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CONTRACT REPORT

UCF Recommissioning, Green Roofing Technology, and Building Science Training; Final Report

Research Meets Application:
Building Commissioning and Roofing Technology

FSEC-CR-1718-07

May 18, 2007

Florida DEP Agreement No. G0148
FSEC #20127036

Prepared for:
Michael Ohlsen, Florida Energy Office
Florida Department of Environmental Protection
3900 Commonwealth Boulevard M.S. 49
Tallahassee, Florida 32399

Prepared by:
James B. Cummings, Chuck R.Withers , Jeff Sonne,
Danny Parker, and Robin K. Vieira
Florida Solar Energy Center
1679 Clearlake Road
Cocoa, Florida 32922

Dustin Jackson and David Norvell
University of Central Florida
Physical Plant
4000 Central Florida Blvd
Orlando, FL 32816

1679 Clearlake Road, Cocoa, FL 32922-5703 • Phone: 321-638-1000 • Fax: 321-638-1010
www.fsec.ucf.edu

A Research Institute of the University of Central Florida

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A Report Prepared for the Project: Research Meets Application --
Building Commissioning and Roofing Technology Project

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Orlando, FL 32816

This documents reports the activities of three tasks; 1) recommissioning of three University of Central Florida (UCF) buildings, 2) energy savings from a green roof on a UCF building, and 3) building science training.

Task 1. Building Recommissioning

Project Reports

In addition to quarterly activity reports, several analyses and reports were prepared at various stages of the project as deliverables for this project. These include:

- On October 17, 2006, submitted a 9-page report titled *Recommissioning Plan for the UCF Student Union Building,* which contains recommissioning cost and energy savings estimates for the Student Union Building. This report and the estimated savings were used in a presentation to the Student Union building manager and staff (the Student Union building operates largely independently from UCF) to pursued them of the benefits of adopting some or all of our recommissioning recommendations.

- On July 20, 2006, submitted a 12-page report titled *Recommissioning and Monitoring Plans for Three University of Central Florida Buildings* (FSEC-CR-1642-06). This report was prepared for the three buildings (Colbourn Hall, Classroom I, and Student Union) that are undergoing diagnosis and recommissioning. It contains summaries of the test findings, diagnostic assessment of building and HVAC system performance, and recommendations for retrofits to HVAC systems schedules, operation sequences, and setpoints.

- On November 3, 2005, a 14-page project report *Recommissioning Diagnostic Test Methods* (FSEC-CR-1536-05) was submitted to FEO.

Field Testing

Inspections, testing, and data gathering were performed at three UCF buildings in order to identify opportunities for energy savings. From this, recommissioning plans were developed for each building.

In the original plan, the Student Union, Colbourn Hall, and the Biology Building were to be recommissioned. Subsequently, it was learned that the Biology Building was going to be reconfigured in 2008, with new uses and tenants, so the energy savings benefits from recommissioning would be lost as the use of the building changed. A substitution was then approved by FEO and the US DOE of Classroom I for the Biology Building.

Implementation of the recommissioning plans were begun in August 2006 at Classroom I building and in September 2006 in Colbourn Hall. A summary of energy savings from those two buildings is presented in this report.

The management of the Student Union Building, which operates in a largely autonomous manner from the university's Physical Plant, has decided to implement essentially all of the recommendations of our recommissioning plan. To this date, no recommissioning has been implemented at the Student Union Building, for the following reasons.

1. The project team was slow in getting the recommissioning plan to the Student Union management. On November 20, 2006 project staff presented their recommissioning plan to the Student Union staff. The latter expressed enthusiasm that projected energy savings were greater than 50% of current building usage, and indicated that they will plan to implement essentially all of the proposed recommissioning actions.
2. The greatest majority of the proposed modifications to the building require reprogramming the Building Automation System (BAS) which also controls the HVAC systems. Since the building had been constructed in stages over a period of 15 to 20 years, there are two different control systems in place in this building. Furthermore, there is no in-house capability (staff skill) to reprogram the existing control systems, and the cost to bring in outside experts (from vendors) to perform this programming would be very expensive.
3. The Student Union management is currently soliciting bids from vendors to install a completely new BAS.
    a. The first bid (Trane) came back in early January 2007 with a price tag of $370,820. Trane has proposed to rewire the entire building at the same time as installing the new computer controls.
    b. A second bid has been received from CES (Comprehensive Energy Services) for $307,900
4. An additional bid is being sought from MC^2.
5. Once the bids have come back, the Student Union management will present the proposals to the Student Union board for approval of expenditure of funds.

Since no recommissioning measures have been implemented, this final report provides a summary of the proposed recommissioning steps and projected energy savings at the Student Union building. Actual monitored energy savings from Classroom I Building and Colbourn Hall are presented in this report.

Note that electricity and chilled water energy savings are measured in each building at five minute intervals. In most cases, we have coagulated the 5-minute data into daily energy use and then normalized to outdoor weather conditions. This daily energy use for total building electricity use and for chilled water use is contained in the second half of each building's energy savings discussion. Additionally, some analysis has been done to identify the sources of the savings. To that end, limited disaggregation of energy savings by end use is also presented, in the first half of each building's energy savings discussion.

Classroom I Building

Recommissioning Measures Implemented

- **Reduce AHU fan speed.** Classroom I building has nine air handler units. Each AHU has VFD speed control. Static pressure reset was implemented in 4 of the 9 AHUs in August 2006, in an additional 2 AHUs in December 2006, and in a seventh AHU in February 2007.
    - Prior to this reprogramming, the AHU fans were running primarily in the range of 85% to 100% of full speed while attempting to meet the 1.5 inWC static pressure setting. With the new BAS programming, the AHU fan speed was reduced because the static pressure was reset based on polling of the VAV box damper positions. If the VAV boxes do not require the available static pressure, then the static pressure is reduced, resulting in fan power savings.
    - The fan speed status was monitored by means of the BAS and the collected trend data stored in Data Collection Modules which UCF Physical Plant installed. The five-minute fan speed control status was converted to fan power by means of a power curve developed from measurements taken by project staff (kW versus VFD control point).

- **HVAC Systems Unoccupied Periods and Night Shutdown.** Prior to this project, the HVAC systems were operated in "occupied" mode essentially all of the time. Static pressure reset and nighttime HVAC shutdown were implemented in August 2006 for 4 of the 9 AHUs, and for two more AHUs in December 2006. At first we programmed a 7-hour shutdown period. However, some faculty members in the building immediately began to complain that they were trying to work during hours when the AC systems were inactive. The building manager then got involved and put considerable pressure on us to curtail the HVAC shutdown period. As a result, the HVAC systems are shut off for only four hours each night, from 12 AM to 4 AM.. They are, however, in "unoccupied" control status for the period 10:30 PM to 4:30 AM. Three remaining AHUs were not reprogrammed because server rooms located in those zones required continuous temperature control. A separate CW AHU was installed on the second floor to serve the largest server room, and this retrofit (at a cost of $15,000) was completed in February 2007. Reprogramming of AHU-6 (where the new AHU was installed) had not been implemented by the end of the project due to the short time-frame to the end of the project (March 31, 2007) and shortage of project staff help.

Analysis was performed to examine the AHU fan motor energy use pre-recommissioning and post-recommissioning for all 9 AHUs, even though recommissioning was implemented in only 6 of the 9 units. The results of this analysis are presented in Table 1.

Projected annual fan energy savings are based on $0.10 per kWh. Actual university electricity costs include kWh use and kW demand charges, but we cannot readily identify the demand reduction resulting from reduced AHU fan use for each month (demand charges are based on monthly peak periods).The results show that the three AHUs that were not modified (numbers 2, 5, and 6) showed almost no reduction in energy use, with average energy savings of $176 per year, while the six AHUs that were modified (numbers 1, 3, 4, 7, 8, and 9) showed average energy savings of $1925 per year. In total, these six AHUs yielded fan motor energy savings of $11,550. It is clear from this data that implementation of static pressure reset and expanded "unoccupied" HVAC operation (plus 4 hours per night of full AHU shut-down) yield dramatic fan motor energy savings. On a percentage basis, these six AHUs showed 57% fan energy use reduction, whereas the three AHUs which were not modified showed an average 4.5% energy use reduction.

Table 1. Long-term average AHU fan electrical energy use (kWh/day) for each of the 9 Classroom Building AHUs.

	AHU1	AHU2*	AHU3	AHU4	AHU5*	AHU6*	AHU7	AHU8	AHU9
April 15-30, 2006	47.49	61.93	50.55	71.7	110.5	150.5	109.4	100.4	165.4
May 1-31, 2006	48.83	68.78	37.03	68.1	102.4	140.6	123.6	86.2	148.9
Pre Avg	48.2	65.4	43.8	69.9	106.5	145.6	116.5	93.3	157.2
March 1-31, 2007	13.78	53.67	21.96	41.11	101.1	155.3	24.48	45.04	47.73
April 1-30, 2007	15.26	55.11	27.21	46.45	103.7	156.4	24.46	56.33	60.87
Post Avg	14.5	54.4	24.6	43.8	102.4	155.9	24.5	50.7	54.3
KWh/day savings	33.7	11.0	19.2	26.1	4.1	-10.3	92.0	42.6	102.9
Percent savings	70.0%	16.8%	43.8%	37.3%	3.8%	-7.1%	79.0%	45.7%	65.5%
Estimated $/yr savings	$1,230	$402	$701	$953	$150	$-376	$3,358	$1,555	$3,756

* No recommissioning changes were made to AHUs 2, 5, and 6.

Figures 1 through 5 illustrate fan energy savings for selected AHUs (AHUs 8, 9, 4, 1, and 7) where static pressure reset, expanded unoccupied periods, and nighttime HVAC shutdown were implemented. These Figures show electrical energy usage for specific 5 or 7-day periods of time, before and after recommissioning changes, and generally comparing periods with similar weather patterns.

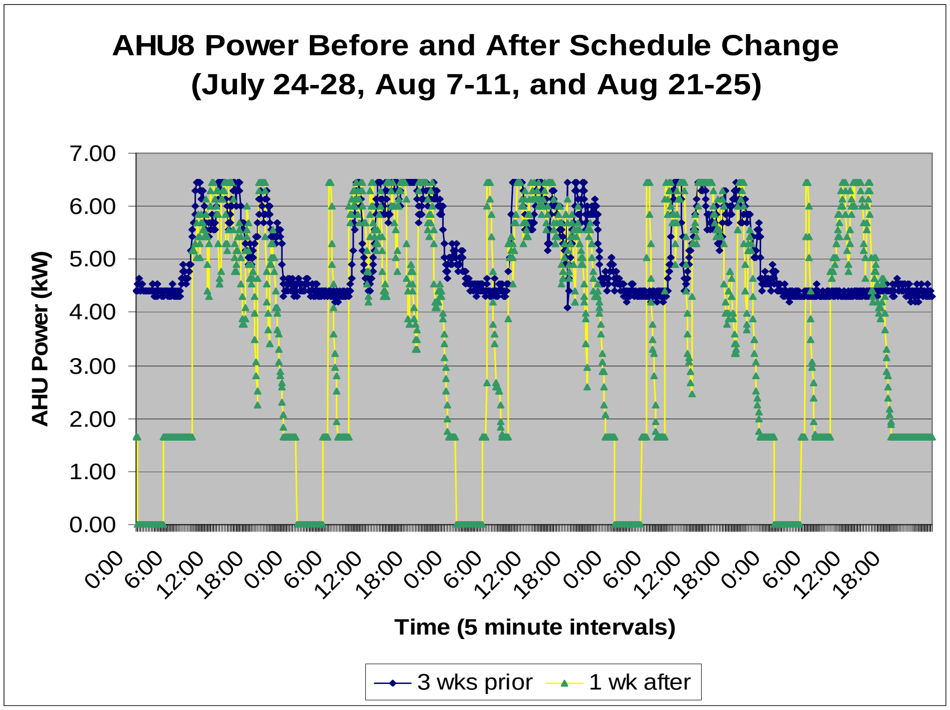


Figure 1. Fan energy savings for AHU-8; $1300 per year. Before change = 122 kWh per day After change = 85 kWh per day.

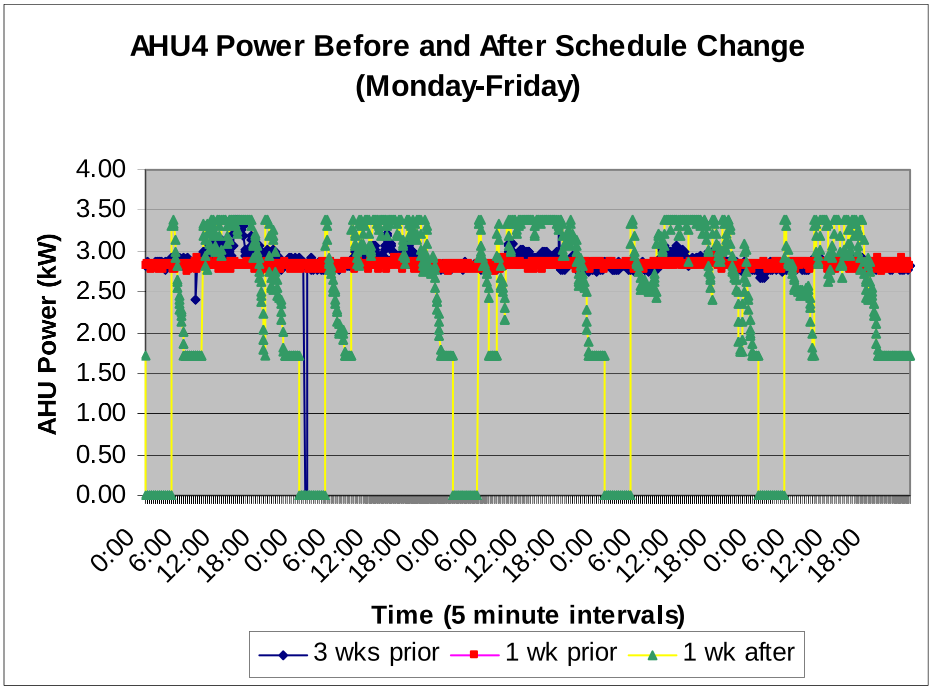


Figure 2. Fan energy use for AHU-4; before change = 68.8 kWh/day and after change = 55.6 kWh/day.

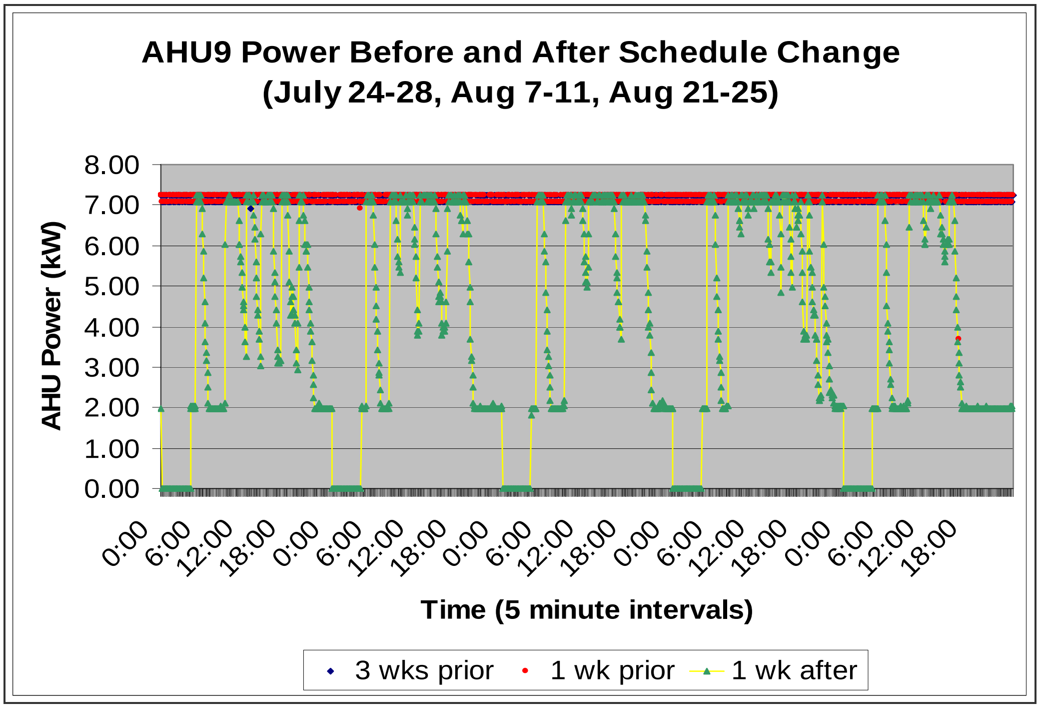


Figure 3. Fan energy savings for AHU-9; $2700 per year. Before change = 172 kWh per day After change = 97 kWh per day.

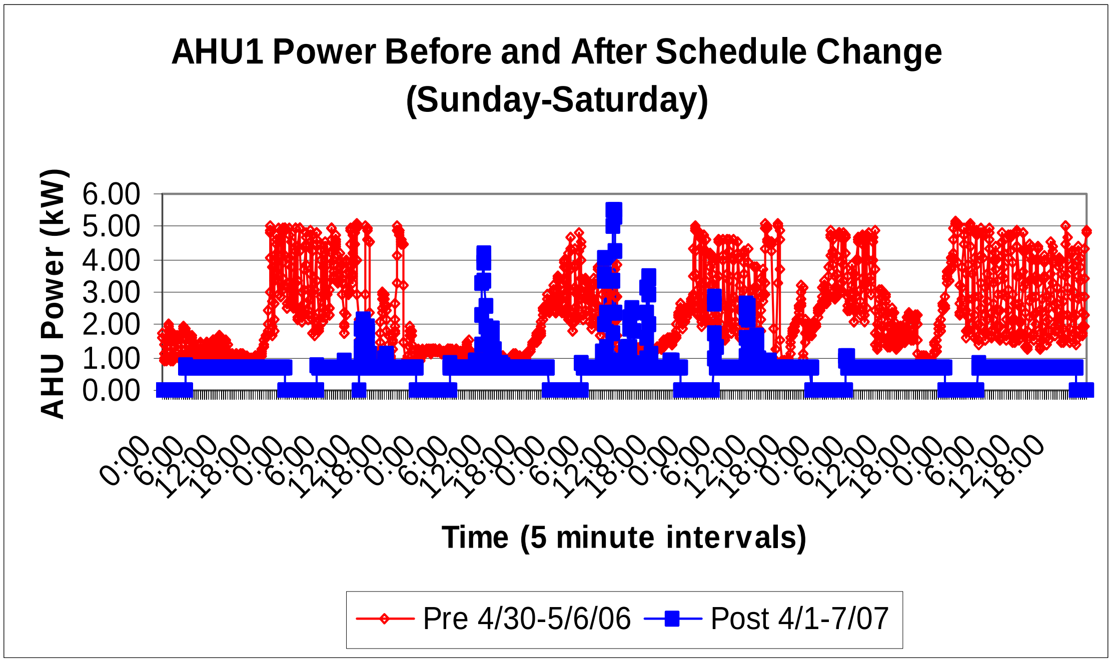


Figure 4. Fan energy use for AHU-1; before change = 55.2 kWh/day and after change = 14.2 kWh/day.

