ENERGY PERFORMANCE ASPECTS OF A FLORIDA GREEN ROOF

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ABSTRACT

Previous green roof studies have found that planted roofs significantly reduce roof temperatures and roof heat flux, and simulations indicate cooling load reductions of up to 25%. This monitored study evaluates summer and winter energy performance aspects of a green roof on a central Florida university building addition that was completed in 2005.

Analysis of 2005 summer data indicates significantly lower peak roof surface temperatures for the green roof compared with the conventional roof and a significant shift in when the peak temperature occurs compared to the conventional roof. Summer roof heat flux estimates show the green roof to have an average heat flux of 0.39 Btu/ft^2/hr or 18.3% less than the conventional roof's average heat flux rate of 0.48 Btu/ft^2/hr.

Winter data again show significantly lower peak roof surface temperatures and higher nighttime surface temperatures for the green roof. For periods during which the ambient temperature was less than 55^{o}F, the weighted average winter heat flux rate for the green roof is -0.40 Btu/ft^2/hr or 49.5% less than the conventional roof's average heat flux rate of -0.79 Btu/ft^2/hr.

BACKGROUND

While green or vegetated roofs are a more recent phenomenon in the U.S., green roofs have been in use in Europe for centuries. Germany has emerged as a leader in modern green roof technology and usage where it's estimated that there are over 800 green roofs that comprise 10 percent of all flat roofs[1,2]. Green roofs are becoming more popular today in the United States however. High profile examples of U.S. green roofs include the Chicago City Hall and Ford Motor Company Dearborn truck plant that has a total green roof area of over 10 acres.

And interest in green roofs continues to grow. A recent Green Roofs for Healthy Cities survey found that member-companies saw an over 80% increase in completed green roof square footage in the United States in 2005 compared with 2004[3]. Local governments are getting involved as well. The City of Chicago, for example, has started a program that provides a limited number of $5,000 grants to help residential and small commercial building owners install green roofs. The interest level in an initial informational seminar held this past October was so high that the city added a second seminar to help residents learn about the grants.

In addition to their rainwater runoff reduction and aesthetic benefits, previous studies have found that green roofs significantly reduce roof surface temperatures and heat flux rates. A study performed in Toronto Canada, for example, found that two green roofs with minimal vegetation reduced peak summertime roof membrane temperatures of a gymnasium by over 35^{o}F and summertime heat flow through the roof by 70% to 90% compared with a conventional roof on the same building[4]. Simulations also indicate cooling load reductions from green roofs ranging from 1% to 25% depending on building specifics and characteristics of the green roof[5,6].

INTRODUCTION

This Florida green roof project is being led by the University of Central Florida's Stormwater Management Academy under a grant from the Florida Department of Environmental Protection (FDEP). While the primary purpose of the project is to evaluate rainwater runoff benefits of the green roof, FDEP, through a U.S. Department of Energy State Energy Program Grant is also funding the author to evaluate the energy performance of the green roof.

One half of this project's 3,300 square foot roof is a conventional, light colored membrane roof. The other half of the roof has the same membrane with a green roof completely covering the surface. The project uses an *extensive* green roof, which means that it consists of vegetation such as grasses and small plants, has a relatively shallow planting media layer and requires relatively little maintenance. The project roof consists of 6" to 8" of plant media and a *variety* of primarily native Florida vegetation up to approximately 2 feet in height. The thermal conductivity of the dry plant media was tested at the Oak Ridge National Laboratory to be 0.800 BTU-in./h-ft^2-°F[7]. The green roof is irrigated twice a week for approximately 15 minutes each time (with collected rainwater when available).

Figures 1 and 2 show the green roof and part of the adjacent conventional roof on April 28th and August 18th, 2005 respectively. The significant difference in the level of vegetation coverage on the green roof is due to plant growth and some vegetation being added. Roof surface solar reflectance tests were conducted on August 18th for the conventional and green roofs according to ASTM Standard E1918-97 methodology[8]. The conventional and green roof reflectances were found to be 58% and 12% respectively.

