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Energy Performance Aspects of A Florida Green Roof
Part 2

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EXECUTIVE SUMMARY

Green roof installation in the United States is growing at a significant rate. There are a number of reasons for this growth including rainwater runoff reduction and aesthetic benefits. Energy performance evaluations of green roofs, the subject of this study, are also becoming available.

This monitored study is an evaluation of summer and winter energy performance aspects of a green roof on a 2-story central Florida university building addition that was completed in 2005. An earlier report on this study was published through the 2006 *Symposium on Improving Building Systems in Hot and Humid Climates*. This report reviews these earlier results and provides second-summer results which show significant performance improvements for the green roof compared with the first summer results.

One half of the two-story project building's 3,300 square foot project roof is a light-colored, conventional flat membrane roof, the other half being the same membrane roof covered with 6" to 8" of plant media and a variety of primarily native Florida vegetation up to approximately 2 feet in height to create an extensive green roof.

Analysis of 2005 summer data from the first year the green roof was installed indicates significantly lower peak roof surface temperatures for the green roof compared with the conventional roof and a significant shift in when the peak green roof temperature occurs compared to the conventional roof. Data analysis of the same 2005 period also shows lower heat fluxes for the green roof. Calculations 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.

Analysis of 2006 summer data when the green roof was more established and conventional roof somewhat darker, shows even greater temperature and heat flux differences between the two roofs. The weighted average heat flux rate over the 2006

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summer period for the green roof is 0.34 $Btu/ft^2{\cdot}hr$ or 44.1% less than the conventional roof's average heat flux rate of 0.60 $Btu/ft^2{\cdot}hr$.

An additional heat flux analysis was performed for an April 1st 2006 through October 31st 2006 monitoring period to provide an estimate of heat flux for an extended cooling season. The weighted average heat flux rate over the period for the green roof is 0.25 $Btu/ft^2{\cdot}hr$ or 45.7% less than the conventional roof's average heat flux rate of 0.46 $Btu/ft^2{\cdot}hr$.

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

Because of air conditioning zoning limitations, an extensive energy savings analysis was not possible for this project. However, an energy savings analysis was performed using the roof heat flux results and equipment efficiency assumptions. Based on this analysis the total estimated cooling and heating season savings for the green roof compared with the conventional roof, if the entire 3,300 square foot project roof were green, would be approximately 489 kWhr/yr.

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 *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 New York has a new green roof program starting in 2009 that provides a one-year tax abatement equal to $4.50 per square foot for buildings that cover at least half of their rooftop space with vegetation, up to the lesser of the building's tax liability or $100,000[4].

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[5]. Energy savings have also been indicated. A DOE-2 simulation study of a green roof on a 5-story Singapore office building showed annual energy consumption savings of 1% to 15% depending on characteristics of the green roof[6]. An earlier study of an actual sod roof building in Tennessee found that the roof provided at least a 25% reduction in the peak cooling load requirement[7].

INTRODUCTION

This Florida green roof project was 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 authors to evaluate the energy performance of the green roof.

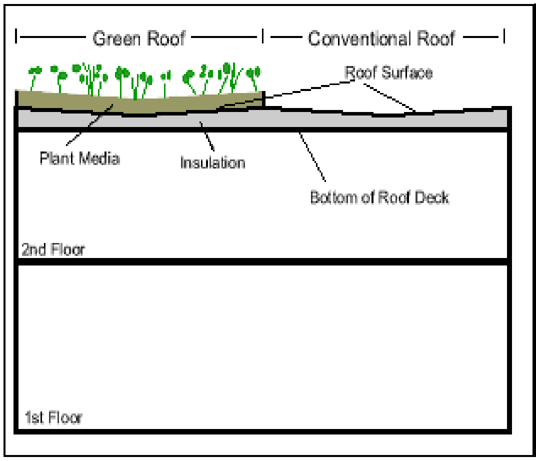
The project roof is part of a 2-story addition to a University of Central Florida student center. One half of the addition's 3,300 square foot roof is a conventional, light-colored membrane roof. The other half of the roof has the same membrane roof with a planted green roof completely covering the surface. The project uses an extensive green roof,

Figure 1. Green roof April 28th, 2005.

Figure 2. Green roof August 18th, 2005

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[8]. The green roof is irrigated twice a week for approximately 15 minutes each time (with collected rainwater when available). Both the conventional and green roofs were installed in the spring of 2005. 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.

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).



