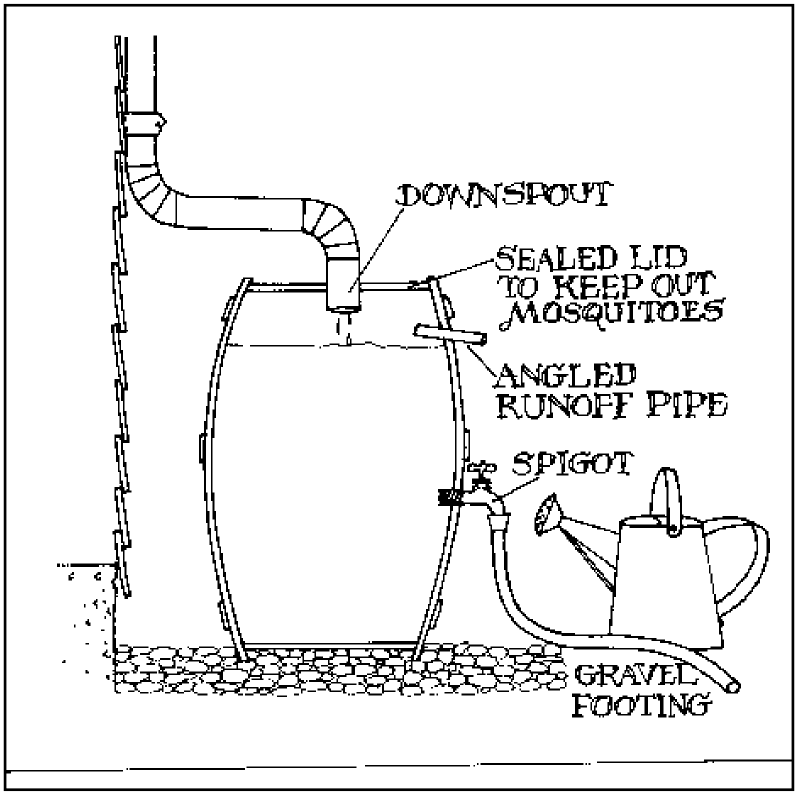

Figure 22: Water capture cistern for irrigation.

Figure 22: Water capture cistern for irrigation. illustrates hoe the water from the penthouse can be captured and used to irrigate the green roof in times of extreme drought.

In conclusion, due to the easy installation and maintenance, weed resistant design, and low saturated weight (12-15 lbs/ft^2) requirements; the XF301 green roof system is recommended.

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COVER PHOTO CREDIT: "Sedum Ground Covered – green roof": http://www.xeroflora.com/XeroFlor4-PageBrochureEdition2-2.pdf

Appendix A

NORMALS, MEANS, AND EXTREMES

DES MOINES, IA (DSM)

LATITUDE: 41° 32′ 16″ N
LONGITUDE: 93° 39′ 58″ W
ELEVATION (FT): GRND: 968 BARO: 971
TIME ZONE: CENTRAL (UTC + 6)
WBAN: 14933