Figure 1. Green roof April 28th, 2005.

Figure 2. Green roof August 18th, 2005.

The energy aspects of this monitored study focus on roof surface temperature and heat flux comparisons between the conventional, light-colored membrane half of the roof and the green roof. The roof geometry and drainage were designed to allow both the conventional and green roofs to have similar "mirror image" insulation levels and corresponding temperature sensor locations as shown in the roof surface and building section diagrams (Figures 3 and 4).

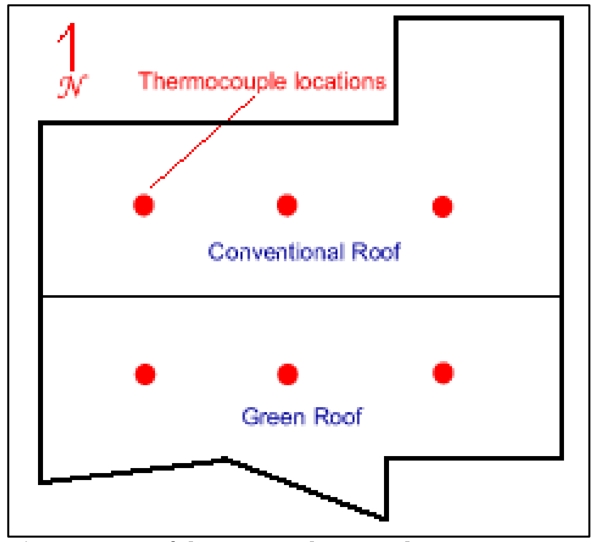

Figure 3. Roof diagram with sensor locations.

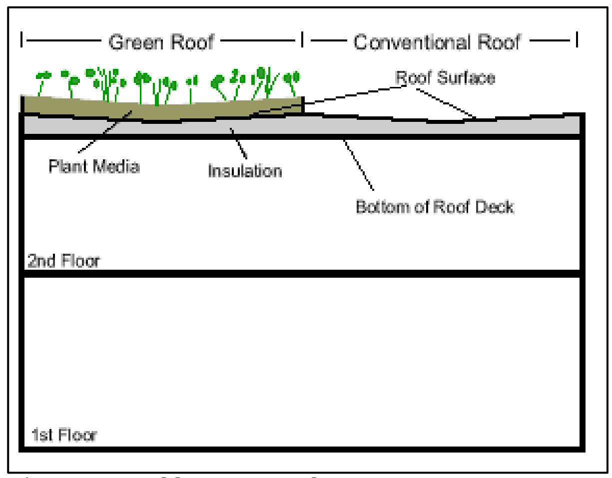

Figure 4. Building section diagram.

Temperature measurements include the roof surface, bottom of roof deck, interior air and green roof plant media surface. Meteorological measurements include ambient air temperature, total horizontal solar radiation, rainfall, wind speed and wind direction. All sensors are sampled every 15 seconds and measurements are averaged or totalized every 15 minutes. The monitoring period includes summer 2005 and winter 2006.

SUMMERTIME RESULTS

Summertime data indicate significantly lower peak roof surface temperatures and higher nighttime surface temperatures for the green roof. Figure 5 provides a comparison of the conventional and green roof surface temperatures for each of the six measurement locations (three conventional roof and three green roof) between July 4th, 2005 and September 1st, 2005 shown as an average day. The maximum average day temperature seen for the conventional roof surface was 130°F while the maximum average day green roof surface temperature was 91°F, or 39°F lower than the conventional roof. There is also a significant shift in when the peak temperatures occur, with peak surface temperatures for the conventional roof occurring around 1pm while the peak green roof surface temperatures occur around 10pm.

the middle sensor location) while the green roof peaks around midnight at approximately 0.6 Btu/ft^2/hr (also at the middle sensor location).