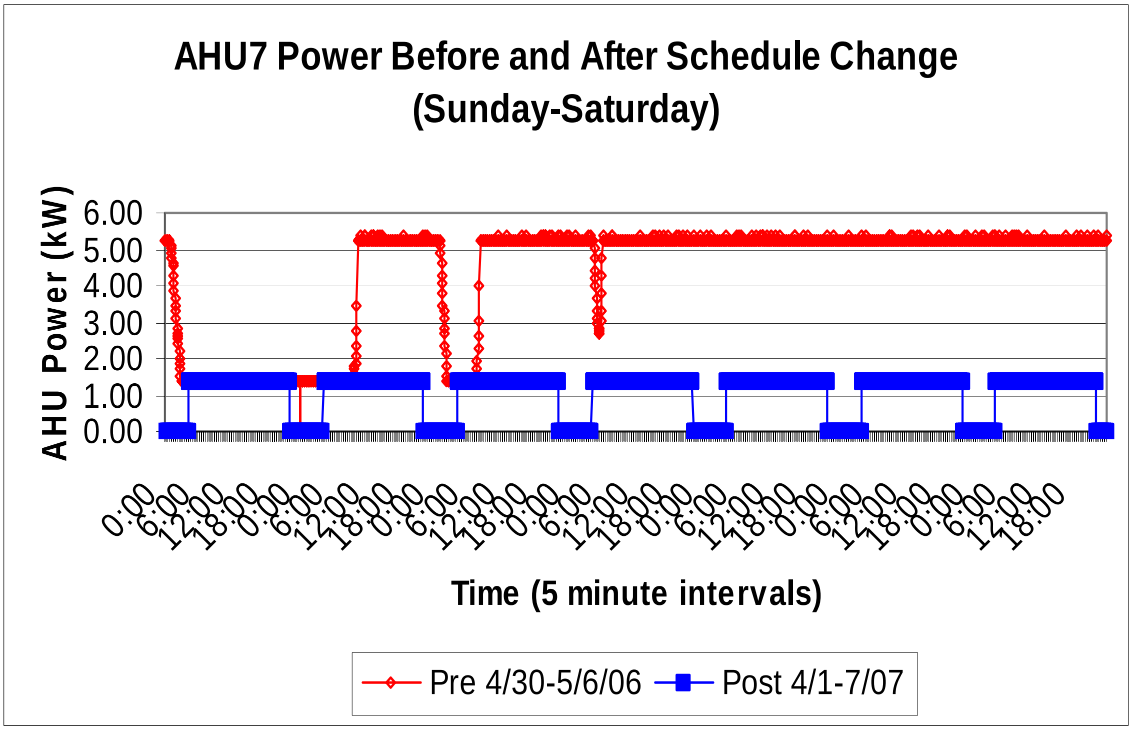


Figure 5. Fan energy use for AHU-7; before change = 104.5 kWh/day and after change = 24.6 kWh/day.

At the end of the third quarter of 2006, five of the nine AHUs still had their original Sequence of Operation (SOO). Delays in implementing changes to the SOO for these five AHUs had occurred because of special circumstances. In the case of AHUs 1 and 7, serving the two auditoriums, on-going humidity control problems had to be resolved. Upon investigation, physical plant staff found that the CO_2 levels and relative humidity levels were extremely high during the regular occupied hours in the auditoriums. The existing sequence basically allowed for modulation of both discharge air temperature and supply fan speed to regulate space temp and a CO_2 sensor to activate/deactivate outside air intake. This type of modulation allowed for unconditioned humid outdoor air to enter the space. Because of a lack of substantial sensible loads the temperature sensors were easily satisfied, so little dehumidification was performed.

This led to a new SOO being implemented for AHU-1 and AHU-7 on December 12, 2006. The newly implemented sequence has improved the humidity control ability of these AHUs, by allowing reheat in certain situations. It is likely that the operation of reheat has increased electricity and CW usage. On the other hand, the AHU fan motors are using much less electricity.

The delay for implementing SOO changes for AHU-6 was caused by a computer server room. Building staff wished to keep that space at 67°F 24/7. In February, installation of a $15,000 dedicated AC unit to provide cooling to that server space was completed. While we anticipated that modifications to the SOO for AHU-6 would be implemented in March 2007, in actual fact, these modifications have not yet been implemented.

There are no plans to modify the SOO for the two remaining AHUs because of issues of office politics. Some faculty members and the building manager have had complaints about environmental conditions (for a period pre-dating our involvement with the building), and seem ready to blame our recommissioning activities for any space conditioning comfort shortfall.

- **Reduce Reheat.** The VAV boxes that serve the classrooms and offices do not, with a few exceptions, have reheat. All the Fan Powered Boxes (FPBs), however, which serve primarily the corridors do have electric resistance reheat. In our recommissioning, the heating setpoints for the Fan Powered boxes were lowered. We had originally believed that changes to the AHU SOO had also changed the FPB SOO. However, we discovered later that the FPB SOO had to be reprogrammed separately. Consequently, the FPB operation had remained largely unmodified from their original control configurations (the only change had been to change the "occupied" setpoints so that reheat was less likely to operate). On February 15, 2007, several reprogramming steps were implemented:
    - We expanded the "unoccupied" period for six AHUs from 6 to 7 hours, with the AHUs continuing to be completely "off" for four hours.
    - The SOO of the FPBs on the first and third floors, which had been in occupied mode 24/7, were changed to unoccupied for 7 hours per night (10:30 PM to 5:30 AM). SOO for second floor FPBs remains unmodified. Setpoints for occupied and unoccupied were modified on February 15, 2007 as well, to 73^{o}F cooling and 68^{o}F heating for occupied and to 80^{o}F cooling and 50^{o}F heating for unoccupied.
    - Analysis of whole building energy use suggests that reheat has indeed been significantly reduced. See the whole building electricity analysis later in this report.
- **Pump Static Pressure Reset.** The tertiary chilled water pump that serves this building was, prior to our recommissioning, running at close to full speed most of the time. As with the AHUs, we implemented static pressure reset programming into the BAS.
    - Previously, the static pressure setpoint (pressure rise across the pump) was set at a constant 16.5 psi. We had, however, in earlier testing identified that this pump could be turned off and the necessary CW flow could still be achieved. However, since we could not be certain that the flow rate would be sufficient for peak cooling days, and because pump power declines as a function of pump speed (VFD control) to the third power, it was concluded that we would still achieve most of the savings that would occur from turning off the pump but still maintain performance certainty.
    - Static pressure reset control is based on the control status of the nine cooling coil valves (CCVs), one valve per AHU. When the valve status is below 90% open for each of the air handlers, then the control program continues to incrementally reduce the CW loop static pressure setpoint as long as the valves remain below the cutoff. The program does not, however, allow the pump VFD control point to drop below 20%. Initially, static pressure reset was implemented in August 2006. However, upon further investigation, it was found that this control routine was not operating. Consequently, pump static pressure reset did not actually become active until January 2, 2007. Analysis of the pump trend data finds that pumping power has been reduced by 87.5%, yielding projected annual electricity savings of about $1252.

- **Outdoor Air Control.** Physical Plant staff concluded that occupancy control of ventilation in this building would not be cost-effective. This conclusion is based upon the fact that the greatest majority of the building space is classrooms, and these classrooms are nearly full throughout the entire “occupied” period of the day. Therefore, time of day scheduling of the outdoor air dampers should work effectively to provide the required levels of ventilation. As part of the recommissioning effort at Classroom I Building, the two CO_2 controllers that were already in place in the two auditoriums were replaced. Additionally, the outdoor air dampers for the two auditoriums, which had been rusted and stuck in one position, were repaired. One had been stuck open and one stuck nearly closed. The other 7 AHUs do not, at this time, have CO_2 control of outdoor ventilation air.
- **Exhaust Fans.** The exhaust fan serving the 3rd floor computer lab was shut down. Because the building was operating at about +6 pascals with this fan operating and +11 pascals when it was turned off, we conclude that shutting off the fan saves fan power only. This fan was turned off “permanently” on in the fall of 2006.
- **Supply air temperature reset.** This was not implemented. The purpose of supply air temperature reset would be to reduce the amount of CW used and the amount of reheat used. Physical Plant staff concluded that fan energy use would increase largely offsetting the savings from reduced CW.
- **Hallway lighting occupancy sensors**. Installation of occupancy sensors to hallways and servicing of existing lighting controllers has not yet been done, but have not been ruled out for future implementation.

Whole Building Energy Savings Analysis for Classroom Building

Classroom I Building uses electricity and Chilled Water. Each is metered separately. A server records the electric and CW meters at five minute intervals. This data has been archived for the period January 20, 2006 through the present.

Analysis of total building electricity use and CW energy use shows significant savings.

Data Analysis Method

Five-minute data was converted into daily energy use, for both electricity and CW. Screening of the data is a critical step to ensuring good analysis. Screening involves identifying any apparent data collection problems (errors), disaggregating the data into weekend days, weekdays, holidays, etc. when building occupancy and use varies.

An initial review was performed for “out of range” errors. These errors were identified as those that do not reasonably fit with the existing data set. For example, if daily total electricity use for the building is in the range of 34 kWh/day to 62 kWh/day (with variations caused by weather, time of year, and building use schedule), and a few data points are found to be in the 0 to 20 kWh/day range, then we conclude that there was a metering problem. This occurs occasionally, we hypothesize, during the download process when the data transfer is interrupted.

Cooling energy use is driven by weather patterns and also by building occupancy. Data was separated into weekends and weekdays, since occupancy changes significantly, and analysis was performed on these groups separately. Holidays, Spring Break, and periods between semesters were eliminated because of greatly reduced occupancy. Separating weekdays from weekends has identified that there is a substantial difference between weekend and weekday energy use. Evaluation of these groups of days separately significantly improves the correlation coefficient of the best-fit lines (correlating energy use to weather).

One interesting pattern was observed. Data outliers (lower than expected daily electricity use) occurred one Friday each month for four consecutive months. One could hypothesize that more students skip classes on Fridays, thus yielding reduced internally generated cooling load. However, it is difficult to identify what would cause this to occur on only one Friday per month. Examination of the general academic calendar provided no evidence of why this pattern emerged.

HVAC energy use varies in significant part with variations in weather conditions, including drybulb temperature, dew point temperature, and solar radiation. In order to reduce some of the variation caused by weather, the pre and post energy use (both kWh/day and CW/day) has been normalized to outdoor drybulb temperature. This is done by plotting energy use versus daily outdoor temperature, and then creating a best-fit line to those data sets. The best-fit line is created using a least-squares best-fit linear regression method for pre and post data. The resulting equations, which define those best-fit lines, can be considered a model which can then be used to calculate projected annual kWh and CW savings based on the TMY2 database. We have used Tampa TMY2 database for this modeling.

While implementing this analysis method, we observed what may be intermittent problems with the University's in-house data collection system. During the period of June 27 through July 30, 2006, for example, the Classroom I Building CW meter began to read about 40% lower than either the preceding or the subsequent period. The cause of this event remains unexplained. Because of this apparent metering problem, those 33 days have been excluded from our data analysis. Metering of building electricity use does not appear to have these problems.

Table 2 presents the best fit equations (for Figures 6-11), including coefficient of determination (r^2) and number of days of data, for both kWh and CW (ton-hours) use in Classroom Building.

One of the side benefits of this recommissioning project will be improvements to the in-house monitoring equipment, as the cause of these metering anomalies are explored and corrected.

Table 2. Data for best fit equations describing electricity and chilled water usage rates as a function of outdoor temperature for the Classroom Building, where Y is the energy use rate (either kWh/day or ton-hours/day) and X is the outdoor temperature.

Energy type	Best fit equation	r^2	# days
kWh (weekend + weekday – pre)	Y=-41.3* X +7390.0	0.39	167
kWh (weekend + weekday – post)	Y=-32.1* X +5721.1	0.20	74
kWh (weekend – pre)	Y=-34.8* X +6331.3	0.78	54
kWh (weekend – post)	Y=-31.8* X +5102.7	0.60	24
kWh (weekend – post 2/15/07)	Y=-28.3* X +4741.1	0.44	20
kWh (weekday – pre)	Y=-41.9* X +7724.7	0.76	112
kWh (weekday – post)	Y=-21.6* X +5452.6	0.48	44
kWh (weekday – post 2/15/07)	Y=-34.3* X +6024.2	0.19	39
CW (weekend + weekday – pre)	Y=63.57* X –2573.9	0.78	138
CW (weekend + weekday – post)	Y=56.05* X –2313.6	0.74	67
CW (weekend – pre)	Y=63.17* X –2837.8	0.88	46
CW (weekend – post)	Y=43.88* X –1837.8	0.88	20
CW (weekend – post 2/15/07)	Y=38.5* X –1661.5	0.84	20
CW (weekday – pre)	Y=64.83* X –2516.5	0.87	92
CW (weekday – post)	Y=63.42* X –2645.1	0.91	47
CW (weekday – post 2/15/07)	Y=54.0* X –2301.8	0.71	38

Classroom Building Electricity Use and Savings

Figure 6 shows total building electricity use before and after recommissioning for weekend days and weekdays together. The building electricity meter monitors electrical energy use from all HVAC functions except chilled water (which is produced at the central chiller plant) plus lighting, plug loads, and all other building electricity uses.

As can be seen, there is quite a bit of scatter, in large part because weekends use much less electricity than weekdays. Total building electricity use pre and post recommissioning includes both weekdays and weekends. There is considerable scatter and relatively low r^2 values because weekends use about 30% less electricity per day than weekdays.

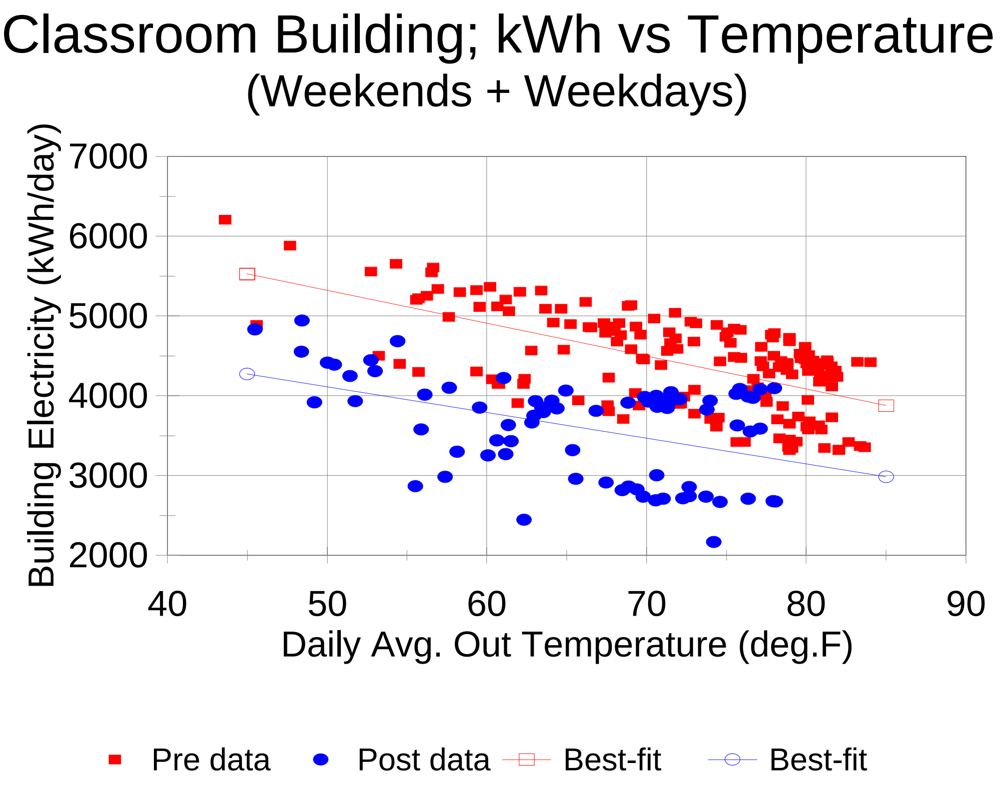


Figure 6 Whole building electricity use pre and post recommissioning, including only commissioning results through February 14, 2007 and including both weekends and weekdays.

Figures 7 and 8 show total building electricity use before and after recommissioning separately for weekends and weekdays (the red and blue data sets, respectively). Holidays and other periods of low building utilization are excluded from the analysis. The coefficient of determination (r^2) improves from about 0.3 when weekend days are included, to about 0.65 when separated. A third series of data (green color) is shown as data after additional changes were implemented on February 15, 2007. These changes were:

- Changed occupancy hours for VAV from 0430 – 2230 to 0530-2230
- FPU from 24 hours to 0530 – 2230
- Changed set points for FPU to 73 cool 68 heat occupied and 80 cool 50 heat unoccupied.

