A Study of the Utilities at the University of Illinois
University of Illinois – Urbana-Champaign

September 2009

Prepared for:

Energy Task Force
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Executive Summary

Overview

The University of Illinois, through its Energy Task Force, commissioned a study to help identify improvements to its utility operations. The study was designed to answer several basic questions about the university's central energy plants and facilities:

1. What are the economics of providing energy from the central plants versus buying energy from external providers?

2. What is the condition of the central energy plants and distribution systems, how efficient are they, what actions can be taken to improve them, and at what cost?

3. What facility energy reduction activities, programs, and investments should be undertaken and what are the priorities?

4. What metering improvements are needed?

The Science Applications International Corporation (SAIC) team, consisting of SAIC and its subcontractors Worley Parsons and ERDC-CERL, was selected to perform the study. Our approach to performing the work was framed around these questions, with specific tasks addressing the "make versus buy" decision (Task A), cost effective investments in the central energy plants and distribution systems (Task B/C), facility energy reduction (Task D), and metering (Task E). The key elements of the approach included:

> Task A – Development of a financial model and the use of an electricity market forecasting tool called Market Power.[1] The financial model integrates information about plant capital and operating costs, financial requirements, and operational assumptions. The focus of the analysis was on electric power generation vs. purchases since of the three utilities of interest – electricity, steam, and chilled water - only electricity is available from an outside source. Scenarios examined included a base case which is the economic dispatch case that used the results of the Market Power software tool to establish the make vs. buy decision; and variations on the economic dispatch case. The metrics used to compare the alternatives was the annual unit energy production costs for the utilities and the net present value of the scenarios relative to the base case.
>
> Task B and C- Performing an Electric Power Research Institute (EPRI) Level I condition assessment covering major plant equipment and subsystems. Information from the assessment, together with observations regarding operations, was used to identify improvement projects. The projects were prioritized and cost estimates were developed. These were included in the Task A financial model.

[1] Market Power, a software available from Ventyx, forecasts electric energy and capacity prices and is widely used by utilities for planning and analytics of the power generation fleet.

Task D – Brief surveys of selected campus buildings, together with energy use information, was used to identify energy conservation measures (ECMs) for the various building systems – envelope, lighting, mechanical/HVAC, controls, etc. The savings estimates based on the representative buildings were generalized to buildings of similar types (e.g., classroom/office, research laboratory, etc.) and used to estimate campus wide opportunities. A portfolio based method was applied based on economics and other criteria to determine the mix of ECMs for investment. Suggested implementation strategies were developed.

Task E – Metering suggestions were provided based on a review of the existing metering coverage and types of meters. This information was compared to metering objectives, including billing, energy use benchmarking, diagnostics, and load management, to determine recommendations for new meters/meter upgrades.

Each task was documented in individual task reports that detail the results of the task work, and are provided as sections within this final report. A summary of the findings and recommendations for the University of Illinois Urbana-Champaign campus is provided below.

Findings and Recommendations for UIUC

Overall:

The University should use an integrated resource planning approach to allocating funds for energy related projects. This means comparing investments to central plants with investments in facilities on a common basis. Given the age and condition of the central plants, and increasing service demands, it will take more resources and a greater emphasis on preventative maintenance to ensure reliable operation. Therefore, investments that improve the reliability of operations – supply side and demand side – should be the highest priority. The cost of utilities can be lowered by investments that enable increased electricity purchases from the grid. Investments in facility efficiency measures can help contain energy operating costs, by reducing fuel use and depending on the measures, provide capacity benefits. Specific findings and recommendations by task follow.

Task A: Production vs. Purchase

1. The average variable cost to generate electricity at Abbott is projected to be more expensive than electricity purchased from the wholesale power markets after the fixed maintenance cost for the gas turbine expires in FY2014. The gas fired turbine generators is able to produce electricity on average for $.081/kWh in the next 15 years as compared to the average wholesale electric price of $.075/kWh for the same 15 year period. While there are time periods during the year when it is advantageous to operate the gas turbine generators – primarily during the peak periods of June through October, for much of the year, purchased electricity is cheaper. However, purchased amounts are presently limited by tie-line capacities with Ameren/IP. Tie-line capacity increases from are underway by Ameren/IP and will increase the capacity from 40MW to 60MW in July 2009 which will benefit the university; however, this increase coincides with an expected increase in demand so further improvements in the capability to import power to UIUC should be

sought. It should be noted that increases transmission capacity are easily accomplished and required the cooperation of the utility.

2. The university could save operating costs by increasing purchases from the market; however, reliability concerns with the gas fired boilers during times of high steam demand require operation of the gas turbine/heat recovery steam generators, even during periods when purchased electricity would be cheaper. Assuming all other costs would stay the same, if the transmission constraint could be lifted in 2014, and if the gas turbine/HRSG could be economically dispatched, the next ten years would yield a reduction in operating costs of approximately $4 million.

3. Increased campus loads of +/-20% would not appreciably change the make vs. purchase decision.

4. The potential impact of a carbon tax was also evaluated as part of this effort. Based on federal budget information, a possible carbon tax could range from $12-$15/ton starting in 2012 and grow to $15/ton-$18/ton by 2020.[2] Such a tax would add more significantly to the cost of operating coal fired power plants than natural gas plants. Coal plants emit upward of 200 lbs of CO_2 per MMBtu versus around 120 lbs of CO_2 per MMBtu for natural gas burning units. For the Abbott plant the carbon tax would be estimated to be between 1.5 and 2 cents per kWh in added cost for the coal fired plant and between 0.7 and 1 cent per kWh for the gas turbines. At the same time, the Market Power model predicts that the carbon tax will increase the annual capacity market price of electricity substantially. This would make the gas turbines more competitive in the market place. The exact level of impact depends on the amount of carbon tax implemented. Given the high level of coal based electricity production in the region, the model predicts the price of electricity to increase by ~50%; however, even with this increase in electricity price the gas turbines still produce electricity at a higher price than can be purchased.

5. When capital cost (major repair and replacement) items are taken into account over the next 15 years, the UIUC’s total operating cost averages to approximately $75 million. Note that the major repair and replacement items will have only slight effects on energy operating costs (e.g., improved efficiency), and are primarily needed to ensure reliable operation.