Table 1 shows average summer heat flux rates over the July 4th through September 1st monitored period. The weighted average heat flux rate over the period for the green roof is 0.39 Btu/ft^2/hr or 18.3%

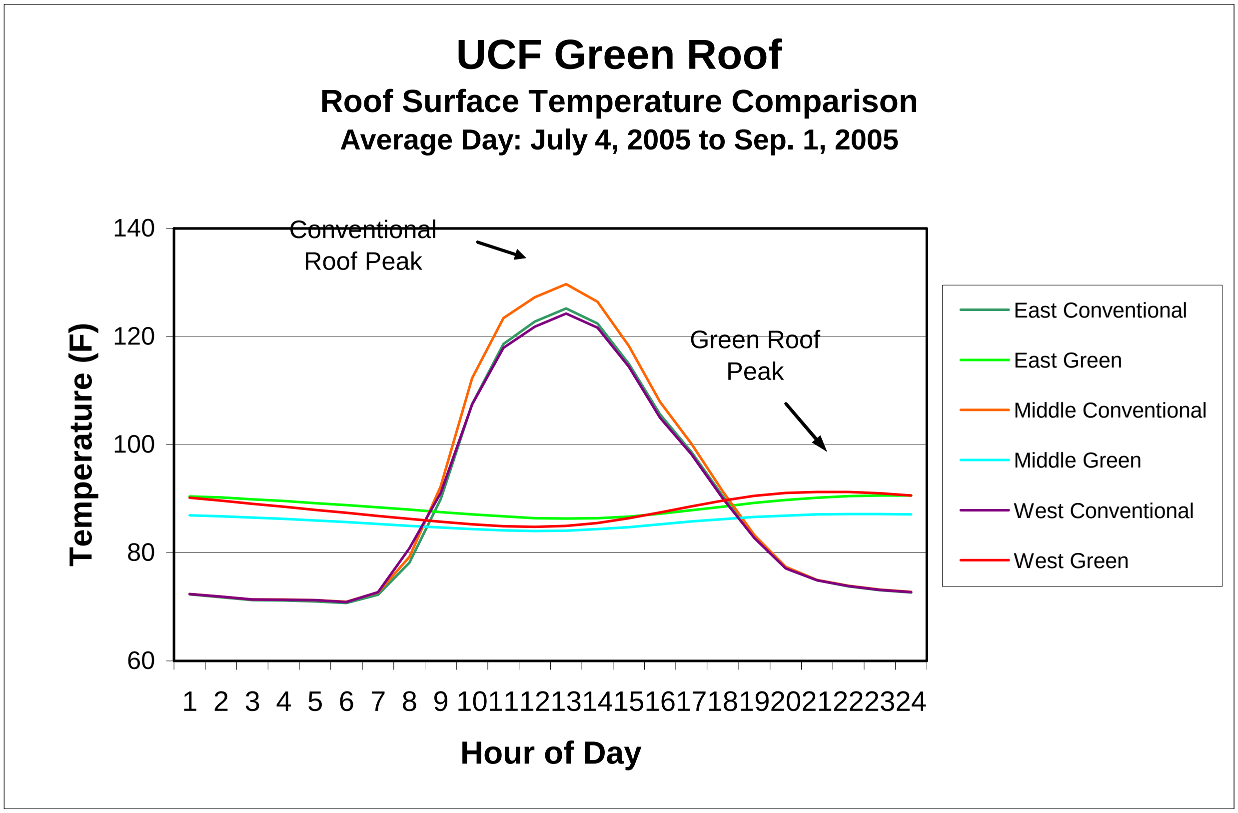

Figure 5. Comparison of average summer day green and conventional roof surface temperatures.

The minimum average roof surface temperature was 71°F for the conventional roof and 84°F for the green roof. The lower conventional roof nighttime temperatures are due to the conventional roof surface being directly exposed to the night sky while the green roof surface is covered with the plant media.