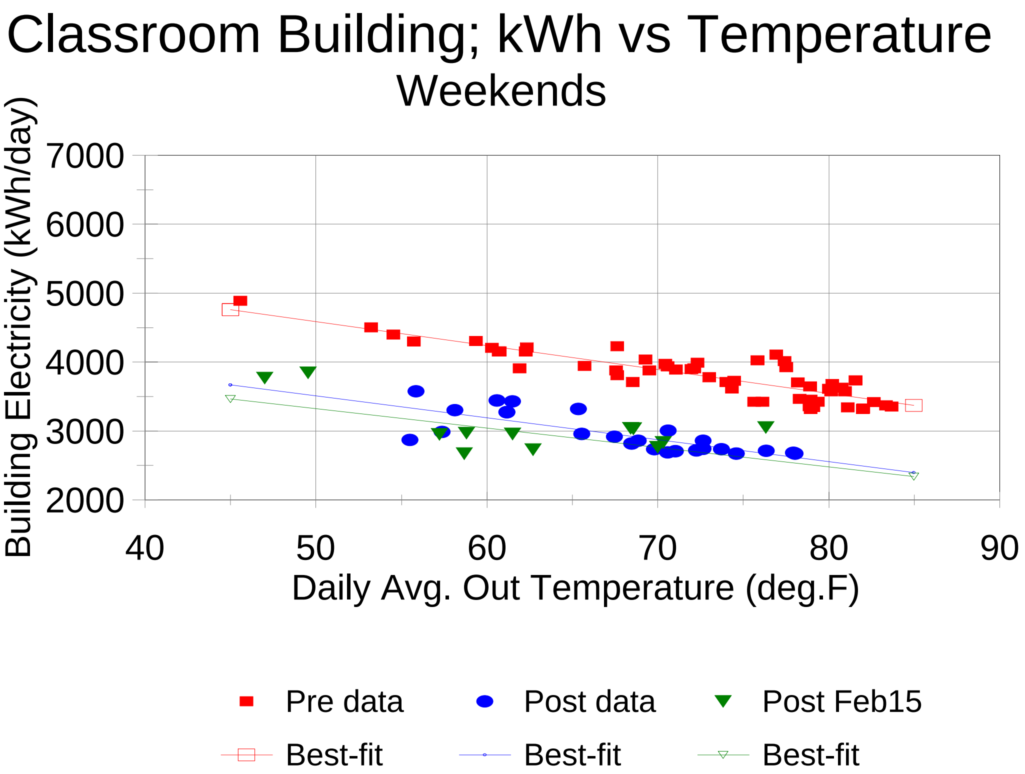


Figure 7 Weekend electricity use pre recommissioning (red), first stage of recommissioning (blue), and second stage of recommissioning (green). Total building electricity use is reduced by 29.1% on weekends.

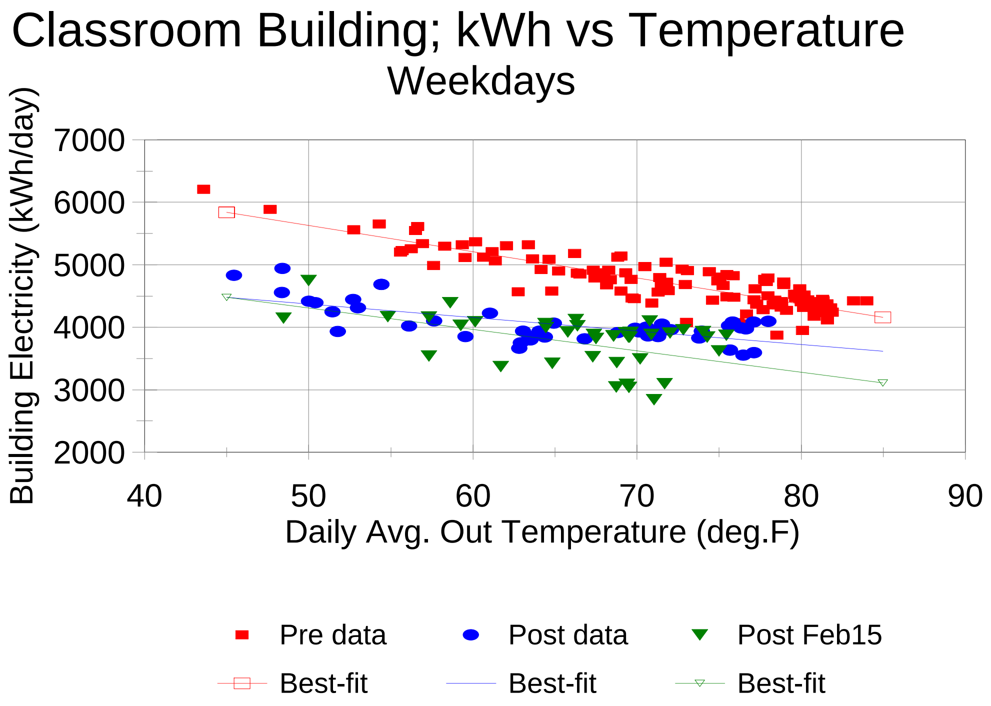


Figure 8 Weekday electricity use pre recommissioning (red), first stage of recommissioning (blue), and second stage of recommissioning (green). Total building electricity use is reduced by 24.4% on weekdays.

Several things can be said about Classroom electricity use.

- It is interesting that building electricity use, including all non-chilled water HVAC electricity use, decreases as outdoor temperature increases. This suggests that electric reheat is contributing substantially to total building energy use, and reheat increases with colder weather.
- Considering that the recommissioning changes were made only to the HVAC systems, outdoor temperature has a surprisingly good predictive power over building energy use.
- Weekdays use about 30% more electrical energy than weekend days.
- Electricity savings from recommissioning (both stages) is about 28% on weekends and 24% on weekdays (savings are at 70^{o}F).

Classroom Building Chilled Water Use and Savings

Figure 9 shows chilled water use before and after recommissioning for weekend days and weekdays together. There is a moderate amount of scatter because weekends use about 35% less CW than weekdays. CW use pre and post recommissioning includes both weekdays and weekends

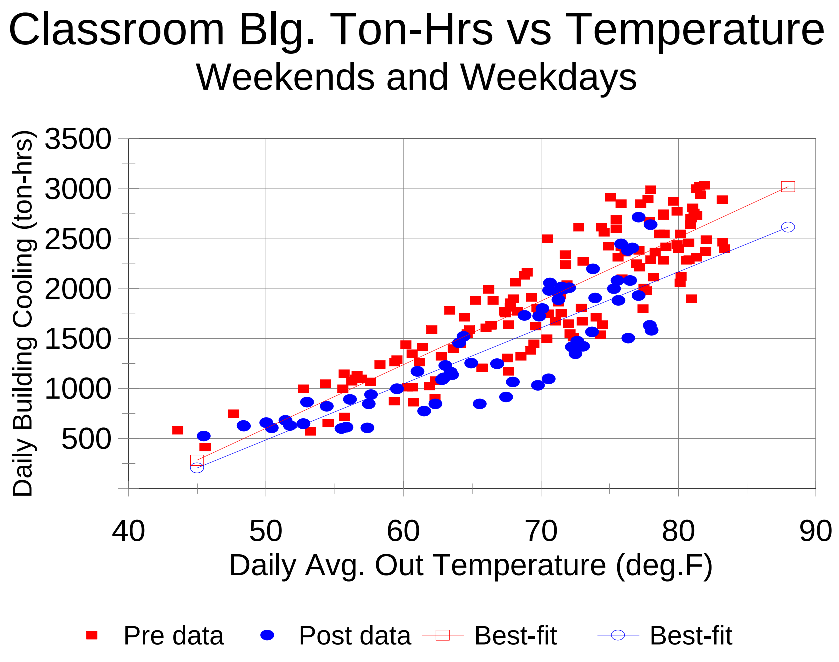


Figure 9 Classroom Building chilled water usage for pre and post retrofit periods (through February 14, 2007) for both weekends and weekdays.

Figures 10 and 11 show CW use before and after recommissioning separately for weekends and weekdays, respectively. As before, holidays and other periods of low building utilization are excluded from the analysis. r^2 improves from about 0.35 when weekend days are included, to about 0.88 when separated. This high r2 value indicates that CW usage can be accurately predicted based on outdoor temperature. An r2 of 0.88 means that about 88% of the variability of

CW usage is accounted for by outdoor temperature alone. A third series of data (green color) is shown as data after previously mentioned changes implemented on February 15, 2007.

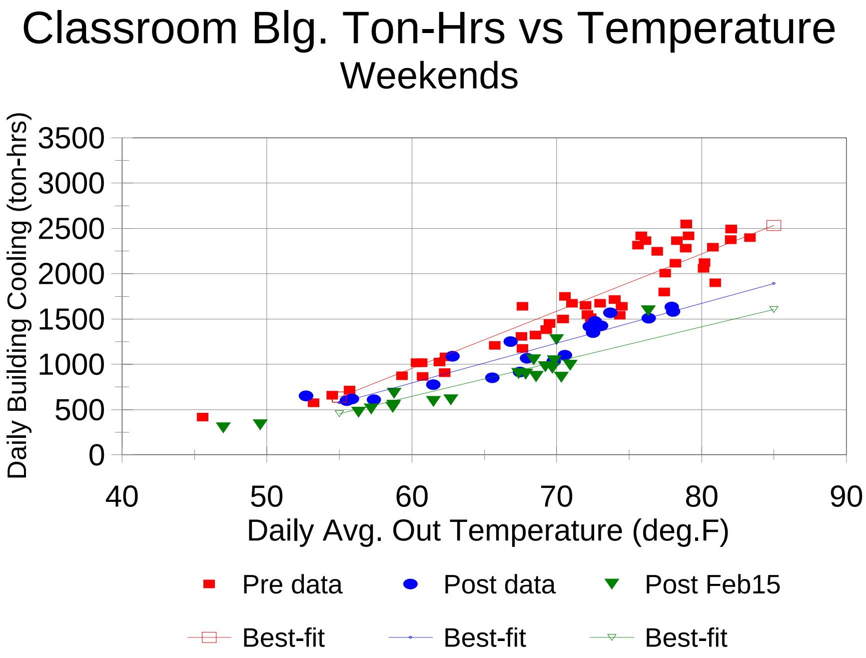


Figure 10 Weekend chilled water use pre recommissioning (red), after the first stage of recommissioning (blue), and after the second stage of recommissioning (green). Chilled water use is reduced by 34.8% on weekends.

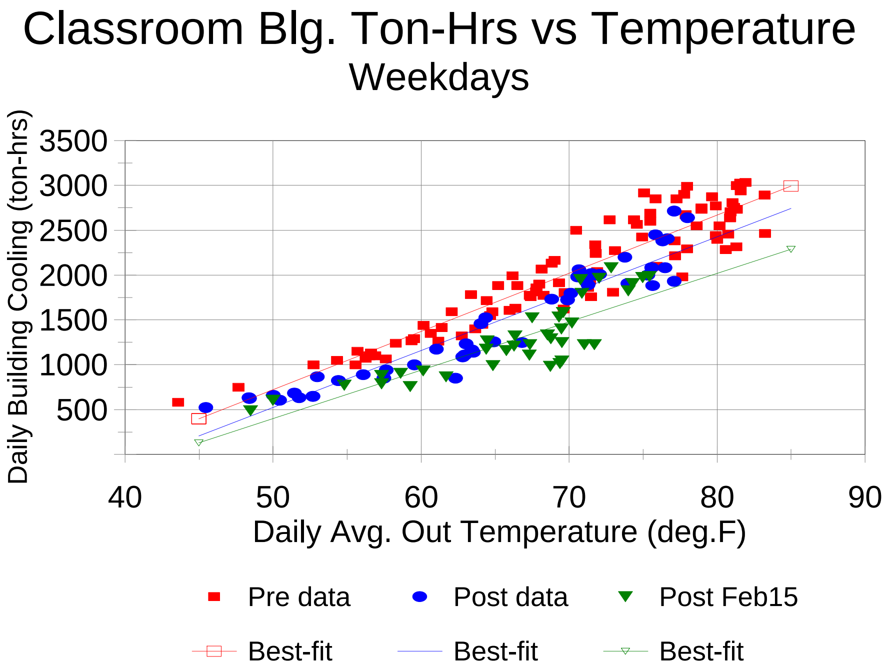


Figure 11 Weekday chilled water use pre recommissioning (red), after the first stage of recommissioning (blue), and after the second stage of recommissioning (green). Chilled water use is reduced by about 26.9% on weekdays.

Several things can be said about Classroom Building chilled water use.

- As would be expected, CW use increases as outdoor temperature increases.
- Weekdays use about 35% more CW than weekend days; 28% pre and 43% post recommissioning.
- CW savings from recommissioning is 35% on weekends and 27% on weekdays (savings are at 70^{o}F).

Modeling Annual Electricity and CW Energy Savings at the Classroom Building

The plots of kWh and CW data versus outdoor temperature, and the accompanying best fit lines, show (predict) energy use and savings for any given outdoor temperature. In order to project these savings to an entire year, it is useful to perform these calculations for each day of the year. To do this, we have used TMY2 data from Tampa Florida (TMY2 for Orlando is not available). For our purposes, hourly TMY2 data is converted to daily outdoor temperature. A day of the week was assigned to each TMY day and the appropriate weekend or weekday model was used for pre and post data. Based on this database and the four equations for kWh and ton-hour usage (for weekend and weekdays), we have calculated annual energy savings. They are shown in Table 3.

Table 3. KWh and ton-hour savings resulting from recommissioning at Classroom I Building. Savings are calculated based on TMY2 data for Tampa and best-fit equations, based on post February 15, 2007 data and with weekend and weekday savings calculated separately.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
kWh	38,248	34,597	36,602	34,878	34,529	32,652	33,474	33,363	32,692	35,216	35,380	38,132	419,764
ton hrs	12,272	10,898	15,284	16,003	19,547	20,717	21,847	22,000	20,596	18,436	15,229	12,137	204,966

Annual total pre kWh = 1,639,891 419,764/ 1,639,891 = 25.6% reduction
Annual total pre ton hrs = 717,876 204,966/ 717,876 = 28.6% reduction

The calculated savings in Table 3 represent a 25.6% reduction in total building electricity use and 28.6% reduction in CW use. Assuming energy costs of $0.10/kWh and $0.117 per ton-hour, the projected annual energy cost savings for the Classroom Building resulting from the performed recommissioning would be $65,957 ($41,976 for electricity and $23,981 for CW). Overall estimated savings as percent of total building energy cost is 26.6% ($65,957 / ($163,989 + $83,991)).

Keep in mind that these monitored savings have resulted from only a partial recommissioning implementation at the Classroom Building. The savings result from changing the sequence of operation for only 6 of the 9 AHUs, changing fan powered box thermostat heating settings for only two of the three floors, taking the HVAC to unoccupied mode for only 7 hours per day, and shutting down the AHUs and exhaust fans for only four hours per night. If these recommissioning steps had been performed on all floors and for all AHUs, and if the overnight shutdown periods had been increased from 4 hours to 10 hours, it is likely that total energy savings could have been 50% to 60% greater. Implementation of CO_2 controlled outdoor ventilation air for all 9 AHUs (instead of just two), and the use of supply temperature reset could yield additional savings. If fully implemented, recommissioning would likely reduce Classroom Building total building energy usage on the order of 45-50%.

Colbourn Hall

Recommissioning Measures Implemented

- Installed Simple Energy Management System
    - EMS installed and programmed
    - This allows both programming of a number of automatic HVAC functions and trending of a limited amount of data
- Install VFD drives
    - VFD drive units have been purchased and installed for the five AHU fans.
        - Four of the five AHU fans have been reprogrammed to operate at 80% VFD control status for the period 6 AM to 10 PM seven days a week, and 30% for eight hours each night. The first floor AHU fan has been reprogrammed to operate at 100% VFD control status for the period 6 AM to 10 PM seven days a week, and 30% for eight hours each night.
    - A VFD controller has been installed on the tertiary CW pump serving this building.
        - Pump speed has been reduced to 80% of full speed during occupied hours (6 AM to 10 PM) and 0% of full speed during unoccupied hours.
- Installed DDC valves on CW and HW coils for all AHUs, replacing existing globe valves on CW coils and no valves on HW coils.
- Cold deck and hot deck discharge temperature controls have been modifier.
    - The cold deck supply air temperature continues to have a 55^{o}F setpoint.
    - The hot deck now has a setpoint of 70-90^{o}F (manually adjusted through the EMS based on changes in weather patterns, as needed). Previously the hot deck, which did not have a control valve and was operating at full flow, had a discharge temperature of about 100^{o}F. Outdoor air (OA) dampers were reworked for the five AHUs.
- For three of the AHUs the OA damper assemblies were repaired or replaced.
    - The fifth floor, which did not previously have an OA damper, now has a damper. All OA dampers are now controlled through the EMS, open 16 hours per day and closed from 10 PM to 6 AM.
- Lighting retrofit has carried out over the period of approximately December 15, 2006 through April 1, 2007.
    - Eighty-eight exterior outdoor mercury light fixtures converted to compact fluorescent.
    - Reduced over-lit office areas from over 3 watts per ft^2 to 1.6 or less.
    - Office areas and hallways have motion sensors.
    - Replaced 20 incandescent 300-watt fixtures with 85 watt Fluorescent.

- Classrooms and labs were previously over-lit; replaced 144 watt T12 fixtures with 72 watt T8 fixtures with only a 13% reduction in lumens.
- One hundred and forty-eight two-lamp fixtures were completely removed.
- Two hundred ballasts & four hundred lamps were completely removed
- Lighting quality and color vividness was enhanced with 4100 k lamps.
- Actual energy savings from this lighting retrofit cannot be accurately estimated since no separate monitoring of lighting circuits or lighting operation schedules was performed.

Calculation of Energy Savings for Individual Recommissioning Measures

Limited disagregation of energy savings can be performed at Colbourn Hall. Trend data (for HVAC operation) is not available at Colbourn Hall. Some calculations, however, can be made, based on the modified scheduling of the HVAC systems, to identify sources of building energy use savings.

AHU fan power measurements were performed (for all five AHUs) to characterize electrical energy usage at three discrete VFD speed settings; 100%, 80%, and 30%. The same was done for the tertiary CW pump serving this building. No changes were made to the hot water circulation pump. Based on the modified operation schedules, the fan energy savings and pump savings are calculated and presented in Table 4.

Table 4. Calculated annual kWh savings for five AHUs and one CW pump at Colbourn Hall.

	"occupied" kWh savings	"occupied" % savings	"unoccupied" savings	"unoccupied" % savings	Overall % annual savings
AHU fan 1st floor	0	0	17987	47.4	15.6
AHU fan 2nd floor	16936	47.5	16936	47.5	67.3
AHU fan 3rd floor	14016	42.9	15476	47.3	64.4
AHU fan 4th floor	31536	47.4	31536	47.4	67.1
AHU fan 5th floor	22192	48.7	21608	47.4	67.9
CW pump	16936	46.8	18104	50.0	69.0
Sum	101616		121647		

At a rate of $0.10 per kWh, this yields projected annual savings for combined fan power and CW pump power of $22,300.

Whole Building Energy Savings Analysis for Colbourn Hall

Colbourn Hall uses electricity, chilled water, and natural gas (the latter for heating and reheat). A server records whole-building electric and CW meters at five minute intervals. This data has been archived for the period January 20, 2006 through the present. Natural gas use has been manually recorded monthly over a five-year period, but no 5-minute or daily data is available.

Analysis of total building electricity use and CW energy use shows substantial savings.