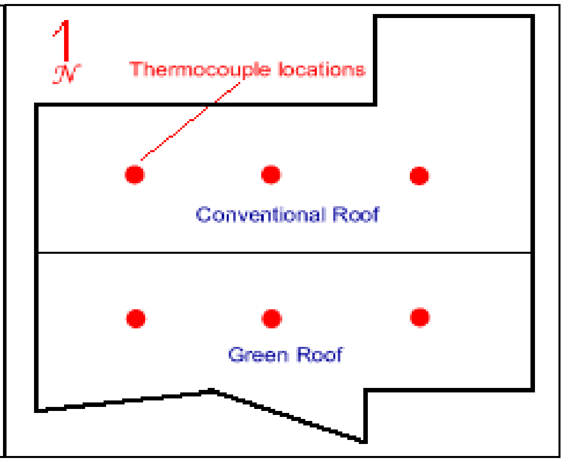


Figure 3. Roof diagram with sensor locations**.** **Figure 4**. Building section diagram

Temperature measurements are made by special limits type-T thermocouples, and include the roof surface, bottom of roof deck, interior air and green roof plant media surface. Roof surface, bottom of roof deck, plant media surface and interior air temperature measurements are all made at three locations each for the green and conventional roofs as indicated on Figure 3. Roof surface thermocouples were attached to the membrane with a structural sealant and the three conventional roof sensors were painted to match the roof color as closely as possible.

Meteorological measurements include ambient air temperature, total horizontal solar radiation, rainfall, wind speed and wind direction. All sensors were sampled every 15 seconds and measurements averaged or totalized every 15 minutes.

SUMMERTIME RESULTS

Summertime Temperatures

Roof surface temperature analyses were performed for both the 2005 and 2006 summer monitoring periods. The 2006 temperature analysis was added to quantify the effects of “darkening” of the conventional roof and the further establishment of the green roof canopy over time. As noted previously, the conventional roof surface sensors were painted to match the color of the conventional roof as closely as possible. During the 2006 summer monitoring period the paint on the sensors had visibly darkened somewhat more than the roof surface, but repainting would have made the sensor surfaces lighter than the surrounding roof and it is not anticipated that this difference has had a significant effect on results.

Roof surface solar reflectance tests for the conventional and green roofs were conducted in the summers of 2005 and 2006 according to ASTM Standard E1918-97 methodology[9]. The conventional and green roof reflectances were found to be 58% and 12% respectively from an August 18, 2005 test and 50% and 13% respectively from an August 14, 2006 test.

The summer 2005 temperature analyses 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 and three green) between July 4th, 2005 and September 1st, 2005 shown as an average day. The average conventional roof surface temperature over this monitoring period was 89.2°F verses 87.5°F for the green roof. The maximum average day temperature seen for the conventional roof surface was 129.7°F while the maximum average day green roof surface temperature was 91.3°F, or approximately 38°F lower than the conventional roof's maximum. There is also a significant shift in when the peak roof temperatures occur, with peak temperatures for the conventional roof occurring around 1pm while the peak green roof surface temperatures occur around 10pm. The minimum average day roof surface temperature was 70.7°F for the conventional roof and 84.0°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 and vegetation.

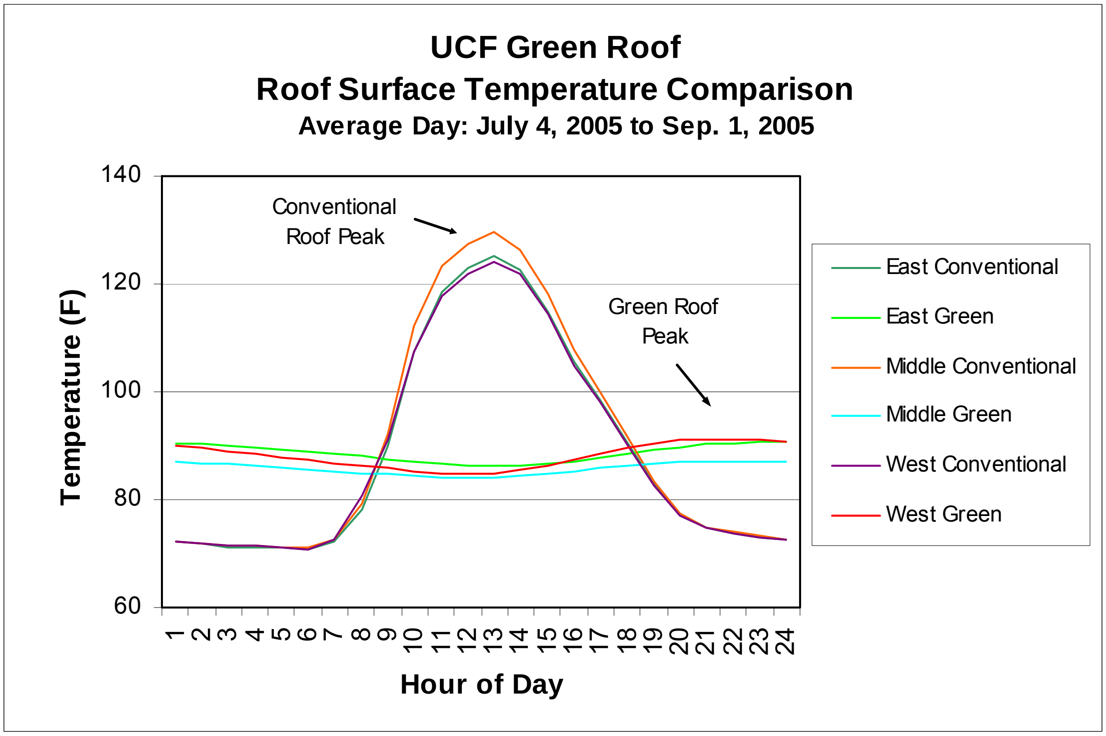


Figure 5: Average 2005 summer day conventional and green roof surface temperatures.

