Green Roof Performance:
Passive design implications in Los Angeles, California

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ABSTRACT: This paper compares the performance of a low-cost green roof to a base case conventional insulated roof with the intent of discussing the interior behavior of a green roof in a semi-arid climate. All test cells were located in Pomona, California. Temperature data loggers were installed at various locations inside and outside all the test cells. The temperatures at all locations were recorded at half hour intervals from October through early January. Daily maximum temperatures during this time period ranged from around 93°F in earlier months to as low as 56°F in winter months. The analysis and comparison of the temperature data indicate that although it may not have as large a benefit as in other climates in the United States, a green roof will provide enough difference in interior air temperature during warm weather months to be beneficial in southern California. What's more, a green roof can still provide a more pleasant outdoor environment than paved, occupied roof spaces in a dry, sunny climate.
Keywords: green roof, passive design, semi-arid climate, temperate data logger

INTRODUCTION

Contemporary green roofs are concentrated in the temperate regions of the Midwest, New England, and Europe. Even the most recent information available to the public is centered on the environmental considerations and benefits in those areas. Almost no information appears to address the implications green roofs could potentially have in the semi-arid climate of the southwestern United States.

There are two types of modern green roofs used today. The simpler of the two is the extensive green roof. Extensive green roofs are shallow with about three to four inches of growing medium [1]. Drought-tolerant plants are used so an irrigation system is not needed, making this type of roof low-maintenance. Typically, the main purposes of an extensive roof are focusing on environmental issues, adding thermal mass, and improving views from neighboring office buildings [2].

The second of the two types of green roofs is the intensive green roof. This roof type has a larger substrate depth and, therefore, more serious weight and structural implications than an extensive roof [3]. Because of the deeper growing medium, intensive roofs are able to support a wider range of plants including trees.

Green Roof Benefits It is generally known that green roofs provide environmental benefits. Research on green roofs in general began in Germany in the 1950s as part of a "wider movement that recognized the ecological and environmental value of urban habitats" [4]. The two benefits that are of importance to this paper are the tempering of exterior air temperatures leading to possible reductions of the Urban Heat Island Effect and the reduction in building thermal loads due to the thermal mass properties of the growing medium and plant life.

One of the researched environmental advantages of green roofs is the reduction of the Urban Heat Island Effect. Heat islands occur in highly concentrated areas of dark-colored, impermeable surfaces that absorb solar radiation and reradiate it back into the ambient air. The majority of roofs in urban areas are composed of asphalt or concrete, materials that absorb and reradiate heat the most. The prevalence of those rooftops is a major contribution to the heat island effect [5].

Green roof surface temperatures are cooler and help to mitigate the increase in urban air temperatures in two primary ways. The first is through shading of the roof. The plant shading prevents the roof surface from absorbing the sun's energy and reflecting it to the surrounding air [6].

The second way green roofs lower urban air temperature is through a physical plant process called evapotranspiration, the combined result of water moving from the roots through the plant to its release into the atmosphere as water vapor and the evaporation of water from the plant leaf surface and soil [7]. Evapotranspiration cools not only the leaf and plant surface but the surrounding air as well. A green roof will only cool through evapotranspiration if the plants are actively growing with an adequate supply of water rather than in a state of dormancy [8].

Some other environmental benefits that green roofs provide but are not relevant to this study include the reduction of stormwater runoff and the filtering of rainwater before its return to the natural water table.

Besides their environmental benefits, green roofs also provide economic advantages. The most widely known is the potential for lower energy costs. The additional thermal mass of the growing medium and plantings help to reduce the heating and cooling necessary for a building. The more stable temperatures of the thermal mass on top of a building prevent it from becoming affected by the fluctuating air-temperature extremes that conventional roof buildings are subject to [9]. When outdoor temperatures in temperate climates are between 77 and 86°F, the indoor temperatures beneath a green roof have been shown to be 6 to 8°F cooler [10].

METHODOLOGY

This paper compares the performance of a low-cost green roof to a base case conventional insulated roof with the intent of discussing the interior behavior of a green roof in a semi-arid climate.