Data Analysis Method

Data analysis was performed in much the same manner as for Classroom Building. In order to reduce some of the variation caused by weather, the pre and post energy use (both kWh/day and ton-hours/day) has been normalized to outdoor average drybulb temperature. This is done by plotting energy use versus daily outdoor temperature, and then creating a best-fit line to those data sets. The best-fit line is created using a least-squares best-fit linear regression method for pre and post data. The resulting equations, which define those best-fit lines, can be considered a model that can then be used to calculate projected annual kWh and CW savings based on the TMY2 database. We have used Tampa TMY2 database for this modeling.

There were some problems with the data collection at Colbourn Hall. Some unexpected problems, for example, emerged when analyzing the chilled water data. Referring to Figure 12, for example, there are unusual patterns of chilled water energy use. The data for the period April 5 through August 24 is much lower than all other periods, including post retrofit periods. (Note that metered data is not available for the period August 25 through November 13, 2006.) At first we thought there might be a problem with the university's in-house data collection system. However, upon further examination of the natural gas use pattern, we identified that natural gas usage for the months of April through October 2006 was about 60% lower than during earlier periods.

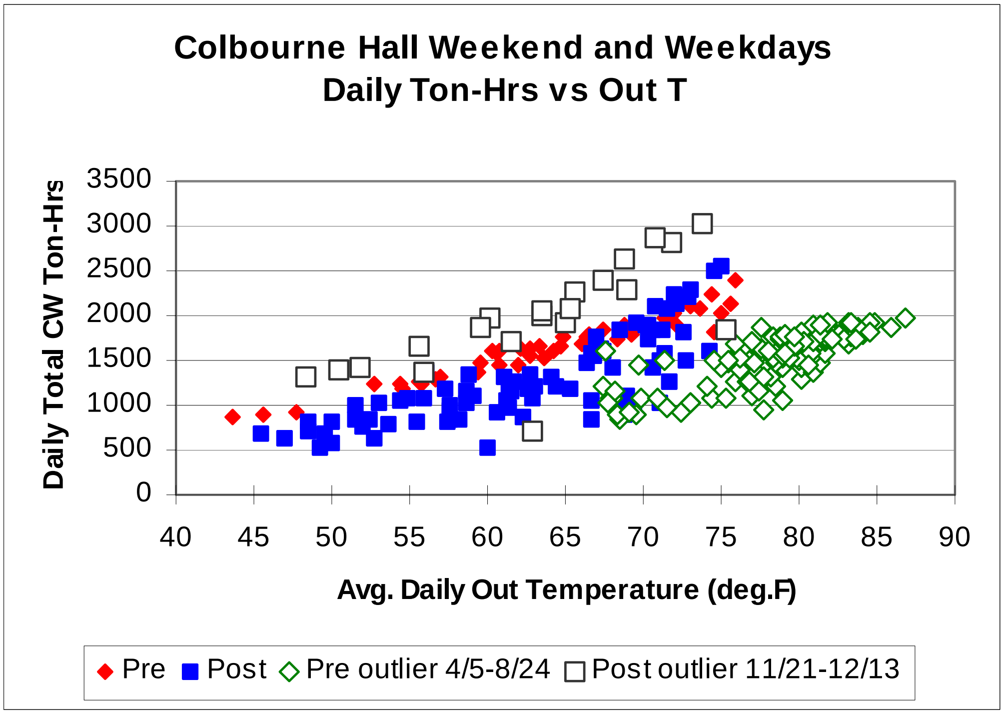


Figure 12 Chilled water versus outdoor daily temperature at Colbourn Hall. The green diamond shaped symbols correspond to a period when natural gas usage declined by about 60%, from about 5500 therms per month to about 2000 therms per month.

This reduced natural gas usage seems to have been the cause of an approximate 42% reduction in building chilled water usage during the same period.

Natural gas is used solely for the purpose of providing hot water to the hot decks of the five AHUs. This inadvertent reduction in natural gas usage, and concomitant decline in CW usage, occurred during one of the first warm periods of the late spring 2006 period. Examining weather data we observed that April 5, 2006 occurs during one of the first warm-to-hot periods of the spring (daily temperatures averaging about 74^oF for three days). At that time, manual shut-off valves for the hot-decks for floors 2 – 5 were shut, and remained shut until November 21, 2006 when the first cold period of the fall occurred (daily temperatures averaging 59^oF for several days). Interestingly, one of the project staff happened to be in the mechanical room on November 21, 2006 when Physical Plant staff was opening the manual hot water valves. At the time when the manual hot water shut-off valves were opened, a spike in natural gas usage can be observed for the month of November (see Figure 20).

Table 5 presents the best fit equations (plots of these best-fit lines shown in Figures 13-18), including coefficient of determination and number of days of data, for both kWh and CW (ton-hours) use in Colbourn Hall.

Table 5. Colbourn Hall best fit line equations.

Energy type	Best fit equation	r^2	# days
kWh (weekend + weekday – pre)	Y=-16.10* X +4082.3	0.22	247
kWh (weekend + weekday – post)	Y=-5.92* X +2526.8	0.02	138
kWh (weekend – pre)	Y=-9.34* X +3286.8	0.49	70
kWh (weekend – post)	Y=-8.46* X +2370.3	0.28	37
kWh (weekday – pre)	Y=-19.47* X +4448.5	0.39	177
kWh (weekday – post)	Y=-8.39* X +2797.7.0	0.14	60
CW (weekend + weekday – pre)	Y=42.93* X –1097.2	0.95	49
CW (weekend + weekday – post)	Y=52.3* X –1968.0	0.68	115
CW (weekend – pre)	Y=40.60* X –977.6	0.92	14
CW (weekend – post)	Y=35.6* X –1062.8	0.55	32
CW (weekday – pre)	Y=43.75* X –1138.6	0.96	35
CW (weekday – post)	Y=55.5* X –2121.4	0.75	82

Colbourn Hall Electricity Use and Savings

Figure 13 shows total building electricity use before and after recommissioning for weekend days and weekdays together. The building electricity meter monitors electrical energy use from all HVAC functions except chilled water (which is produced at the central chiller plant) plus lighting, plug loads, and all other building electricity uses. There is considerable scatter and relatively low r^2 values because weekends use about 30% less electricity per day than weekdays.

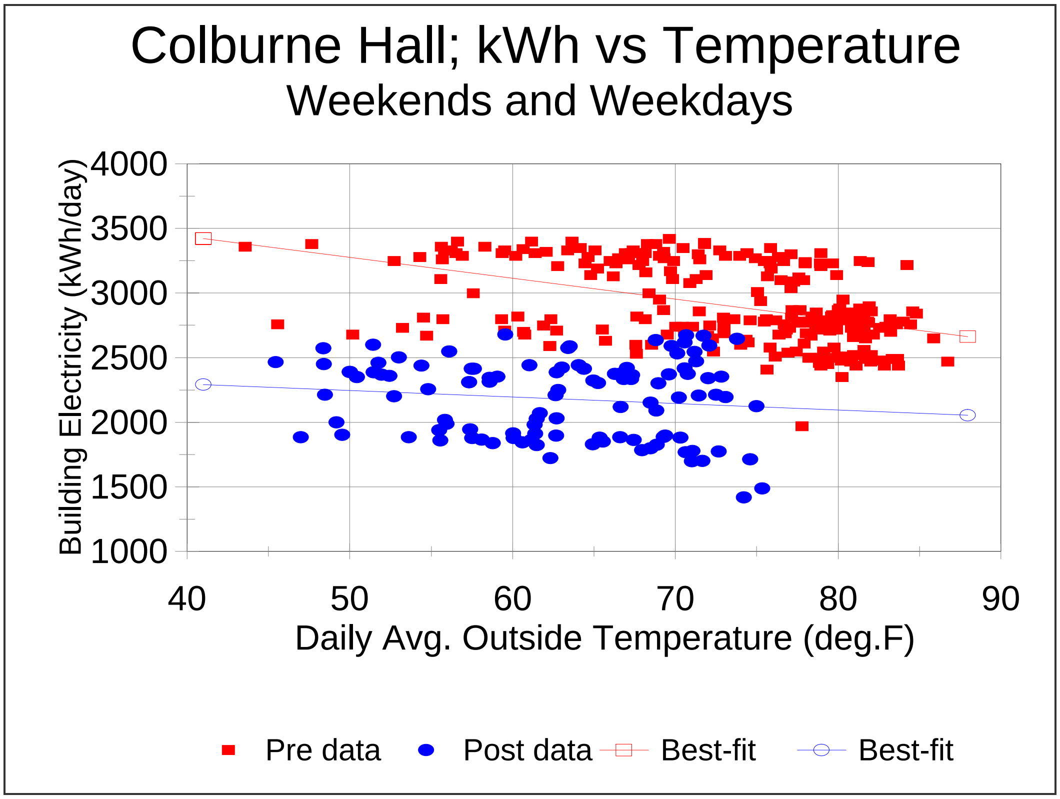


Figure 13 Whole building electricity use pre and post recommissioning for Colbourn Hall, including both weekends and weekdays.

Figures 14 and 15 show total building electricity usage before and after recommissioning separately for weekends and weekdays, respectively. Holidays and other periods of low building utilization are excluded from the analysis. The coefficient of determination (r^2) improves from about 0.12 when weekend days are included, to about 0.38 for weekends alone and 0.26 for weekdays alone.

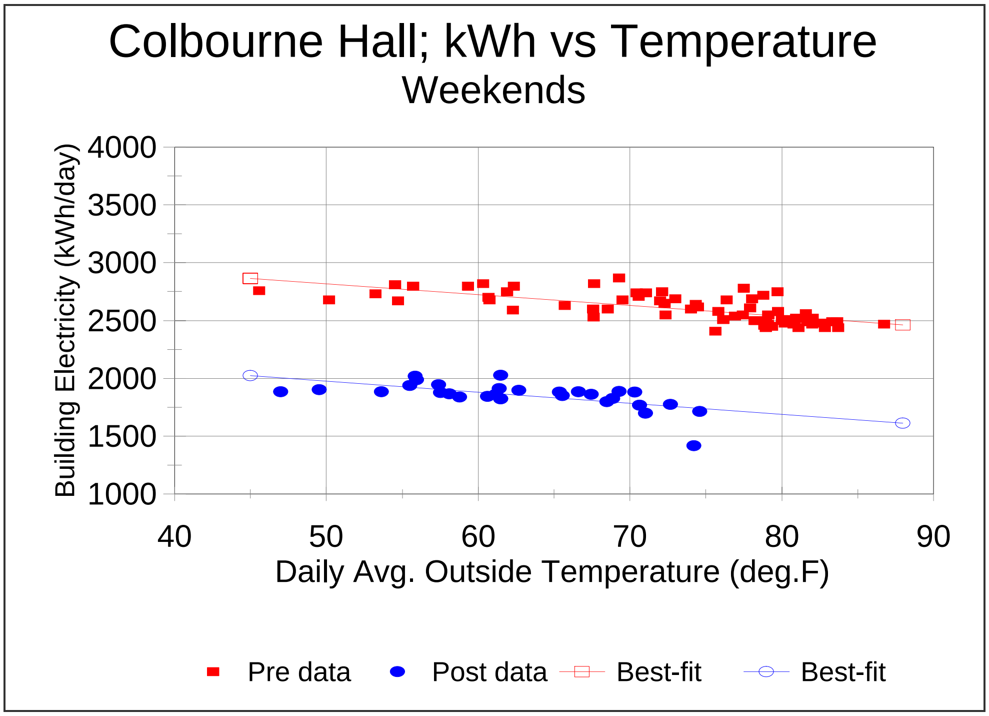


Figure 14 Building electricity usage for weekends for pre-recommissioning (January 10 – October 13, 2006) and post-recommissioning (January 12 – April 4, 2007).

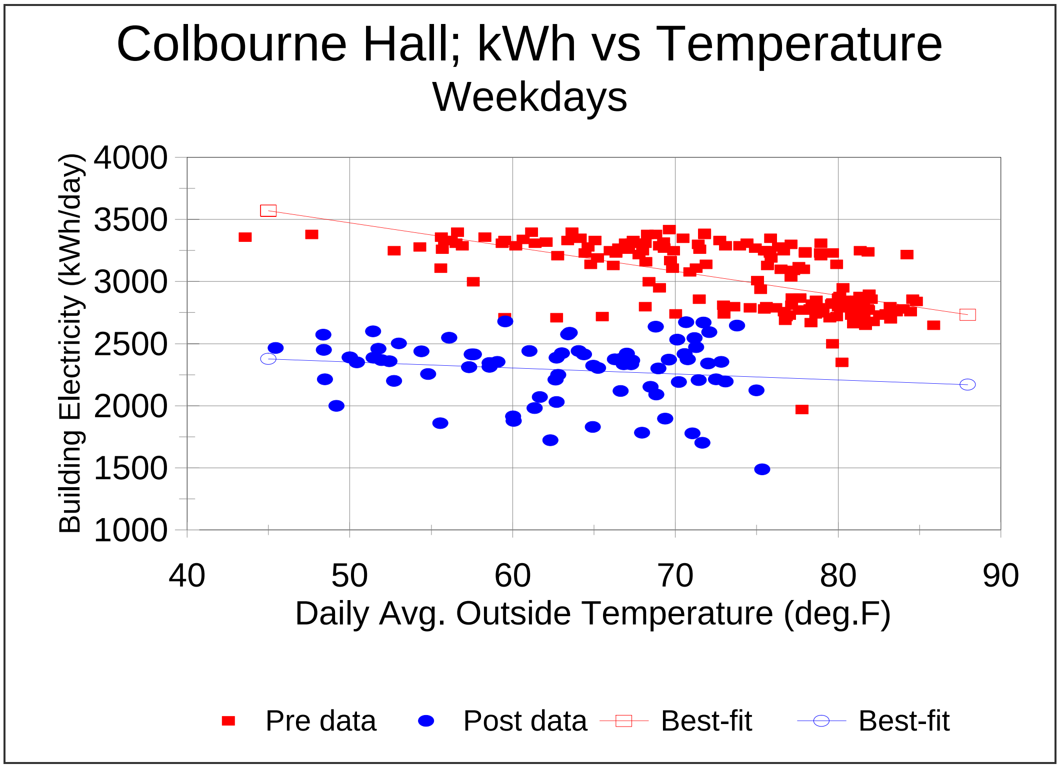


Figure 15 Building electricity usage for weekdays for pre-recommissioning (January 10 – October 13, 2006) and post-recommissioning (January 12 – April 4, 2007).

Colbourn Hall Chilled Water Use and Savings

Figure 16 shows chilled water use before and after recommissioning for weekend days and weekdays together. Figure 16 is the same as Figure 12 except that the periods of April 5 – August 24, 2006 and November 21- December 13, 2006 have been excluded, due to dramatic and unexpected changes CW usage (and as we shall see, is related to a dramatic reduction in natural gas reheat energy use). (Note that CW data for the period 8/25/06 – 11/14/06 is missing.)

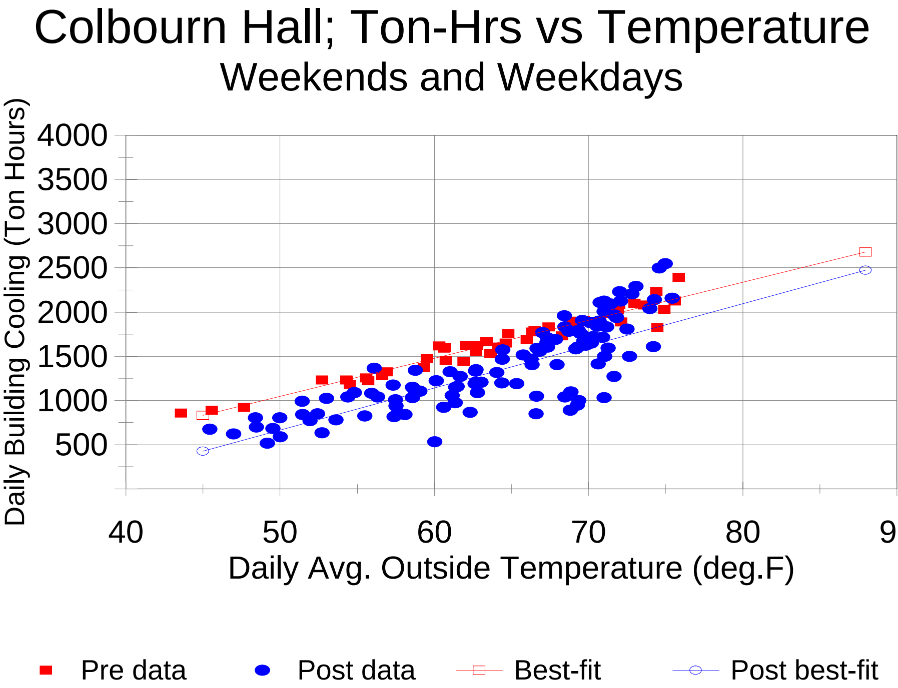


Figure 16. Pre recommissioning data for weekends and weekdays but excluding the period from April 5 - August 24, 2006 (when there was a substantial drop in natural gas use).

As mentioned earlier, the period April 5 – August 24, 2006 was excluded from the data of Figure 16. When this data is plotted separately against the period immediately preceding (2/8/06 – 4/4/06), a dramatic reduction in chilled water usage can be observed (Figure 17). Essentially all use for natural gas in this building is for reheat. The need for space heating in Colbourn Hall is very minimal. At 70^{o}F outdoor temperature, the CW usage declined from 1908 ton-hours/day to 1108 ton-hours/day, or 42% (from the 2/8/06 – 4/4/06 to the 4/5/06 – 8/24/06 period) as a result of reduced reheat boiler operation.

We can conclude, therefore, that a 60% reduction in natural gas reheat usage yields a 42% reduction in chilled water usage. By extrapolation, we can conclude that natural gas reheat has been accounting for about 70% of the total chilled water use in this building. Shutting off the reheat boiler entirely would apparently yield CW energy savings of about 70%.