Summer heat flux estimates have also been made for each of the six roof measurement locations for the same July 4th, 2005 through September 1st, 2005 period. Heat flux is calculated from roof surface and bottom of roof deck temperature measurements and estimated insulation R-values which because of drainage taper, range from approximately R-15 at the drains to R-60 at the East and West ends of each roof. Figure 6 shows roof heat flux rates for the average day. Heat flux rates for the conventional roof peak in the early afternoon at approximately 2.9 Btu/ft^2/hr (at

less than the conventional roof's average heat flux rate of 0.48 Btu/ft^2/hr, with the most significant differences occurring near the middle of the roofs at the points of lowest insulation.

Table 1: UCF Green Roof Average Summer Heat Flux Estimates For July 4, 2005 – Sept. 1, 2005

Location	Approximate R-Value	Avg. Green Roof Flux (Btu/ft^2/hr)	Avg. Conventional Roof Flux (Btu/ft^2/hr)
East	38	0.33	0.36
Middle	17	0.53	0.74
West	38	0.31	0.34

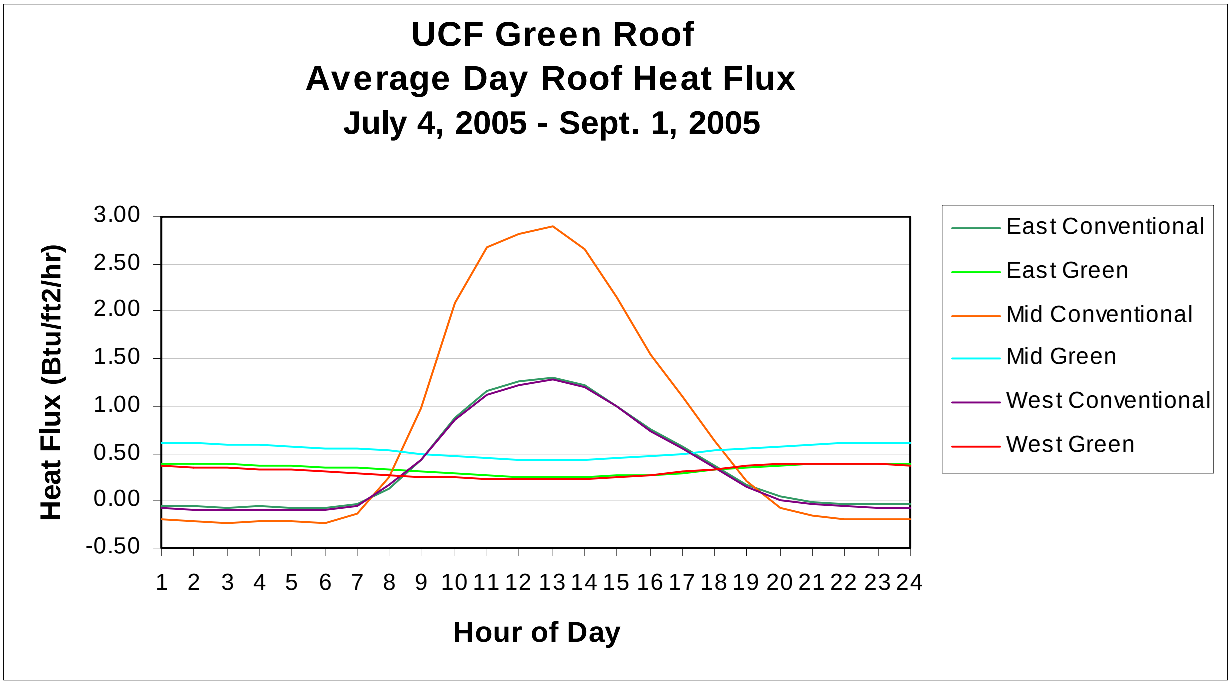

Figure 6. Comparison of average summer day green and conventional roof heat fluxes.