Testing Cells The test cells used were constructed by Associate Professor Pablo LaRoche of Cal Poly Pomona, located 25 miles east of Los Angeles, California, along with students of Architecture and Master of Science in Regenerative Studies to study the performance of different types of passive cooling systems (Fig. 1). All the test cells have identical external dimensions of 1x1x1 meters and identical building construction materials of 2”x4” studs, drywall inside and plywood outside with batt insulation between, and 1½” concrete pavers as slab [11]. All exteriors are painted white and have 2’x2’ double glazed windows facing south.

Figure 1: Test cells at the Lyle Center

The green roof currently on the testing cell is a trial version of a low cost green roof solution that was implemented on a prototype house built at the Lyle Center at Cal Poly Pomona. “Cal Earth” bags were placed directly on top of the wood decking. The bags were filled with a growing medium of native soil with vermiculite added to reduce the load. The “Cal Earth” bags are biodegradable to sunlight, allowing water to pass through them while still containing the growing medium [12]. When the bags were in place, they were cut open, and a variety of sedums and succulents native to Tijuana were planted (Fig. 2). The green roof was intended as a low cost example, so the plants are not regularly watered or cared for.

Figure 2: Succulents and sedums on the green roof cell

Interior Temperature Measuring One of the documented advantages that green roofs provide in temperate climates includes energy savings. One research group which has recorded information that illustrates these energy savings is Environment Canada. The group found that in Toronto a typical one-story building with 4 inches of growing medium and a grass roof had a 25% reduction in summer cooling [13] when compared to a conventional reference roof.

The climate in Los Angeles has large diurnal swings which generally mean that buildings need to be cooled during the day and warmed once the sun goes down. American Indians in parts of New Mexico and Arizona used adobe, a high mass material, to construct their dwellings. The thermal lag provided by the adobe allowed the interiors of the houses to remain comfortable during the day while the outside reached high, unpleasant temperatures. When the temperature dropped severely at night, the heat gained by the adobe during the day would reach and warm the inside.

The author believed, based on the use of thermal mass in the same type of climate, that a green roof in Los Angeles would provide similar energy savings to those found in temperate climates. Although it was not possible to directly measure savings in energy with the test cells, it was possible to measure the interior temperatures of a green roof and conventional insulated roof and compare the two.

Data loggers were placed at the interior ceiling level in both test cells at 6", 12", and 24" from the south-facing interior wall with the window. Three more data loggers were installed at 10", 20", and 30" from the floor of the test cell to measure any temperature stratification that might occur within the space.

Roof Surface and Above Measuring Another documented benefit of green roofs is the reduction of the Urban Heat Island Effect due to lower roof surface and ambient air temperatures. Previous studies have shown that green roof surfaces have recorded lower temperatures than traditional roof surfaces. The shading of the roof surface by the plants helps to lower the surface temperatures, while evapotranspiration, the physical plant process that cools the surface of the leaves, helps to lower the air temperatures above the roof through the evaporation of water.

The author wanted to determine if temperatures at the green roof surface and above would register cooler temperatures than the conventional roof as previous studies in other climates noted. She believed that the green roof testing cell surface would indeed be cooler than the conventional roof testing cell surface but might not be as extreme as other testing results.

For one, other tests compared green roof surface temperatures to those of a neighboring black roof surface. The roof surface of the conventional insulated cell was painted white, not black.

Also, other tests had the coolest surface temperatures in the areas of denser plant growth. The testing cells used for the data collection were planted with succulents. The succulents have been left to their own devices and, as a result, have not grown in thick with complete coverage of the surface. Less surface coverage would most likely lead to higher temperatures than found in other studies.

In addition, because the green roofs were intended as low cost examples, the plants are not regularly tended. Any watering the plants receive is through natural means such as rain. This means that the plants do not have adequate, if any, water to perform evapotranspiration. Lower air temperatures are still expected above the green roof, but, again, not as much as other studies have shown.

A set of data loggers was placed at the roof surface of the conventional insulated roof test cell and the green roof test cell. The loggers were positioned at 6", 12", and 24" from the exterior edge to verify if an edge condition existed. The existence of an edge condition will not be discussed. Only the data taken at 24" from the edge, near the middle of the test cells, will be looked at.

