Rooftop Membrane Temperature Reductions with Green Roof Technology in South-Central Texas

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ABSTRACT

Early green roof cooling and energy reduction research in North America took place in Canada and the northern latitudes of the United States, where green roofs reduced rooftop temperatures by 70% to 90%. Less is known about green roof technology in the southern Untied States; where energy demand for cooling buildings is high, and the urban heat island effect is more pronounced. This paper reports early findings for rooftop membrane temperature reductions from 11.6-cm-deep modular green roof trays, typical of large-scaled, low-maintenance applications. Measurements observed during May, 2010 reveal that temperatures below the modular planted green roof units were 82% to 91.6% cooler compared to the surface temperatures of the control roof membrane. These findings on low-input modular green roof trays reinforce other research findings that indicate green roof technology can dramatically reduce and modify temperatures on roof deck surfaces during peak energy demand periods in hot sunny climates.

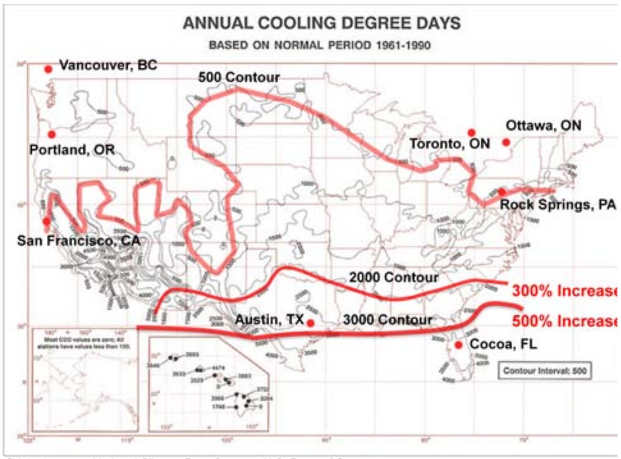
INTRODUCTION

Green roof technology has become regarded in some North American cities as an effective tool for managing stormwater. Researchers and urban planners have also begun to explore its possibilities for managing urban heat islands and energy reduction in buildings. Conventional dark colored rooftops contribute to the urban heat island phenomena especially when applied across large urban areas. U.S. cities with large metropolitan regions located in warm climates are found to have temperatures up to 5.6°C warmer than the surrounding rural landscape (EPA 2008). Rooftops can make significant contributions to urban heat islands during the summer when dark surfaced roofs can have albedos as low as .05 and absorb up to 95% of the solar energy that makes contact with roof surfaces. Not only is solar heat energy radiated back into the atmosphere, but it can become emitted through the roof deck to climate controlled spaces below. Elevated rooftop temperatures can also cause stress for HVAC units, air intakes and solar arrays (Cantor 2008).

In North American cities, rooftops typically comprise from 20% to 35% of the urban fabric (EPA 2008, Peck and Richie 2009). The U.S. Environmental Protection Agency (EPA) reports that over 90% of the rooftops in the United States are dark colored roofs (EPA 2010). These low reflectance surfaces can reach temperatures of 66° to 88° Celsius (150 to 190°F) during the summer, almost twice the ambient temperature. Because of these conditions, the interior occupied spaces of buildings see an increase in energy used to keep interior spaces cool. Higher demands for electricity take place during peak daytime temperatures, which creates conditions where power grids can become overburdened, and contribute to accelerated atmospheric pollution (EPA 2008).

In one study in Ottawa, Ontario researchers found during a two-year investigation, a 95% reduction of heat flow through the roof membrane by the use of green roof technology (Liu and Baskaran 2003). The researchers concluded that the heat reduction benefits are more applicable to warmer regions since summers in Ottawa are short and annual energy demands for cooling are not high compared to southern regions of North America. Other studies in Canada and the U.S. found similar results ranging from 70% to 90% heat gain reduction with green roofs (Connelly and Liu 2005, Gaffin, et al. 2005, Liu and Bass 2005, Liu and Minor 2005, Roehr, et al. 2008, Sailor, et al. 2007, Sonne 2006, Weeks 2008). In Cocoa, Florida one investigation during the summer found irrigated green roofs were 70% cooler than white reflective cool roofs (Sonne 2006). In Austin, Texas, green roofs were found to be cooler by 38°C at the surface and 18°C cooler inside than conventional roofs (Simmons, et al. 2008). Other studies and reports follow similar patterns for green roofs, but a majority of this research is taking place in northern climates.