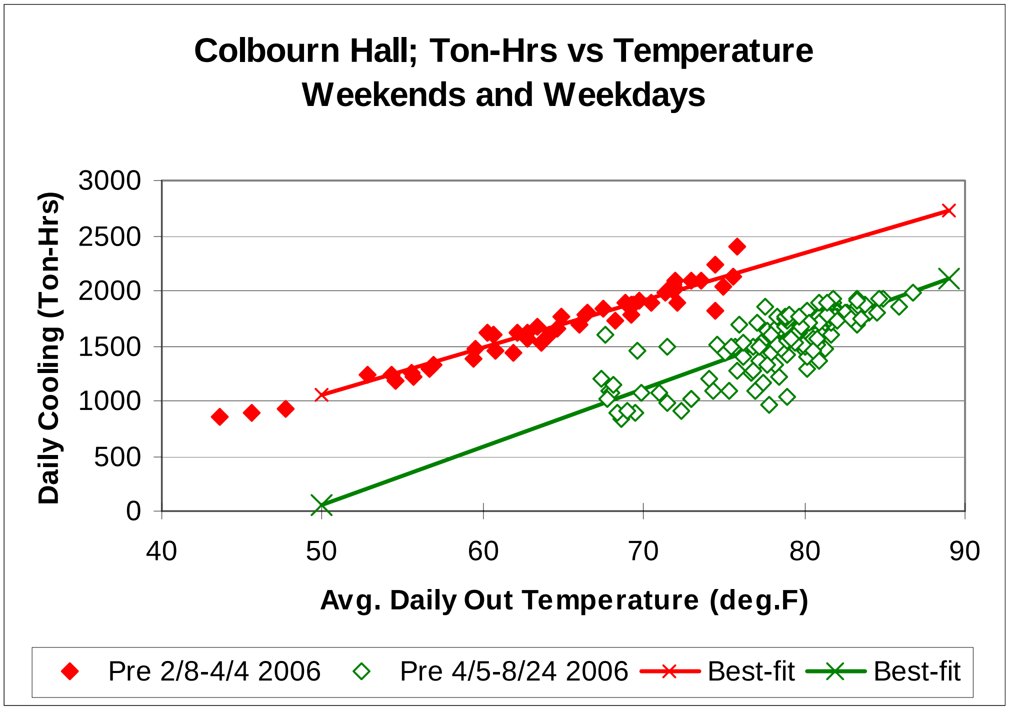


Figure 17

Pre best-fit 2/8-4/4	Y=42.93 x out Temp. –1097.2	R square = 0.9457
Pre best-fit 4/5-8/24	Y=52.36 x out Temp. –2557.4	R square = 0.6235

Figures 18 and 19 show CW use before and after recommissioning separately for weekends and weekdays, respectively. As before, holidays and other periods of low building utilization are excluded from the analysis. r^2 improves substantially when weekend days are separated from weekdays. r^2 values are considerably lower at Colbourn Hall than at the Classroom Building. While the pre data shows less scatter, there are substantially fewer days available for analysis than post data. It is expected that more pre data for days with average outdoor temperature greater than 68º F would result in an increase of the slope of the pre best-fit line. The post data period is represented by 26 days with average temperatures greater than 70º F, whereas the pre data period had only 8 days with average temperature greater than 70º F. More pre data would have been available if the natural gas usage associated with the boiler had remained about the same and if this usage did not have such an impact upon chilled water use. This is discussed in further detail under the section called Natural gas usage.

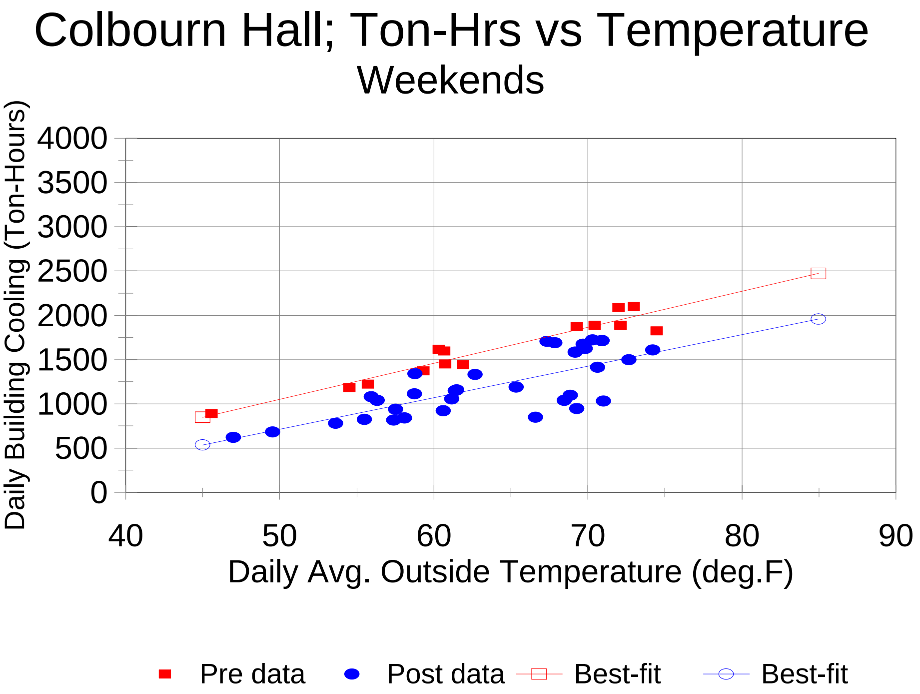


Figure 18 Chilled water usage at Colbourn Hall for weekends.

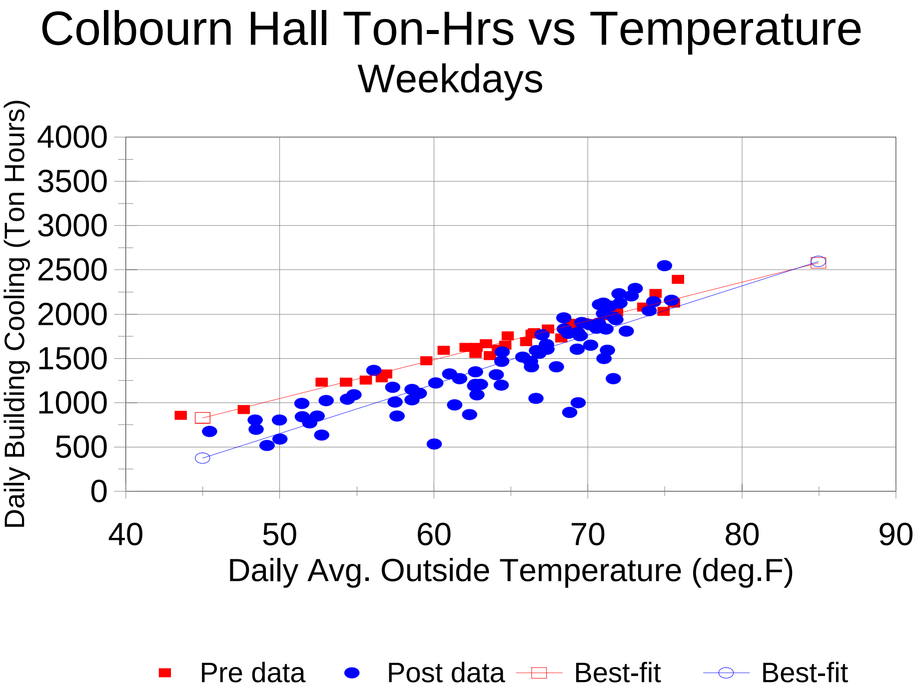


Figure 19 Chilled water usage at Colbourn Hall for weekdays.

Modeling Annual Energy Savings for Colbourn Hall

The plots of kWh and CW data versus outdoor temperature, and the accompanying best fit lines, show (predict) energy use and savings for a given outdoor temperature. In order to project these savings to an entire year, it is useful to perform these calculations for each day of the year. To do this, we again used TMY2 data from Tampa Florida. Each day of the week was assigned to each TMY day and the appropriate weekend or weekday model was used for pre and post data. Based on this database and the four equations for kWh and ton-hour usage (for weekend and weekdays), we have calculated annual energy savings. The calculated savings are shown in Table 6.

Table 6. Predicted Energy Reduction for TMY Month and Year

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
kWh	29,726	26,800	27,704	26,175	25,316	23,913	24,228	24,117	23,879	26,241	26,926	29,334	314,361
Ton hrs	9,673	8,813	8,334	7,041	5,690	5,859	4,844	5,045	5,488	6,618	8,123	9,377	84,905

Annual total pre kWh= 1,072,844 314,361/1,072,844 = 29.3% reduction
Annual total pre ton hrs= 713,237 84,904/713,237 = 11.9% reduction

The calculated savings show a 29.3% reduction in building electricity use and 11.9% reduction in CW use. If we assume energy costs of $0.10/kWh and $0.117 per ton-hour, the projected annual energy cost savings for Colbourn Hall resulting from the performed recommissioning would be $41,369 ($31,436 for electricity and $9,934 for CW).

Natural gas usage

Natural gas is used at Colbourn Hall by only one boiler, whose sole function is to provide hot water to the hot decks for the five AHUs. Natural gas is, therefore, used only for the heating/cooling systems. Because of the mild central Florida climate, almost none of the natural gas usage is for space heating (as opposed to reheat).

Natural gas metering is not available as five-minute data. It has been collected only on a monthly basis, with one manual meter reading each month.

Figure 20 shows Colbourn Hall natural gas usage for the past five years ending on January 2007. One major change occurred starting in April 2006, where monthly natural gas usage declined from an average of about 5000 therms per month to about 2000 therms per month. During that same period, CW consumption for Colbourn Hall declined rather substantially as well (see Figure 17). This reduction in CW usage appears to have occurred as a direct result of reduced natural gas usage. It appears that manual shut-off valves serving the hot decks of four of the five AHUs that serve this building were closed on April 5, 2006. This corresponds with the first hot weather of the season. Those valves remained closed until November 2006, at a time when the first call for heating occurred. During that 7 month period, an approximate 60% reduction in natural gas usage (all natural gas usage in this building is for "reheat") produced an approximate 42% reduction in building CW usage.

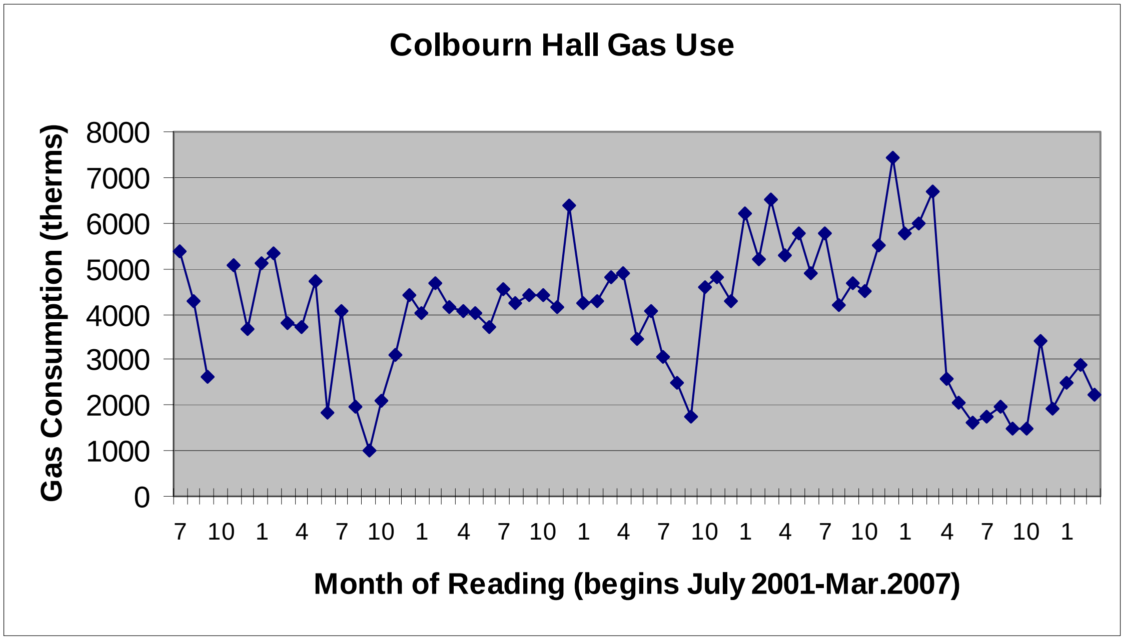


Figure 20 Colbourn Hall natural monthly natural gas usage for a nearly six-year period, showing a substantial drop in usage starting in April 2006.

Student Union Building

No recommissioning modifications have been done to this building at this time. Student Union building management is actively seeking estimates to install a new building automation system that will allow reprogramming of the HVAC systems operation. In the absence of recommissioning at this building, the following contains estimates of energy savings projections presented to the Student Union management in November 2006.

Executive Summary

Inspections and testing were carried out in the UCF Student Union building in March of 2006. From this assessment, a recommissioning plan was developed. A summary of the recommended modifications, a ballpark estimate of the cost of each measure, and a ballpark estimate of the potential energy savings are presented in Table 7.

Table 7. Recommended recommissioning steps, with estimated cost and savings.

DESCRIPTION	Estimated Cost ($)	Estimated Savings ($/year) **
Control Chilled Water pump speed • Install VFD • Program EMS	$1500	NA
Turn off unneeded exhaust fans	$8000	$4000

• Install relays & seal exhaust ducts • Program EMS		
Raise room temperature during occupied hours to 76^{o}F • Program EMS	$600	$38,000
During unoccupied hours • Set 82^{o}F room temperature, disable reheat, turn off exhaust fans, close OA dampers • Program EMS	$600	$50,000
Modify AHU speed (supply pressure reset) during occupied hours • Program EMS	$1000	$10,000
Control OA with CO$_2$ control • Purchase/install CO$_2$ controller & actuator • Program EMS	$30,000	$43,000
TOTAL	$41,700	$145,000

** Savings are calculated based on $0.10 per kWh – disregarding demand charges.

This recommissioning proposal is part of a research project, and as such, a major objective of this project is to identify the energy savings that will result from these measures. Therefore, after the recommissioning measures are implemented, an analysis will be performed to characterize (document) the energy savings that result from recommissioning.

Background

Inspections, testing, and data gathering have been performed at the UCF Student Union building in order to identify opportunities for energy savings.

The following contains findings, monitoring plans, and recommendations for modifications to the building.

Findings

Testing was performed on March 13 and 15, 2006. These days were during spring break and there was relatively limited traffic in and out of the building.

Significant areas of the building are operating at negative pressure with respect to (wrt) outdoors. The central zone of the building (atrium and hallways) is operating at near neutral to slightly positive wrt outdoors. The food court was at slight positive pressure wrt outdoors with none of the food court kitchen exhaust (and make-up) air fans operating. The ballroom pressures were not measured, but visual observation indicates that they are at substantial positive pressure compared to the central zone.

The following rooms or suits were operating at negative pressure wrt the central zone; second floor SGA offices (-3.0 Pa), rooms 221,224, and 224A (-3.1, -5.8, -5.6 Pa, respectively), second floor hall –1.0 Pa wrt out, room 218 (not divided) (+8 Pa), third floor administration office (-5.6 Pa), rooms 305, 316A, and 316D (each about +5.0 Pa), four bathrooms (about –10 Pa), and rooms 302, 303, 304, 312, and CF suite all substantially negative (-4.1 to -2.7 Pa). In summary, the central zone is generally at slight positive pressure wrt to outdoors, the ballrooms are at substantial positive pressure, but about 75% of the remaining spaces are at negative pressures wrt the central zone.

The building is operating at low temperatures, typically in the range of 67^{o}F to 71^{o}F (see Table 8). Low building temperatures appear to continue through the night. One member of the cleaning staff pointed to the medium weight jacket that he brings for overnight work because the building is so cold. It appears that the building HVAC systems are operated in “occupied” mode throughout the day and perhaps weekends as well.

Table 8. Room temperature and RH measurements.

Room # →	Computer lab	SGA	214	218a	218c	220	221	224	301	316c
Temp.(^{o}F)	68	72	71	69	67.5	69	65	70	70	70
RH (%)	54	53	59	69	70	65	70	66	57	68

Indoor RH appears to be under control. However, our monitoring occurred during periods when outdoor dew point temperatures were fairly low and therefore should not be considered representative of summer humidity control performance.

Based on limited monitoring (temperature and RH dataloggers located in four supply air streams from VAV air handlers), it appears that considerable electric reheat is occurring in this building. For example, the supply air serving Room 209 was at 80^{o}F and 35% RH for essentially the entire two-day period of March 13-15. This suggests that reheat was used to warm the supply air to 80^{o}F continuously for these two days when outdoor temperatures ranged between 55^{o}F and 85^{o}F.

The building ventilation rate appears to be about 0.9 ach based on a tracer gas test with all HVAC operating in normal mode, except restaurant EA and MA units not operating. Based on a volume of 3.2 million ft^{3}, this represents an estimated total ventilation rate of 48,000 cfm. This is sufficient ventilation for 3200 people. Many spaces within the building experience large variations in occupancy, such as the second floor meeting rooms and the ballrooms.

There are a number of exhaust fans operating in the building that are drawing air from general spaces, not from hoods or bathrooms. The purpose of these fans is not clear, but may be designed to prevent overpressurization of the building envelope. Exhaust fans serve the second floor meeting rooms. There is no need for these fans. There is a large exhaust fan that draws air from inside the dining area and just outside the dining area. There is no clear purpose for this exhaust fan.

The building is fairly airtight (about 2 ACH50). This means that when (if) the HVAC systems are turned OFF, then the building can maintain much of its coolness and especially dryness for an extended period, perhaps as much as two days, before humidity levels exceed a target of 65%. Even if cooling operation does occur during “unoccupied” periods, the amount of cooling required will be much reduced compared to that required in a leaky building.

Airflows were measured in three meeting rooms on the second floor. Table 9 shows the total supply air, return and exhaust for each room. Room 221 was clearly depressurized, however, the flow balance on the room contradicts this result. There may be some duct leakage on the return side that the flow hood would not measure.

Table 9. Second floor meeting room airflows (cfm) and pressure (pascals) with respect to hallway.

Room	Supply total	Return total	Supply-return	Exhaust	Room pressure
221 (A&B)	2610	1867	743	518	-3.1
224A	1102	546	556	573	-5.6
224B	1459	1202	257	315	-5.8

Recommendations

- Reduce air handler VFD speed
    - Force to a lower value, such as 20%, during “unoccupied” periods
    - Assuming that project staff can gain access to the building EMS, program changes for static pressure reset and supply temperature reset, similar to that proposed for Classroom I Building.
        - It is anticipated that the EMS will be programmed to iteratively implement reduction in duct static pressure control point with VAV box damper status being the feedback mechanism. For example, we anticipate that if the damper status for the classrooms is 90% or greater open, then the duct static will be reduced in 0.10 inWC increments.
        - We anticipate that the lower static pressure settings will allow the air handler fan to operate more efficiently, that less air will be forced into the fan powered VAV boxes, and consequently less consumption of CW energy and reheat energy will occur.
        - When the EMS programming is implemented, we will examine trend data to determine if there are VAV boxes that are repeatedly keeping the static pressure higher than needed. Modification or replacement of the VAV box may be implemented to allow the air handler to go to lower fan speeds.
- Program the EMS to allow reductions in CW pump static pressure control based on CCV control status. When the valve status is below xx% on all (or critical) air handlers, then continue to incrementally reduce CW loop static pressure setpoint as long as the valves are below the cutoff control status.
- Raise zone temperature settings during “occupied” hours to 76^{o}F as default, and then reduce to no lower than 74^{o}F if a request is made for lower temperatures.
- *Scheduling.* Expand HVAC “unoccupied” hours, and raise unoccupied temperature set-points throughout the building to 82^{o}F. If requested, set to 78^{o}F during cleaning crew work periods.

