

LABREPORT

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Green Roof in the Desert

tempe transportation center roof garden

This report presents a summary of findings from a study of green roof systems with various configurations of soil, plants, and irrigation procedures. The test was conducted during the summer and fall of 2005. The main purpose of this research project was to produce new knowledge about the thermal performance of a roof garden in the hot and dry climate of Tempe, Arizona at 33 degrees Northern latitude. Findings from the study represent in-

sight that widen the knowledge upon which decisions will be made regarding the construction of a roof garden on the new Tempe Transportation Center building.

Client for the Tempe Transportation Center is the City of Tempe. This study has been conducted with partial funding from OTAK/ARCHITEKTON, the transportation center design team. Plant selection and irrigation procedures for four of the five test

boxes was provided by Michele A. Shelor at A Dye Design.

A research team was formed at ASU with Vidar Lerum as Principal Investigator. Professor David Tait conducted the experiment at the Solar Lab, with Hemant Thakare as research assistant.

prior art

green roofs in opposite climates



Two homes with green roofs were designed by the author and built in the town of Sogndal, Norway. One of these roofs was instrumented and monitored for two years. Findings from the analysis of data from this full scale experiment was presented in two scientific papers. In “Green Roof Turning White”, the performance of a green roof is examined during summer, fall, and winter conditions. The main findings from this study show that a green roof will stabilize the temperatures that the roof construction sees at the interface with the outdoor (ambient) climate conditions. This phenomenon leads to lower peak heating loads coming from heat loss through the roof, which in turn may allow for downsizing the heating system. The study also provided insight into the effect of snow on the conductance of the whole roof assembly. Varying depths of snow on the roof represent a dynamic R-value that add to the nominal R-value of the roof. More surprisingly, it was found that the temperature at the interface layer between the green roof and the roof construction below seldom reached below 0 degrees C (32 degrees F). The temperature would reach zero and stabilize there for 4-5 days. This phenomenon is related to the fact that energy is released as the phase of H₂O changes from liquid (water) to solid (ice).

A subsequent study was performed at the ASU Solar Lab during the 2005 Spring semester. This study formed the bases for final term projects by Master of Science students Hemant B. Thakare and Brooke L. Bogart in Professor David Tait’s class Experimental Evaluation. A paper by Vidar Lerum and Hemant Thakare was published in the proceedings from the PLEA (Passive and Low Energy Architecture) conference in Beirut, Lebanon in 2005. The main finding from this experiment was that a green roof system planted with vines and watered regularly would perform well. This roof configuration (#3 below) stabilized the temperatures at the interface between soil and roof membrane in a similar fashion as seen previously in the cold climate study. The irrigated test box even provided a cooling effect on the interior, as measured by the MRT (Mean Radiant Temperature) globe inside the box and below the ceiling. This phenomenon is associated with the energy required to change the phase of H₂O from liquid (water) to gas (vapor). This evaporative process will cool the soil and could also cool the building interior when conditions are optimal.

Electronic copies of the articles reporting on these two projects are available for download from Dr. Vidar Lerum’s web site: http://www.caed.asu.edu/vidar/pages/r_pbl.html.



research design

five test boxes

The five test boxes used in the previous experiment were rebuilt to fit the specifications provided by A Dye Design, with a soil depth of 12 inches. Over structure Soil Mix was used as distributed by Western Organics with 40% fine sand without silt, 40% moisture light (2mm-8mm size), 10% Black Bottom mulch, and 10% Omni soil amendment. The soil was placed on top of a Hydrotech prototype green roof system.

Test box #1 was used as a reference case with a white waterproof roofing membrane and no soil or plants. The four remaining test boxes were configured as follows (from left to right, see picture below). Plants were provided by Mountain States Wholesale Nursery.

#2: *Dalea frutescens* - Black/ Loose-Flowered Dalea - irrigated with 3 gallons of water per week.

#3: *Nolina microcarpa* - Bear Grass - irrigated with 1/2 gallon of water twice a day for three days - 3 gallons per week.

#4: *Muhlenbergia rigens* - Deer Grass - irrigated with 1/2 gallon of water four days - 2 gallons per week.