The last set of data loggers was placed 4" above both roof surfaces to measure the air temperature. The locations of all the data loggers are shown in Fig. 3 and 4.

TESTING RESULTS

The data loggers recorded the temperatures at all locations at half hour intervals from October through early January. The test results that will be discussed were recorded from October 24 to 27. These days were chosen because they offer a look at the interior conditions on days with different outdoor temperatures. It is important to note that the data logger recording the nearby outdoor temperature produced higher than accurate temperatures. Because of this inaccuracy, temperatures for each testing cell will be compared only to each other and not the outdoor temperature recorded by the data logger.

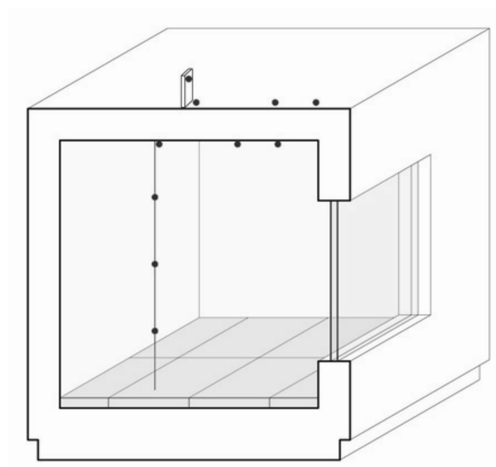

Figure 3: Conventional insulated roof data logger locations

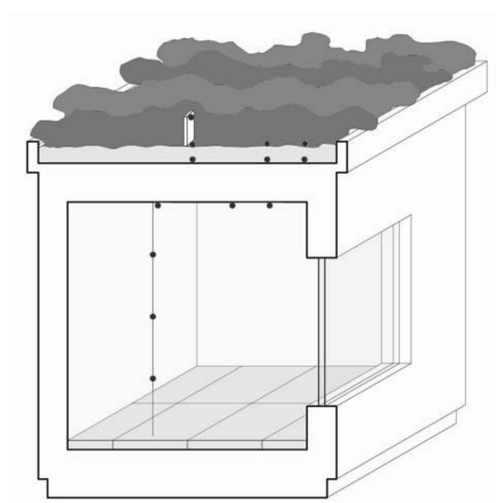

Figure 4: Green roof data logger locations

Interior Temperature Results As noted, the exterior temperatures displayed were inaccurate. The correct maximum temperatures for October 24 to 27 are as follows in chronological order: 98°F, 91°F, 84°F, and 78°F.

When looking at the data for all the testing cells (Fig 5), the first data of note is the time lag in the interior temperatures within the green roof test cell. The maximum temperature inside the conventional insulated cell occurred around 3 p.m. The maximum temperatures within the green roof were recorded almost an hour later. Because the only difference between the two cells is the green roof, the author believes the data illustrate how the thermal mass of the green roof is absorbing some of the heat and delaying the amount of time it takes for the outdoor heat to reach the inside.

The biggest differences in temperature between the conventional roof and the green roof took place during the daytime hours. The data show the interior of the green roof cells about 5°F cooler than the conventional roof on the hotter days and around 3°F cooler on the comparatively less warm last day of the set. At night, the conventional roof and green roof show almost identical temperatures.

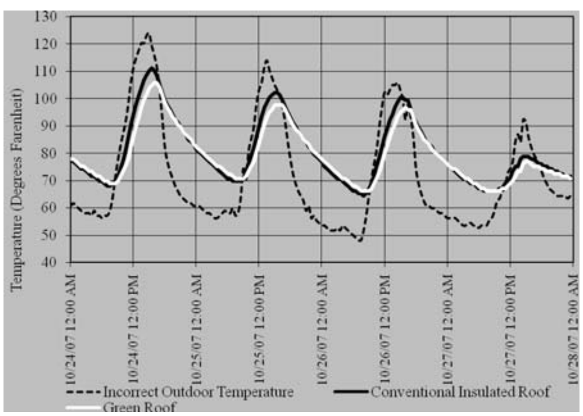

Figure 5: Interior temperatures at 20" from the floor for October 24 to 27

Roof Surface Temperature Results The main trend visible from the data (Fig. 6) is the daytime temperature difference between the conventional roof surface and the green roof surface. The correct outdoor temperatures during the first three days of the set were warm and summer-like. During these warm days, the conventional roof surface is close to 20°F warmer than the green roof surface. The last day in the set has much cooler outdoor temperatures and surface temperatures at the conventional roof. There is a much smaller 5°F difference between the conventional and green roof surfaces.