6. By outsourcing the plant O&M, UIUC could save approximately $1.3 million annually, producing a net present value of $13 million improvement over the base case. It should be noted, however, that the estimate was based on a very preliminary review of the staffing levels. A more detailed assessment would be needed to confirm these assumptions.

7. Given the market position of the university’s generation assets the sale or lease of the plant to an outside entity is highly uncertain.

[2] * Sources: EPA's Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2007 (2005 Emissions), available at: http://www.epa.gov/climatechange/emissions/usinventoryreport.html; OMB's 2010 Fiscal Year Budget Proposal (Projected Climate Revenues & 2020 Cap Levels), available at: http://www.whitehouse.gov/omb/

Task B and C: Cost Effective Investments in Production and Distribution Systems

1. The Abbott Power Plant is old by industry standards. With the exception of the newer additions of the combined-cycle equipment, the main steam and power generating equipment is well past its original design age. The Abbott operation and maintenance (O&M) staff has done a creditable job of keeping this equipment serviceable over this time period.

2. Plant operation is complex due to the variety of equipment and operating limitations. Compared to comparable plants of this size, the UIUC plant is performing reasonably well. However, additional redundancy is needed to overcome reliability issues with aging equipment.

3. Plant staffing levels appear to be reasonable for a plant of this size. However, separation of operations and maintenance functions and restrictions on workers in operations from performing maintenance and vice-versa, limit opportunities for optimizing staffing levels. Such restrictions do not exist at the Chicago or Springfield campuses. If such restrictions did not exist, and cross-training of staff was implemented, savings are likely. However, a more detailed staffing analysis would be needed to determine specific savings levels.

4. Consideration should be given to establishing key performance indicators (KPIs) or metrics against which to benchmark plant operations. This would include metrics related to reliability, performance, training, etc. This approach is used in performance contracts with private sector plant operators, as a way to manage risk.

5. In order to maintain reliable operation of the plant, significant investments will be required – on the order of $15 to 20 million per year, over the next 15 years. This equates to between $173 million and $234 million in central plant investments and between $51 million and $69 million in thermal distribution systems. This will involve investments in equipment repair/replacement – including major overhauls, but also increased investments in plant maintenance. Specific priority areas for investment include:

   <u>Capital Equipment</u>

   - New condensate polishing (cleaning) system to reduce premature corrosion of plant equipment, along with new condensate storage tanks – this will deal with the ongoing boiler water quality issues that are increasing boiler corrosion and tube failures.
   - Additional reverse osmosis water treatment capability for makeup water
   - Repairs to the coal handling equipment
   - Ongoing boiler maintenance and repair to maintain reliability
   - Repairs to steam distribution system piping to address concerns with heat loss, structural integrity, and personnel safety, along with reliability

Operation & Maintenance

- Condition based monitoring – this will highlight preventative maintenance required to keep units on line.

- Equipment flow metering – will improve efficiency of operations

6. Environmental regulations on emissions limit the maximum throughput of the flue gas desulfurization equipment (wet scrubber). This in turn limits the generating capacity of the three coal-fired boilers to below their rated capacity. In addition, reliability of the 'Green Fan' for the wet scrubber will need to be addressed. Currently, this is a single point of failure that could force the three coal-fired boilers out of environmental compliance (and hence out of service) at the same time.

7. The distribution systems will require substantial investments in future years. A more detailed assessment of the system is needed to quantify the investment levels with a degree of confidence.

8. Metering of campus utilities has improved, although issues with metering steam to the steam-turbine driven chillers remain. In addition, the output from two of the chiller plants is not presently metered. Metered data from these plants would help more accurately allocate the cost of plant operations.

Task D: Consumption Reduction Measures

1. The potential campus wide annual energy operating cost savings from representative energy conservation measures (ECMs) ranges from $6.5 million assuming only projects with a benefit-cost (B/C) ratio equal to or greater than 1 (Project B/C>1) are considered to $9.8 million assuming the B/C of the entire portfolio of measures is equal to or greater than 1 (Portfolio B//C >1) is considered. The associated annual energy savings are 20% and 32%, respectively. To realize these savings, an investment of $51.7 million to $151.2 million, respectively, would be needed by the university. The environmental benefits associated with implementing the ECMs for the nominal case (Project B/C>1) is a reduction of 72,234 tons of carbon dioxide, 168 tons of sulfur dioxide, and 202 tons of nitrous oxides annually. For the for the Portfolio B//C >1 case the corresponding reductions are114,572 tons of carbon dioxide, 267 tons of sulfur dioxide, and 202 tons of nitrous oxides annually.

2. Implementation of the ECMs could reduce steam requirements from the central plants by 80,000 to 150,000 pounds per hour (14%-25%), chilled water by 5,000 to 8,000 tons (16%-25%), and electrical loads by 6 to 9 MW (8%-12%) for the nominal case and portfolio case, respectively. While these figures are broad estimates (and dependent on the amount and type of conservation that is implemented) they do indicate that energy conservation efforts can impact equipment operating margins and reserves or defer capacity additions. Energy conservation measures that reduce the need for new capacity are considered economic if they can be save energy at a cost that is less than the costs of meeting the needs through new plant equipment. For new steam capacity this would be a

cost of saved energy of $14.87/MMBtu and for new chilled water capacity this would be a cost of saved energy of $9.19/MMBtu.

3. The suggested priorities for the ECMs are as follows:

Near Term

- Lighting and select HVAC energy conservation measures (ECMs) offer the greatest opportunities. Within the lighting category, interior fixture replacements (e.g., T12 to T8 or T5) offer the greatest opportunity. While a significant lighting upgrade is in progress, financial constraints have limited its scope and additional opportunities are available.

- The most cost effective HVAC opportunities include retro-commissioning, conversion of constant speed fans to variable speed and expanding the direct digital control (DDC). Expansion of DDC controls will also help facilitate coordinated load management efforts including the ability to strategically reduce loads in response to favorable utility price signals or to internal requirements. While utility-driven demand response incentives are not currently offered, they may be a source for additional savings at some future time. Furthermore, the building automation system/controls capability, together with metering efforts and facilities maintenance are the main components of continuous commissioning or measurement based commissioning – an effective means of locking in the results of the retrocommissioning activities.

