Viability Analysis of Living Roof Systems in Albuquerque, New Mexico: Thermal Performance, Water Efficiency, and Carbon Sequestration Potential

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ABSTRACT

Building efficiency technologies are critical for reducing human impact on the Earth's biosphere and for transitioning towards biogeophysical sustainability. Living roof systems have not been assessed for the specific climatic conditions in Albuquerque, NM in terms of their thermal performance and water requirements. This paper analyses the temperature regime, water demands, and carbon sequestration capacity of an existing green roof located on the School of Architecture and Planning's building--George Peal Hall. Measurements were taken over a three month period between June 2010 to August 2010. Results are given as thermal trend graphs derived from daily temperature monitoring over the study period and via yearly calculations for water and carbon respectively. During the study period, the George Pearl Hall living roof demonstrated higher efficiency in its thermal performance in comparison to an analogous conventional roof. On average the temperature variation was 10 degrees Fahrenheit cooler at the soil-membrane interface as compared to the surface temperature of the analogous roof. By using a rainwater harvesting system the Pearl Hall living roof's native grass ground cover meets its yearly water requirements and needed no supplemental aquifer water. In Albuquerque, NM a native grass living roof tops require a 1: 0.5 ratio of living roof area to rooftop collection area to eliminate the need for supplemental aquifer water. The carbon sequestration potential of the George Pearl Hall living roof was found to be 8.15lbs CO2 per year or 1Mt CO2/ha/yr.

INTRODUCTION

According to Teemusk and Mader's 2009 analysis *Temperature regime of planted roofs compared with conventional roofing:* "Planted roofs are nowadays the best means to increase green areas in cities, where the amount of vegetated surface on the ground has fallen…green roofs improve the quality of the urban environment." Research has shown that green roofs can retain the runoff from roof surfaces (Moran et al., 2003; Villarreal and Bengtsson, 2005; Mentensetal., 2006; Carter and Jackson, 2007; Teemuskand Mander, 2007; Getteret al., 2007); reduce the pollution of urban rain water runoff (Moran et al., 2003; Berndtssonetal., 2006; Emilssonetal., 2007; Teemusk and Mander, 2007; Berndtssonetal.,2009); reduce building energy consumption and keep buildings cool in summer (Eumorfopoulou and Aravantinos, 1998; Palomodel Barrio, 1998; Wonget al., 2003; Theodosiou, 2003; Bass and Baskaran, 2003; Santamouriset al.,2007); mitigate the urban heat island effect (Wongetal., 2003; Takebayashi and Moriyama, 2007); and improve urban biodiversity (Brenneisen, 2003).

Analysis has shown that "both green roofs and sod roofs are capable of reducing the influence of temperature fluctuation on the base roof. The results of the green and sod roof were similar; the thicker sod roof had higher temperatures in cool periods that the thinner green roof. In warmer periods, the surface of the planed roof heats up too much, so plant cover must be well developed. However, such high and rapid heating of the surfaces did not cause a considerable temperature rise under the substrate layers, so the substrate layer preserves cool near the base roof. The difference between the temperature amplitude under the planted roofs and the surfaces of the conventional roofs was on average 20 degrees centigrade" (Teemusk and Mader, 2009). Teemusk and Mader's analysis employed the use of statistical data analysis to develop findings that prove living roofs reduce the temperature fluctuation of the roof membrane to a median fluctuation of 5-7 degrees centigrade throughout the year. Analysis conducted by Bass and Baskaran (2003) generated results of the same roof temperatures profile monitoring on typical days in different seasons, where membrane temperatures on living roofs fluctuated by around 25 degrees centigrade. DeNardo et al. (2005) found that living roof systems maximum surface temperatures were, on average, 19 degrees centigrade lower in the summertime in comparison to conventional roofing.

A recent analysis conducted by Getter et al. (2009) entitled C*arbon Sequestration Potential of Extensive Green Roofs* used known above and below ground primary productivity figures to develop carbon sequestration potential of living roof systems dominated by sedum species in Michigan. The study was performed on eight roofs in Michigan and four roofs in Maryland, ranging from 1 to 6 years in age. "All 12 green roofs were planted with sedum species, and substrate depths ranged from 2.5 to 12.7 cm. Above ground plant material was harvested in the fall of 2006. On average, the roofs stored 162 g C · m-2 in aboveground biomass. The second study was conducted on a roof in East Lansing, MI. Twenty plots were established on 21 April 2007 with a substrate depth of 6.0 cm. In addition to a substrate only control, the other plots were sown with a single species of sedum (S. acre, S. album, S. kamtshaticum, or S. spurium). Species and substrate depth represent typical extensive green roofs in the United States. Plant material and substrate were harvested seven times across two growing seasons. Results at the end of the second year showed that aboveground plant material storage varied by species, ranging from 64 g C · m-2 (S. acre) to 239 g C·m-2 (S. album), with an average of 168 g C·m-2. Below ground biomass ranged from 37 g C · m-2 (S. acre) to 185 g C · m-2 (S. Kamtschaticum) and averaged 107 g C · m-2. Substrate carbon content averaged 913 g C · m-2, with no species effect, which represents a sequestration rate of 100 g C · m-2 over the 2 years of this study. The entire extensive green roof system sequestered 375 g C · m-2 in above- and belowground biomass and substrate organic matter (Getter et al. 2009)."