Figure 6 is the same roof surface temperature comparison over the 2006 summer monitoring period. The average temperature of the conventional roof surface for the July 4th through September 1st 2006 monitoring period was 90.4°F verses 83.5°F for the green roof surface. The maximum average day temperature for the conventional roof surface over the period was 133.6°F verses a maximum average day temperature for the green roof surface over the same period of 85.8°F, or a difference of approximately 48°F. The minimum average day roof surface temperature was 68.8°F for the conventional roof and 81.6°F for the green roof. Comparing the 2006 roof surface temperatures with the 2005 temperatures indicates significant effects from both conventional roof darkening and establishment of the green roof. Figure 7 shows a comparison of the averaged conventional and green roof temperatures over the 2005 and 2006 average days.

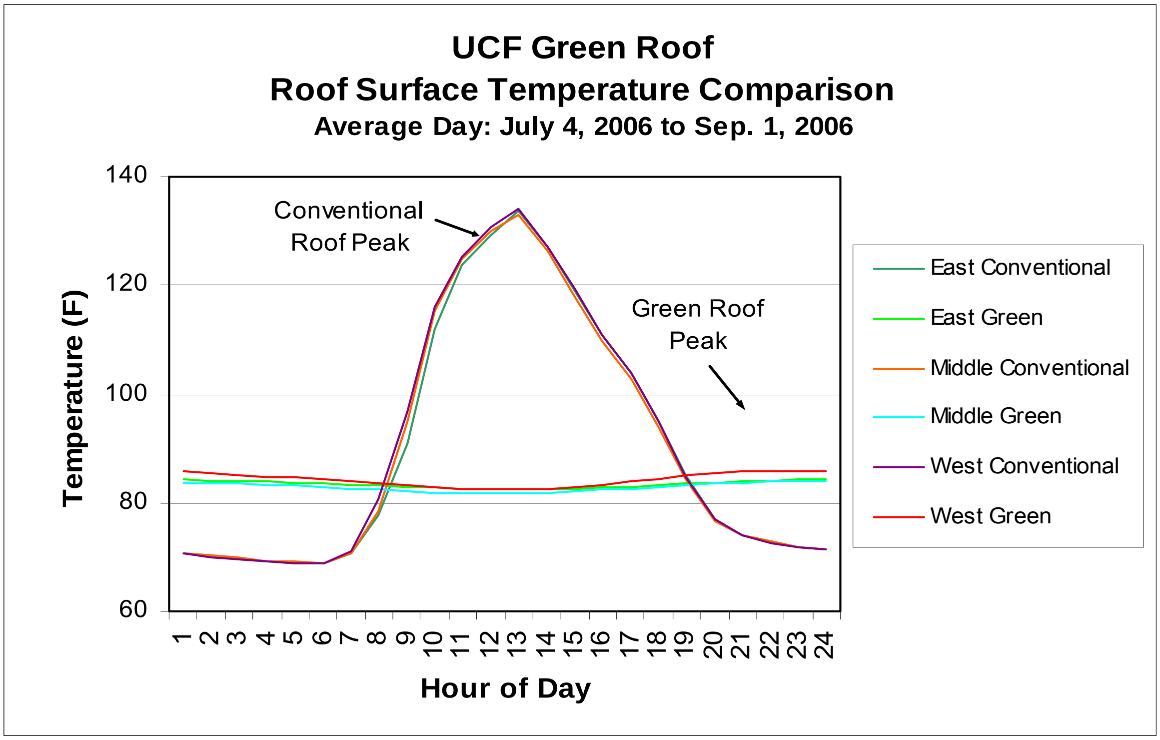


Figure 6: Average 2006 summer day conventional and green roof surface temperatures.