WINTER RESULTS

Winter data again show significantly lower peak roof surface temperatures and higher nighttime surface temperatures for the green roof. Figure 7 provides a comparison of the conventional and green roof surface temperatures for each of the six measurement locations (three conventional roof and three green roof) between January 1st, 2006 and February 28th, 2006 shown as an average day. The maximum, average and minimum average day temperatures seen for the conventional roof surface were 96.9°F, 62.1°F and 45.1°F respectively. The maximum, average and minimum average day temperatures for the green roof surface were 65.4°F, 63.5°F and 61.1°F respectively. There is also again a significant shift in when the peak temperatures occur, with peak surface temperatures for the conventional roof occurring in the early afternoon while the peak green roof surface temperatures occur around midnight.

The lower conventional roof nighttime temperatures are again due to the conventional roof surface being directly exposed to the night sky while the green roof surface is covered with the plant media.

Winter analysis has also been performed for each of the six roof measurement locations for the 2005 / 2006 winter period using data limited to when the ambient air temperature was less than 55°F, to approximate times when heating would be required. Figures 8 and 9 show roof surface temperatures and heat flux rates respectively for the average ambient temperature-limited winter day. The maximum, average and minimum average day temperatures for the conventional roof surface under these conditions were 83.2, 49.5°F and 35.7°F respectively. The maximum, average and minimum average day temperatures for the green roof surface under the same conditions were 63.9, 60.2°F and 53.3°F respectively.

Heat flux rates only show an actual heat gain to the building through the conventional roof, with the maximum gain being for the middle sensor (at the point of lowest roof insulation) in the early afternoon at approximately 0.63 Btu/ft^2/hr. The greatest heat loss for the conventional roof is again at the middle sensor location, occurring between 3am and 7am during which time the average day flux was approximately -1.90 Btu/ft^2/hr.

The lowest heat loss rate for the green roof occurs between 11pm and 7am, during which time the average day flux for the East and West sensor locations ranged between -0.23 and –0.28 Btu/ft^2/hr. The greatest heat loss rate for the green roof occurs at the middle sensor location (at the point of lowest insulation) in the mid afternoon at which time the average day flux was approximately -0.80 Btu/ft^2/hr
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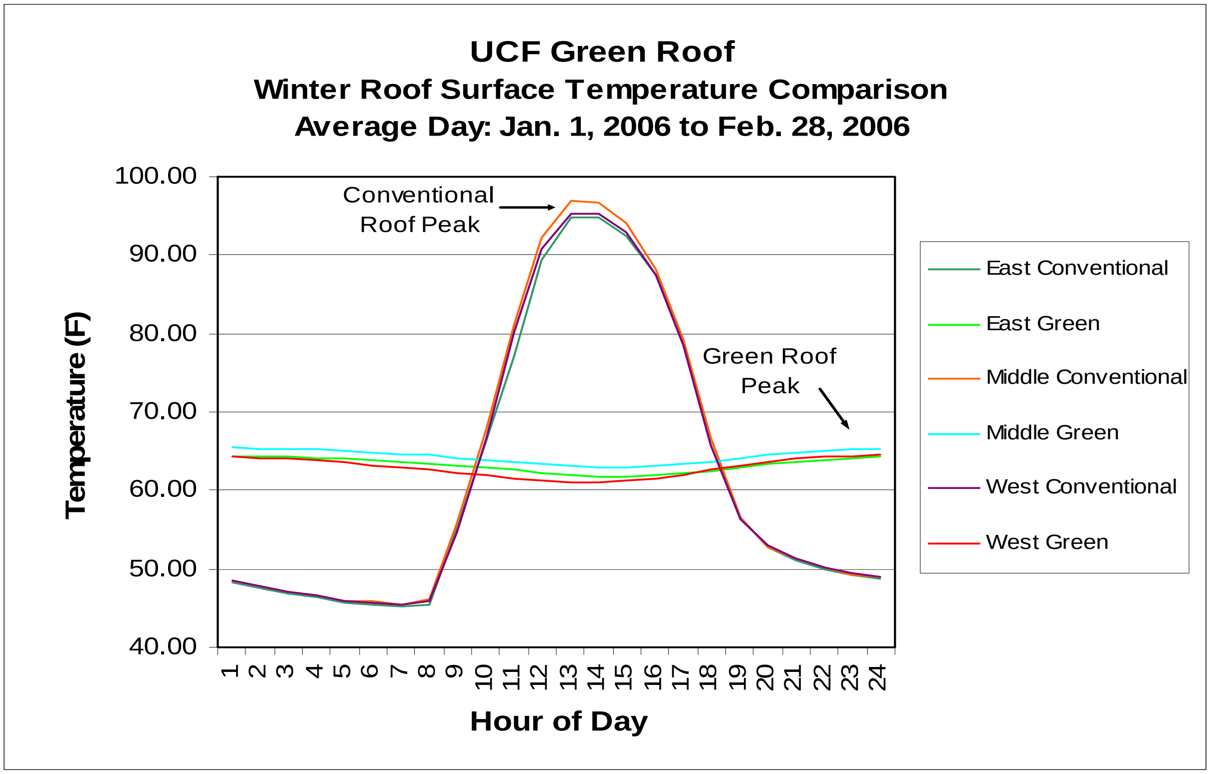