- Weatherization of buildings and judicious use of solar film to reduce heat losses/gains through the building envelope is also a good near-term investment.

Mid-Longer Term

- Mid-longer term investments include variable speed drives for pumps, adding economizer capability, and variable air volume controls for laboratory fume hoods. Retrocommissioning of laboratories and daylighting controls have marginal economics, but are worth implementing as part of the overall portfolio of measures

4. Many of the ECMs apply broadly across the various campus building types – classroom/office, research laboratory, etc. The top 100 energy consuming buildings offer the greatest opportunity for savings since they reflect more than 90% of campus energy use. Priority should be given to ECMs that align with the university's deferred maintenance requirements. Deferred maintenance projects with energy savings attributes generally provide better economics while meeting important functional needs. Examples are: incorporating variable air volume controls and/or heat recovery when replacing air handling units; adding roof insulation and/or specifying reflective coatings when replacing roofs.

5. A comparison of the university's energy use intensity (EUI) to benchmark information from comparable institutions indicates the university has higher EUIs than many of the other institutions.

6. The university has done a good job of establishing an energy conservation program. It should accelerate its efforts, particularly in the area of HVAC retrocommissioning and lighting. Resources should be provided to lock-in the results of the retrocommissioning via continuous commissioning/measurement based commissioning in coordination with metering efforts, building automation system activities, and facilities maintenance. Policy guidelines regarding energy reduction goals, building schedules, temperature set points, etc. should be reinforced.

7. The university should establish a funding source for the energy conservation programs. This could be supplemented by a revolving fund that would be replenished from future savings, plus annual additions.

8. Energy awareness campaigns used in conjunction with the university's metering/billing initiative should provide a solid foundation for energy behavioral changes. However, this information must be put into context with regard to what occupants can do. Providing building level energy use data and operating parameters (e.g., space temperatures) via web access, including comparisons to previous years and benchmarks would be beneficial. In addition, the campaign could include energy efficiency competitions between buildings/academic units, based on energy use/reduction targets. Providing energy and emissions impact data for behaviors under an occupant's control could help foster some accountability.

9. In addition to requiring new buildings to be LEED certified, an energy master plan and strategy and/or minimum standards should be developed and implemented for new buildings and/or renovations. Items such as use of demand controlled ventilation; use of heat recovery and/or variable flow laboratory hoods; daylighting/dimming controls; peak shaving, etc should be identified.

Task E: Metering

Overall, the existing metering system at the UIUC campus provides excellent coverage of buildings that use the vast majority of campus energy. From the perspective of ESPC projects the existing metering should be adequate for developing average energy use baselines at the whole building level. For projects where peak demand reductions are an important component of the cost savings guarantees, additional metering may be required. However, investments in this type of monitoring are best made after the decision to move forward with specific types of projects.

Nonetheless, there are opportunities to improve the benefits of metering, as well as to expand the metering on campus. Based on our review we suggest that:

- Bring the total number of fully metered academic buildings to 120 which accounts for 96% of campus energy use. This would require installing a total of 5 steam condensate meters and 4 chilled water meters.

- Existing meters that are not already linked to the energy management systems be connected to the system, where practical. Connecting the existing meters to the system would automate the process of meter reading, and with the appropriate software, enable energy use data to be evaluated at much finer time intervals. This would enhance the ability to identify inefficient energy use through load profiling and enhance diagnostic and troubleshooting capabilities. To benefit from this additional staff time/resources would be needed.

- A meter calibration program should be established. This would help maintain the accuracy of the readings, and establish confidence for billing purposes. Electrical meters should be calibrated once every three to four years. Steam condensate and chilled water meters should be calibrated annually. In addition, consideration should be given to using short-term steam measurements as a means of checking energy estimates based on the condensate meters in selected buildings. This could be used to develop adjustment factors to apply to the condensate meter based energy values to get them closer to a true steam usage value.

UIUC has embarked on a course to raise awareness through its billing system. In order for a metering system to be successful it needs trained users, management buy-in/leadership, campus wide awareness and it needs to be maintained. Furthermore, if the potential of the metering system is to be fully realized, there need to be staff resources to review the energy use data on an ongoing basis and be in a position to act on the information.

Production versus Purchase
University of Illinois - Urbana-Champaign

Task A Final Report

September 2009

Prepared for:

Energy Task Force
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Summary

SAIC performed an analysis of the University of Illinois Urbana Champaign (UIUC) campus cogeneration (combined heating and power) plant to determine the economics of on-site generation of utilities relative to purchases from an external provider. The focus of the analysis was on electric power generation vs. purchases since of the three utilities of interest – electricity, steam, and chilled water - only electricity is available from an outside source. The approach involved the development of a financial model to determine the cash flows associated with operating the plant over the next fifteen years. Inputs to the model included capital and operating costs, with operations dictated by various scenarios. The scenarios included a base case which is the economic dispatch case that used the results of the Market Power software tool to establish the make vs. buy decision; and variations on the economic dispatch case assuming changes in constraints (e.g., no limits on power import capacity), and campus load variations. In addition, the potential impacts of carbon taxes and the economics of alternative plant operation/ownership was examined. The metrics used to compare the alternatives was the annual unit energy production costs for the utilities and the net present value of the scenarios relative to the base case.

Table ES-1 below summarizes the University's unit energy costs for production of utilities from 2009 to 2023 for the base case and also shows the purchased price of electricity. These reflect variable operating costs (primarily fuel and other consumables) for electricity, steam, and chilled water. The blended electricity costs represent the weighted average cost of electricity produced by the steam turbines and the gas turbines.