	ELEMENT	POR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
TEMPERATURE °F	NORMAL DAILY MAXIMUM	30	29.1	35.4	48.2	61.3	72.3	81.8	86.0	83.9	75.9	63.5	46.7	33.1	59.8
	MEAN DAILY MAXIMUM	60	29.1	34.8	46.3	61.5	72.4	81.6	85.9	83.9	74.7	64.5	47.5	33.8	59.7
	HIGHEST DAILY MAXIMUM	66	67	73	91	93	98	103	105	108	101	95	81	69	108
	YEAR OF OCCURRENCE		2003	1972	1986	1980	1967	1988	1955	1983	1939	1963	1999	1984	AUG 1983
	MEAN OF EXTREME MAXS.	60	51.8	56.9	73.1	83.6	87.8	93.4	96.9	95.7	89.7	83.6	68.5	57.0	78.2
	NORMAL DAILY MINIMUM	30	11.7	17.8	28.7	39.9	51.4	61.0	66.1	63.9	54.3	42.2	29.0	16.7	40.2
	MEAN DAILY MINIMUM	60	11.7	17.0	27.2	39.9	51.1	61.3	65.9	63.7	53.6	43.0	29.4	17.6	40.1
	LOWEST DAILY MINIMUM	66	-24	-26	-22	9	30	38	47	40	0	14	-4	-22	-26
	YEAR OF OCCURRENCE		1970	1996	1962	1975	2005	1945	1971	1950	1996	1972	1991	1989	FEB 1996
	MEAN OF EXTREME MINS.	60	-10.9	-4.9	7.2	23.6	36.3	48.3	55.1	52.1	37.0	26.3	11.0	-4.2	23.1
	NORMAL DRY BULB	30	20.4	26.6	38.4	50.6	61.9	71.4	76.1	73.9	65.1	52.8	37.9	24.9	50.0
	MEAN DRY BULB	60	20.4	25.8	36.7	50.6	61.8	71.5	75.8	73.9	64.3	53.8	38.5	25.8	49.9
	MEAN WET BULB	20	20.8	25.2	33.9	44.9	55.3	64.2	68.8	63.9	55.7	47.1	34.5	24.2	44.9
	MEAN DEW POINT	20	15.6	19.8	27.2	37.4	49.2	56.5	65.2	60.5	51.2	41.4	29.0	19.7	39.4
	NORMAL NO. DAYS WITH:														
	MAXIMUM ≥ 90°	30	0.0	0.0	*	0.1	0.3	4.5	9.6	6.9	2.1	0.1	0.0	0.0	23.6
	MAXIMUM ≤ 32°	30	16.8	12.1	3.9	0.3	0.0	0.0	0.0	0.0	0.0	0.0	3.7	13.4	50.2
	MINIMUM ≤ 32°	30	30.0	24.6	19.4	6.2	0.1	0.0	0.0	0.0	0.2	4.7	19.0	28.7	132.9
	MINIMUM ≤ 0°	30	7.3	3.3	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	4.0	15.1
H/C	NORMAL HEATING DEG. DAYS	30	1385	1090	826	439	153	16	1	6	103	386	804	1227	6436
	NORMAL COOLING DEG. DAYS	30	0	0	1	12	60	219	353	285	110	12	0	0	1052
RH	NORMAL (PERCENT)	30	72	71	67	63	64	66	69	72	70	67	72	76	69
	HOUR 00 LST	30	74	76	72	69	71	73	77	80	78	74	76	79	75
	HOUR 06 LST	30	76	78	78	77	78	80	83	86	85	80	80	81	80
	HOUR 12 LST	30	67	65	58	54	55	56	58	60	58	56	64	70	60
	HOUR 18 LST	30	70	67	58	52	53	54	57	60	59	58	67	73	61
S	PERCENT POSSIBLE SUNSHINE	51	51	54	57	56	61	68	72	70	66	62	49	46	59
W/O	MEAN NO. DAYS WITH:														
	HEAVY FOG(VISBY≤1/4 MI)	56	2.6	2.3	2.0	1.0	0.9	0.7	0.7	1.3	1.2	1.2	1.7	2.8	18.4
	THUNDERSTORMS	66	0.3	0.4	2.1	4.3	7.0	8.8	8.2	6.9	4.9	2.6	1.1	0.3	46.9
CLOUDINESS	MEAN:														
	SUNRISE-SUNSET (OKTAS)	0						4.8							
	MIDNIGHT-MIDNIGHT (OKTAS)														
	MEAN NO. DAYS WITH:														