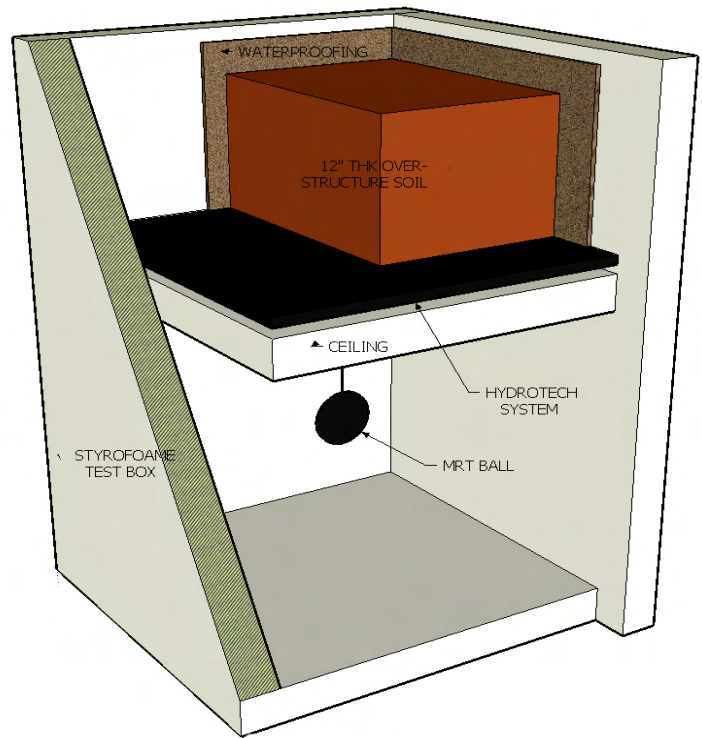
#5: *Malephora lutea* - Rocky Point Ice Plant - irrigated with 2 gallons of water per week.

The irrigation procedures were automated, using a Rain Bird system. As seen in the picture below, some of the plant types grew sparingly in the small (3 ft by 3 ft) test boxes. However, the deer grass doubled in size since it was planted and the Rocky Point Ice Plant grew to provide a full ground cover.

Each test box was instrumented with an MRT ball at the center of the enclosed volume below the roof, and temperature sensors (thermocouples) in the soil, at the interface between the Hydrotech system and the roof membrane, and inside the enclosed volume. The sensors were connected to an HP-9047-A data logger. Periodic data were recorded by the data logger and exported to a spreadsheet format for data analysis.

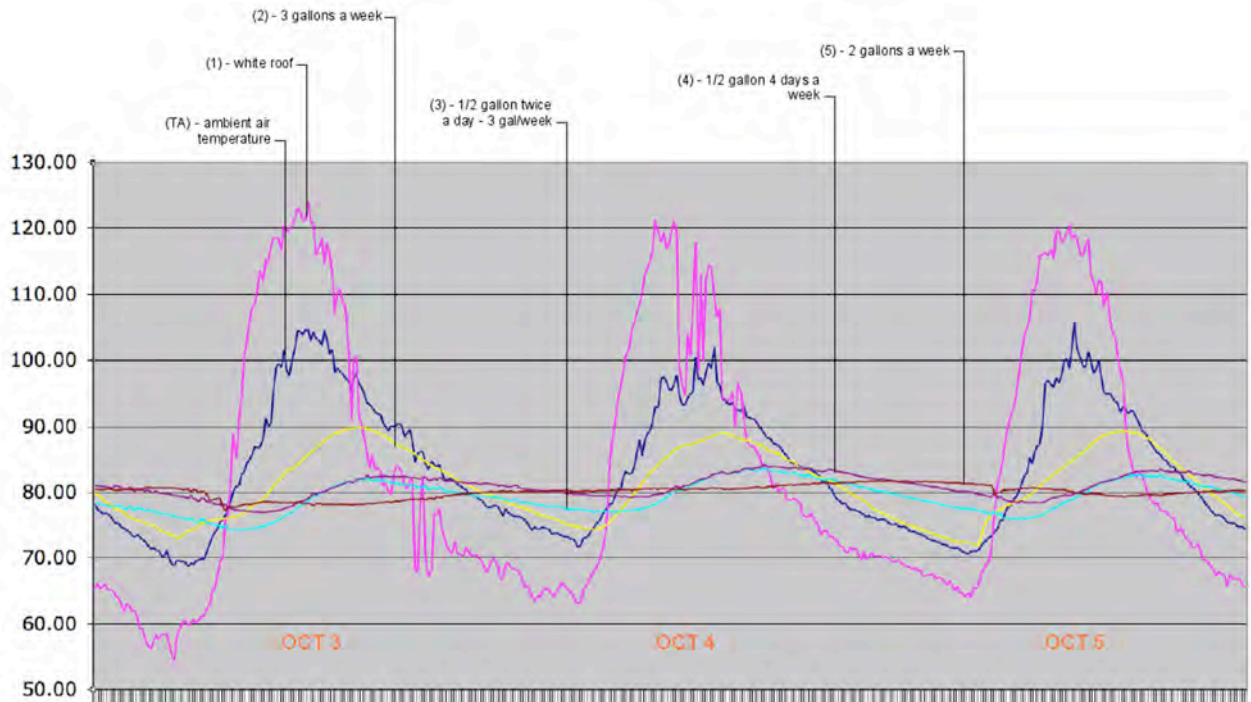
This report present findings from analyzing data for a two-day period towards the end of August 2005 and a four week period in September and early October 2005. Data for a three-day period in early October are used to illustrate the main results.