Table ES-1. UIUC – Cost of Production (FY2009 – FY 2023)

Variable Cost		FY2009	FY2010	FY2011	FY2012	FY2013	FY2014	FY2015	FY2016
Steam (w Electricity credit)	$/Klbs	$5.5760	$6.0165	$6.0026	$7.4419	$8.4404	$8.6847	$9.1853	$9.6839
Electricity from Gas Turbines	$/Kwh	$0.0948	$0.0377	$0.0439	$0.0529	$0.0537	$0.0642	$0.0714	$0.0814
Electricity Purchased	$/Kwh	$0.0516	$0.0637	$0.0688	$0.0642	$0.0641	$0.0654	$0.0684	$0.0737
Blended Electricity	$/Kwh	$0.0530	$0.0505	$0.0558	$0.0592	$0.0601	$0.0650	$0.0694	$0.0761
Chilled Water	$/ton-hr	$0.0425	$0.0425	$0.0460	$0.0496	$0.0514	$0.0547	$0.0582	$0.0633

Variable Cost		FY2017	FY2018	FY2019	FY2020	FY2021	FY2022	FY2023
Steam (w Electricity credit)	$/Klbs	$10.4589	$10.6814	$11.1066	$10.9879	$11.0526	$11.4455	$12.1032
Electricity from Gas Turbines	$/Kwh	$0.0961	$0.0949	$0.1002	$0.0906	$0.0864	$0.0921	$0.0999
Electricity Purchased	$/Kwh	$0.0799	$0.0826	$0.0857	$0.0856	$0.0867	$0.0918	$0.0945
Blended Electricity	$/Kwh	$0.0842	$0.0857	$0.0893	$0.0871	$0.0866	$0.0919	$0.0961
Chilled Water	$/ton-hr	$0.0695	$0.0709	$0.0738	$0.0724	$0.0723	$0.0763	$0.0798

Based on this we find that:

1. The average variable cost to generate electricity at Abbott is projected to be slightly more expensive than electricity purchased from the wholesale power markets after the fixed maintenance cost for the gas turbine expires in FY2014. The wholesale power market cost is a monthly average of hourly on-peak and off-peak prices from Market Power's forecast of hourly energy prices. Market Power dispatches UIUC's gas turbines based on their competitive cost structure on an hourly basis, in the same manner in which UIUC considers generating or buying electricity. The gas fired turbine generators are able to produce electricity on average for $.081/kWh in the next 15 years as compared to the average wholesale electric price of $.075/kWh for the same 15 year period. UIUC's variable cost of generating electricity is lower than the market in F2010 – F2013 due to

the fixed price maintenance contract that locks in its O&M costs. The higher than market natural gas contract fixed at $10.33/MMBtu in F2009 has made UIUC's cost of producing electricity higher than market even with the fixed contract on variable cost. While, the wholesale price of electricity is lower than the cost of generating electricity on an aggregate monthly basis, there are opportunities on an hourly basis throughout the month where UIUC generates at a lower cost. During these hours, Market Power dispatches UIUC's gas turbines. Outside of F2010 – F2013 when the contract that fixes variable O&M costs is in place, the gas turbines are dispatched on average approximately 35 – 45% of its capacity mainly from June to October. On an average annual basis (not on an hourly basis), the gas turbines are projected to generate at $.081/ kWh, which includes a credit for co-generated steam[1.] While there are time periods during the year when it is advantageous to operate the gas turbine generators – primarily during the peak periods of June through October, for much of the year, purchased electricity is cheaper. However, purchased amounts are presently limited by tie-line capacities with Ameren/IP. Tie-line capacity increases are underway by Ameren/IP and will increase the capacity from 40MW to 60MW in July 2009, which will benefit the university; however, this increase coincides with an expected increase in demand so further improvements in the capability to import power to UIUC should be sought. It should be noted that increases transmission capacity are easily accomplished and required the cooperation of the utility.

2. The university could save operating costs by increasing purchases from the market; however, reliability concerns with the gas fired boilers during times of high steam demand require operation of the gas turbine/heat recovery steam generators, even during periods when purchased electricity would be cheaper. Assuming all other cost would stay the same, if the transmission constraint could be lifted in 2014, and if the gas turbine/HRSG could be economically dispatched, the next ten years would yield a reduction in operating costs of approximately $4M.

3. Increased campus loads of +/-20% would not appreciably change the make vs. purchase decision.

4. The potential impact of a carbon tax was also evaluated as part of this effort. Based on federal budget information, a possible carbon tax could range from $12-$15/ton starting in 2012 and grow to $15/ton-$18/ton by 2020.[2] Such a tax would add more significantly to the cost of operating coal fired power plants than natural gas plants. Coal plants emit upward of 200 lbs of CO2 per MMBtu versus around 120 lbs of CO2 per MMBtu for natural gas burning units. For the Abbott plant the carbon tax would be estimated to be between 1.5 and 2 cents per kWh in added cost for the coal fired plant and between 0.7 and 1 cent per kWh for the gas turbines. At the same time, the Market Power model predicts that the carbon tax will increase the annual capacity market price of electricity substantially. This would make the gas turbines more competitive in the market place, which will induce new builds of more efficient combined cycles using natural gas with lower heat rates. Given the cost of carbon, Market Power retires less competitive coal

[1] The steam credit is calculated by taking the amount of HRSG steam times the cost of producing steam from the boilers.
[2] * Sources: EPA's Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2007 (2005 Emissions), available at: http://www.epa.gov/climatechange/emissions/usinventoryreport.html; OMB's 2010 Fiscal Year Budget Proposal (Projected Climate Revenues & 2020 Cap Levels), available at: http://www.whitehouse.gov/omb/

plants and anticipates new builds of combined cycles to replace the lost generation. The exact level of impact depends on the amount of carbon tax implemented. Given the high level of coal based electricity production in the region, the model predicts the price of electricity to increase by ~50%; however, even with this increase in electricity price the gas turbines still produce electricity at a higher price than can be purchased.

5. When capital cost (major repair and replacement) items are taken into account over the next 15 years, the UIUC's total operating cost averages to approximately $75 million. Note that the major repair and replacement items will have only slight effects on energy operating costs (e.g., improved efficiency), and are primarily needed to ensure reliable operation.

6. By outsourcing the UIUC could possibly save an average of approximately $1.3 million annually, producing a net present value of $13 million over the base case. However, due to the limitations of this study and the complexity of plant operations, a more detailed review of staffing and operations would be required before definitive conclusions could be drawn.