	CLEAR	1	1.0	1.0	6.0		3.0	10.0							
	PARTLY CLOUDY	1	2.0		3.0		2.0	1.0							
	CLOUDY	1	3.0	3.0	7.0		12.0	10.0							
PR	MEAN STATION PRESSURE(IN)	31	29.10	29.09	29.00	28.90	28.90	28.90	29.00	29.00	29.00	29.01	29.00	29.10	29.00
	MEAN SEA-LEVEL PRES. (IN)	19	30.13	30.12	30.05	29.94	29.94	29.99	29.97	30.01	30.03	30.05	30.06	30.12	30.03
WINDS	MEAN SPEED (MPH)	53	11.4	11.3	12.5	12.8	11.0	10.2	8.9	8.7	9.5	10.4	11.7	11.2	10.8
	PREVAIL.DIR(TENS OF DEGS)	34	32	32	32	18	18	18	18	15	18	18	32	32	18
	MAXIMUM 2-MINUTE:														
	SPEED (MPH)	10	44	41	48	51	52	53	49	53	52	46	52	44	53
	DIR. (TENS OF DEGS)		32	30	27	29	32	22	02	28	29	26	25	31	22
	YEAR OF OCCURRENCE		2005	1999	2002	1996	2000	2000	2000	1998	2001	2004	1998	2004	JUN 2000
	MAXIMUM 5-SECOND:														
	SPEED (MPH)	10	53	51	59	64	59	68	61	70	60	57	62	52	70
	DIR. (TENS OF DEGS)		33	29	26	28	32	21	01	29	28	28	26	31	29
	YEAR OF OCCURRENCE		2005	1996	2002	1996	2000	2000	2000	1998	2001	1996	1998	2004	AUG 1998
PRECIPITATION	NORMAL (IN)	30	1.03	1.19	2.21	3.58	4.25	4.57	4.18	4.51	3.15	2.62	2.10	1.33	34.72
	MAXIMUM MONTHLY (IN)	66	4.38	2.99	5.82	7.76	12.13	14.19	10.51	13.68	10.19	7.29	6.52	3.43	14.19
	YEAR OF OCCURRENCE		1960	1951	1990	1976	1996	1947	1958	1977	1961	1941	1983	1982	JUN 1947
	MINIMUM MONTHLY (IN)	66	0.04	0.13	0.17	0.23	1.23	1.02	0.04	0.25	0.41	0.03	0.03	0.03	0.03
	YEAR OF OCCURRENCE		1997	1968	1994	1985	1949	1992	1975	1984	1950	1952	1969	2002	DEC 2002
	MAXIMUM IN 24 HOURS (IN)	66	2.97	1.77	2.42	3.80	3.23	5.50	5.14	6.18	4.47	2.81	3.55	1.69	6.18
	YEAR OF OCCURRENCE		1960	1961	1945	1974	1996	1947	1958	1975	1961	1947	2003	1982	AUG 1975
	NORMAL NO. DAYS WITH:														
	PRECIPITATION ≥ 0.01	30	7.6	7.7	9.5	11.0	12.0	11.0	9.9	9.4	8.5	8.1	8.6	8.5	111.8
	PRECIPITATION ≥ 1.00	30	0.1	0.1	0.5	0.6	0.9	1.4	1.2	1.5	0.7	0.8	0.3	0.1	8.2
SNOWFALL	NORMAL (IN)	30	8.8	8.2	4.1	2.7	0.*	0.0	0.0	0.0	0.*	0.4	4.5	7.7	36.4
	MAXIMUM MONTHLY (IN)	62	22.3	21.3	18.8	15.6	0.2	T	T	0.0	T	7.4	14.7	23.9	23.9
	YEAR OF OCCURRENCE		1996	1962	1948	1982	1944	1993	1992		1992	1980	1991	1961	DEC 1961
	MAXIMUM IN 24 HOURS (IN)	61	19.8	12.1	15.6	10.4	0.2	T	T	0.0	T	7.4	11.8	11.0	19.8
	YEAR OF OCCURRENCE		1942	1950	2004	1973	1944	1993	1992		1992	1980	1968	1961	JAN 1942
	MAXIMUM SNOW DEPTH (IN)	55	16	17	18	12	0	0	0	0	0	5	10	30	30
	YEAR OF OCCURRENCE		2001	1979	1960	1973						1980	1968	1962	DEC 1962
	NORMAL NO. DAYS WITH:														
	SNOWFALL ≥ 1.0	30	2.5	2.5	1.2	0.6	0.0	0.0	0.0	0.0	0.0	0.1	1.3	2.3	10.5