Figure 1 shows a contour map of the United States delineating the number of annual cooling degree days (CDD). A cooling degree day is an expression of a day's mean temperature above 18.3° C (65° F). A CDD is the day's mean temperature minus 18.3° C. In many regions 18.3° C is considered the threshold mean temperature for a day where people tend to begin to use air conditioning. For example, on a day where the mean temperature is 26.7° C (80° F), the degree days is 8.37° C or 15° F as measured above the threshold. If an entire month averaged 26.7° C each day, the monthly demand would be 251.1° C or 450 F for a 30 day month. Regions with more than 1500 annual CDD are considered to have long hot summers and have high demands for cooling energy.



Original source: National Climate Data Center – U.S. Dept. of Commerce

Figure 1. Green Roof Cooling Research Sites and Annual Cooling Degree Day Contours (Original map source: U. S. National Climate Data Center)

The bolded contour lines in Figure 1 show three major divisions in potential energy use. The top line shows the 500 CDD contour (annual CDD contours are degrees Fahrenheit), the middle line shows the 2000 CDD contour, and the bottom line shows the 3000 CDD contour. Green roof cooling research sites are located to correlate with the CDD contours. Research sites located at or above the 500 contour have 500 mean annual cooling degree days (F) of energy demand and is considered mild. Comparatively, the Cocoa, Florida and Austin, Texas research sites are located near the 3000 contour. Using the CDD as a reference, there is a 500% increase from the 500 CDD contour to the 3000 CDD. Thus, with only two of the eight research sites located in high CDD regions, it is apparent that research of green roof cooling benefits is still in the early stages of investigation in North America and there is much to be learned about how green roofs perform in high CDD regions.

Green roof technology use is growing in the northern regions of North America in areas where natural rainfall makes it possible to maintain green roofs with little if any irrigation. Very little is known about designing and maintaining low-input green roofs in the south, where in addition to stormwater management benefits, they are thought to reduce rooftop surface temperatures and minimize heat gain. To further investigate these conditions, a low-input green roof investigation was conducted in south-central Texas, at the Texas A&M University in College Station.

METHODS

To measure the effectiveness of green roofs to cool rooftop surfaces, modular green roof trays were installed on top of the Langford Architecture Center, a four-story building on the campus of Texas A&M University. The modular trays represent the TectaGreen™ (Tecta America) modular green roof system, with an 11.6 cm deep substrate. Twelve trays were assembled and planted on April 3, 2009. Three succulent species of plants were investigated including *Talinum calycinum*, *Delosperma cooperi* and *Sedum kamtschaticum.* Nine individual plants of each species were installed in three modules. A total of 27 plants were installed across 9 trays, with 3 trays left unplanted. All species of plants were provided in the form of 6.35 cm deep plugs installed directly into the growth media and periodically irrigated through August 2009. The plants became established during a year marked by extreme drought, however, not all species performed equally. During the drought, *Talinum calycinum* performed best, *Delosperma cooperi* performed well with only a few signs of stress, and *Sedum kamtschaticum* did not establish well, as a little more than one-half of the plants became established. The following spring (2010) all individual plants that established during the previous growing season re-emerged and continued to grow. One tray of LiveRoof™ with a mix of pre-grown green roof vegetation was placed on the roof the week beginning June 4th, 2010.

Figure 2. Modular green roof tray with *Sedum kamtschaticum* planted on the left, and unplanted module used as control on the right

Figure 2 shows the modular green roof trays placed inside boxes constructed of insulation board to collect water and insulate each module. The 12 trays were randomly assigned locations and placed across a structural shelf to expose the units to a rooftop environment typical to the Texas A&M campus. The insulated boxes were replaced with wood boxes in August of 2009 to provide a more structurally sound and stable able growing environment.

Figure 3. *Sedum kamtschaticum* tray updated with wood and plastic lined box (photo May 28, 2010

In order to measure the surface temperature effect of green roofs, provisions for automated measurement were made at multiple locations. Campbell Scientific 109-L temperature probes were purchased and installed on modules and the control roof on Langford. Temperatures were measured at four locations including above and below the surfaces of planted green and non-planted modules, just beneath the existing roof membrane as a control, and the ambient temperature on the roof (Figures 4-6). A Campbell Scientific CR-1000 data logger program was set up to record temperatures beginning in October of 2009 through June 25, 2010. The data logger was set up to measure temperatures once every minute, and then store mean temperatures for every fifteen minute period.