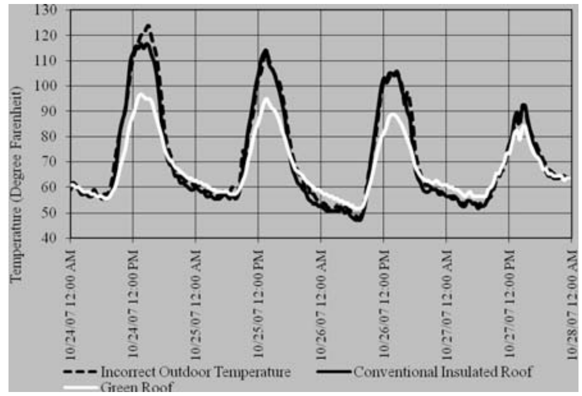

Figure 6: Roof surface temperatures at 24" from the edge for October 24 to 27

It would be easy to speculate that the roof surface temperatures are much closer on cooler days, but there is not enough evidence to definitively state that. It is possible that lower conventional roof temperatures were recorded that one day because of overcast skies. Without any sun to heat up the roof surface, much lower temperatures would be collected by the logger at that location.

Above Roof Surface Temperature Results The data collected (Fig. 7) appear to indicate that the air temperature above the green roof was approximately 5°F cooler than the air above the conventional insulated roof on the warmer days.

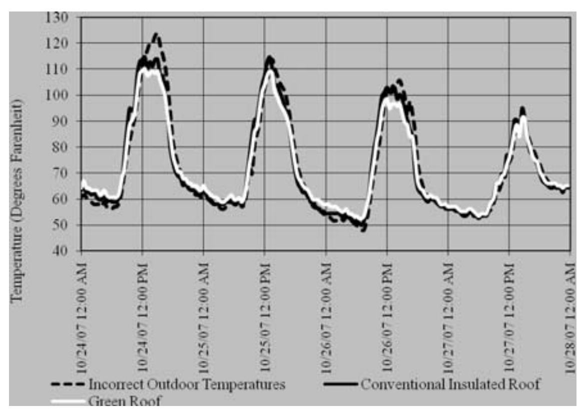

Figure 7: Temperatures 4" above the roof surfaces

It was not surprising to see that the air above the green roof was only moderately cooler and not 20 - 30°F cooler than the air above the conventional roof as testing in other locations indicated. It was noted that the physical plant process of evapotranspiration cools the plant surface and, in turn, the surrounding air. But the plants will only be able to cool through this process if they are actively growing with a sufficient supply of water and not in a state of dormancy. The green roof above the testing cell was intended as a low-cost example of the technology, so the plants are not regularly tended for. Any watering the plants receive is through natural means like rain. This means that the plants do not have adequate, if any, water to perform evapotranspiration and contribute to cooling the surrounding air.

CONCLUSIONS

The purpose of this paper was to determine how a green roof in a semi-arid climate like Los Angeles would perform compared to published reports of operations in temperate climates. Based on the data results collected at various locations from October 24 to 27, the following conclusions were made.

Interior Temperature Conclusions A study of the data recorded from October 24 to 27 implies that given identical material and glazing situations, a green roof in southern California will behave similarly to the green roof testing cell which kept interior temperatures about 5°F cooler than a conventional roof cell during days with hot fall temperatures. Nighttime temperatures do not appear to be affected by the thermal mass of the green roof.

The author recognizes that because of issues of scale, such as skin to volume, and fenestration to floor area ratios, the actual interior temperatures will vary from building to building, but the relationship and interactive behavior of the values will be similar. In the author's opinion, the data still strongly suggest that a green roof is a viable, passive solution in a semi-arid climate during the fall and winter and may provide even more indoor temperature benefits over the summer.