METHODS

Using quantative data derived from a test roof system located on George Pearl Hall at the University of New Mexico, this assessment draws on several mathematical and environmental assessment techniques. There are two primary goals of this analysis: (1) to determine the thermal performance of the George Pearl Hall living roof and extrapolate the thermal data trends to predict levels of energy/environmental savings in the building and (2) to determine the carbon emissions offset by the George Pearl Hall living roof compared to the carbon footprint of George Pearl Hall. Secondary goals of the assessment are to monitor water consumption of the living roof to determine its applicability in the environmental and climatic conditions of New Mexico.

Thermal trends of the George Pearl Hall living roof were recorded along with those of a non-living analogous roof system on the same building using wireless thermal recorders. Using graphical trends from both roof systems, an analysis was conducted to compare the thermal properties of each roof system. In general, the higher the temperature (surface and air) the higher the expected heat transfer through a given roofing substrate. Using this comparative assessment technique, thermal trends were developed and extrapolated in order to determine the relative performance of each system.

This assessment also uses the ecological footprint method (EFM). The EFM is a measurement for relating waste streams to the assimilation capacity of the earth's biosphere. Since the earth has a finite amount of available bio-productive land, we can determine the area needed in terms of generic global bio-productive hectares (gha) required to re-assimilate the waste of a population, activity, or material. A subset, and often the largest component, of the EFM is the Carbon Footprint Model (CFM). The CFM model uses known emission coefficients for converting energy used into greenhouse gas emissions, expressed as carbon dioxide equivalence. In calculating the footprint area, the CFM uses two primary coefficients. One pertains to the carbon sequestration capacity of a specific portion of the earth's biosphere and the second is an equivalence factor, which relates the carbon sequestration capacity of a specific land type (ha) to the overall bio-productivity of the earth's surface (gha). This analysis uses the sequestration capacity of an average desert grassland, which has a capacity of .111 ha/ metric ton of carbon dioxide and a land equivalence factor for forest land of 1.17 (Brown, Joel, 2006).

Thermal assessment of the George Pearl Hall Living roof was conducted over a two month period from 06/06/2010 to 08/06/2010 in order to compare thermal performance during the peak of summer temperatures. Data were collected via wireless thermal recording sensors produced by the T&D Corporation of Japan. Sensors were calibrated over a three month interval from March 2010 through May 2010. Sensors had a + - 1 degree temperature variation from the average.

DESCRIPTION OF SYSTEMS

The Pearl Hall Living Roof System is a 400 square foot demonstration living roof system located on the southeast corner of the second floor of George Pearl Hall. The Pearl Hall Living Roof measures 17'6" by 20'0" with an area of 350 square feet. The primary plant species were native New Mexican grass species (Bouteloua gracillis and Buchloe dactyloides) and wildflowers during the spring and summer of 2010.

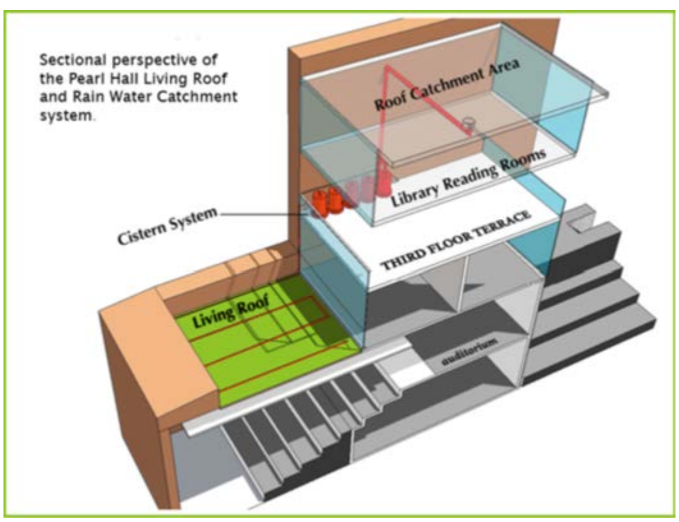

Figure 1. *Sectional perspective through George Pearl Hall shows the living roof, adjacent classroom, third floor terrace, library reading rooms, and the roof area feeding the rain water catchment barrels.*