    - Shut OFF all exhaust fans in the building during “unoccupied” periods. If it is determined that bathroom exhaust fans should operate at night, install VFD control and set fans to a low speed during “unoccupied” periods.
    - Raise the temperature settings for hallways to 78°F for “occupied” periods, and shut down HVAC to hallways completely during “unoccupied” hours.
    - Shut OA dampers during unoccupied hours.
    - Set the air handler fan VAV minimums for “occupied” periods to as low a level as possible while still achieving the required ventilation rates.
    - Disable reheat during unoccupied hours.
    - Lighting should be shut down during “unoccupied” hours.
- *Ventilation.* Reduce ventilation air by eliminating ventilation that is not required.
    - Put OA on CO_2 control for all AHUs. Consider setting the control to 500 ppm higher than outdoors to ensure that ventilation begins before too long a delay. For example, if outdoor CO_2 levels are 400 ppm, then have the OA dampers open at 900 ppm. Establish a regular schedule to replace these CO_2 controllers every five years.
    - Service, repair, or replace all OA dampers and control mechanisms to ensure correct operation. Test systems to confirm correct operation.
    - After recommissioning is performed, monitor CO_2 levels throughout the building to confirm that ventilation is neither too high nor too low.
- *Supply air reset.* Implement supply air temperature reset when outdoor conditions permit. Supply temperature reset will help to reduce unnecessary overcooling and reheat. This supply temperature reset would be based on outdoor dew point temperature. This would require installation of a dew point sensor (at the building or on campus), and periodic maintenance of that sensor. Alternatively, the dew point temperature value could be obtained from a weather service provider.
    - A control strategy could be employed, such as the following. If outdoor dew point temperature is between 55 and 60°F, then $T_s = 60^{o}F$. If outdoor dew point temperature is between 50 and 55°F, then $T_s = 62^{o}F$. If outdoor dew point temperature is between 45 and 50°F, then $T_s = 64^{o}F$. If outdoor dew point temperature is between 40 and 45°F, then $T_s = 66^{o}F$. If outdoor dew point temperature is below 40°F, then $T_s = 68^{o}F$.
    - Program the EMS so that if overnight low drybulb temperature is 42°F or below, then force AHU fans to minimum flow and CW valves to closed unless the zone temperature rises above the room setpoint temperature.
- Consider implementing modifications in July.
- Install VFD control for FCUs serving 2nd floor conference area to convert these CV with modulating valve systems to VAV systems. Program EMS to allow supply temperature reset based on outdoor conditions. Exhaust fans serving those spaces should be disabled and the exhaust discharge sealed.
- Seal unwanted holes in the building envelope
    - Passive roof openings

Estimated Energy Savings

Estimated energy savings from various proposed recommissioning measures have been prepared (Table 10). These should be considered as “ballpark” savings estimates designed to provide guidance regarding the likely energy savings outcome from implementation of the specified measures.

Table 10. Recommissioning sequence and estimated energy savings for Student Union.

Recommissioning Task	**Probable Energy Savings and Other Benefits**
Install VFD control of CW pump. Cost for installing VFD controllers for the CW pumps is unknown.	Pumping energy savings are unknown. Dustin, can you provide an estimate of cost and savings?
Shut OFF unneeded exhaust fans, such as those serving the second floor meeting rooms, and a large unit serving the dining areas.	This zone is operating at negative pressure. This creates higher than necessary ventilation, increases indoor RH, and creates the potential for moisture problems inside exterior walls. Savings would result from eliminating fan energy consumption and also from reduced infiltration. Fan energy savings: assume 6000 cfm of total air flow. Assume fan power of 400 W per 1000 cfm. Fan motor energy savings would be about 58 kWh per day. Infiltration savings: with the FCUs and exhaust fans operating, the zones run at negative pressure. This means the exhaust flow is greater than the outdoor air flow. If we assume that the exhaust is 25% greater than the outdoor air flow, then 25% of the exhaust flow rate would be contributing to building infiltration. Savings calculation: indoor enthalpy 28.14 Btu/lb (76^{o}F and 50% RH); outdoor enthalpy 39.69 Btu/lb (82^{o}F and 77% RH). 6000 cfm x 25% x 60 / 13.33 ft3/lb x (39.69 – 28.14) / 3413 Btu per kWh/ 3.0 (COP) = 7.6 kW. This is about 180 kWh per day of air conditioning energy use.
Raise zone temperatures during “occupied” hours (5 AM – 11 PM weekdays; different on weekends?) per new campus guidelines.	The building is currently operating at about 69^{o}F. For energy assessment purposes, assume we raise room temperature to 75^{o}F during occupied hours. Research finds an 8% increase in cooling energy use per degree drop in indoor temperature. This suggests, therefore, a 7.4% decrease in cooling energy use for each degree that the indoor temperature is increased. Therefore, a 6^{o}F increase in indoor temperature would produce an approximate 45% reduction in cooling energy use. Proposed calculation: take current CW consumption times 0.45 times 0.75 (occupied period is 75% of day). Overnight (unoccupied) savings are being calculated separately in the following section. If we assume 4,000 ton-hours per day average, then savings would be 1350 ton-hours per day. This is equivalent to approximately 1600 kWh per day. Consider raising the building setpoint to 76^{o}F for the week of August 5-12, and then returning the building to current settings for August 13-19. This would allow us to assess the energy savings from a temperature change, with comparable occupancy.

Raise "unoccupied" (11 PM – 5 AM weekdays; different on weekends?) space temperature setting to 82°F (default), or 78°F during periods when cleaning staff is working and requests a lower setting. Disable reheat and building exhaust fans, and close OA dampers during overnight.	The building is currently operating at about 69°F during the overnight period. Raise the temperature to 82°F (and 78°F for cleaning crews). This might yield an average overnight temperature of 80°F. Research finds an 8% increase in cooling energy use per degree drop in indoor temperature. This suggests, therefore, a 7.4% decrease in cooling energy use for each degree that the indoor temperature is increased. Therefore, an 11°F increase in indoor temperature would produce an approximate 80% reduction in cooling energy use for the overnight period. However, since the building will heat up during the overnight, and this stored cooling load will have to be removed at the beginning of the occupied period of the day, I would suggest that we claim only 70% of the calculated savings. Proposed calculation: take current CW consumption times 0.80 times 0.25 (unoccupied period is 25% of day) times 0.70 (adjustment for stored cooling load). If we assume 4,000 ton-hours per day average, then savings would be 560 ton-hours per day. This is equivalent to approximately 650 kWh per day. Exhaust fan savings from reduced fan power. If we assume that the exhaust fans that currently operate during the overnight total 12000 cfm and fan power is 400 W per 1000 cfm, then the fan power savings would be about 30 kWh per day. Energy savings from shutting OA. Assume that outdoor ventilation air goes from 40,000 cfm to 0 cfm, then the calculated energy savings would be as follows. Assume indoor conditions of 76°F and 50% RH. Savings calculation: indoor enthalpy 28.14 Btu/lb (76°F and 50% RH); outdoor enthalpy 39.69 Btu/lb (82°F and 77% RH). 40000 cfm 60 / 13.33 ft3/lb x (39.69 – 28.14) / 3413 Btu per kWh/ 3.0 (COP) = 202 kW. This is about 1200 kWh per day (6 hours) of air conditioning energy use. This is equivalent to approximately 1400 kWh per day. Reheat savings, while unknown, may be substantial.
Alternative to preceding item. Take most AHUs to 20% or OFF during unoccupied hours (11PM-5AM. All EA OFF overnight). Disable reheat during unoccupied periods.	Assume current AHU fan status averages 50% overnight. Assume 500W per 1000 cfm. Assume 320 cfm per ton, and assume 800 tons of total capacity. 128000 cfm reduced to 51000 cfm. Fan savings would be 38.5 kW, or 231 kWh per night. Cooling savings. Going from 50% AHU status to 20% AHU status. Assume return of 70°F and 50% RH, and supply of 55°F and 91% RH. Enthalpy drop is (25.33 – 22.30) = 3.03 Btu/lb. 350000 lb per hour reduction in flow rate. 1.1 million Btu/hr reduction in CW requirement. Assuming 3.0 COP for delivered cooling, this converts to 650 kWh per night. Electric reheat would also be reduced. Savings are unknown but would likely be very large.
Modify AHU speed (supply pressure reset) during occupied hours.	If we assume that the AHU fans now run at an average 70% status during occupied hours, and if we assume a 25% reduction in AHU fan energy use could be achieved, then the current estimated fan power of 90 kW (for 180,000 cfm flow at 70% status) could be reduced to 67.5 kW, yielding savings of 405 kWh during each 18 hour day. Reduced AHU fan speed would also reduce overcooling of space, which would reduce consumption of CW. The amount of overcooling that occurs now is unknown. Electric reheat would also be reduced. Savings are unknown but could be very large.

Implement OA control using CO_2 controllers. Cost of $1000 per AHU.	Ventilation savings: tracer gas decay testing found the building ventilation rate to be approximately 48,000 cfm. Assume that 40,000 cfm is in the form of outdoor air. Assume that CO_2 control would eliminate 50% of that outdoor ventilation air. Assume indoor conditions of 76°F and 50% RH. Savings calculation: indoor enthalpy 28.14 Btu/lb (76°F and 50% RH); outdoor enthalpy 39.69 Btu/lb (82°F and 77% RH). 20000 cfm 60 / 13.33 ft3/lb x (39.69 – 28.14) / 3413 Btu per kWh/ 3.0 (COP) = 101 kW. This is about 1800 kWh per day (18 hours not including night which already has OA dampers closed) of air conditioning energy use. If we assume that CO_2 control would be installed on 30 combined AHU and FCUs, for a total cost of $30,000, then the payback for this would be 167 days.
Supply temperature reset starting in November. Trial run. Install outdoor dew point measurement.	During periods of cooler weather, cooling supply air to 55°F may lead to overcooling of the space. Reheat is used in some cases to prevent this overcooling. Therefore, energy is wasted twice – once to unnecessarily cool the air and then again to reheat the air. Note that short-term monitoring on one Student Union air handler found that reheat was being used intermittently. Some of the overcooling may be eliminated by reducing AHU fan speeds (see earlier item). However, during some weather conditions when outdoor dew point temperatures are lower, supply temperature reset can be used to further reduce the amount of overcooling that occurs and the amount of reheat that is required. Energy savings are not known but may be rather large.

Table 11 summarizes the estimated savings, extracted from Table 10. These results are also summarized (with annual energy savings) in Table 7.

Table 11. Summary of estimated energy savings (assume $0.10 per kWh).

	Monthly Estimated Savings kWh ($)
Control CW pumps with VFD	unknown
Turn off unneeded exhaust fans	7200 ($720)
Raise room temperature during occupied hours to 76°F	48000 ($4800)
Raise room temperature during unoccupied hours to 82°F plus disable reheat, turn off exhaust fans, and close OA dampers	63000 ($6300)
Modify AHU speed (supply pressure reset) during occupied hours	12000 ($1200)
Control OA with CO_2 control	54000 ($5400)
TOTAL	184200 ($18,420)

These estimates show annual energy savings of about $220,000. Given that the calculations were performed based upon summer weather conditions, actual annual savings might be more on the order of $175,000.

Does this level of savings make sense? Consider the following.

As a point of reference, building energy use for May 2005 was about 540,000 kWh per month (excluding natural gas and converting CW usage at a rate of 1.17 kWh per ton-hour). Of this amount, about 170,000 kWh is CW. Including AHU and EA fans, and reheat, total HVAC may be on the order of 250,000 kWh per month. Note that estimated savings, not including pump energy and reheat energy, is about 185,000 kWh, or about 75% of the ballpark total. While at first blush this seems high, keep in mind that raising the building temperature by 6^{o}F by itself (on a 24 hour basis) would save a projected 60,000 kWh (25% of HVAC). When we start to eliminate most of the nighttime cooling, EA and OA flows, and reheat, and then cut average building ventilation by 50% (CO_2 control), the possibility of reducing 75% of current HVAC energy use does not seem to be too far off base.

If only half of these projected savings are realized, the result would be truly outstanding.

Task 2. Green Roof

EXECUTIVE SUMMARY

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. One half of the 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 $Btu/ft^2 \cdot hr$ or 18.3% less than the conventional roof’s average heat flux rate of 0.48 $Btu/ft^2 \cdot hr$.

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 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^oF, 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 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, 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 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°F and summertime heat flow through the roof by 70% to 90% compared with a conventional roof on the same building[4]. 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[5]. 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[6].

INTRODUCTION

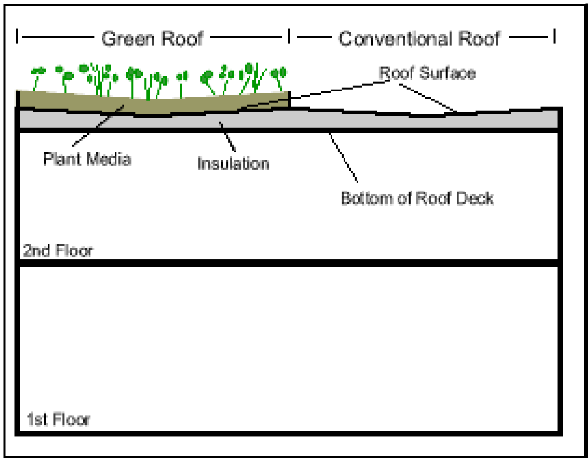
This Florida green roof project is being led by the University of Central Florida's Stormwater Management Academy under a grant from the Florida Department of Environmental Protection (FDEP). While the primary purpose of the project is to evaluate rainwater runoff benefits of the green roof, FDEP, through a U.S. Department of Energy State Energy Program Grant is also funding the authors 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 roof with a planted 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). Both the conventional and green roofs were installed in the spring of 2005. Figures 21 and 22 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.

Figure 21. Green roof April 28th, 2005.

Figure 22. 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 23 and 24).



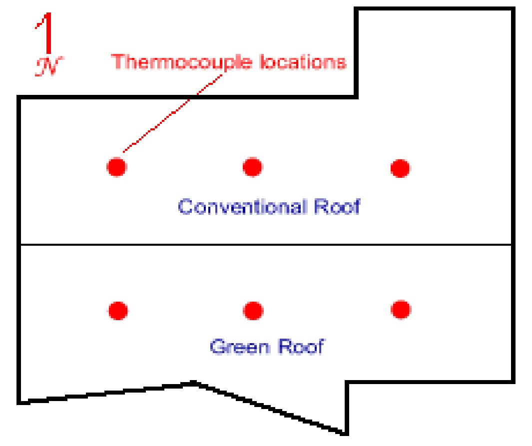


Figure 23. Roof diagram with sensor locations. **Figure 24**. Building section diagram.

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 23. 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 it was noted that 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[8]. 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 25 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^{o}F verses 87.5^{o}F for the green roof. The maximum average day temperature seen for the conventional roof surface was 129.7^{o}F while the maximum average day green roof surface temperature was 91.3^{o}F, or approximately 38^{o}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^{o}F for the conventional roof and 84.0^{o}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.

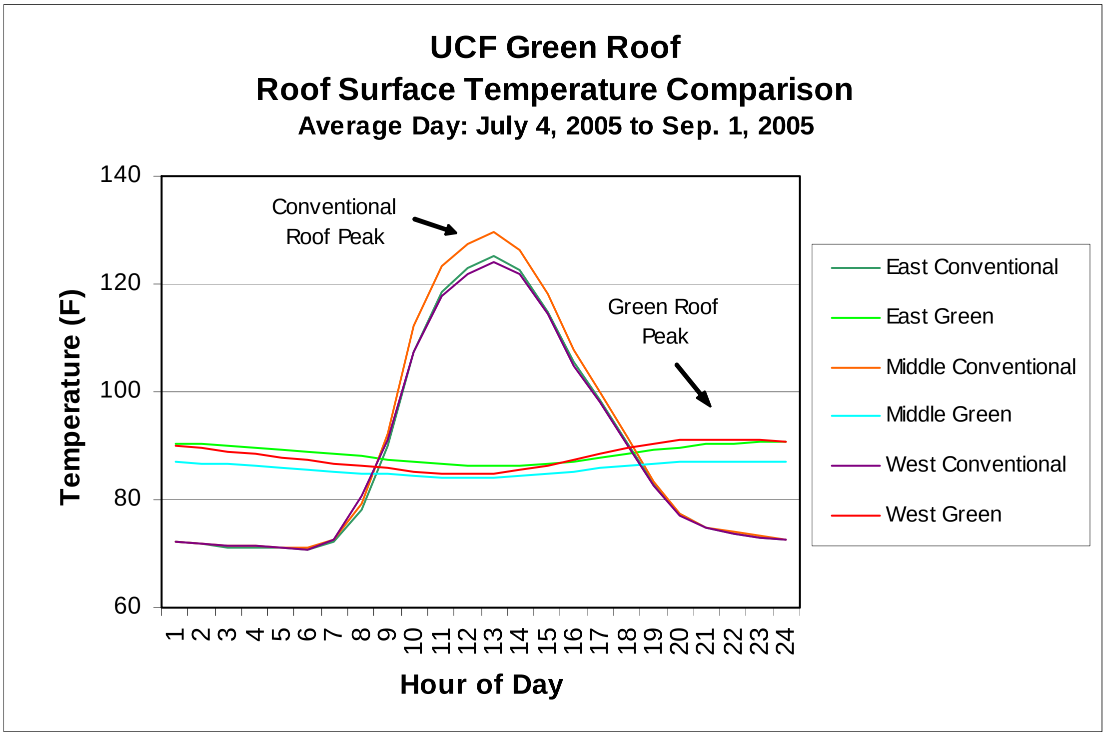


Figure 25: Average 2005 summer day conventional and green roof surface temperatures.

Figure 26 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 27 shows a comparison of the averaged conventional and green roof temperatures over the 2005 and 2006 average days.