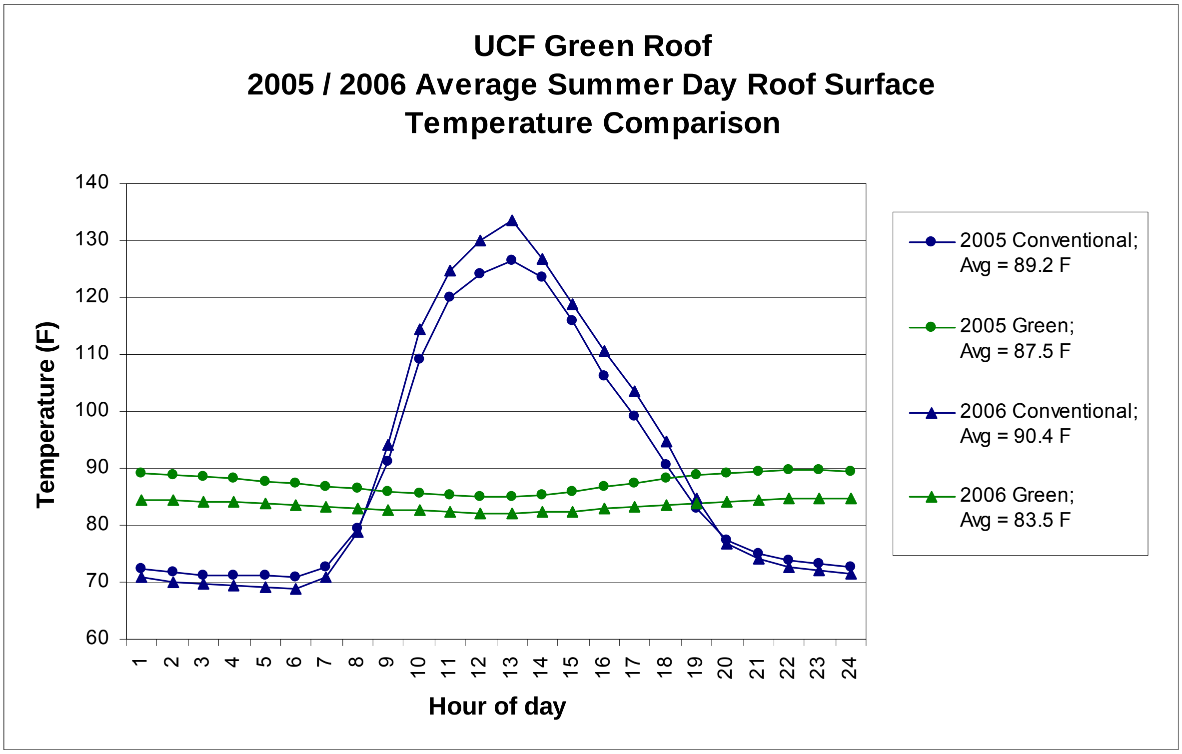


Figure 7: Comparison of 2005 and 2006 average summer day averaged conventional and green roof surface temperatures.

Summertime Heat Flux

Summer heat flux estimates have also been made for each of the six roof measurement locations for the July 4th through September 1st monitoring period for both 2005 and 2006, and also for an April 1st 2006 through October 31st 2006 monitoring 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 at the middle of each roof, to R-60 at the East and West ends of each roof.

Figures 8 and 9 show average day roof heat flux rates from the 2005 and 2006 summertime monitoring periods respectively. For the 2005 period, the heat flux rates for the conventional roof peak in the early afternoon at approximately 2.9 $Btu/ft^2 \cdot hr$ (at the middle sensor location) while the green roof peaks around midnight at approximately 0.6 $Btu/ft^2 \cdot hr$ (also at the middle sensor location).