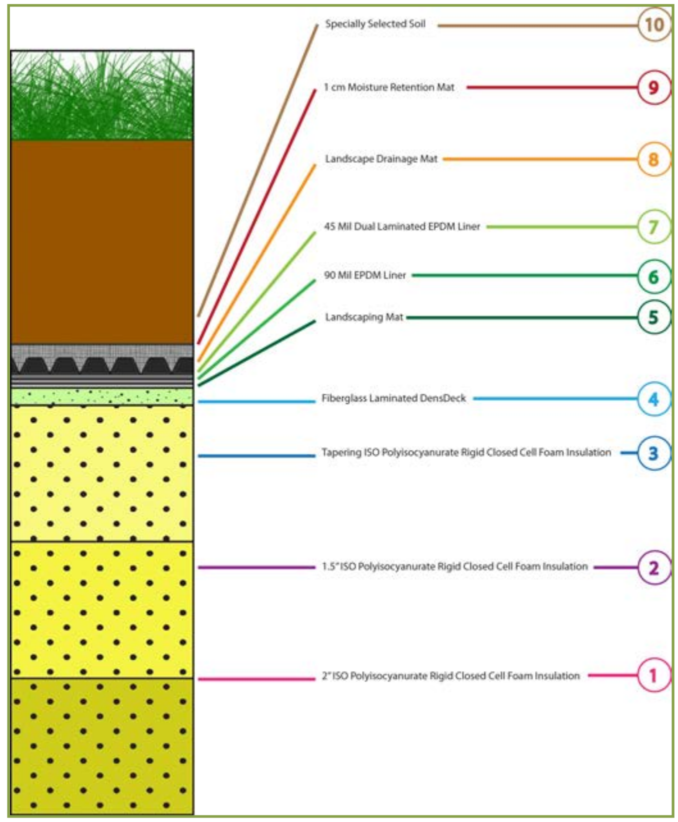

Figure 2: *Pearl Hall Living Roof Section. Materials as listed from 1-10:*

1.Polyisocyanurate exhibits the highest R-factor (insulating value) to thickness ratio of commercially available insulation. Polyisocyanurate, also referred to as PIR, polyiso, or ISO, is essentially an improvement on polyurethane (PUR). 2" = R-13

2. A second flat Polyisocyanurate board layer rests above the 2" layer with a thinckness of 1.5" and a corresponding R-value of 9.

3. Tapered ISO board. This layer tapers from 1.5" to a minimum thickness of 0.5" to give the living roof its drainage of 1/4" per foot. Average R value of 6.5 gives the combined ISO board a R-value of 27.5

4. DensDeck is a patented fiberglass mat faced panel with a specially treated gypsum core that resists moisture and mold growth and also provides sound isolation.

5. A thin layer of landscaping mat rests above the DensDeck to provide cushion between the first water proof layer and the Insulation Layers.

6. 90 Mil EPDM roofing membrane forms the first waterproofing layer. EPDM (ethylene propylene diene terpolymer) single-ply rubber roofing membrane and is widely used in low-slope commercial roofing.

7. A second EPDM layer 45 Mil rests above the 90 Mil layer to provide an additional layer of waterproofing and is highly resistant to penetration. This layer is dual laminated.

8. A landscape drainage mat rests above the 45 Mil layer. This layer ensures all excessive moisture drains out of the soil, giving the living roof excellent drainage and prevents root rot in plantings.

9. The moisture retention mat provides additional water retention for the living roof. With only a thin soil layer approx. 8" there is a need to employ the use of this 1 centimeter moisture mat.

10.Specially selected soil: 40% pumice, 40% scoria, 20% compost provides the living roof with excellent drainage, moisture retention and fertilization.

Analogous Roof System

The Pearl Hall roof system is a standard R-31 tar-paper flat roof.

Thermal Monitoring Sensor Locations

A total of 5 sensors were used to obtain the thermal results for this assessment. Three sensors were located on the living roof and two sensors were located on the analogous roof. Sensors were placed at locations with similar solar exposures for accurate comparison. Sensors were positioned to have the most accurate comparative solar exposure on the two different roofing mediums. Three sensors were located on the living roof: 6" above the surface, on the surface soil/vegetation level, and at soil membrane interface 6" below grade. Two sensors were located on the analogous tar paper roof: 6" above the surface and on the roof surface.

THERMAL PERFORMANCE ANALYSIS FINDINGS

This section summarizes the measured thermal trends for comparison of the two studied roofing types, the living roof and the analogous tar paper roof. The following figures graphically shows the findings of the analysis by plotting recorded temperatures for different sensor locations in the study area.

Living Roof Thermal Results

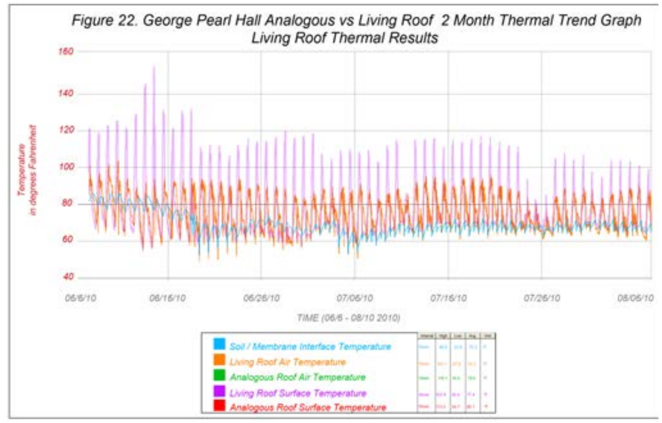

Figure 3: *Thermal trends of the Pearl Hall living roof system.*

The thermal recordings of the sensors located on the Pearl Hall living roof at three locations: 6'' in the air, on the grass surface, and 8" below the surface at the soil/membrane interface. As described in the figure legend the air temperature of the living roof had an average of 74.7 degrees F, with a high of 103.1 degrees F and a low of 47.8 degrees F. The surface temperature of the Living Roof had an average of 77.4 degrees F, with a high of 153.9 degrees F and a low of 55.4 degrees F. The soil/membrane interface temperature of the Living Roof had an average of 70.3 degrees F, with a high of 86 degrees F and a low of 53.8 degrees F.