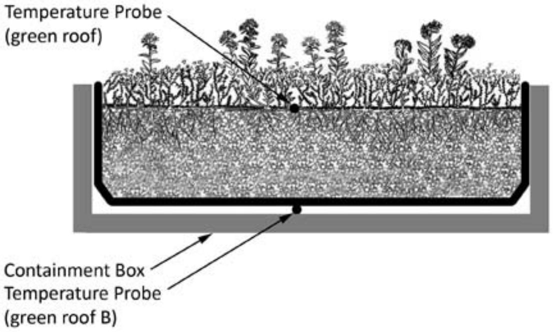


Figure 4. Temperature probe locations for variables "green roof" and "green roof B"

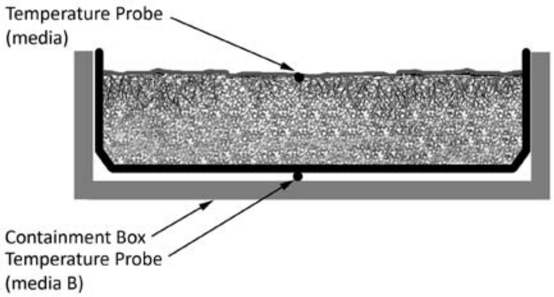


Figure 5. Temperature probe locations for variables "media" and "media B"

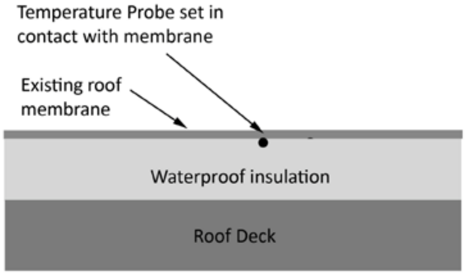


Figure 6. Temperature probe location for variable "control"

RESULTS AND DISCUSSION

Temperatures were collected from Oct. 1^{st,} 2009 to June 25^{th,} 2010. Plants were dormant from December 2009 through April 2010. Data reported here is from May 1-31st and June 17th, 2010. Figure 7 shows data for the month of May for the initial 12 modules installed in April of 2009. The four locations of temperature data were collected and stored on spreadsheets. Raw data was examined in spreadsheets and basic analysis was produced. The time period shown in Figure 7 expresses monthly averages from 6 AM to 8 PM to show detail during the peak ambient temperature. Data outside this time period was not considered in this analysis, as the temperature fluctuation extremes only take place during midday. The figure shows averages for the month, so the multitude of variances from hour to hour and cloudy day effects do not show. Essentially, days dominated by heavy cloud cover do not elevate control roof temperatures. Differences between surfaces remain very similar to the ambient temperature (Dvorak 2009). Although May, 2010 was dryer and warmer than average for College Station, it did not set a monthly record for highest average temperature or driest month for May but came close. The College Station Easterwood Field airport recorded the month of May, 2010 had 2 record high temperatures and tied record