The focus of the analysis presented here are on two measurements: the temperature at the interface between the green roof system and the roof construction below, and the mean radiant temperature in the enclosed space under the roof. The first of these parameters provides evidence of the relative decrease in the diurnal temperature swings caused by the green roof system. The second parameter acts as an indicator of the effect on the interior climate as a function of the various green roof configurations.



peak cooling loads

temperatures at the interface between the green roof system and the roof construction below



Towards the end of September, the performance of the green roof systems had stabilized. The Rain Bird irrigation system had been functioning for several weeks. The test boxes had been rebuilt after being damaged during a summer storm. The plants had established growth. While the Deer Grass plants had doubled in size, only the Rocky Point Ice Plant had built a complete ground cover.

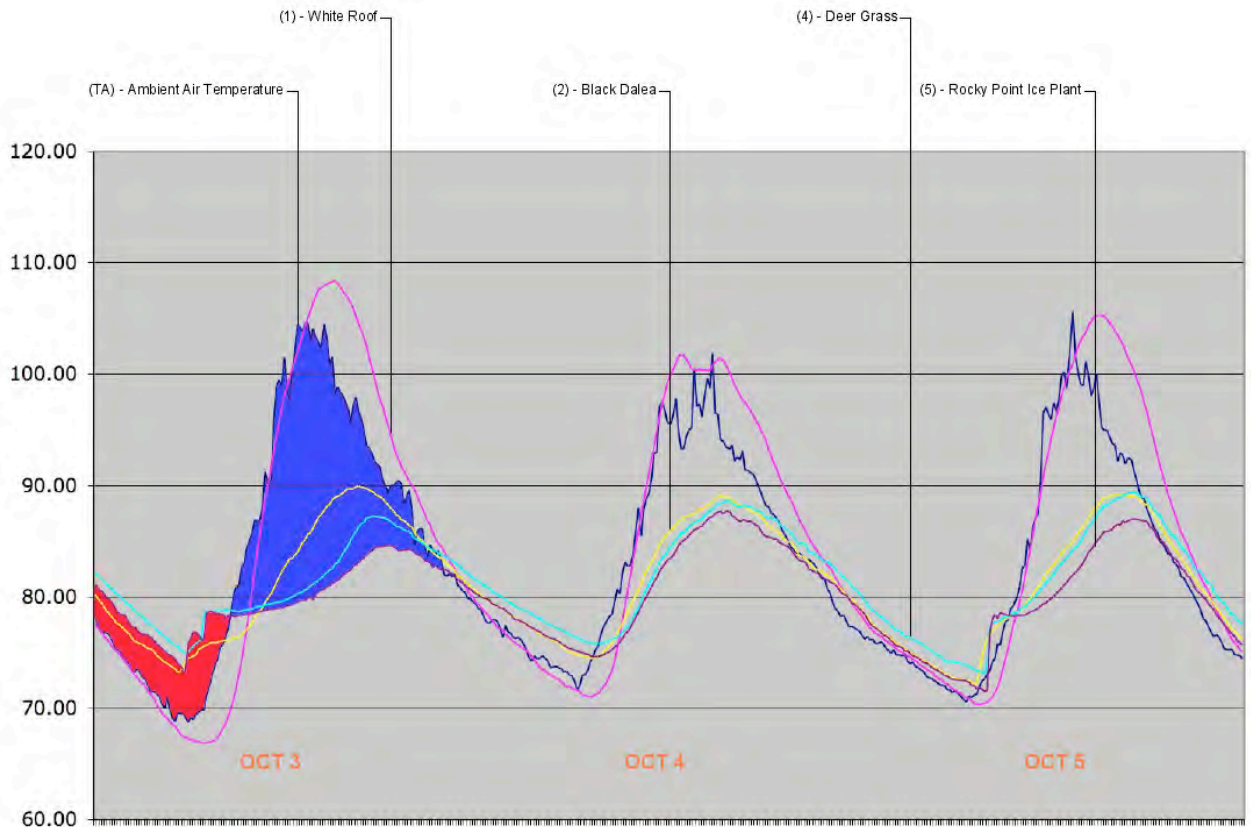
The graph above shows the temperature swings over a 3-day period from October 3rd to October 5th. With ambient air temperatures ranging from 70 degrees F in the early morning hours before sunrise to 105 degrees F in the afternoon, these three days represent typical summer conditions in Tempe. The temperatures at the interface between the green roof system and the roof construction below are superimposed on the ambient air temperatures. The white roof temperature was measured at the roof membrane which was exposed to the ambient conditions.