As hypothesized, the surface temperature of the living roof far exceeded the air temperature directly above the living roof, specifically in terms of maximum high temperatures that had a drastic difference of near 50 degrees F nearly ten days in a row from 6/6/2010 to6/16/2010. This abnormality in high temperature variation occurred during the exact period of no watering due to lack of access to the living roof from 6/6/2010 to 6/16/2010. It is suspected that the dieback of grass increased the abledo of the living roof and thereby increasing the incoming solar radiation absorbed by the roof surface as infrared energy (heat). After 6/16/2010 there is a reduction in the maximum temperature for the surface of the living roof. This is suspected to have dropped because an automatic watering device was installed on the roof to provide adequate water to the grass species. The temperature curves of the soil/membrane sensor remained the most constant, with relatively low variation in terms of both high and low values over the study period. This suggests that the amount of infrared energy reaching the upper layers of the roof insulation has been substantially reduced by the living roof system.

Analogous Roof Thermal Results

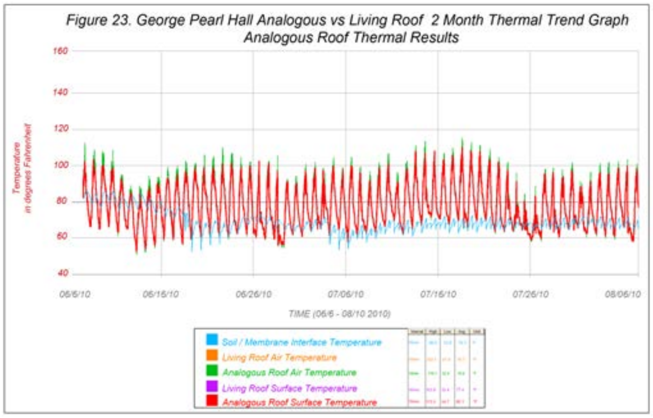

Figure 4: *Thermal trends of the Pearl Hall analogous roof system.*

The thermal recordings of the sensors located on the Pearl Hall analogous roof at two locations: 6'' in the air and on the roof surface. As described in the figure legend the air temperature of the analogous roof had an average of 79.9 degrees F, with a high of 116.1 degrees F and a low of 52.9 degrees F. The surface temperature of the analogous roof had an average temperature of 80.1 degrees F, with a high of 113.5 degrees F and a low of 54.7 degrees F. The values for both the air and surface temperatures follow very closely with the large temperature fluctuations occurring in the air temperatures (which consistently had a higher maximum daily value than the surface temperature. The blue line, representing the temperature inside the soil at the membrane interface on the living roof, has been included as a base comparison.

Compared Air Temperature Results

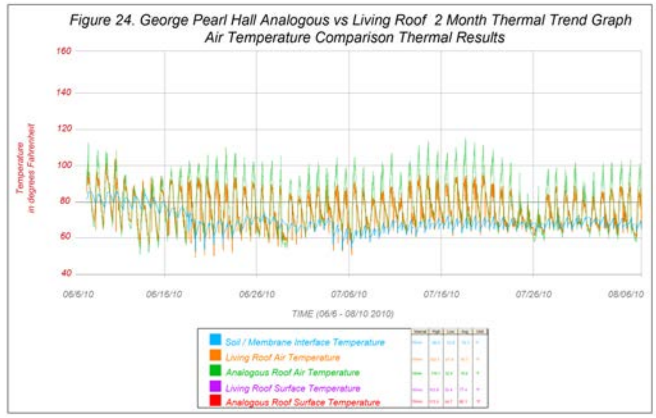

Figure 5: *Thermal trends of compared air temperatures.*

The compared air temperatures of the living and analogous roofs at 6" above the surface. As mentioned in section one, a benefit of living roof systems in studied climates is the reduction of the urban heat island effect. Comparison of the thermal trends in air temperatures between the two studied roofs is an indicator as of the benefits of living roof systems in the climatic conditions of Albuquerque in terms of reducing the urban heat island effect from building roof tops. The green line represents the air temperatures of the analogous roof system and the orange line represents the air temperatures of the living roof system. Comparison of the maximum temperatures shows that the living roof had a high of 103 degrees F and the analogous roof had a high of 116 degrees F. Both maximum values were recorded during the hottest point in the summer (6/6/2010 – 6/16/2010). This means that the living roof had a maximum value 13 degrees F cooler than the analogous roof, although the maximum values for each roof did not occur on the same day. As shown on the graph, the high value of the analogous roof is consistently higher than that of the living roof during the daytime by nearly 10-13 degrees F. The low values for each roof types air sensors were somewhat similar with the living roof having a minimum temperature of 47.8 degrees F while the analogous roof had a minimum temperature of 52.9 degrees F. This would be a maximum difference of 5.1 degrees F. Comparison of the average temperatures of the air sensors shows that the living roof was 5.2 degrees F cooler on average than the analogous roof (74.7 vs. 79.9 F). Averages, which include highs and lows are important in the discussion of energy savings. However, the peak cooling load for buildings occurs in the day (late afternoon). This gives more preference to the daily high value comparison of the living roof with the analogous roof as an indicator of energy savings than the average values.