Figure 7. Comparison of average winter day green and conventional roof surface temperatures.

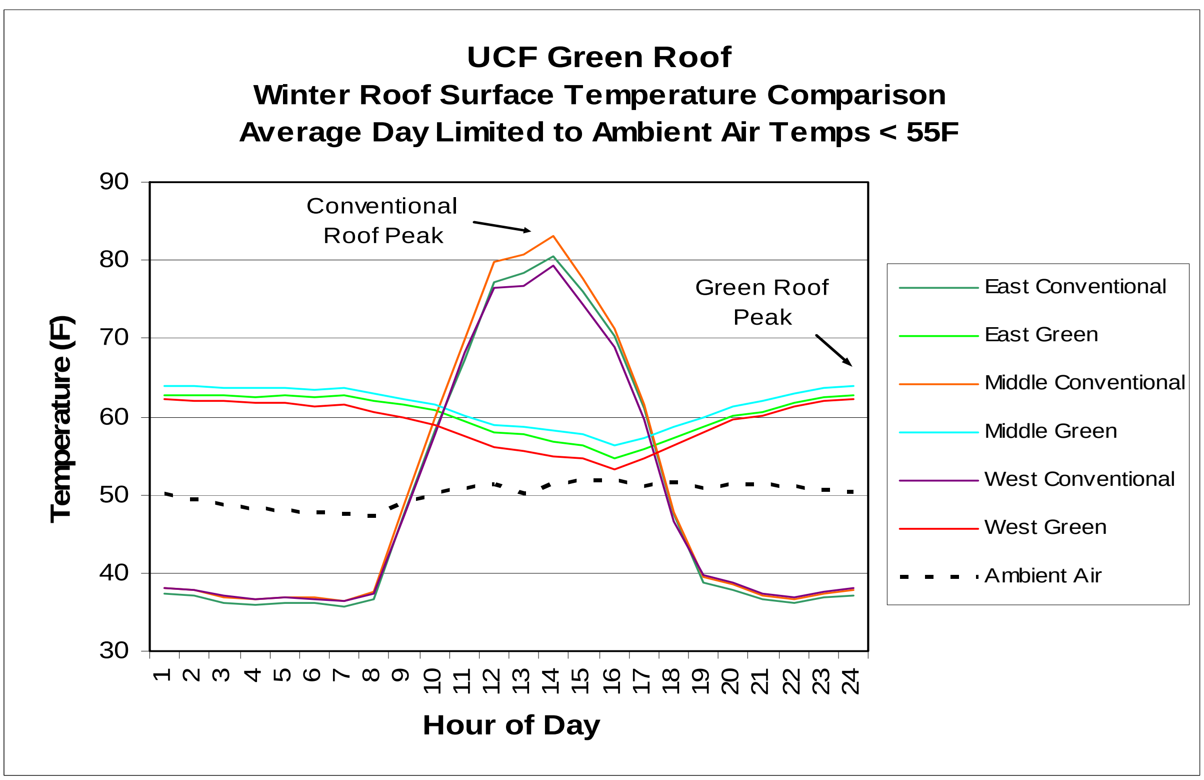

Figure 8. Comparison of average winter day, ambient temperature limited