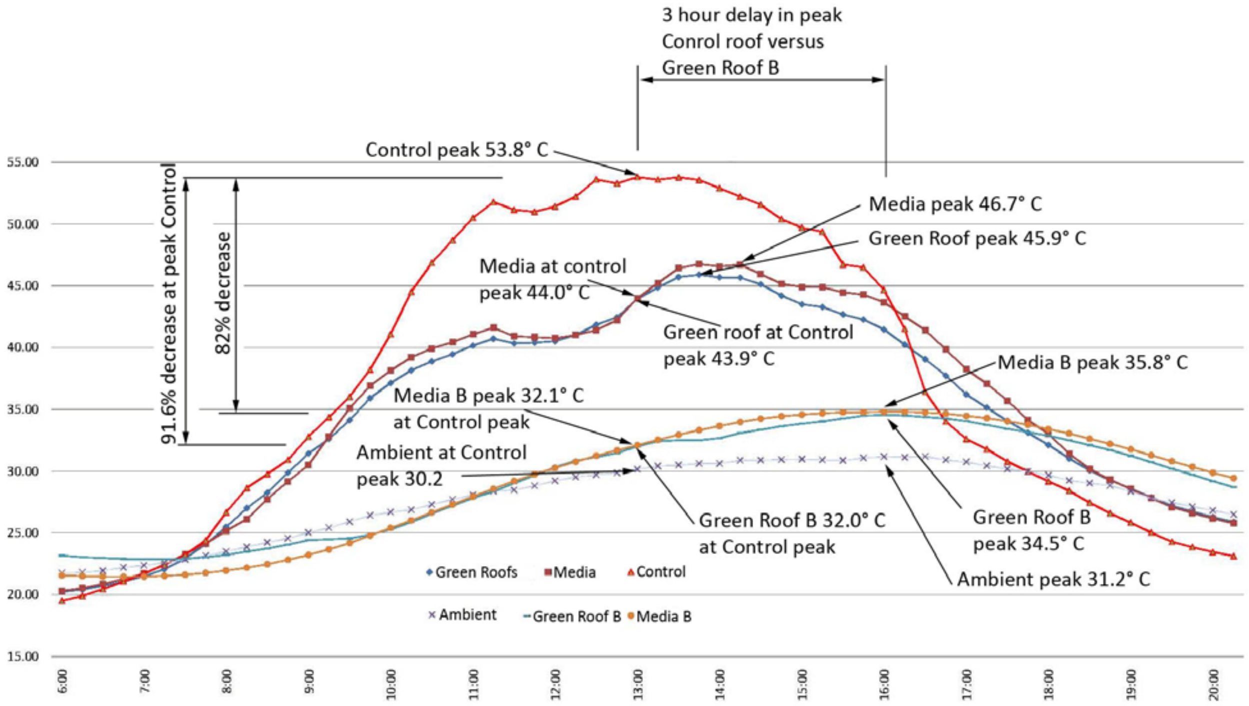


Figure 7. Summary of May, 2010 rooftop temperatures in degrees Celsius

temperatures for 2 other days. The monthly mean temperature for May, 2010 was 2.28 C (4.1° F.) over the monthly average and was second the highest May over the past 60 years. The CDD value for the month was 456 which was 156 above the mean of 300 for the month of May. Precipitation for May, 2010 was considered dry as precipitation was measured at 5.08 cm which is 7.7 cm or about 40% below the monthly average of 12.82 cm at Easterwood airport.

Figure 7 reveals monthly temperatures for variables for May 2010. The average ambient peak temperature on the roof for the month was 31.2° C and typically occurred between 4 and 5 PM. The control roof surface was subject to a wide heat gain compared to the ambient temperature and other roof surfaces during the same time period. The maximum control roof peak average temperature of 53.8° C occurred at midday between noon and 1 PM. The media only module had a maximum peak average surface temperature of 46.7° C which occurred between 2 and 3 PM. The vegetated green roof module had a peak average surface temperature of 45.9° C that occurred between 1 and 2 PM. As expected, temperatures found below the modules were less than surface temperatures. The media only modules had an average peak temperature of 35.8° C below, and the green roof modules had an average peak temperature of 34.5° C located beneath as shown in Figure 7 and Table 1.

Table 1. Temperature C differences between mean control peak temperature and other means

Variable	Temp ..	Temperature Difference	control at peak time
^{a}Ambient	30.2°	--	
^{b}Control peak	53.8°	+ 23.6°$^{a\&b}$	+78.1%$^{a\&b}$
^{c}Green roof	43.9°	+13.7°$^{a\&c}$	-18.5%$^{b\&c}$
^{d}Media	44.0°	+13.8°$^{a\&d}$	-18.4%$^{b\&d}$
^{e}Green roof B	32.0°	+1.8°$^{a\&e}$ -21.8°$^{b\&e}$	-91.6%$^{b\&e}$
	34.5°	-19.3°$^{b\&e}$	-82% $^{b\&e}$
^{f}Media B	32.1°	+1.9°$^{a\&f}$	-91.5%$^{b\&f}$

Note: (a-f) superscripts identify variable differences.

Table 1 shows a 21.8° C difference between the peak temperature of the control roof at 53.8° C and corresponding temperature beneath the green roofs 32.0° C (green roof B) during the control's peak temperature results in a 91.6% reduction in heat gain and at the green roof B peak of 34.5° C an 82% reduction. There was also a 3 hour delay in the peak temperatures between the control and the average maximum temperature below the green roof modules (Green Roof B), which means that peak energy emissivity from the surface of the module to below the module takes place well after the control roof membrane and near peak ambient temperatures. This