Compared Surface Temperature Results

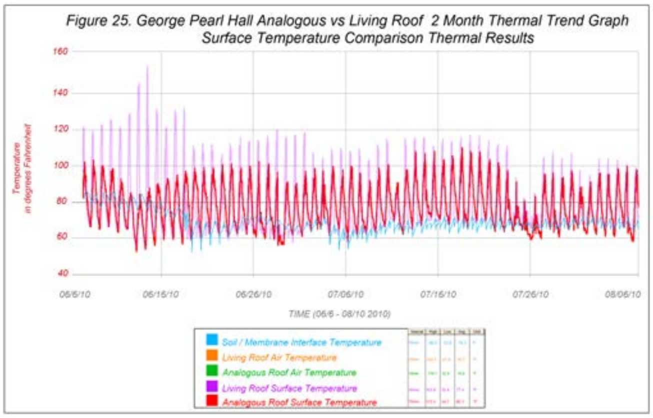

Figure 5: *Thermal surface trends of the Pearl Hall analogous roof system vs. the living roof system.*

The compared surface temperatures recorded during the two month study period of the living and analogous roofs. The red line denotes the thermal trends of the surface temperatures of the analogous roof and the purple line denotes the thermal temperatures of the living roof surface. At first glance it appears that the analogous roof has a much lower average high temperature than the living roof. This is suspected to be due to the highly reflective grey colored coating on the analogous roof and the darker color of the living roof. As mentioned in section 2.4.1 the living roof received little to no water during the first 10 days of the study, which effectively reduced the density of the ground cover vegetation thereby exposing more of the dark colored soil surface. Increases in exposure of soil to incoming solar radiation may have caused in higher temperatures in noted above. The highest recorded temperature of the living roof surface was 153.9 degrees F while the highest temperature of the analogous roof was 113.5 degrees F, a difference of 40.4 degrees F. Low temperatures were almost identical showing 55.4 F and 54.7 F for the analogous roof. Interestingly, the average surface temperature over the two-month period was 3 degrees F cooler on the living roof despite the drastic difference between the two roof types daily high temperatures as shown.

ENVIRONMENTAL ASSESSMENT OF THE PEARL HALL LIVING ROOF SYSTEM

Carbon Dioxide Sequestration Potential of the Pearl Hall Living Roof

The study area of the Pearl Hall living roof system was dominated by blue gramma grass (Bouteloua gracilis) which has an above-ground net primary productivity of average of approximately 0.9 Mg/C/yr and an aboveground carbon absorption rate of 1 mt/ha/yr (Ubechel, 2007). Using the growing area of the roof we can determine the yearly carbon dioxide emission sequestration capacity. The Pearl Hall living roof has a yearly carbon sequestration capacity of 8.15 pounds of carbon per year for its aboveground biomass production.

Carbon Dioxide Emissions Footprint Assessment

In a previous analysis, the total greenhouse gas emission of Pearl Hall was calculated (Ubechel, 2008). This analysis found that George Pearl Hall has a substantial yearly carbon deficit exceeding 3.5 million pounds of carbon dioxide each year. The corresponding yearly carbon footprint deficit for this emission quantity totals 1,531 acres of New Mexican forests and grassland or 864 acres of global average forestlands. Carbon dioxide emissions from the concrete used in the building of the structure was found to exceed 3 million pounds and have a corresponding carbon footprint of 932 global acres of average forest lands. This would require an approximate living roof area using blue gramma grass of 67,247,440 square feet or 1,544 acres. The current living roof absorbs only 0.000594 percent of the total green house gas emissions of the building.

WATER MODELING

Since living roof systems require substantial water resources for their continued survival, this section addresses the water constraints of Albuquerque and to provide a baseline assessment for the water consumption of the living roof and to develop rainwater cistern sizing criteria for living roofs in Albuquerque.

Water Demands of the Pearl Hall Living Roof System

Review of literature denotes that native blue gramma lawns need require 8-10 inches (1-2 inches of irrigation per growing month) (Morrow, 2001). If we solve for the volume of water based on the data provided by Baker Morrow using we find that the water requirement for the living roof is 2,509 gallons. This is expressed in the following equation:

Living Roof Dimensions: 17.5 feet x 23 feet

Living Roof Dimensions: 210 inches (base) x 276 inches (width)

Water Requirements (Height): $10\ \frac{\text{inches}}{\text{year}}$

Volume Equation of Cube: $V = BxWxH$

$$V = (10\frac{\text{inches}}{\text{year}})(210)(276)$$

$$V = 579{,}600 in^3$$

$$579{,}600 in^3 = 2{,}509\ galons$$

Albuquerque receives 8 inches of precipitation annually. This is 80 percent (given an additional 20 percent requirement to ensure survival of grass species) of the total water requirement of the living roof. This means that the supplemental water demand of the living roof is only 20 percent of the total demand (2,509 gallons) or 501.8 gallons annually. Although supplemental water was used during the study period the Pearl Hall living roof is not dependent on aquifer water for its survival. The Pearl Hall living roof has a rainwater harvesting system that provides adequate supplemental water as described below.

During the study period, a total of 1,000 gallons were used to support the native vegetation on the living roof (quantity derived by using the sprinkler flow rate [1 gallons/min] and water duration [20 min/day] over 50 of 60 days in the study period). This was done to ensure survival of the living roof during the summer break when the building and existing rainwater system was inaccessible. Between June and August the living roof used 20 gallons of supplemental water per day. This is 39% of the total water requirements for the living roof for the 2010 year. The remaining water requirement for the year would be 1,509 gallons (2,509gallons – 1,000 gallons). Leaving a remainder 150.9 gallons per month over the remaining 10 months of the year.