green and conventional roof surface temperatures.

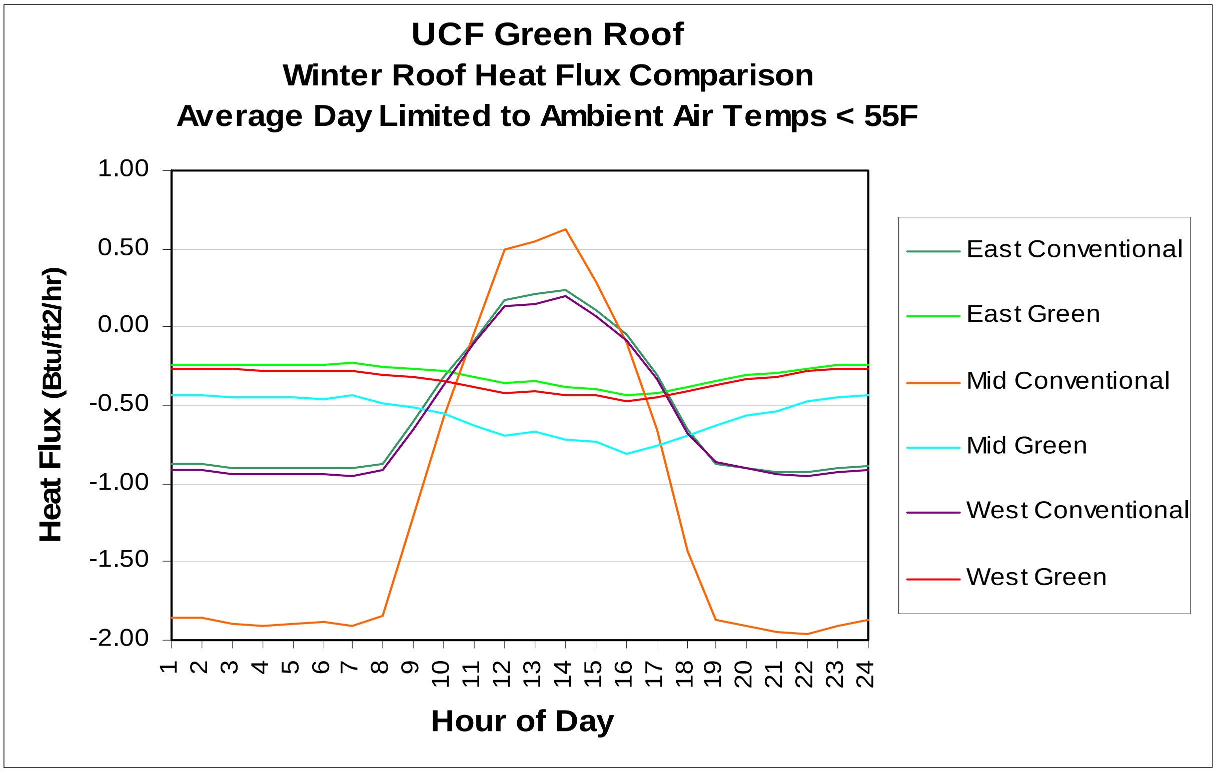

Figure 9. Comparison of average winter day, ambient temperature limited green and conventional roof heat fluxes.