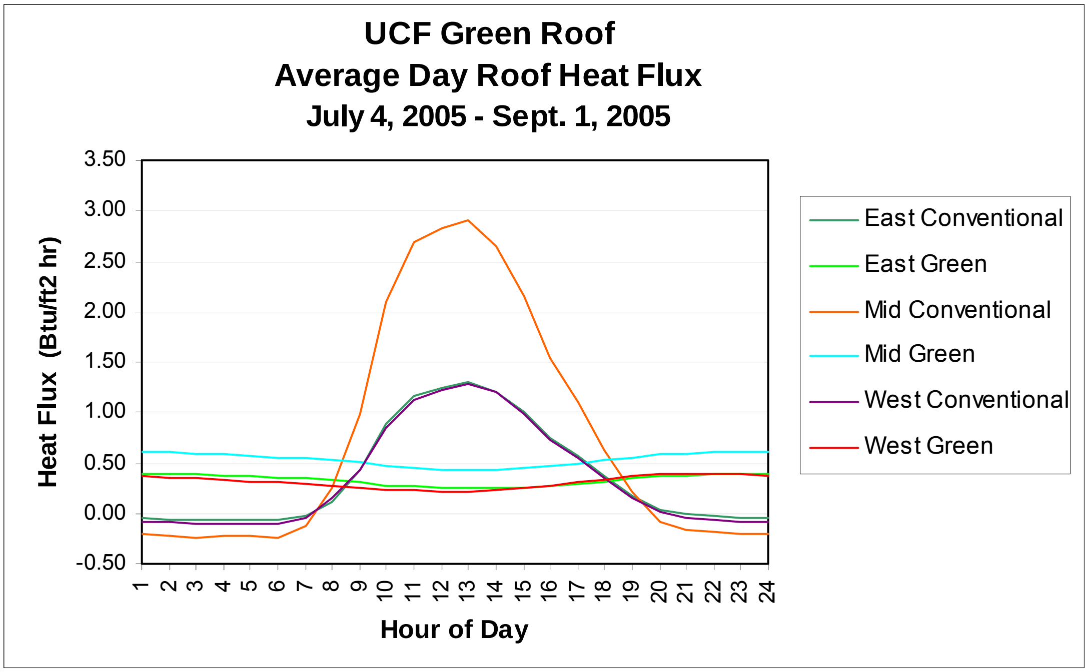


Figure 8: Average 2005 summer day conventional and green roof heat flux rates.

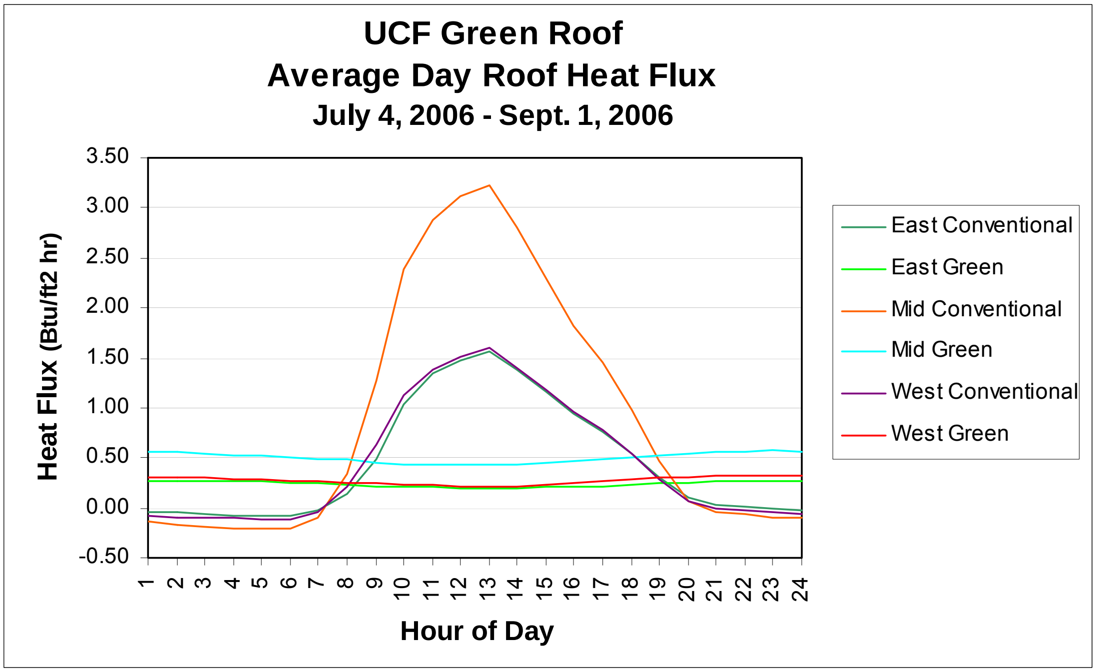


Figure 9: Average 2006 summer day conventional and green roof heat flux rates.

Table 1 shows average summer heat flux rates over the July 4^{th} through September 1^{st} 2005 monitored period. The weighted average heat flux rate over the period for the green roof is 0.39 $Btu/ft^2 \cdot hr$ or 18.8% less than the conventional roof's average heat flux rate of 0.48 $Btu/ft^2 \cdot hr$, 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 ($^oF\cdot ft^2\cdot h/Btu$)	Avg. Green Roof Flux ($Btu/ft^2\cdot hr$)	Avg. Conventional Roof Flux ($Btu/ft^2\cdot hr$)
East	38	0.33	0.36
Middle	17	0.53	0.74
West	38	0.31	0.34

Table 2 shows average summer heat flux rates over the July 4th through September 1st 2006 monitored period. The weighted average heat flux rate over the period for the green roof is 0.34 $Btu/ft^2\cdot hr$ or 43.3% less than the conventional roof's average heat flux rate of 0.60 $Btu/ft^2\cdot hr$, with the most significant differences again occurring near the middle of the roofs at the points of lowest insulation.

Table 2: UCF Green Roof Average Summer Heat Flux
Estimates for July 4, 2006 – Sept. 1, 2006

Location	Approximate R-value ($^oF\cdot ft^2\cdot h/Btu$)	Avg. Green Roof Flux ($Btu/ft^2\cdot hr$)	Avg. Conventional Roof Flux ($Btu/ft^2\cdot hr$)
East	38	0.24	0.45
Middle	17	0.50	0.90
West	38	0.27	0.46

Comparing the results in Tables 1 and 2 further shows both lower heat flux rates for the green roof and higher heat flux rates for the conventional roof for the summer of 2006 verses 2005, indicating significant effects from both the establishment of the green roof and conventional roof darkening.