Images showing the condition of the Pearl Hall Living Roof after receiving supplemental watering over the summer study period of 60 days between June and August 2010.

Rainwater Harvesting

In order to decrease dependence on aquifer water a rain water harvesting system was installed on the 3rd floor terrace of George Pearl Hall.

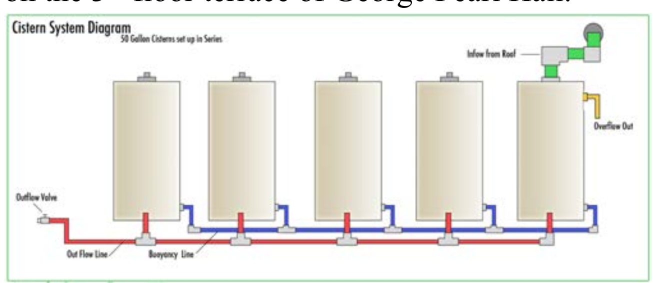

Figure 6: *Pearl Hall rainwater harvesting system.*

The rainwater harvesting system maximizes the use of passive irrigation and non mechanical systems for watering and collection. The inflow from the roof, when switched on with a valve in the George Peal Hall Library, only flows into one of the rainwater barrels located on the terrace. Using buoyancy, the pressure generated by water flowing into the first rainwater barrel will cause the remainder of the rainwater barrels to fill, as denoted by the blue line in the graphic above. An overflow valve is located three inches below the top of the first rainwater barrel. The physical infrastructure of the rainwater systems inflow and overflow is integrated into the building's façade. There are 5 rainwater barrels located on the terrace with a holding capacity of 50 gallons per barrel. This corresponds to a total holding capacity of 250 gallons. The storm water calculations to fill this rainwater harvesting system are as follows:

Rainwater Harvesting System 1"/hour Storm Equation

Rational Equation: $Q = ciA$

X = capacity: 250 gallons

c = Rooftop Coefficient: 90%

Q = Peak Discharge, cfs

i = Rainfall Intensity, 1 inch/hour

A = Drainage Area, 336 square feet

Q = 3.115 gallons per min (**assumes conversion prior to calculation)

$$\text{Time to Fill} = \frac{X}{Q} = \frac{250 \text{ gallons}}{3.115 \, galons/\text{min}} = 80.25 \text{ min or } 1.33 \text{ hours}$$

As calculated above a rainstorm of 1 inch per hour would fill the rainwater catchment system in 80.25 minutes. Over the monsoon season in Albuquerque between May and October, the average rainfall is 6.32 inches (value derived from 1971-2000 average rainfall, Source: National Weather Service, 2007). Over this time period, the total roof top harvesting capacity of the 336 sf roof area is 305,786 (cubic inches) or 1,323.74892 US gallons. Equation: (area)(rainfall) = volume. The 250 gallon rainwater harvesting system captures only 18.89 percent of the total monsoon rainfall.

As derived in above supplemental water requirements for a native grass species living roof is 501.8 gallons annually given an average rainfall of 8 inches in Albuquerque, NM. This means that the total required rainwater catchment would need to equal the demand of 501.8 gallons. The following table summarizes the catchment capacity of the Pearl Hall rainwater harvesting system using the data provided by the National Weather Service in Figure 30 and monthly water demands for blue gramma grass.

Fig 31. Monthly Precipitation, Roof Rainfall and Monthly Water Need

Monthly Precip		RWH Potential	Rain fall on Roof	Water need	Total Incoming Water
Jan	.49 in	92.23	122	43.68	215
Feb	.44 in	82.73	109	101.92	192
Mar	.61 in	114.84	152	159	267
Apr	.50 in	94.05	124	252.4	219
May	.60 in	113.1	149.6	291	261
Jun	.65 in	122.32	162	365	283
Jul	1.27 in	239.4	316	379	555
Aug	1.73 in	325.91	431	336	756
Sep	1.07 in	202.55	266	261	468
Oct	1.00 in	188.37	249	189	437
Nov	.62 in	116.71	154	87	270
Dec	.49 in	92.36	122	44	214

*all figures in gallons

Figure 7: *Monthly Precipitation, Roof Rainfall, and Water Need.*

Solving for the water deficit of the Pearl Hall living roof is the relationship between the water demand and the total water supply. The total water supply is the sum of the rainfall on the living roof and the rain water harvesting potential. As shown in figures 32 and 33 there are only three months out of the year when the water demand (labeled water need) exceeds the total water supply: April, May, and June. During the months between January and March the total demand for water is 304 gallons, of which no rainwater from the harvesting system need be used. Therefore, rainwater harvesting can be cumulative during these months up to the capacity of the system (250 gallons). The total incoming rainwater to the harvesting system between January and March is 289, which accounts for a ten percent transmission loss from the harvesting surface. The monthly deficit between the rainfall on the roof and the water demand in April is 128 gallons. Giving timely watering from the cistern system the demand deficit can be cut to 33 gallons, carrying over 217 gallons into May. Timely watering would denote draining water from the cistern system prior to a rainfall event in the quantity of water expected to be harvesting during the rainfall event. In May, the deficit between incoming water and demand is 30 gallons. Again, using timely watering from the cistern system the deficit can be overcome leaving 187 gallons of reserve water for the month of June. In June, the deficit between incoming water and demand is 82 gallons, a figure smaller than the calculated reserve of 187 gallons in the cistern system. Therefore, the Pearl Hall rainwater harvesting system is of sufficient size to overcome the shortages between May and July.