7. Given the market position of the university's generation assets the sale or lease of the plant to an outside entity is highly uncertain.

1. *Overview*

1.1 Introduction/Objectives

The University of Illinois Urbana Champaign (UIUC) campus cogeneration (combined heating and power) plant and chilled water plants provide campus utilities in the form of electricity, steam and chilled water. A key concern of the university is the rising costs of providing these utilities, particularly in the face of increasing fuel costs and fuel cost volatility, the need for capital upgrades, and increasing maintenance requirements. The objective of this analysis is to determine the economics of on-site generation of utilities relative to purchases from an external provider. The focus of the analysis is on electric power generation vs. purchased power since only electricity is available from an outside source. The key metrics of comparison are the unit production costs (variable costs) of site generated electricity vs. electricity available on the wholesale market and annual cash flows. A net present value (NPV) analysis covering a fifteen year time frame is used to determine the economics of plant operations under a variety of scenarios. These scenarios include a base case and cases where demand is expected to increase or decrease by twenty percent as well as a case with unconstraint transmission from the power grid. In addition, the sensitivity of the results to potential carbon taxes and to fuel price assumptions (e.g., forward price curves) is examined. The economics of alternative plant operation and maintenance and ownership is also analyzed.

Key considerations in the analysis involve the operating assumptions for the plant. The plant provides a great deal of flexibility through multi-fuel capability (gas, oil, coal) and with a variety of equipment (steam boilers/steam turbines; gas turbines/heat recovery steam generators). The older equipment, primarily the boilers and steam turbine generators are operated with the primary function of providing steam. The electricity generated by the steam turbine generators is a byproduct of the steam production. The gas turbine generators produce electricity, but also provide steam through heat recovery steam generators. During periods of high steam demand, or when there is uncertainty regarding the reliability of operation of the steam boilers, the operation of the gas turbines/HRSGs is considered essential ("must run" situation). These limitations can constrain current operations and day-to-day dispatch decisions. Furthermore, there are constraints based on the capacity of electric power that can currently be imported. These considerations were taken into account in the analysis. Ultimately, the make vs. buy decision centered largely on the gas turbine (GT) generators, and their competitiveness vs. power that could purchased on the wholesale power market.

1.2 Approach

The SAIC approach centered on the development of an MS-Excel spreadsheet based financial model and the use of an electricity market forecasting tool called Market Power.[3] The financial model integrates information about plant capital and operating costs, financial requirements, and operational assumptions. A two-step iterative process is used. In the first step, plant operating characteristics from the spreadsheet model are fed into the Market Power software. Market Power then analyzes the university plant as part of the overall regional electricity generating capacity and demand picture and develops the most cost effective operating scenario. In the

[3] Market Power, a software available from Ventyx, forecasts electric energy and capacity prices and is widely used by utilities for planning and analytics of the power generation fleet.

second step, the Market Power results are fed back into the Excel financial model to determine the overall variable operating costs of the plant. These costs are subsequently combined with the remaining operation and maintenance (O&M) costs and fixed costs. In addition, major repair and replacement costs, as well as debt service are included to arrive at the financials. The information used in the model relied on data collected from the university, as well as the results of the analysis of the plant condition and operations performed by the SAIC team on a separate task.

2. *Model Framework*

The fundamental operating assumption for the UIUC campus is that the heating load for the campus needs to be supplied by the university plant. Since the steam is supplied by the campus cogeneration plant, there is an interaction between the amounts of steam and electricity that are being produced. Also, at times when the campus electric chillers cannot meet the cooling load steam needs to be produced to feed the steam driven chillers.

The UIUC predicted steam demand was based on the metered 2008 hourly data aggregated at the monthly level to enable month by month comparisons. The predicted total steam required for UIUC was based on two separate categories that comprise the total demand, the campus steam demand and the plant steam demand. The campus steam demand represents all exported steam from the Abbott plant for campus usage including steam that goes through the pressure reducing valve (PRV). The plant steam demand encompasses the plant auxiliary equipment steam demands, parasitic losses, and the exhaust steam sent to the condensers. The campus demand for 2008 was parabolic in nature with the highest loads in the winter and the lowest in the summer as shown in Figure 2-1 below. The exception was the months of July and August. These two months had steam demands higher than the general parabolic trend due to the operation of the steam turbine driven chillers. When calculating the predicted demand for July and August, a separate calculation which takes into account the steam turbine driven chiller demand was implemented. The baseline 2008 plant predicted steam demand was developed using a polynomial regression comparing the monthly UIUC steam demand to the corresponding months.