An additional heat flux analysis was performed for an April 1st 2006 through October 31st 2006 monitoring period to provide an estimate of heat flux for an extended cooling season. Table 3 shows average summer heat flux rates over the extended monitored period. The weighted average heat flux rate over the period for the green roof is 0.25 $Btu/ft^2\cdot hr$ or 45.7% less than the conventional roof's average heat flux rate of 0.46 $Btu/ft^2\cdot hr$, with the most significant differences again occurring near the middle of the roofs at the points of lowest insulation.

Table 3: UCF Green Roof Average Summer Heat Flux
Estimates for April 1, 2006 – Oct. 31, 2006

Location	Approximate R-value ($^oF\cdot ft^2\cdot h/Btu$)	Avg. Green Roof Flux ($Btu/ft^2\cdot hr$)	Avg. Conventional Roof Flux ($Btu/ft^2\cdot hr$)
East	38	0.16	0.34
Middle	17	0.37	0.69
West	38	0.21	0.35

WINTERTIME RESULTS

Wintertime Temperatures

Winter data again show significantly lower peak roof surface temperatures and higher nighttime surface temperatures for the green roof compared with the conventional roof. Figure 10 provides a comparison of the conventional and green roof surface temperatures for each of the six measurement locations (three conventional 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 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 and vegetation.

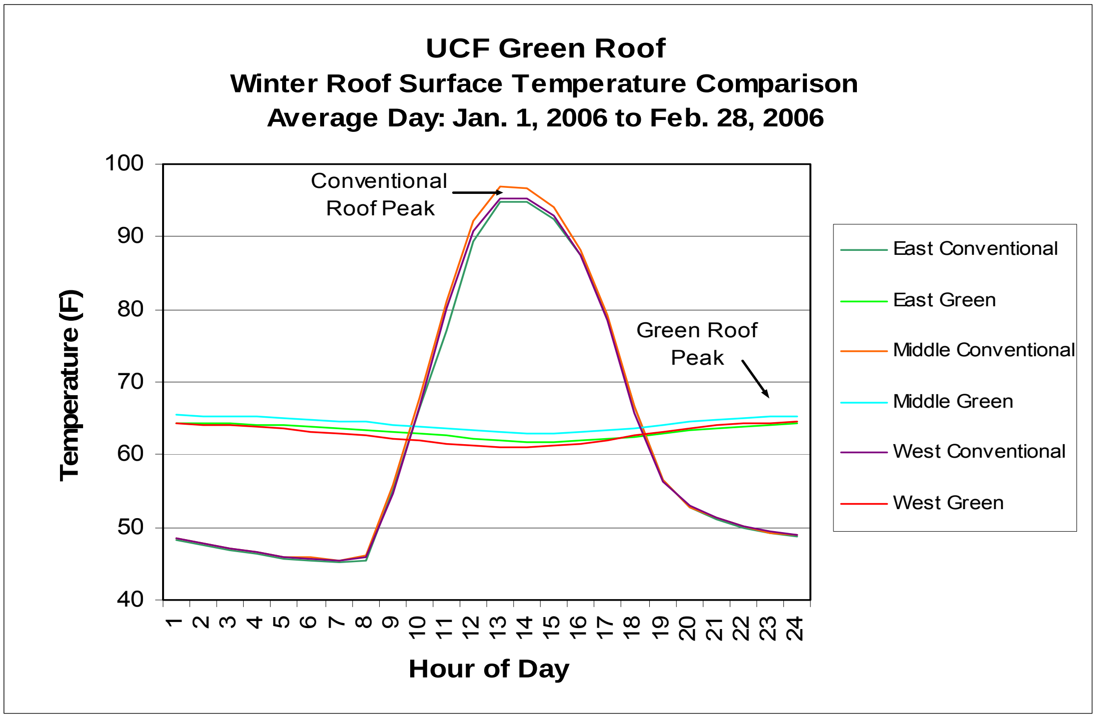


Figure 10: Comparison of average winter day green and conventional roof surface temperatures.

Winter analysis has also been performed for each of the six roof temperature measurement locations for the 2005/2006 winter monitoring period using data limited to when the ambient air temperature was less than 55°F, to approximate times when heating would be required. Figure 11 shows roof surface temperatures 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°F, 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°F, 60.2°F and 53.3°F respectively.