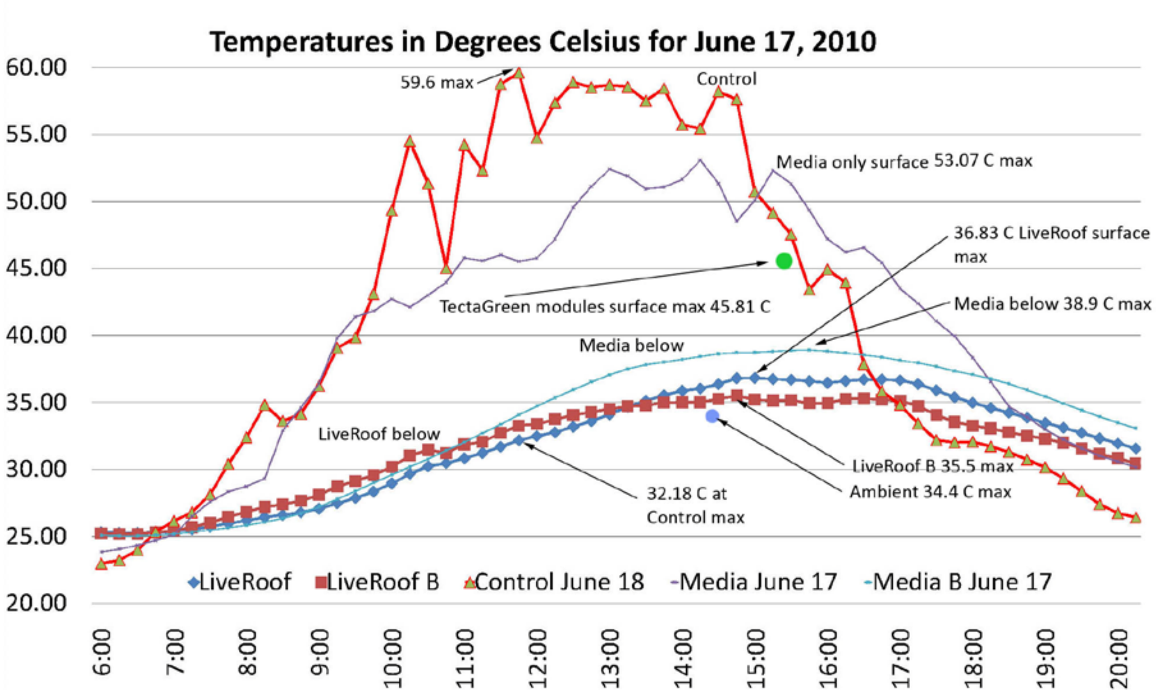


Figure 8. LiveRoof™ module temperatures in degrees Celsius

could help reduce cooling energy use during peak demands.

The planted and unplanted modules tend to parallel each other. The average surface temperatures for both variables are very similar at the surface and below the module. One possibility is that the planted modules do not represent their full potential as vegetated roofs. Figure 3 shows one of the most heavily canopied *sedum* modules and covers only 45% of the media surface. To further investigate the effect of percent canopy coverage, a LiveRoof™ green roof module was evaluated in June, 2010. LiveRoof™ manufactures their modules with vegetation grown to full canopy in greenhouses prior to installation. Figure 9 shows the canopy coverage of the LiveRoof™ module at 100% canopy cover, typical for a healthy mature green roof. The coverage of vegetation is noticeably full and dense.

The unirrigated LiveRoof™ module was evaluated over a 24-hour period (Figure 8). Temperatures were collected every fifteen minutes for the LiveRoof™ and the control roof from 9AM June 16th through 8 AM June 18th and reported for June 17, 2010. Continuous ambient temperatures were not available for June 17 on the rooftop, but peak ambient temperature for the day at Easterwood Airport was 34.4° C between 2 PM and 4 PM.

Figure 8 and Table 2 show that the LiveRoof™ module peak surface temperature was 36.8° C and the TectaGreen™ partially covered module surface peak temperatures were 45.81° C. The media only (non-planted) surface peak temperature was 53.07° C between 3 and 4 PM, and the peak control roof temperature was 59.6° C between 11 AM and 12 PM. The media only surface temperatures are very near that of the control roof temperatures. The LiveRoof™ surface temperature is only 2.4° C more than the peak ambient temperature, where the control roof surface temperature was up to 25.2° C more than peak ambient temperature. The temperatures recorded below the LiveRoof™ module are slightly below the LiveRoof™ surface temperatures and hover just slightly above the peak ambient temperature. Most interesting are the differences between the control roof temperature at a peak of 59.6° C and the corresponding LiveRoof™ fully covered module surface temperature at 32.18° C. The media only module had a surface temperature of nearly 46° C which is 13.6° C cooler than the control, but not nearly as effective as the fully covered module which was 27.42° C cooler than the control. This comparison of different densities of vegetative cover demonstrates that plant coverage and plant shading may play a large role in reducing heat gain. More research on the role of plant shading is warranted.