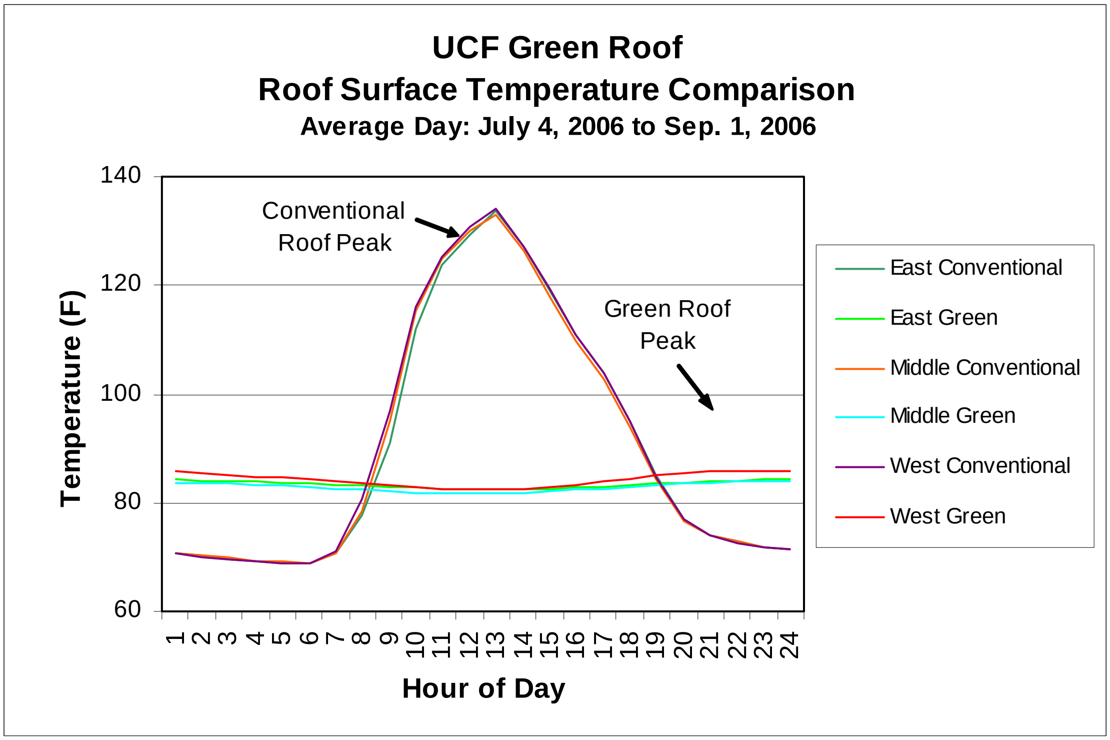


Figure 26: Average 2006 summer day conventional and green roof surface temperatures.

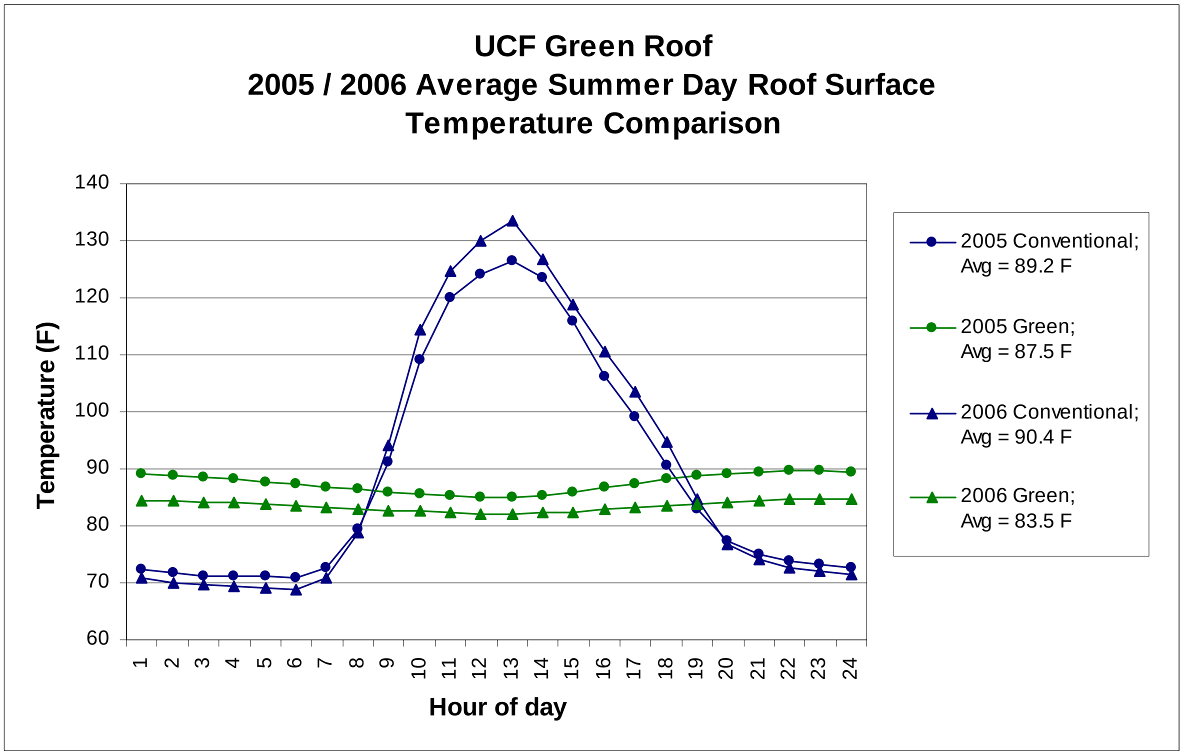


Figure 27: Comparison of 2005 and 2006 average summer day averaged conventional and green *roof surface temperatures.*

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 28 and 29 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·hr (at 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).

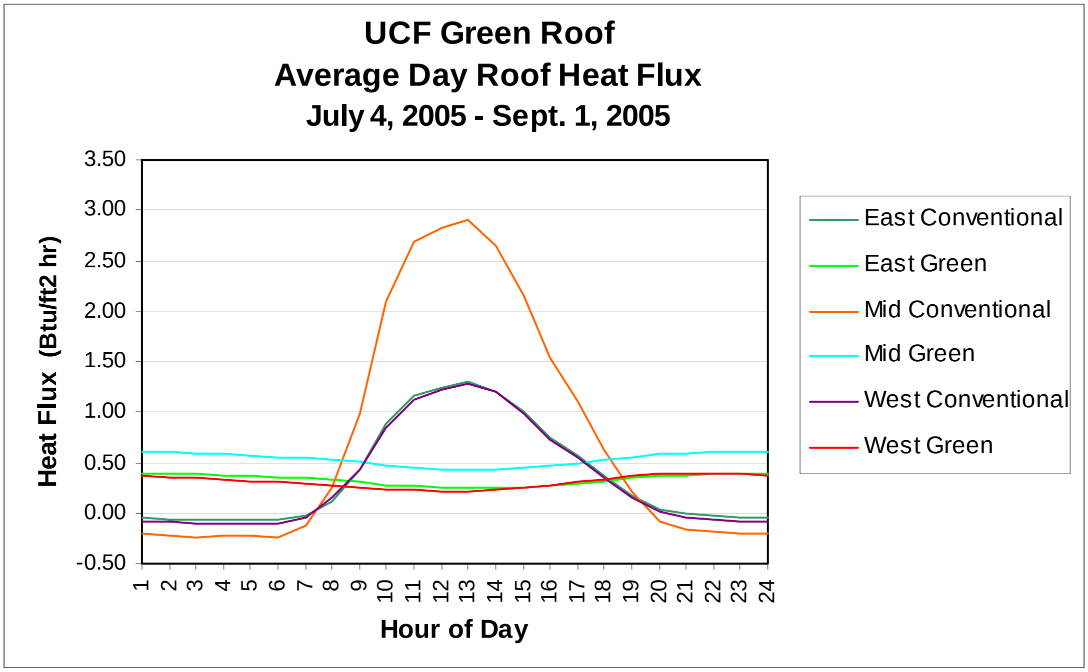


Figure 28: Average 2005 summer day conventional and green roof heat flux rates.

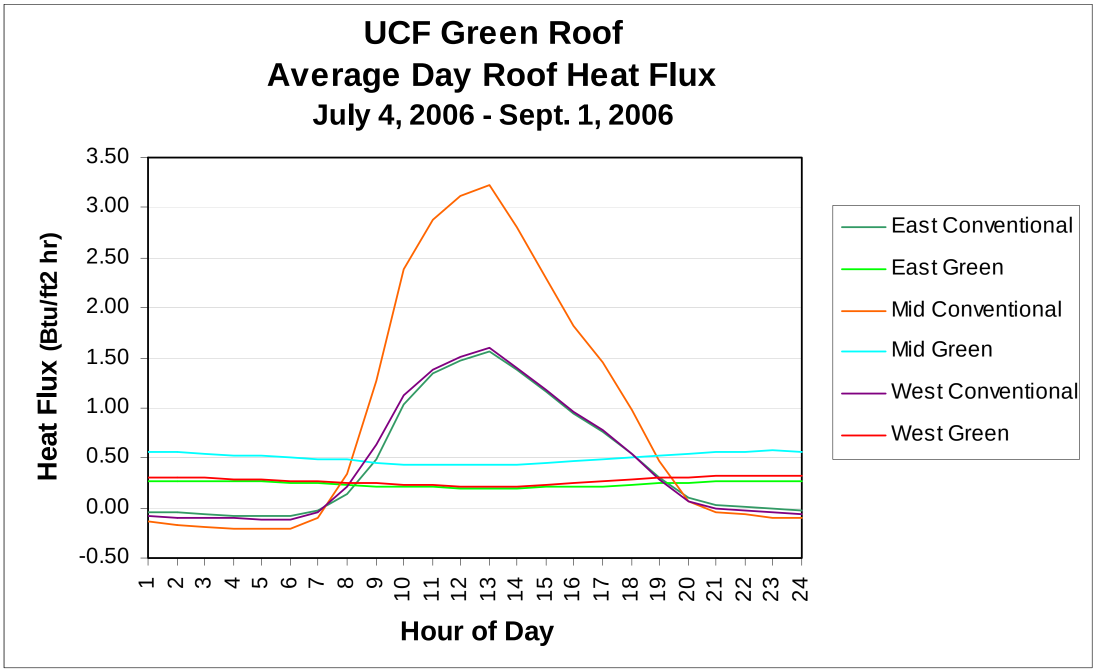


Figure 29: Average 2006 summer day conventional and green roof heat flux rates.

Table 12 shows average summer heat flux rates over the July 4th through September 1st 2005 monitored period. The weighted average heat flux rate over the period for the green roof is 0.39 Btu/ft^2·hr or 18.8% 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 12: UCF Green Roof Average Summer Heat Flux
Estimates for July 4, 2005 – Sept. 1, 2005

Location	***Approximate R-value (^{o}F·ft^2·h/Btu)***	***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***

Table 13 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·hr or 43.3% less than the conventional roof's average heat flux rate of 0.60 Btu/ft^2·hr, with the most significant differences again occurring near the middle of the roofs at the points of lowest insulation.

Table 13: 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***

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 14 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.

*Table14**: 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 30 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^{o}F, 62.1^{o}F and 45.1^{o}F respectively. The maximum, average and minimum average day temperatures for the green roof surface were 65.4^{o}F, 63.5^{o}F and 61.1^{o}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.

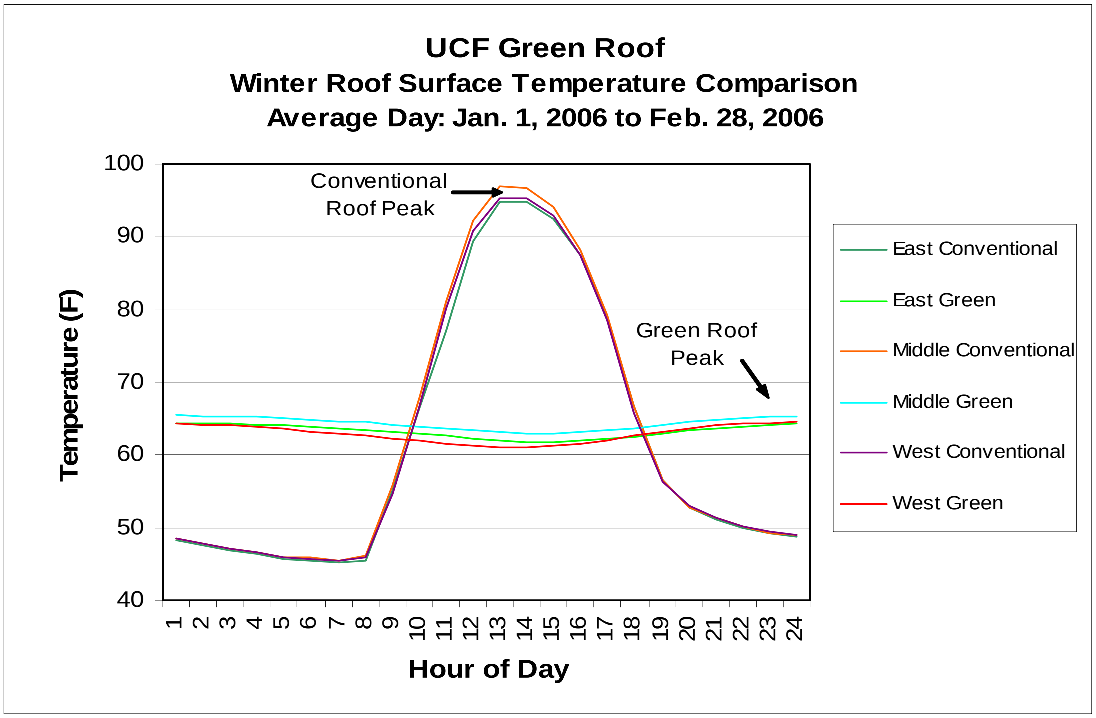


Figure 30: Comparison of average winter day green and conventional roof surface temperatures.

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^{o}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^{o}F, 49.5^{o}F and 35.7^{o}F respectively. The maximum, average and minimum average day temperatures for the green roof surface under the same conditions were 63.9^{o}F, 60.2^{o}F and 53.3^{o}F respectively.

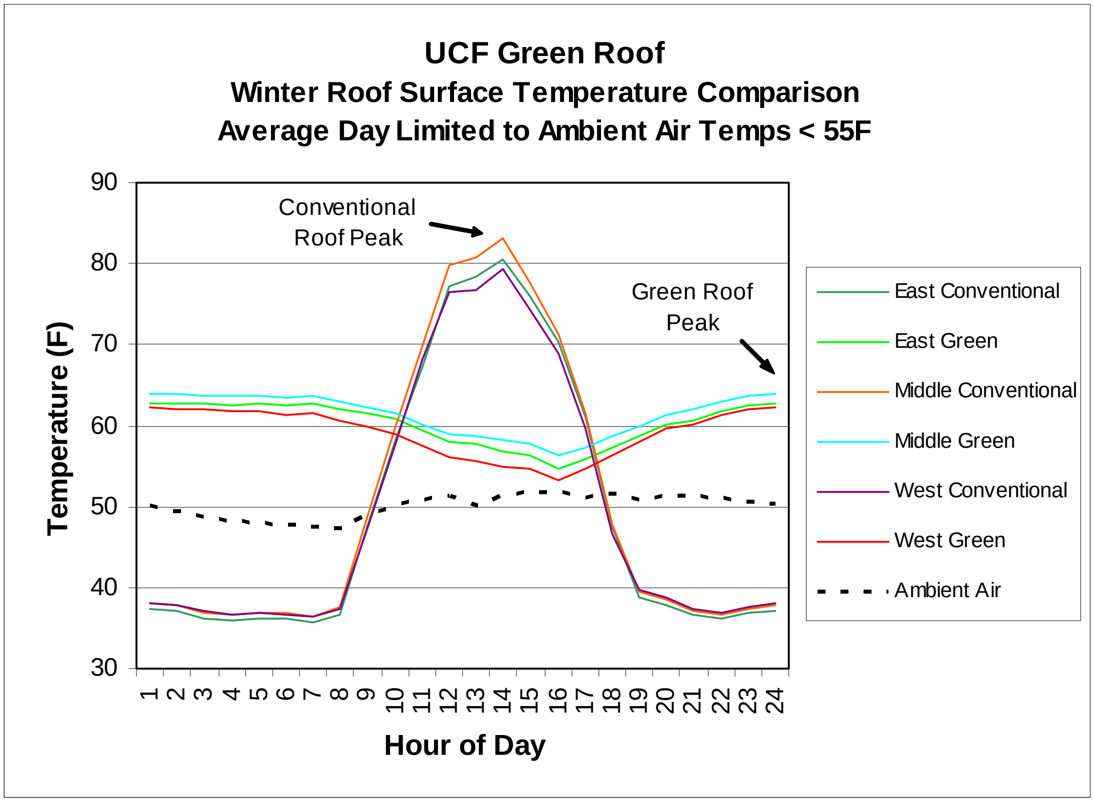


Figure 31: Comparison of average winter day, ambient air temperature-limited green and conventional roof surface temperatures.

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 32. 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.

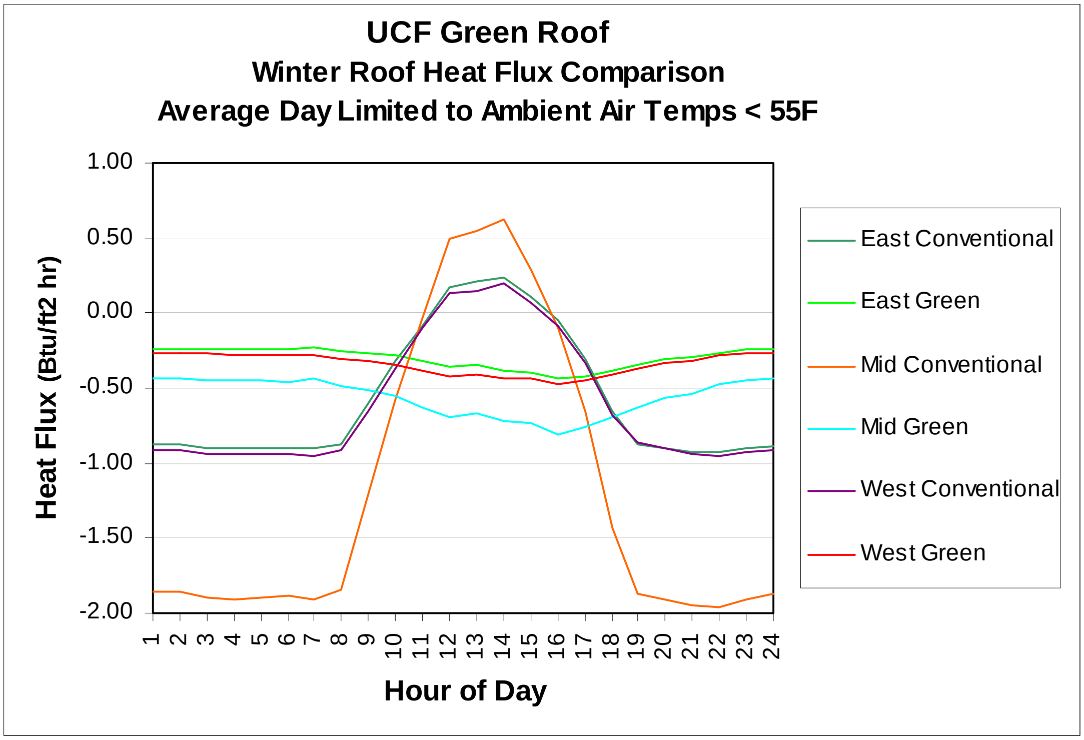


Figure 32: Comparison of average winter day, ambient air temperature-limited green and conventional roof heat fluxes.