Table 2 shows average winter heat flux rates using ambient temperature limited data over the monitored winter period. The weighted average heat flux rate over the period for the green roof is –0.40 Btu/ft^2/hr or 49.5% less than the conventional roof's average heat flux rate of -0.79 Btu/ft^2/hr, with the most significant differences occurring near the middle of the roofs at the points of lowest insulation.

Table 2: UCF Green Roof Average Winter Heat Flux Estimates Limited to Ambient Temperatures < 55^{o}F

Location	Approximate R-Value	Avg. Green Roof Flux (Btu/ft^2/hr)	Avg. Conventional Roof Flux (Btu/ft^2/hr)
East	38	-0.30	-0.58
Middle	17	-0.56	-1.19
West	38	-0.34	-0.61

ENERGY USE

Estimating building energy use impacts from green roofs is somewhat involved, being dependant on individual building characteristics such as size, use, number of stories and roof/attic design. Side-by-side monitoring studies are often also further complicated by sub-metering issues since it is typically difficult to separate out HVAC power use for sections of the building under the conventional roof verses sections under the green roof.

As a rough estimate however, assuming that all heat gain through the roof must be removed by the AC system, an air conditioning system efficiency of 10 Btu/hr/Watt (including fan power and distribution losses) and a total roof area of 3,300 square feet, the average energy use to remove the additional heat gain from the conventional roof over the monitored summer period is approximately 0.7 kWh/day. For the monitored winter period using times when outside ambient temperatures were less than 55^{o}F, given the same roof area and assumptions, and a heating system efficiency of 7 Btu/hr/Watt, the average energy use to replace the additional heat loss from the conventional roof would be approximately 183 Watt hrs/hour< 55 F (relative to annual savings, there are many more cooling hours in Central Florida than heating ones, so the winter energy use estimate is expressed per hour).

It should be noted that most commercial low slope roofs are much darker than the conventional roof used in this study[9]. Thus, if the conventional roof color were more typical, summer benefits of the green roof would be considerably greater and winter benefits slightly lower than those seen here. Over time, the green roof's vegetative canopy will continue to spread and likely reduce green roof summer heat gains and winter heat losses somewhat while the conventional roof will darken and absorb more heat, somewhat increasing this roof's summer heat gains and reducing its winter heat losses.

REFERENCES

1. Wark, Christopher G. and Wendy W. Wark, "Green Roof Specifications and Standards: Establishing an Emerging Technology", *The Construction Specifier*, Vol. 56, No. 8, August 2003

2. *The Green Roof Research Program at MSU* (2002, October 28), Retrieved November 29, 2005, from http://www.hrt.msu.edu/faculty/Rowe/Green_roof.htm.

3. *Green Roof Industry Posts Greater than 80% Growth*, Green Roof for Healthy Cities press release, April 13, 2006, Toronto.

4. Liu, Karen and Brad Bass, "Performance of Green Roof Systems", *Cool Roofing…Cutting Through the Glare Proceedings*, Atlanta, GA, May 2005.

5. Wong, et al., "The Effects of Rooftop Garden on Energy Consumption of a Commercial Building in Singapore", *Energy and Buildings*, Volume 35, 2003, p. 353-364.

6. Christian, Jeffrey E. and Thomas W. Petrie, "Sustainable Roofs with Real Energy Savings", *Proceedings of the Sustainable Low-Slope Roofing Workshop*, Oak Ridge, TN, October 1996.

7. Christian, Jeffrey E, *Re: Soil Thermal Conductivity*, Personal email to Robin K. Vieira, November 30, 2005.

8. American Society for Testing and Materials, 1997, *ASTM E1918-97 Standard Test Method for Measuring Solar Reflectance of Horizontal and Low-Sloped Surfaces in the Field*, West Conshohocken, PA.

9. *Cool Roofs* (2006, January 5), Retrieved January 9, 2006, from http://www.epa.gov/heatisland/strategies/coolroofs.html.