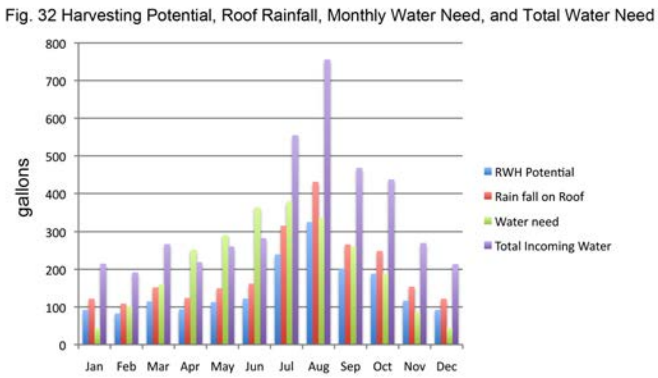

Figure 8: *Harvesting Potential, Roof Rainfall, Monthly Water Need, and Total Water Need.*

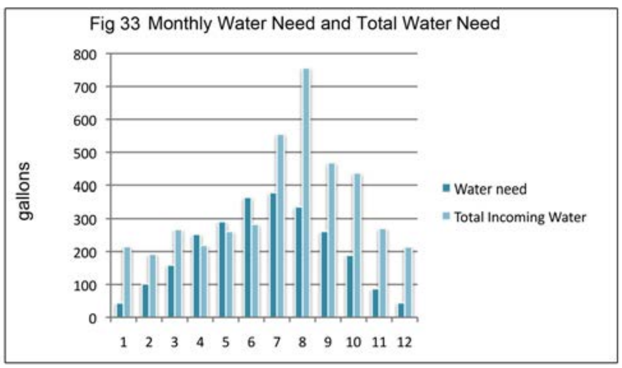

Figure 9: *Monthly Water Need versus Total Water Need.*

Water Assessment Analysis

Water is the most limiting variable when considering the use of living roof systems in Albuquerque. Limitations in water supply and increasing demand within the city pose as fundamental obstacles when looking to use building technologies that require supplemental water over their life spans. Over the course of the study period a total of 1000 gallons of supplemental water was used due to access limitations to the rainwater harvesting system. The rainwater harvesting system is the key component in the viability of the Pearl Hall living roof. Given the added benefit of the 336 square foot roof catchment area and the 250 gallon rain water harvesting system the Pearl Hall living roof can meet its yearly water demands. Without this system, however, the living roof would require supplemental water from the Albuquerque aquifer. Between April and June there is more water demand than there is water supply making it critical to build up water reserves to the months prior to April. Efficient watering from the rainwater harvesting system is critical to ensure enough supplemental is available during the months of shortage.

Water Demand and Rainwater Harvesting Areas

This section evaluates the roof top area needed to supplement native grass living roof systems over one calendar year in Albuquerque, NM. Given 30 year precipitation averages of roughly 8 inches per year and an average water demand of 10 inches per year for native grass, there is a 2 inch deficit between water demand and water availability. This assessment uses a 1 square foot hypothetical living roof area to make its calculations for water demand.

Rain Water Harvesting Area for 1 sf Living Roof in Albuquerque
Area: 1 square foot (sf)
Rooftop Efficiency: .90
Water Demand: 10 inches = 1440 in^3 = ((10in)(144in^2)) = 6.23 gallons/sf
Water Supply: 8 inches = 1152 in^3 = ((8in)(144in^2)) = 4.98 gallons/sf
Water Deficit = Supply - Demand = (4.98g/sf) - (6.23g/sf) = -1.25 gallons /sf

Equation: A = 2.5 * G / R
G = Gallons Harvested
R = Precipitation in inches (yearly)
A = Area of Roof in Square Feet

$$A = \frac{1.25}{(8)}(2.5) = .4 ft^2$$

Based on these calculations, the roof area per square foot required to overcome the deficit of 2 inches of rainfall per year is .4 square feet per 1 square foot of living roof surface. This does not however account for a 90 percent efficiency for the roof surface to supply water to the harvesting system. This drop in efficiency would increase the area to roughly .5 square feet per 1 square foot of living roof.

SUGGESTED IMPROVEMENTS AND FUTURE WORK

There is a clear need to conduct baseline assessments for building efficiency technologies specific to geographic locations and climatic conditions. This baseline assessment has investigated the thermal and water properties of a living roof system in Albuquerque, NM as well as its carbon dioxide mitigation potential. Contained within this chapter are summaries of the key lessons learned during this analysis and conclusions regarding the applicability of living roof systems as a viable building efficiency technology in Albuquerque, NM given their thermal properties, water demands and greenhouse gas mitigation potential.