Table 15 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 15**: UCF Green Roof Average Winter Heat Flux Estimates Limited to Ambient Air 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 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°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°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[9]. The comparison between 2005 and 2006 summer results from this project underscore how roof color and level of green roof canopy affect temperatures, heat flux and in turn, savings. 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 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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Task 3. Training

Failure-Proof Building Course

The project deliverables call for offering *"3 to 4-course series in two different cities. Indicate the numbers of students attending each course and summary of course evaluations in the final report. Include copies of training agendas and course materials. Incorporate project results into the Designing and Maintaining the Failure-Proof Building series suited for architects, engineers, facility and energy managers, and IAQ diagnosticians."*

- A five-course series titled Designing and Maintaining the Failure-Proof Building was developed. Materials had previously (in 2003) been developed for a larger course with a total of 10 days of training offered. Two days of the original course had been developed and presented by Joe Lstiburek and Terry Brennan. The portions of the course that they had presented, and which was then incorporated into the current five-day course, had to be newly developed. Other portions of the course were more easily adapted from the original into the current course offering.
- Two hours of lectures for Course 3 were developed from recommissioning activities from this project, and were presented by Dustin Jackson.
- Detailed outlines of the course content were submitted to the Florida Boards that govern continuing education credits for engineers, architects, and contractors. Each of the five courses gained approval for 7.5 continuing education hours for each completed course.
    - Dates and locations for the five courses were finalized. Each five-day course was scheduled to be given in three Florida cities. This involved significant effort to coordinate the schedules of 6 key speakers and the availability of instruction sites for 15 course offerings (five courses times three cities).
    - Courses were scheduled in Sarasota for January 23 and 24, February 7, 21, and 22. Due to low registration numbers (typically 2 to 5 persons per course were signed up with one week to go), all five courses were cancelled.
    - Courses were scheduled for Cocoa (at FSEC) for February 26, March 1, 2, 5 and 6. All of these classes were held, except for Course 4 (the Design Charrette) which had only 4 registrants.
    - Courses were scheduled for West Palm Beach for March 21, April 10, 11, 25, and 26. All five courses were held.
- A 12-page marketing brochure was developed during the fourth quarter of 2006 and finalized the first week of December. A copy of this brochure is contained on the accompanying CD.
    - A total of 10,000 copies of the brochure were mailed to architects, engineers, mechanical contractors, AC contractors, building contractors, and various specialists in the fields of energy or IAQ consulting. Thousands of mailing addresses were assembled using several sources. Database files from internal FSEC records were combined with many files

  from purchased mailing lists. All records were screened to include only building professionals such as engineers, architects, energy raters, or air quality specialists. The lists were then screened for repeat names or insufficient data.
  - The electronic brochures (in .pdf and .html formats) were also distributed to eight local ASHRAE Chapters that serve areas representing about 80% of the State's population.
  - An HTML version of the brochure was also produced. It was distributed to a mailing list of 2245 persons who have attended or previously shown interest in FSEC courses.

A summary of course attendance and course evaluations is contained in Appendix A.

Course materials, consisting primarily of 3-to-a-page copies of slide images, were handed out to course attendees. PDF versions of the course presentation materials and agendas are also included on the accompanying CD.

Another deliverable of this project is: *"The project team shall offer to make presentations to such professional organizations as the Association of Energy Engineers and the American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc."*

- On September 12, Jim Cummings (Project Principal Investigator) gave a presentation to the Jacksonville Area ASHRAE chapter *titled Energy Savings Opportunities in Commercial Buildings*. The presentation focused on energy waste and savings opportunities resulting from unbalanced airflows and space depressurization in commercial buildings. This material reflects, in part, results from this recommissioning project. The presentation lasted about 35 minutes with 5 minutes of questions/discussion. About 40 persons were in attendance.
- On January 11, 2007, Jim Cummings gave a presentation to the Central Florida ASHRAE chapter titled *Recommissioning a UCF Building for Improved Energy Efficiency*. Approximately 35 persons attended that 45 minute presentation.
- On March 13, 2007, Chuck Withers gave a presentation to the Jacksonville Area ASHRAE chapter titled *Recommissioning a UCF Building for Improved Energy Efficiency*. The presentation focused on energy waste and savings opportunities resulting from unbalanced airflows and space depressurization in commercial buildings. This material contains results from this recommissioning project. The presentation lasted about 50 minutes with 10 minutes of questions/discussion. About 50 persons were in attendance.

ACKNOLWEDGEMENTS

The authors would like to thank Michael Ohlsen of the Florida Department of Environmental Protection, and for the funding for this project from the Florida Department of Environmental Protection and the U.S. Department of Energy State Energy Program. Technical assistance was provided by Don Shirey of the Florida Solar Energy Center and University of Central Florida engineering student Matt Branch provided assistance with equipment preparation and sensor installation at the project site. Finally the authors are grateful for the work of our division administrative assistants Wanda Dutton and Mable Flumm for their invaluable help with everything from sensor purchasing to final report preparation.

APPENDIX A
Course Attendance and Evaluations

Summary of attendance at the *Designing and Maintaining the Failure-Proof Building* course offerings in three cities; “C” = cancelled due to low registration.

	Course 1	Course 2	Course 3	Course 4	Course 5
Sarasota	C	C	C	C	C
Cocoa	15	8	8	C	10
West Palm Beach	16	15	16	9	12

Course 1: Designing Building Envelopes to Control Air and Moisture Flows

Course Description: This course examines the role of the building envelope in controlling moisture, humidity, mold, and IAQ in buildings in hot and humid climates.
Key Speakers: Neil Moyer, Jim Cummings, and Chuck Withers
Scheduled Locations and Dates
- Sarasota, FL Jan. 23, 2007
- Cocoa, FL Feb. 26, 2007
- West Palm, FL Mar. 21, 2007

Course 2: Controlling Building Air Flows to Achieve Energy Efficiency, Humidity Control, and Good Indoor Air Quality

Course Description: This one-day course uses years of research and field investigation experience to provide specific examples of how air flow, pressure differentials and leakage of HVAC systems impact occupant health and comfort, building damage, and energy use. Relationships between the building envelope and uncontrolled air flow impacts are examined in detail.
Key Speakers: Jim Cummings, Chuck Withers
Scheduled Locations and Dates
- Sarasota, FL Jan. 24, 2007
- Cocoa, FL Mar. 1, 2007
- West Palm, FL Apr. 10, 2007

Course 3: Designing and Maintaining HVAC Systems to Achieve Energy Efficiency, Humidity Control, and Good Indoor Air Quality

Course Description: This one-day course examines cooling system characteristics related to their ability to control humidity, advanced dehumidification technologies suitable for hot and humid climates, and commissioning strategies that will result in improved comfort, air quality, and energy efficiency.
Key Speakers: Jim Cummings, Chuck Withers, Dustin Jackson

Scheduled Locations and Dates
- Sarasota, FL Feb. 7, 2007
- Cocoa, FL Mar. 2, 2007
- West Palm, FL Apr. 11, 2007

Course 4: Design Charrette -- Practice Designing the Failure-Proof Building

Course Description: This course will have students select and describe optimum construction details and equipment for a high performance commercial building. The content of the first three courses will be put to use in an extended design practice session by integrating issues of building envelope, air flow management, cooling system selection, and advanced dehumidification technologies into a good building design. Class size is limited. It is recommended that Courses 1, 2 and 3 be taken prior to participating in this course.
Key Speakers: Stephanie Thomas-Rees and Chuck Withers
Scheduled Location and Date
- Sarasota, FL Feb. 21, 2007
- Cocoa, FL Mar. 5, 2007
- West Palm, FL Apr. 25, 2007

Course 5: Optimizing Building Energy Efficiency Using the FlaCom Modeling Tool

Course Description: This course provides training in the use of an energy analysis tool – FlaCom. While normally considered a code-compliance software for commercial buildings, it also has “hidden” capabilities which can be used to evaluate the cost-effectiveness of building and system options. Lab sessions will use the software to evaluate the energy savings potential of various design options. It is recommended that you bring your own laptop computer. A limited number of computers will be available at the course.
Key Speakers: Tei Kucharski, Dr. Muthusamy Swami, and Chuck Withers
Scheduled Location and Date
- Sarasota, FL Feb. 2, 2007
- Cocoa, FL Mar. 6, 2007
- West Palm, FL Apr. 26, 2007

Key Speakers

Chuck Withers is a hands-on building scientist at FSEC where he has performed field research in more than 300 residential and commercial buildings. He has over 15 years experience using building diagnostics tools and methods to evaluate building pressures, building and duct tightness, air flow balance, ventilation rates, thermal qualities, air quality and energy use. He has shared his knowledge and experiences through 24 published papers, and at more than 40 conferences and courses. Mr. Withers has a B.S. in Secondary Education Physics.

James B. Cummings has been principal investigator for 32 research projects during 21 years at FSEC, where he has conducted field research in more than 250 homes and 100 commercial buildings, identifying air flow, pressure differential, HVAC, and moisture control failures. He has developed extensive courses in building science, combining his considerable diagnostic field experience into his enlightening presentation. Mr. Cummings holds an M.S. degree in Applied Solar Energy.

Neil Moyer is a nationally recognized expert in the field of building science and building air flow diagnostics. He brings an entertaining style to his training, along with unparalleled field experience of testing thousands of homes and hundreds of commercial buildings. He is recognized for many innovative building science diagnostic test procedures widely used across the country. He has conducted training for many utilities, the Energy Efficient Building Association (EEBA) and Affordable Comfort conferences. Mr. Moyer has a B.S. in Electrical Engineering.

Dustin Jackson is a mechanical engineer currently serving as a commissioning agent at the University of Central Florida. In that role he tabulates and analyzes data from university buildings, designs and implements recommissioning activities, and assesses energy savings.

Stephanie Thomas-Rees is a research architect at FSEC where she has been involved with high performance buildings research since 2001. She has taught building science and environmental subjects and has worked for private architectural firms as a project architect. Mrs. Rees is the co-author of Eco-House: A Design Strategy, which is in its 3rd Edition of printing. She holds a B.S. in Architecture from Clemson University and a M.S. in Architecture from Oxford University.

Tei Kucharski is the coordinator for the Florida Energy Gauge program at FSEC. She has extensive experience providing training to new raters, educating diversified groups about the rating system, providing software technical support, and maintaining the ratings database. She has conducted workshops on the Florida energy code and the code compliance software for both residential and commercial buildings.

The evaluation score summaries for each course are included here. The average course evaluation score (for questions 1 through 5, but not including question 6 – course length) was 3.66 out of 4.00. Based upon these evaluations, we conclude that this course was well received, the instructors’ quality was considered high, and the students obtained useful information that will be used on the job.

Failure Proof Buildings Course1 (Cocoa)

Presented by Chuck Withers, Jim Cummings and Neil Moyer February 26, 2007

Course Evaluation Summary

students given scale from 1-4
with 1 being poor or of less value and 4 being excellent

highest score	lowest score	Standard Deviation	MODE	AVERAGE
Organization and coordination 4	3	0.469	4	3.7
Instructor quality 4	3	0.519	4	3.5
Learn new insights? 4	3	0.469	4	3.7
Worth the cost? 4	3	0.514	4	3.6
Plan to use info? 4	3	0.426	4	3.8
length of course 1=short, 2=long, 3=right 3	1	0.756	3	2.6

Failure Proof Buildings Course 2 (Cocoa)

Presented by Chuck Withers and Jim Cummings March 1, 2007

Course Evaluation Summary

students given scale from 1-4
with 1 being poor or of less value and 4 being excellent

Highest Score	lowest score	Standard Deviation	MODE	AVERAGE
Organization and coordination 4	3	0.518	4	3.6
Instructor quality 4	3	0.518	3	3.4
Learn new insights? 4	2.5	0.623	4	3.4
Worth the cost? 4	2	0.744	4	3.4
Plan to use info? 4	3	0.535	3	3.5
length of course 1=short, 2=long, 3=right 3	1	0.756	3	2.5

Failure Proof Buildings Course 3 (Cocoa)

Presented by Chuck Withers and Jim Cummings, and Dustin Jackson March 2, 2007

Course Evaluation Summary

students given scale from 1-4
with 1 being poor or of less value and 4 being excellent

highest score	lowest score	Standard Deviation	MODE	AVERAGE
Organization and coordination 4	3	0.535	4	3.6
Instructor quality 4	3	0.535	4	3.6
Learn new insights? 4	3	0.535	4	3.6
Worth the cost? 4	3	0.488	4	3.7
Plan to use info? 4	3	0.378	4	3.9
length of course 1=short, 2=long, 3=right 3	1	0.787	3	2.6

Failure Proof Buildings Course 5 (Cocoa)

Presented by Tei Kucharski and Chuck Withers March 6, 2007

Course Evaluation Summary

students given scale from 1-4
with 1 being poor or of less value and 4 being excellent

highest score	lowest score	Standard Deviation	MODE	AVERAGE
Organization and coordination 4	2	0.756	4	3.5
Instructor quality 4	3	0.463	4	3.8
Learn new insights? 4	3	0.518	4	3.6
Worth the cost? 4	1	1.061	4	3.4
Plan to use info? 4	3	0.463	4	3.8
length of course 1=short, 2=long, 3=right 3	1	0.916	3	2.4

Failure Proof Buildings Course1 (West Palm Beach)

Presented by Chuck Withers and Jim Cummings and Neil Moyer March 21, 2007

Course Evaluation Summary

students given scale from 1-4
with 1 being poor or of less value and 4 being excellent

Highest Score	lowest score	Standard Deviation	MODE	AVERAGE
Organization and coordination 4	3	0.522	4	3.5
Instructor quality 4	3	0.522	3	3.5
Learn new insights? 4	3	0.452	4	3.8
Worth the cost? 4	2	0.778	4	3.3
Plan to use info? 4	3	0.452	4	3.8
length of course 1=short, 2=long, 3=right 3	3	0.000	3	3.0

Failure Proof Buildings Course2 (West Palm Beach)

FSEC presented by Chuck Withers and Jim Cummings April 10, 2007

Course Evaluation Summary

students given scale from 1-4
with 1 being poor or of less value and 4 being excellent

highest score	lowest score	Standard Deviation	MODE	AVERAGE
Organization and coordination 4	3	0.469	4	3.7
Instructor quality 4	3	0.426	4	3.8
Learn new insights? 4	3	0.267	4	3.9
Worth the cost? 4	3	0.469	4	3.7
Plan to use info? 4	2	0.535	4	3.9
length of course 1=short, 2=long, 3=right 3	1	0.535	3	2.9

Failure Proof Buildings Course3 (West Palm Beach)

Presented by Chuck Withers and Jim Cummings and Dustin Jackson April 11, 2007

Course Evaluation Summary

students given scale from 1-4
with 1 being poor or of less value and 4 being excellent

Highest Score	lowest score	Standard Deviation	MODE	AVERAGE
Organization and coordination 4	1	0.855	4	3.5
Instructor quality 4	1	0.855	4	3.5
Learn new insights? 4	1	0.825	4	3.7
Worth the cost? 4	1	0.802	4	3.8
Plan to use info? 4	1	0.802	4	3.8
length of course 1=short, 2=long, 3=right 3	1	0.535	3	2.9

Failure Proof Buildings Course 4 (West Palm Beach)

FSEC presented by Chuck Withers and Stephanie Thomas-Rees April 25, 2007

Course Evaluation Summary

students given scale from 1-4
with 1 being poor or of less value and 4 being excellent

highest score	lowest score	Standard Deviation	MODE	AVERAGE
Organization and coordination 4	3	0.463	4	3.8
Instructor quality 4	3	0.354	4	3.9
learn new insights? 4	4	0.000	4	4.0
worth the cost? 4	3	0.354	4	3.9
Plan to use info? 4	3	0.463	4	3.8
length of course 1=short, 2=long, 3=right 3	3	0.000	3	3.0

Failure Proof Buildings Course 5 (West Palm Beach)

FSEC presented by Chuck Withers and Tei Kucharski April 26, 2007

Course Evaluation Summary

students given scale from 1-4
with 1 being poor or of less value and 4 being excellent

highest score	lowest score	Standard Deviation	MODE	AVERAGE
Organization and coordination 4	3	0.422	4	3.8
Instructor quality 4	3	0.483	4	3.7
Learn new insights? 4	3	0.422	4	3.8
Worth the cost? 4	3	0.527	3	3.5
Plan to use info? 4	3	0.527	3	3.5
length of course 1=short, 2=long, 3=right 3	3	0.000	3	3.0

Following is a summary of all the course evaluations.

Summary for all nine courses in two cities

Course Evaluation Summary

students given scale from 1-4
with 1 being poor or of less value and 4 being excellent

highest score	lowest score	Standard Deviation	MODE	AVERAGE
Organization and coordination 4	1	**(avg)** 0.56	**(avg)** 4	3.6
Instructor quality 4	1	0.52	4	3.6
Learn new insights? 4	1	0.46	4	3.7
Worth the cost? 4	1	0.64	4	3.6
Plan to use info? 4	1	0.51	4	3.7
length of course 1=short, 2=long, 3=just right 3	1	0.48	3	2.7

A computer disc has been prepared containing electronic copies of the Power Point presentations for Courses 1 through 3 of the series titled *Designing and Maintaining the Failure-Proof Building.* This disc will be forwarded to the Florida Division of Environmental Protection. Note that Courses 4 and 5 had no presentation materials and only limited hand-outs.