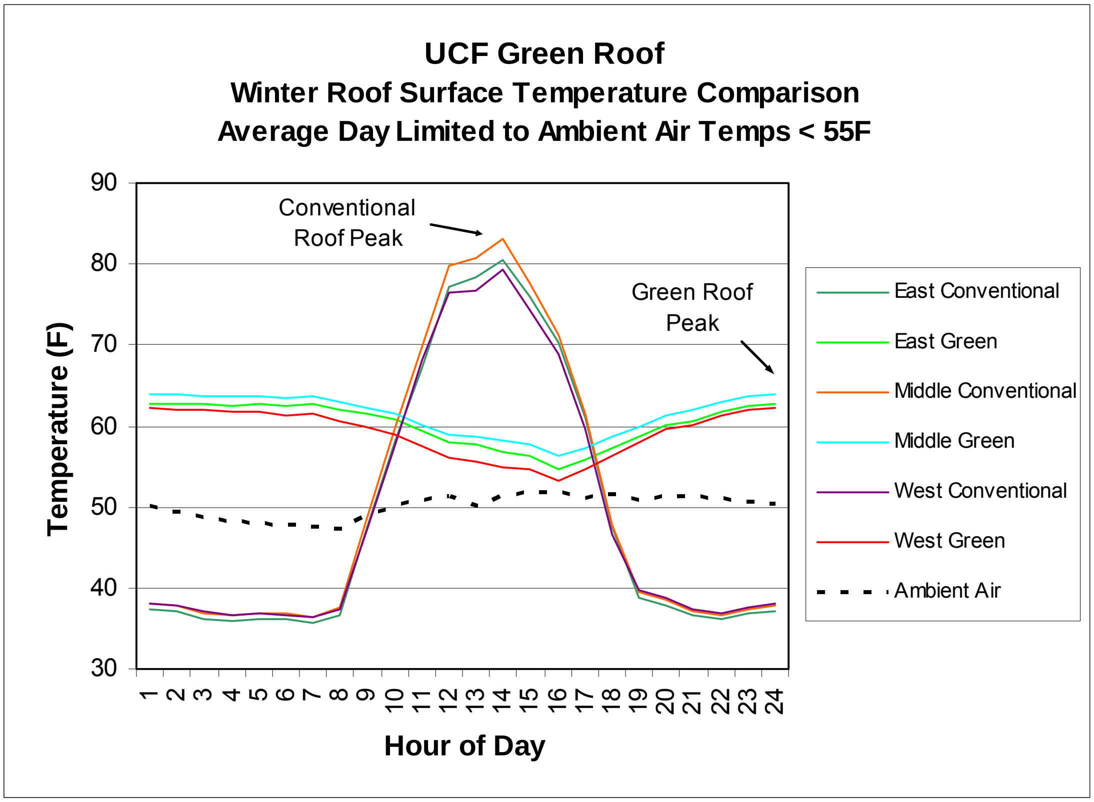


Figure 11: Comparison of average winter day, ambient air temperature-limited green and conventional roof surface temperatures.

Wintertime Heat Flux

Winter monitoring-period heat flux rates for periods with ambient air temperatures limited to less than 55°F are shown in Figure 12. Winter 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 afternoon at which time the average day flux was approximately -0.80 Btu/ft^2·hr.

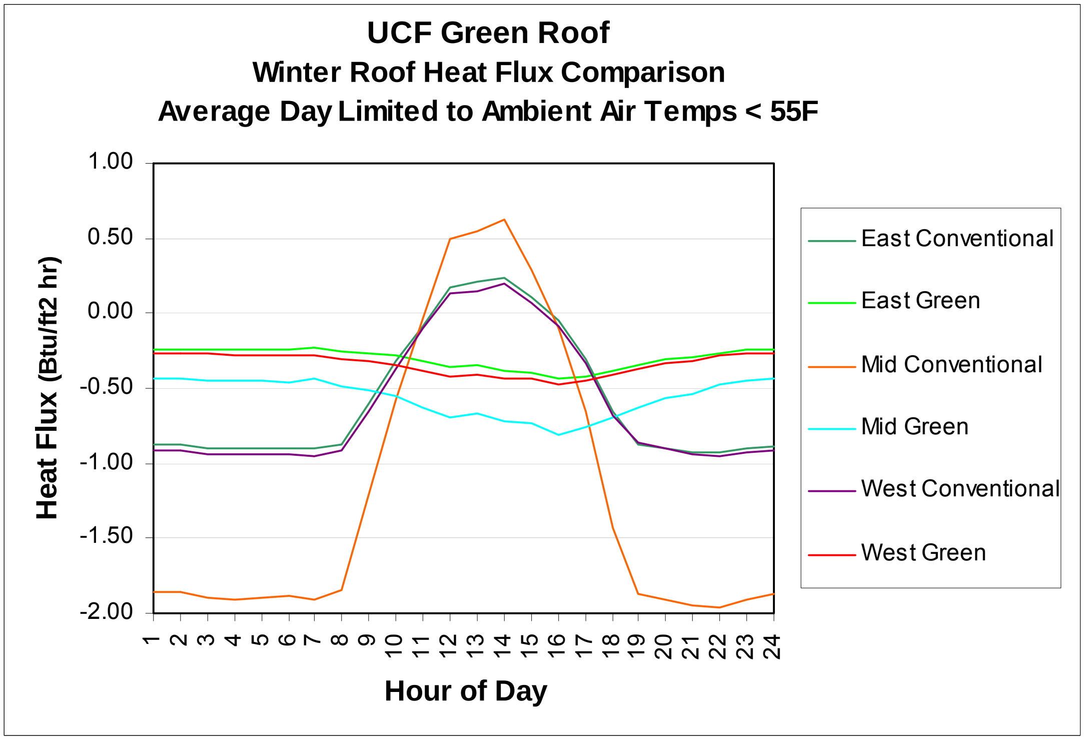


Figure 12: Comparison of average winter day, ambient air temperature-limited green and conventional roof heat fluxes.