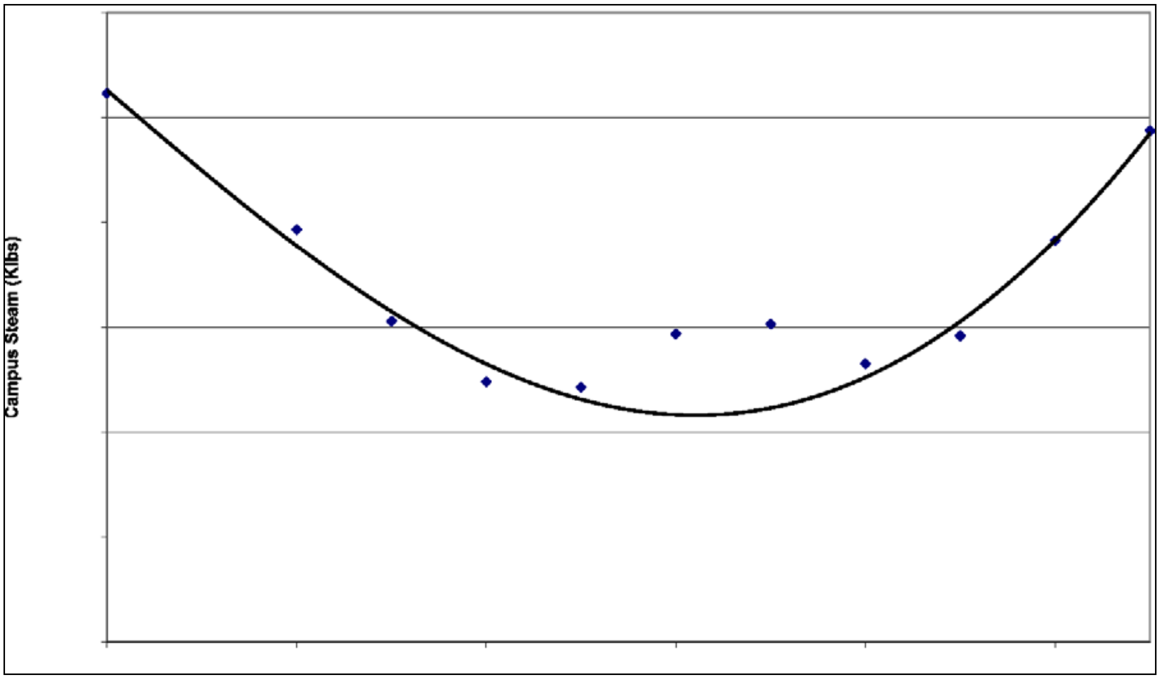

Figure 2–1. UIUC Steam Demand Curve

There are different possibilities to produce the needed steam in the Abbott plant. There are both coal and gas boilers to make steam to send to the turbines as well as Heat Recovery Steam Generators (HRSGs) attached to two gas turbines primarily used for producing electricity. The model compares the cost of producing steam from the boilers using either coal or gas and utilizes the more cost effective fuel to the greatest extent possible, i.e., if coal is cheaper it is used until the coal boiler capacity is reached and the remainder of the needed steam is produced using natural gas. The resulting required hours of operation for the boilers is combined with the heat rate[4] to determine the amount of energy required and corresponding fuel consumed. The hours of operation for the boilers is based on the steam demand and that amount of time is used as the "must run" input for the steam turbines in Market Power. The steam turbines produce electricity as a byproduct of the steam production even if running these assets would not be efficient for electricity production alone (e.g., operating in a condensing mode).

The overall electricity demand for UIUC based on historic consumption is fed into Market Power along with operating characteristics such as heat rate, capacity, and minimum required run hours, for each of the electricity production assets operated. Based on the regional electric power demand and generating capacity as well as transmission capabilities, Market Power calculates the wholesale market price of electricity. It should be noted that the UIUC campus currently has a restriction on transmission from the grid of 40MW. This import capability will be expanded to 60MW in July 2009. Market Power runs as an hourly model and takes peak demand impacts into account. The results of each Market Power run are the percentage capacity utilization for each of the UIUC generating assets, the amount of energy imported from the grid, and the associated forward curve of electricity prices. This is based on price as well as capacity constraints; e.g., if the gas turbines can produce energy more cheaply that it can be purchased from the grid, electricity may still need to be purchased if the turbines reach their capacity limit without meeting the UIUC energy demand.

[4] Heat rate is defined as the input energy required to generate the output electricity. Typical units are Btu/kWh or MMBtu/MWh.

The Market Power output is fed back into the Excel model and if the gas turbine and associated HRSG are utilized than the amount of steam produced by the boilers is adjusted accordingly. For all generating assets the run time is combined with the respective heat rate to calculate the fuel consumption. The amount of coal consumed is combined with the forecasted coal price for each period to determine the monthly and annual cost for coal consumption. The overall gas consumption from steam production and gas turbines is combined with the forecasted natural gas price for each period to determine the monthly and annual cost for natural gas consumption. A schematic of the model process described is shown below.