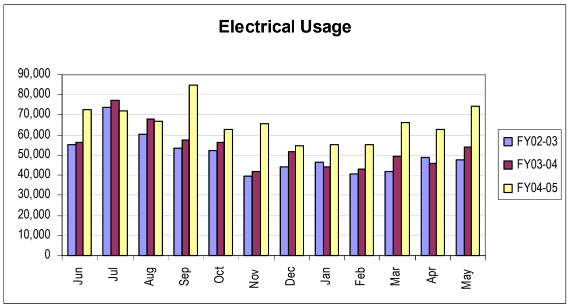
Appendix B

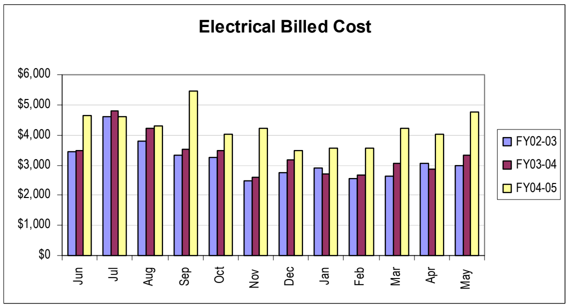
			FY 02-03	FY 03-04	FY 04-05	FY 05-06 YTD
BLDG#:	**024**					
BLDG:	**Hydraulics Labo**	$/GSF	$1.45	$1.52	$1.86	$1.51
GSF:	33,984	Elec $/GSF	$1.11	$1.17	$1.50	$1.21
		Steam $/GSF	$0.34	$0.35	$0.36	$0.30
		CW $/GSF	$0.00	$0.00	$0.00	$0.00
		kWh/GSF	17.76	18.98	23.32	19.08
		Stm MMBtu/GSF	0.04	0.04	0.04	0.03
		CW MMBtu/GSF	0.00	0.00	0.00	0.00
		Tot MMBtu/GSF	0.10	0.10	0.12	0.09

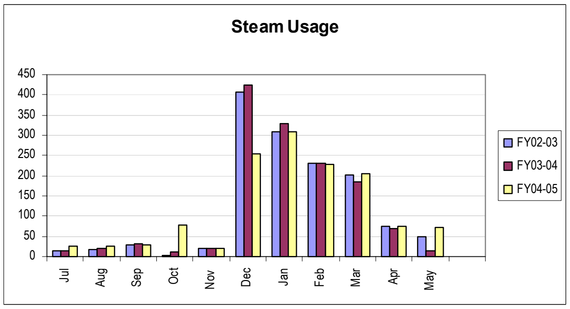
Electricity	FY02-03 Usage (kWh)	FY02-03 Billed Cost	FY03-04 Usage (kWh)	FY03-04 Billed Cost	FY04-05 Usage (kWh)	FY04-05 Billed Cost	FY05-06 Usage (kWh)	FY05-06 Billed Cost	
Jun	55,051	$3,441	56,526	$3,493	72,379	$4,647	80,760	$5,112	
Jul	73,620	$4,601	77,493	$4,789	72,009	$4,623	88,266	$5,587	
Aug	60,415	$3,776	67,973	$4,201	66,979	$4,300	75,159	$4,758	
Sep	53,144	$3,322	57,200	$3,535	84,959	$5,454	80,760	$5,112	
Oct	52,097	$3,256	56,240	$3,476	62,588	$4,018	78,099	$4,944	
Nov	39,448	$2,466	41,771	$2,581	65,793	$4,224	68,534	$4,338	
Dec	44,116	$2,757	51,463	$3,180	54,494	$3,499	60,643	$3,839	
Jan	46,449	$2,903	43,920	$2,714	55,204	$3,544	58,153	$3,681	
Feb	40,747	$2,547	43,040	$2,660	55,187	$3,543	58,078	$3,676	
Mar	42,000	$2,625	49,198	$3,040	65,915	$4,232	0	$0	
Apr	48,871	$3,054	46,095	$2,849	62,937	$4,041	0	$0	
May	47,627	$2,977	54,050	$3,340	74,174	$4,762	0	$0	
Total	603,585	$37,724	644,969	$39,859	792,618	$50,886	648,452	$41,047	
Average	50,299	$3,144	53,747	$3,322	66,052	$4,241	78,596	$4,975	YTD AVE