The best performing green roof system is #5 which was covered with Rocky Point Ice Plant and irrigated with 2 gallons of water per week. Roof system #4 (Deer Grass) also performed well. These configurations stabilize the temperature at the roof membrane at around 80 degrees F, which means that there will be near zero heat gain from the roof to the interior. The white roof may cool off to ten degrees F below ambient during a night with clear skies, but it also heats up to 15-20 degrees above ambient during the day. The data represented in the graph above offers evidence of two major advantages of the best green roof configuration: The peak cooling loads resulting from heat gain through the roof are cut dramatically, which could lead to downsizing the cooling system. This roof configuration will also help counteract the heat island effect experienced in the Valley of the Sun.



seasonal cooling effect

mean radiant temperatures in the enclosed space below the roof



This graph illustrates the mean radiant temperatures as measured by the MRT ball at the center of the enclosed space below the roof. Test box #3 is not included here, since there were intermittent errors in the data reported by the thermocouple inside the MRT ball for this test box.

The data produced by the MRT balls do not accurately represent a real world situation, since the boxes were constructed out of styrofoam with no insulated floor. The data can, however, be used to analyze the relative performance of the various green roof system configurations as compared to each other and to the white roof. The areas on the graph defined by the temperature curves for the actual roof system and the ambient air are indicators of accumulated heat gain (red) and avoided heat gain (blue). The blue area may therefore be seen as a cooling effect on the interior.




The graph illustrates how the white roof system produces the lowest interior MRT during the night, with a minimum 2-3 degrees below ambient. This night time performance of the white roof is counteracted by daytime temperatures that peak 4-5 degrees above ambient. While the best performing green roof system (#5) produces a night time minimum MRT 3-4 degrees above ambient, the daytime MRT peaks at about 20 degrees below ambient. The deer grass (#4) also performs quite well. This finding indicates that, if constructed and maintained properly, a green roof could actually have a measurable seasonal cooling effect on the interior spaces below the roof.

conclusions

beautiful and beneficial

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Winter			Spring			Summer			Fall																										
Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov																								
Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes																								

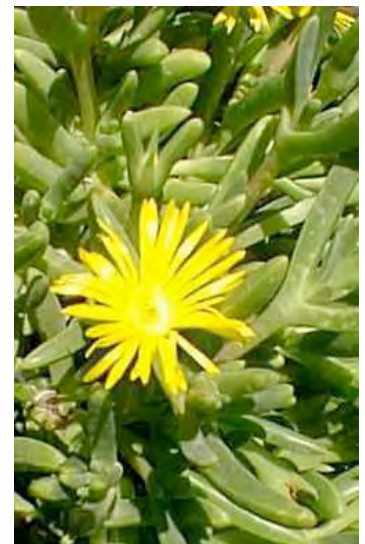
Additional Specifications

-  Low Water Use
-  Low Litter Rate
-  Moderate Growing

The findings from this study of various green roof configurations in consideration for the Tempe Transportation Center Roof Garden clearly indicate that a green roof system will add beauty to the building's 5th facade as well as benefits in terms of energy savings for the building owner and environmental benefits to the Phoenix metropolitan area. The added cost of a green roof should be measured against potential annual energy savings and the possibility of reducing the size of the cooling system as a response to decreased peak cooling loads coming from the roof of the building.

It is important to keep in mind that the beneficial performance characteristics of the best performing green roof configurations depend on proper construction and maintenance of the system, including a modest but regular irrigation scheme. A properly maintained and irrigated ground cover not only can create a cooling effect due to evaporation but can also become a beneficial and beautiful garden.

The validity of the data that form the base for this report are limited by the modest scope of the research. The data may still be seen as clear indications of the expected energy performance of a properly constructed and well maintained green roof in a desert climate. Since there is very little or no experimental data available from monitoring desert roof gardens as built, a separate proposal will be developed for instrumentation, monitoring, and data acquisition from the Tempe Transportation Center Roof Garden post construction. This performance evaluation scheme will help produce deeper understanding of how a desert roof garden actually works, thus presenting valuable design input for future projects by the City of Tempe.



William Lyman