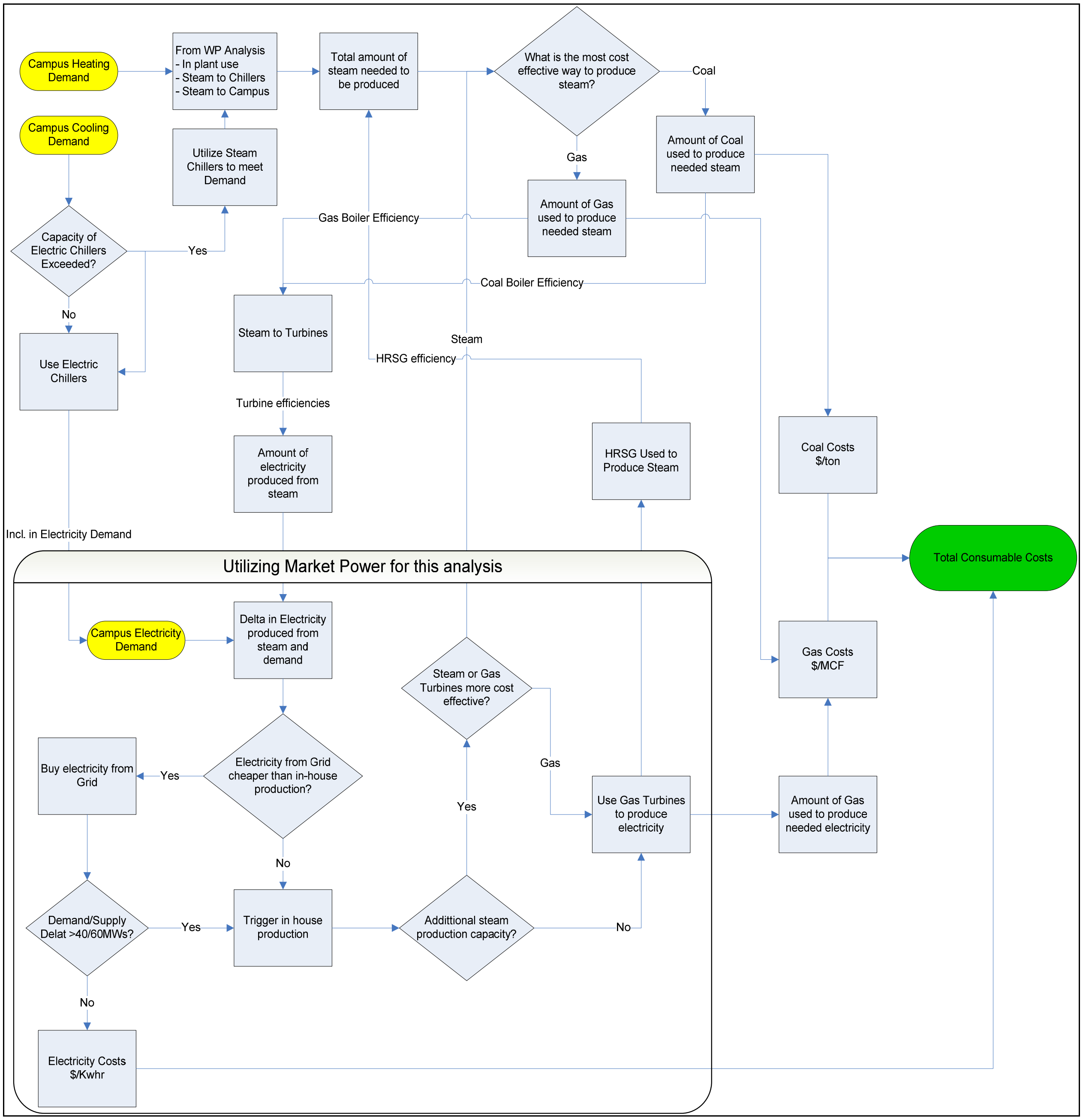

Figure 2–2. Financial Model Flow Chart

2.1 Market Power

Market Power is an electric power valuation model widely used in the electric utility sector for determining energy prices. It uses linear programming algorithms to optimize generation, transmission flows, and load curtailment over the entire regional area. Market Power will balance the supply and demand of electricity subject to the capacity and energy limitations inherent to the region. The tool optimizes the supply and demand equilibrium, while minimizing the total cost of generation for the given area. The resulting energy price represents the incremental cost of meeting the small increase in demand for the area. This price is the marginal cost or the "shadow price" of balancing supply and demand in the area.

Market Power contains all the relevant market inputs for the area. In particular, it has updated generation assets in use, power plants slated for retirement or mothballing, and new builds. It includes basic plant attributes, such as heat rate, fuel use, unit capacity, and planned maintenance for each plant. The user can make modifications to an existing unit's operation, add a new plant to the area generation mix, or schedule unit retirement or mothballing. Market Power will use the user-specified generator inputs—namely, its variable O&M, heat rate, fuel costs, and emissions costs—to calculate its energy cost in conjunction with other units in the region.

Market Power also includes all the transmission links that allow energy to be moved from one area to another, subject to tariffs, losses, and capacity limits. Every link is associated with a source and a destination area, that allow for a forward and backward flow—movement of energy between the source and the destination. Market Power will adjust the energy price to account for losses and the difference in prices between two areas will be reported as congestion costs. Users are able to remove flow restrictions and model open access and allow for free flow of energy into a region.

2.2 Market Power Commodity Forward Curves

The fuel price forecast in Market Power is region specific, by commodity, with transportation costs, and available by month for the user defined time frame. The commodity prices are based on current prices traded or settled in the market. For natural gas, liquid fuels, and coal the costs are based on the New York Mercantile Exchange (NYMEX) settles for the extended period in which each commodity is traded. Following periods of market quoted futures prices, Market Power forecasts prices using mean reversion, and for extended periods, long term price forecasts from the U.S. Department of Energy's Energy Information Administration (EIA) is applied. Market Power allows commodity and transportation price overrides to accommodate user-defined fixed price contracts for an extended period. Users may also define the forward curves by a price escalation index. In this instance, Market Power will escalate the last available price curve by the factor specified by the user. Forward prices are expressed in nominal dollars. Please see documentation on data sources from Market Power in Appendix A. Note that the forward curves shown below do not include delivery charges for electricity.

Table 2.2-1 Forward Curves

Forward Curves		FY2009	FY2010	FY2011	FY2012	FY2013	FY2014	FY2015	FY2016
Gas	$/MCF	$4.520	$5.725	$6.292	$7.476	$7.837	$7.943	$8.695	$9.821
Electricity	$/Kwh	$0.035	$0.043	$0.047	$0.046	$0.047	$0.049	$0.053	$0.058

Forward Curves		FY2017	FY2018	FY2019	FY2020	FY2021	FY2022	FY2023
Gas	$/MCF	$11.186	$11.139	$11.752	$11.135	$10.776	$11.446	$12.370
Electricity	$/Kwh	$0.063	$0.066	$0.069	$0.069	$0.070	$0.075	$0.078

2.3 Market Power Inputs

To model the cogeneration units at UIUC in Market Power, the following assumptions were used:

Table 2.3-1 Market Power Inputs

Units	Attributes
Capacity Abbott - Coal (MW)	25.0
Capacity Abbott - Gas (MW)	31.0
Capacity Abbott - Solar Titan (MW)	26.7
Heat Rate Abbott - Coal (MMBtu/MWh)	11.5
Heat Rate Abbott - Gas (MMBtu/MWh)	15.0
Heat Rate Abbott - Solar Titan (MMBtu/MWh)	Average is 10.9 see monthly values below
Peak Demand (MW)	80 until July 2009 108 thereafter
Total Annual Demand (GWh)	453 until July 2009 693 thereafter
Fuel Costs ($/MMBtu)	$10.33 first year; market price thereafter
Fuel Costs ($/Ton)	$91.55 first year, $101.82 second year, market price thereafter
Transmission Constraints (MW)	40 MW until July 2009, 60 MW thereafter

The first three lines of Table 2.3-1 show the total MW capacity of electricity production by fuel type and mode, e.g., the two Solar Titan gas turbines have a combined capacity of 26.7 MW.

The next two lines show estimated values for the heat rates for the steam cogenerating plant in cogenerating mode in order to capture the amount of fuel needed to produce a given amount of electricity. Market Power does not consider cogeneration. The model deployed these assets for electricity production based on the defined ‘must run’ capacity of each asset, which was based on the steam need of the campus (electricity is the ‘free’ by product).

The heat rate for the GT was used on a monthly basis calculated as a function of average ambient temperature.