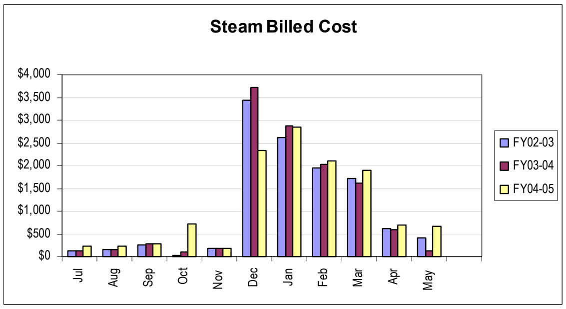
Steam	ge (MMbtu)	3 Billed Cost	03-04 Usage (MMbtu)	3-04 Billed Cost	Usage (MMbtu)	Y04-05 Billed Cost	ge (MMbtu)	FY05-06 Billed Cost	
Jun	10	$85	12	$105	22	$203	25	$270	
Jul	14	$119	14	$123	25	$230	27	$291	
Aug	18	$152	19	$167	25	$230	22	$237	
Sep	30	$254	32	$280	30	$276	27	$291	
Oct	4	$34	11	$96	78	$719	81	$873	
Nov	21	$178	20	$175	20	$184	127	$1,369	
Dec	407	$3,446	423	$3,707	254	$2,341	214	$2,307	
Jan	308	$2,607	328	$2,874	310	$2,857	207	$2,231	
Feb	230	$1,947	232	$2,033	227	$2,092	229	$2,469	
Mar	203	$1,719	185	$1,621	206	$1,898	0	$0	
Apr	74	$626	68	$596	75	$691	0	$0	
May	49	$415	15	$131	72	$664	0	$0	
Total	1,368	$11,581	1,359	$11,910	1,344	$12,386	959	$10,338	
Average	114	$965	113	$992	112	$1,032	52	$555	YTD AVE

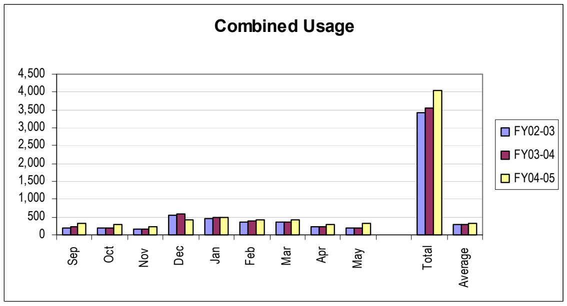
Chilled Water	FY02-03 Us	FY02-03 Bil	FY03-04 Usage (MMbt	FY03-04 Billed C	FY04-05 Usage	FY04-05 Billed Co	FY05-06 Us	FY05-06 Billed Cost	
Jun	0	$0	0	$0	0	$0	0	$0	
Jul	0	$0	0	$0	0	$0	0	$0	
Aug	0	$0	0	$0	0	$0	0	$0	
Sep	0	$0	0	$0	0	$0	0	$0	
Oct	0	$0	0	$0	0	$0	0	$0	
Nov	0	$0	0	$0	0	$0	0	$0	
Dec	0	$0	0	$0	0	$0	0	$0	
Jan	0	$0	0	$0	0	$0	0	$0	
Feb	0	$0	0	$0	0	$0	0	$0	
Mar	0	$0	0	$0	0	$0	0	$0	
Apr	0	$0	0	$0	0	$0	0	$0	
May	0	$0	0	$0	0	$0	0	$0	
Total	0	$0	0	$0	0	$0	0	$0	
Average	0	$0	0	$0	0	$0	0	$0	YTD AVE

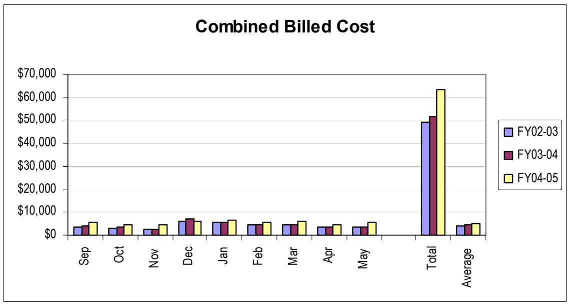

Electrical Usage
90,000
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
FY02-03
FY03-04
FY04-05

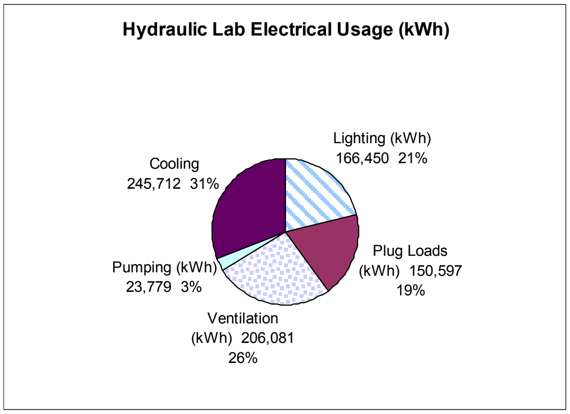

Electrical Billed Cost
$6,000
$5,000
$4,000
$3,000
$2,000
$1,000
$0
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
FY02-03
FY03-04
FY04-05