Roof Surface Temperature Conclusions The data showed that on warm days with temperatures 80°F or above, the surface of a green roof close to the center of the cell was 20°F cooler than the surface of the conventional roof at the same location. That indicated to the author that the plywood material of the conventional roof surface, while absorbing the same amount of solar gain, had a larger temperature swing during the day than the green roof growing medium. At night, the surface temperatures showed the green roof was warmer, signifying again that the green roof surface did not have as large a temperature swing as the conventional roof surface.

A green roof surface, even when not completely shaded by the plants, will have less surface temperature fluctuation on warm, sunny days than a conventional roof and, therefore, lower surface temperatures. The green roof surface absorbs as much solar gain and may release more heat than the conventional roof surface, but the high mass of the green roof allows the surface temperatures to change less. A building will lose more heat through the roof surface than through the sides due primarily to night reradiation. This potentially means that a green roof in a semi-arid climate will have less energy loss from the interior through the roof surface than a conventional roof will.

Additionally, the author concludes that the outdoor temperature is not the only factor in the surface temperatures of both roof surfaces. On cold days, there may still be the same differences in surface temperatures that occur on hotter days as long as it is sunny. Cold days with overcast skies will likely have surface temperatures similar to each other because the conventional roof will not have as much solar gain to absorb through the surface material. Less solar gain means the surface temperatures of the conventional roof will fluctuate less and exhibit similar behavior to the high mass green roof.

Above Roof Surfaces Temperature Conclusions The set of data that was looked at had hot fall outdoor temperatures. The data indicated that the biggest difference in air temperature above a green roof and a conventional roof will occur on the warmer and not the cooler days.

The logger above the green roof recorded air temperatures somewhat cooler than the temperatures above the conventional roof. It was not entirely surprising that the air above the green roof was not 20 - 30°F cooler than the air above the conventional roof as testing in other locations indicated. The effects of not having constant watering were apparent from the data.

The green roof above the testing cell was intended as a low-cost example of the technology, so the plants are not regularly tended for. Any watering the plants receive is through natural means like rain. This means that the plants do not have adequate, if any, water to perform evapotranspiration and contribute to cooling the surrounding air.

A perhaps more accurate reason for the higher temperatures could be because of the type of plants that were used for the green roof. A variety of sedums were used for the test cells. Sedums are known to be drought resistant. What makes these plants able to withstand drought for extended periods is their ability to conserve water through a metabolic process unique to them called Crassulacean acid metabolism (CAM). The CAM process allows the plants to reduce water loss by opening their stomates at night and store carbon dioxide for photosynthesis. During the day, they close their stomates, reducing water loss from transpiration. If these plants are not going through as much evapotranspiration as other plants types, it seems logical that less water evaporation would lead to higher temperatures above the plants.

The biggest differences in temperatures above the roof surfaces occurred on the hotter days. Therefore, it seems logical to conclude that testing above the surfaces would need to be conducted with moisture added to the growing medium during months with warmer temperatures. Only then would it be possible to state if watered succulents would have more of a cooling effect on the air above a green roof in Los Angeles.

FUTURE WORK

Many issues were encountered while conducting the testing on the cells at the Cal Poly campus. The main concern was for the size of the test cells. Although the interior temperature differentials were similar to what was found in other climates by other testing agencies, the author believes that anyone interested in future testing of green roofs in southern California would benefit from performing those tests inside spaces closer to full-scale building sizes. Additionally, the glazing to floor area of the testing cell was quite large. Future interior testing of green roofs could also benefit from a more realistic fenestration-to-floor ratio.

Testing conducted over summer months will likely provide more concrete information about potential energy savings in southern California. The data collected over fall months showed a 5°F reduction to interior temperatures in a green roof space. That is within the same range in reduction seen in green roofs in other climates and could possibly be greater during summer months.

There are numerous other issues that can also be addressed when testing green roof performance. Natural ventilation, building geometry, and roof slope were not discussed in this paper but are still important. Natural ventilation in conjunction with a green roof will likely reduce interior temperatures further but will also lower interior temperatures inside a conventional insulated roof space. Future testing could discuss what, if any, difference natural ventilation could make when comparing both spaces. Building geometry will change the skin to volume ratio of a space, and perhaps, interior temperatures as well. Any of these matters would make for valid testing and should also be considered by anyone interested in green roof performance.

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