SUMMARY OF FINDINGS

Thermal Results

This assessment has determined that living roof systems have superior thermal performance at the soil/membrane interface at an average depth of 8 inches below the soil surface during the summer months. The average difference between the membrane interface and the surface temperature of the analogous roof system was 10 degrees F, with variations as high as 40 degrees F during peak daytime temperatures. Hypothesized surface temperature curves matched actual readings at all measured surfaces (soil, surface, and air). The temperature on the surface of the living roof far exceeded that of the analogous roof by as much as 70 degrees, as predicted. Numerous factors could be responsible for the large differences in daytime temperature readings over the study period. It is assumed that this was caused by the low albedo of the living roof as compared to the analogous roofs high albedo. Air temperatures between the two studied revealed that the living roof system had an average temperature difference of -10 degrees F, supporting claims that living roof systems decrease urban heat island effects.

The thermal performance of the living roof far exceeded that of the analogous roof system specifically at the soil membrane interface. This however does not necessarily denote energy savings in the study building as there were no data sets available to conduct a heat transfer assessment though the two roofing sub-surface insulative mediums. This baseline assessment can only speculatively note that during summer months there may be energy savings due to decreased heat gains and corresponding decreased cooling loads within the building envelope.

Water Assessment

Given the limitations in water supply in the arid city of Albuquerque, NM it is critical to decrease growing water demands. Introducing a building efficiency technology that requires supplemental water from the Albuquerque aquifer is a major limiting factor when looking at the viability of living roof systems. Using systems dynamics modeling, a model of the Albuquerque aquifer was constructed and predicted a deep aquifer crash by the year 2050 given current demands[1]. This crash could be expedited given increased demand from living roof systems. Over the study period a total of 1000 gallons of supplemental water was consumed by the living roof, which when extended over the predicted life span of the building (100 years) would total 100,000 gallons. Rainwater harvesting plays a key role when looking to employ the use of living roof systems in Albuquerque. The ratio between living roof space to required rainwater harvesting space is 1: 0.5 (as measured in square feet). This ratio assumes that the rainwater harvesting areas are only needed to supplement the difference between yearly precipitation falling on a living roof and the demand of a native grass planted roof. Using an efficient watering strategy the Pearl Hall rainwater harvesting system has been calculated to meet the entire yearly supplemental water demands of the Pearl Hall living roof, overcoming the time lag between peak growing season and summer monsoon months.

Carbon Sequestration Capacity

This section of the analysis sought to develop a metric of assessment to determine the green house gas mitigation of native grass living roof systems in Albuquerque, NM. The Pearl Hall Living

[1] Sabu, Sandeep and Ubechel, Norion. Albuquerque Ground Water Model, Group Project under Dr. W. Fleming CRP 570. December 2009.

Roof system has a measurable sequestration capacity for of the green house gas carbon dioxide and this value can be deducted from the total yearly carbon dioxide emissions of the building. Using data derived from the yearly electricity, heating and cooling demands of George Pearl Hall a total emissions value was found to be in excess of 3.7 million pounds. The Pearl Hall living roof has a yearly sequestration capacity of 8.15 pounds of carbon dioxide, a negligible amount given the total emissions figure of the building.

CONCLUSION

Human demand placed on the Earth's biosphere far exceeds the planet's yearly capacity to regenerate renewable resources by as much as 30 percent (Living Planet Report, 2007). This drawdown of the ecological goods and services of the planet erodes essential life supporting services and human sustainability. As the gap between human demand and natural supply increases, humans must rely on increasingly efficient technology to fill in the gap or face ecological collapse. The biogoephysical sustainability of human interactions with the Earth's biosphere must make adequate provisions for the maintenance of biological diversity and develop strategies to maintain the biogeochemical integrity of the biosphere through conservation and suitable use of its water, air, and land resources. In order to reach these conditions we must use planning and action at all levels of development: local, regional, and global. This must be coupled with specific short and long-term objectives that allow for a transition to sustainability. Buildings and the built environment are significant consumers of natural resources and producers of waste worldwide. For this reason, the need to increase efficiency levels in buildings and the built environment is paramount in the transition to sustainability (Mazria, 2008).

Building efficiency technologies are a key component in decreasing environmental impacts generated by buildings and reducing resource consumption. Living roof systems are one such building efficiency technology. Though highly studied in some climates, its true applicability remains unknown in others ---desert climates in particular. This assessment of the George Pearl Hall Living Roof evaluated thermal, water, and carbon sequestration capacities of a native grass planted living roof in Albuquerque, New Mexico. Results revealed superior thermal performance compared with an analogous conventional roofing system. Rainwater harvesting systems are an essential component to the viability of living roofs in Albuquerque. Without this technology, the use of drought tolerant native grass species may not be a suitable. Dependence on aquifer and city water resources would deem this technology unsuitable in the city of Albuquerque and its surrounding areas. The carbon sequestration capacity of native New Mexican grass planted living roof systems is measurable but is also relatively inconsequential in terms of mitigating a commercial/institutional building's yearly carbon emissions due to the low primary productivity of the studied species.

There exists future need to further investigate the costs and benefits of living roof systems in Albuquerque, NM, especially in terms of thermal performance and its potential relationship to building energy savings. As resources become increasingly scarce, building scientists, architects, and planners must find innovative means to reduce human draw on the earth biosphere and develop technologies and design systems that reduce resource use and environmental impact while respecting local and regional environmental constraints.

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