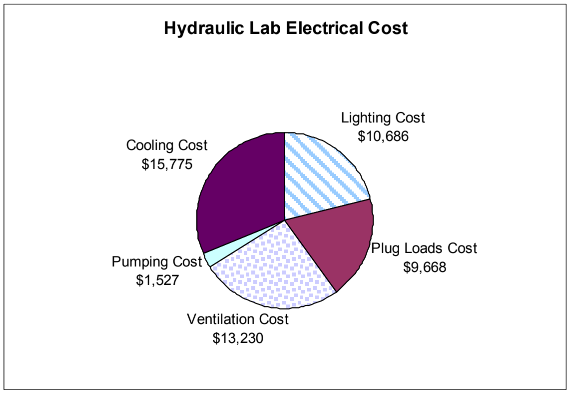

Steam Usage
450
400
350
300
250
200
150
100
50
0
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
FY02-03
FY03-04
FY04-05


Steam Billed Cost
$4,000
$3,500
$3,000
$2,500
$2,000
$1,500
$1,000
$500
$0
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
FY02-03
FY03-04
FY04-05


Combined Usage
4,500
4,000
3,500
3,000
2,500
2,000
1,500
1,000
500
0
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Total
Average
FY02-03
FY03-04
FY04-05


Combined Billed Cost
$70,000
$60,000
$50,000
$40,000
$30,000
$20,000
$10,000
$0
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Total
Average
FY02-03
FY03-04
FY04-05


Hydraulic Lab Electrical Usage (kWh)
Lighting (kWh) 166,450 21%
Plug Loads (kWh) 150,597 19%
Ventilation (kWh) 206,081 26%
Pumping (kWh) 23,779 3%
Cooling 245,712 31%


Hydraulic Lab Electrical Cost
Lighting Cost $10,686
Plug Loads Cost $9,668
Ventilation Cost $13,230
Pumping Cost $1,527
Cooling Cost $15,775

Appendix C

Common varibles

T_{inside} =	22.3	I_b (W/m	900	h (W/m2	13.3		
A (m2) =	167	I_d =	200	boltz	5.67E-08	vw (m/s	2

Conventional																
a =	0.9	U (W/m2 K)	0.476				q_{rad}			Flux				w/A		
Mo.	% Po	Hrs.	I_b	dT	$T_{outside}$	T_{roof}	Sun in	G_{sky}	E_{roof}	q_{rad}	q_{cond}	q_{conv}	Q_{total}	Q_{total}	kW-h/mo	MMBTU/mo
Jan	0.36	0.4	130	8.76	-6	2.8	117	259	-295	81	-13	-116	-49	-8188	-5895	-20
Feb	0.46	0.5	207	10.9	-2	8.9	186	275	-322	139	-12	-146	-18	-3020	-2174	-7
Mar	0.64	0.6	346	13.1	4	17.1	311	300	-362	250	-9	-175	66	11100	7992	27
Apr	0.73	0.7	460	15.3	11	26.3	414	332	-410	336	-5	-204	127	21218	15277	52
May	0.72	0.8	518	17.5	17	34.5	467	361	-456	371	-3	-233	136	22662	16317	56
Jun	0.79	0.9	640	19.7	23	42.7	576	392	-507	461	0	-262	199	33235	23929	82
Jul	0.85	0.9	689	19.7	25	44.7	620	402	-520	502	1	-262	241	40319	29030	99
Aug	0.85	0.9	689	19.7	24	43.7	620	397	-513	503	1	-262	242	40430	29110	99
Sep	0.75	0.9	608	19.7	19	38.7	547	371	-482	436	-2	-262	172	28792	20730	71
Oct	0.57	0.7	359	15.3	13	28.3	323	341	-421	244	-4	-204	36	5959	4290	15
Nov	0.54	0.6	292	13.1	4	17.1	262	300	-362	201	-9	-175	18	2983	2148	7
Dec	0.43	0.5	194	10.9	-3	7.9	174	271	-318	127	-12	-146	-30	-5043	-3631	-12