Table 4 shows average winter heat flux rates using the same ambient air 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 49.4% less than the conventional roof's average heat flux rate of -0.79 Btu/ft^2·hr, with the most significant differences again occurring near the middle of the roofs at the points of lowest insulation.

Table 4: UCF Green Roof Average Winter Heat Flux Estimates Limited to Ambient Air Temperatures <55°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 SAVINGS

Estimating building energy use impacts from green roofs can be 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.

Even though this University of Central Florida project had these same sub-monitoring constraints, rough savings estimates were still calculated.

Cooling Savings

The initial summer energy savings analysis uses data from the July 4th – September 1st 2005 monitoring period. It assumes an A/C system efficiency of 10 Btu/hr·W (including fan power and distribution losses), a total roof area of 1,650 square feet and that all heat gain through the roof is removed by the AC system. Given these assumptions, the average energy use to remove the additional heat gain from the conventional roof is calculated using the following project results:

Average conventional roof heat flux = 0.48 Btu/ft^2·hr
Average green roof heat flux = 0.39 Btu/ft^2·hr.

Calculating additional average daily energy use for the 1,650 square foot conventional roof:

Energy use = ((0.48 Btu/ft^2·hr – 0.39 Btu/ft^2·hr) / 10 Btu/hr·W) x 1,650 ft^2 x 24 hr/day = 356 Whr/day

An energy savings analysis of the 2006 summer period was also performed to further quantify the effects of conventional roof darkening and establishment of the green roof. The 2006 energy use analysis again uses a July 4th – September 1st monitoring period as was used in the 2005 summer analysis. The summer 2006 analysis uses the average conventional roof summer heat flux of 0.60 Btu/ft^2·hr and green roof summer heat flux of 0.34 Btu/ft^2·hr with the same assumptions as the 2005 analysis. These 2006 results compute to a daily energy use to remove the additional heat from the 1,650 square foot conventional roof of approximately 1,030 Whr/day, a 189% increase compared with the 2005 results.

A final energy savings analysis of the extended April 1st through October 31st 2006 summer period was also performed. This extended summer analysis uses the average conventional roof summer heat flux of 0.46 Btu/ft^2·hr and green roof summer heat flux of 0.25 Btu/ft^2·hr with the same assumptions as the other analyses. These extended monitoring results compute to a daily energy use to remove the additional heat from the 1,650 square foot conventional roof of approximately 832 Whr/day.

Heating Savings

A similar energy use savings estimate is made for the monitored 2005/2006 winter period, using hours when outside ambient air temperatures were less than 55^{o}F (to again approximate hours when heating would be required). The estimate uses the average roof heat flux rates found for the period of -0.79 Btu/ft^2·hr for the conventional roof and -0.40

Btu/ft^2·hr for the green roof. Given the same roof area and assumptions and an overall heating system efficiency of 7 Btu/hr·W, the average energy use to replace the additional heat loss from the 1650 square foot conventional roof would be approximately 92 Whr/hour<55^{o}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).

Overall Savings

Using the extended summertime 2006 project results (using heat flux averages for April 1st through October 31st), the roughly estimated cooling savings, assuming the entire 3,300 square foot project roof is green, is approximately 356 kWhr/yr. From the winter 2005/2006 results, and estimating from TMY data that the Orlando outdoor air temperature is less than 55^{o}F for 725 hours per year, the roughly estimated heating savings, again assuming the entire 3,300 square foot roof is green, is 133 kWhr/yr. The total estimated cooling and heating season savings then for the 3,300 square foot green roof is approximately 489 kWhr/yr.

It should be noted that most commercial low slope roofs are significantly darker than the conventional roof used in this study[10]. Thus, if the conventional roof color were more typical, summer benefits of the green roof would be somewhat greater and winter benefits somewhat less than those seen here. The comparison between 2005 and 2006 summer results from this project underscores how roof color and level of green roof canopy affect temperatures, heat flux and in turn, savings.

The total estimated savings derived from the project results of 489 kWhr/yr is approximately 29% of the work plan estimated savings. While the difference in these savings estimates is significant, the original work plan estimate was necessarily rough, being based on findings from a limited number of previous studies.

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