Table 2. Temperature C differences between mean control peak temperature and other variables

Variable	Temp.	Difference in Ambient Temp.	Control at peak time
^{a}Ambient	34.4°	--	
^{b}Control peak	59.6°	+ 25.2° $^{a\&b}$	+73.2%$^{a\&b}$
^{c}LiveRoof	36.8°	+2.4°$^{a\&c}$	-90.0%$^{b\&c}$
^{d}Media	53.0°	+18.6°$^{a\&d}$	-26.2%$^{b\&d}$
^{e}LiveRoof B	35.5°	+1.1°$^{a\&e}$	-95.6%$^{b\&e}$
^{f}Media B	38.9°	+4.5°$^{a\&f}$	-82.1%$^{b\&f}$

Note: (a-f) superscripts identify variable differences.

Although the LiveRoof™ results are from a limited data set, the results indicate that the density of plant cover can make a dramatic difference in green roof surface temperatures. Both green roof vender modules used in this investigation are 11.4 cm deep and contain some of the same families of succulents, but were not identical species. Although these results are impressive, most of the plant species used in the LiveRoof™ experiment did not survive later in the summer. All plant species in the TectaGreen™ modules were still growing and showing only little signs of stress by late summer. Species selection and plant establishment methods need to be investigated more for this climate zone, as both module suppliers used FLL approved growth media. FLL is a German organization responsible for producing green roof guidelines.

Figure 9. LiveRoof™ module with 100% canopy cover on June 17, 2010

When reviewing surface temperatures, the LiveRoof™ surface temperatures wavered near the peak ambient temperatures during the period of peak potential solar irradiance. This means that green roofs that have full plant coverage can help mitigate for rooftop contributions toward urban heat islands. The media only or unplanted module surface temperatures were near, but still less than the control roof. The media only modules however, when looking at effectiveness of reducing temperatures at the roof membrane, are still effective at reducing temperatures although not as effective as the full canopy module.

The findings in this study show 82% to 91.6% reductions in heat gain with partially vegetated modules and up to 95% reductions with fully covered modules compared to a sand colored roof. These findings are similar to heat gain reductions found by Liu and Baskaran who reported a 95% reduction of heat gain in Toronto with a grassed roof. In Florida, green roofs were 70% cooler at the membrane surface than white reflective roofs. Simmons et al. found a 38° C maximum reduction at the surface of green roofs compared to conventional dark colored roofs in Austin. Our findings of 7.9° C reductions at the surface for the TectaGreen™ partially covered modules and 22.8° C for fully covered LiveRoof™ modules are similar to the ranges for the six vender provided systems in Simmons et al. Clearly, green roofs are beginning to demonstrate a high capacity to reduce membrane temperatures during the summertime, which helps to prevent emissivity of heat passing through the roof deck to climate controlled spaces below.

It may also be possible to realize efficiency benefits for rooftop mechanical systems and air intakes systems on rooftops. With cooler temperatures on rooftops, the mechanical systems may perform better and last longer. This topic should be further investigated. Research in Europe has demonstrated a higher efficiency of solar panels with green roofs, as the panels benefit from cooler temperatures provided by the green roofs. The green roof plants in turn benefit from the shade of the solar panels (Cantor 2008).

CONCLUSION

When considering alternative methods for reducing rooftop temperatures during periods where ambient temperature and sunlight are maximized, the green roof was a very effective roof surface compared to the conventional roof surface. The unplanted modules were also effective at reducing temperatures below the module and somewhat effective at reducing surface temperatures. The inclusion of the LiveRoof™ module with 100% plant coverage brings to light that there may be significant variances between differences of plant coverage and at various stages of canopy maturity. Considering the June 17th data, it is evident that more research is needed to better understand the role of vegetation and its contribution to different types of results.

ACKNOWLEDGEMENTS

Funding for this study was provided by the Texas A&M University College of Architecture Research and Interdisciplinary Council Grant

Program (CRIC); materials were donated by Tecta America™, LiveRoof™, Rooflite™ and Emory Knoll Nursery.

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