Green Roof																
a =	0.3	U (W/m2 K)	0.413				q_{rad}			Flux				w/A		
Mo.	% Ib	sunlight	Ib	dT	$T_{outside}$	T_{roof}	Sun in	G_{sky}	E_{plant}	q_{rad}	q_{cond}	q_{conv}	Q_{total}	Q_{total}	kW-h/mo	MMBTU/mo
Jan	0.36	0.4	130	2.92	-6	-3.1	99	86	-90	95	-12	-39	45	7435	5353	18
Feb	0.46	0.5	207	3.65	-2	1.6	122	92	-97	117	-10	-49	58	9767	7033	24
Mar	0.64	0.6	346	4.38	4	8.4	164	100	-107	157	-8	-58	91	15264	10990	37
Apr	0.73	0.7	460	5.11	11	16.1	198	111	-119	190	-5	-68	117	19570	14090	48
May	0.72	0.8	518	5.84	17	22.8	216	120	-130	206	-2	-78	126	20992	15114	52
Jun	0.79	0.9	640	6.57	23	29.6	252	131	-143	240	0	-87	153	25539	18388	63
Jul	0.85	0.9	689	6.57	25	31.6	267	134	-146	254	1	-87	168	28072	20212	69
Aug	0.85	0.9	689	6.57	24	30.6	267	132	-144	254	1	-87	168	28023	20177	69
Sep	0.75	0.9	608	6.57	19	25.6	242	124	-135	231	-1	-87	142	23719	17078	58
Oct	0.57	0.7	359	5.11	13	18.1	168	114	-122	159	-4	-68	88	14629	10533	36
Nov	0.54	0.6	292	4.38	4	8.4	147	100	-107	141	-8	-58	75	12558	9042	31
Dec	0.43	0.5	194	3.65	-3	0.6	118	90	-95	113	-10	-49	54	9031	6503	22

Appendix D

	Time	Roof $	21000	
I elec =	0.04	Simple Payb	5.9	years
I =	0.168331357			
NPV	1099.58779			

Year	Savings	maint	Dep	PVF	PV
1	$3,567	$300	$525	1.17	$2,347
2	$3,709	$312	$525	1.36	$2,104
3	$3,858	$324	$525	1.59	$1,886
4	$4,012	$337	$525	1.86	$1,690
5	$4,172	$351	$525	2.18	$1,514
6	$4,339	$365	$525	2.54	$1,356
7	$4,513	$380	$525	2.97	$1,214
8	$4,693	$395	$525	3.47	$1,087
9	$4,881	$411	$525	4.06	$973
10	$5,076	$427	$525	4.74	$870
11	$5,279	$444	$525	5.54	$779
12	$5,491	$462	$525	6.47	$696
13	$5,710	$480	$525	7.56	$623
14	$5,939	$500	$525	8.83	$557
15	$6,176	$520	$525	10.32	$497
16	$6,423	$540	$525	12.05	$445
17	$6,680	$562	$525	14.08	$397
18	$6,947	$584	$525	16.45	$355
19	$7,225	$608	$525	19.22	$317
20	$7,514	$632	$525	22.46	$283
21	$7,815	$657	$525	26.24	$253
22	$8,128	$684	$525	30.65	$226
23	$8,453	$711	$525	35.81	$202
24	$8,791	$739	$525	41.84	$180
25	$9,142	$769	$525	48.88	$161
26	$9,508	$800	$525	57.11	$143
27	$9,888	$832	$525	66.72	$128
28	$10,284	$865	$525	77.96	$114
29	$10,695	$900	$525	91.08	$102
30	$11,123	$936	$525	106.41	$91
31	$11,568	$973	$525	124.32	$81
32	$12,031	$1,012	$525	145.25	$72
33	$12,512	$1,052	$525	169.70	$64
34	$13,012	$1,095	$525	198.26	$57
35	$13,533	$1,138	$525	231.64	$51
36	$14,074	$1,184	$525	270.63	$46
37	$14,637	$1,231	$525	316.19	$41
38	$15,223	$1,280	$525	369.41	$36
39	$15,832	$1,332	$525	431.59	$32
40	$16,465	$1,385	$525	504.24	$29

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[vi] *Cool Roofing Materials Data Base*. (2000, January 4). Retrieved April 22, 2006, from http://eetd.lbl.gov/coolroof/ref_01.htm