Table 2.3-2 Gas Turbine Monthly Heat Rates

Jan	10.692
Feb	10.698
Mar	10.735
Apr	10.830
May	10.992
Jun	11.185
Jul	11.253
Aug	11.200
Sep	11.070
Oct	10.865
Nov	10.735
Dec	10.697

3. *Analysis of Base Case*

3.1 Basic Assumptions

The general plant operations were outlined in the preceding section. For the Base Case steam production is economically dispatched based on the cost of producing steam and the capacity limitations (available vs. nameplate capacity) of the boilers. For example the coal boilers have a limit of 250,000 lbs/hr due to scrubber capacity. The monthly coal capacity also reflects the planned outage for maintenance including the four weeks that the scrubber is shut down for preventative maintenance.

Table 3.1-1 Monthly Coal Firing Capacity

Month	Capacity (tons)
July	15,000
August	15,000
September	14,500
October	7,500
November	14,500
December	15,000
January	15,000
February	13,600
March	15,000
April	7,250
May	15,000
June	14,500

Typically, this means operating the coal-fired units first and then the gas fired equipment after that. The model does not incorporate specific turn-down levels (minimum capacities), but does account for performance (efficiency) of the units, including variations in gas turbine efficiency/capacity due to monthly variations in ambient temperature:

Table 3.1-2 Variation in Gas Turbine Capacity

Month	Capacity (KW)
July	11,181
August	11,304
September	11,630
October	12,252
November	12,850
December	13,228
January	13,356
February	13,207
March	12,850
April	12,382
May	11,846
June	11,340

The amount of electricity produced by the steam turbine generators is a function of the steam demand. The gas turbines/HRSGs are dispatched based on the economics of electricity production and import electricity restrictions. The electric demand that is not satisfied by the electricity produced by the steam turbine generators is met either by gas turbine operation or imports. In other words, the steam turbine generating assets act as a base load operation while the gas turbine generator acts as an intermediate or peaking plant. The distribution charge for the electricity imported is assumed to be $0.01 per KWh.

In addition to these operating assumptions there were also financial, market and regulatory assumptions made. For the financial analysis a discount rate of 5.00 percent was assumed based in part on the guidance provide by the OMB Circular A-94 for 20 year analyses. Labor costs are assumed to grow at an annual rate of 5 percent from the base year and other O&M costs are assumed to grow at an annual rate of 3%. Capital expenditures are comprised of the currently budgeted maintenance projects as provided by the University and the additional projects identified by Worley Parsons to be required. The cost for those additional major repair and maintenance items is captured in the reserve fund line item. The reserve fund accumulates funds for the projects scheduled to be funded over the next 5 years. The general maintenance as currently planned for by the University is captured as part of the fixed plant and equipment costs.

On the regulatory side it was assumed that no CO_2 emission costs are incurred for the base case. A later case deals specifically with the effects of a potential carbon tax being implemented. It is further assumed that after the current commodity contracts expire the University will be able to procure their needed fuel at the market rate as forecasted by Market Power. The current contract assumptions are as follows:

Coal Costs, including limestone, ash and haul-back:

FY09 $91.55 per ton

FY10 $101.82 per

Gas prices are assumed to be the following for FY09 and market rate there after:

Table 3.1-3 FY 2009 UIUC Gas Prices

Month in FY 09	**Natural Gas Price in $/MCF**
July	$10.30
August	$10.29
September	$10.30
October	$10.35
November	$10.66
December	$11.02
January	$11.19
February	$11.20
March	$10.93
April	$9.31
May	$9.19
June	$9.17

The cost for purchased electricity is based on the forecasted values derived by Market Power for the region. The following graph exhibits the electricity forward curves for 2010 – 2023 that do not include the delivery charge that was assumed to be $0.01/KWh. It should be noted that the analysis is based on the hourly model utilized by Market Power. The outputs are provided on a monthly basis in order to facilitate the analysis timeframe of 15 years.

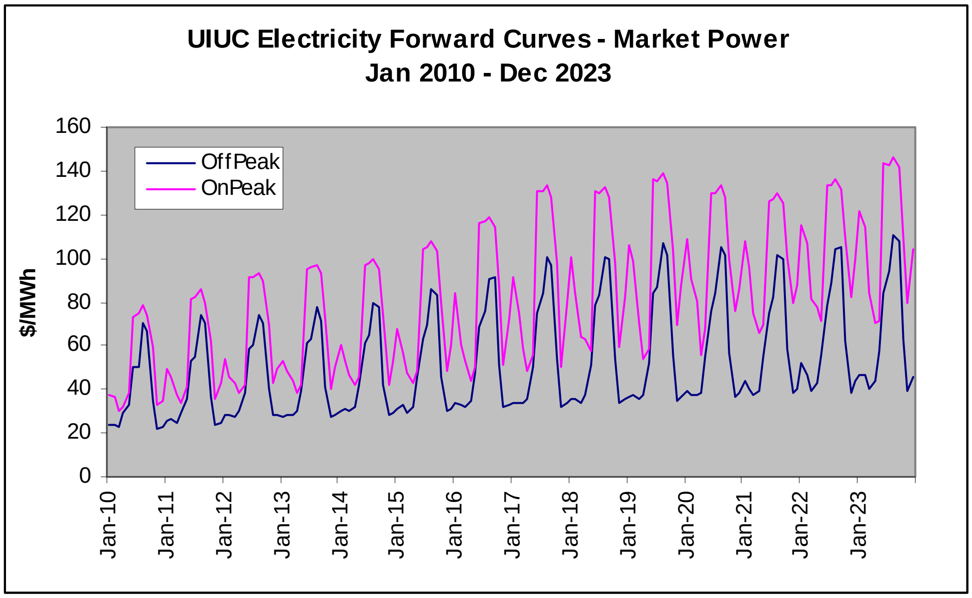

Figure 3–1.2. Electricity Forward Curves

Table 3.1-4 2010 – 2015 Market Power – Electricity Forward Curves (On Peak Prices)

OnPeak ($/MWh)	2010	2011	2012	2013	2014	2015
Jan	$37.939	$49.512	$54.390	$52.884	$60.665	$67.843
Feb	$36.257	$45.619	$46.040	$48.510	$53.006	$56.582
Mar	$30.272	$37.165	$42.858	$44.006	$46.453	$47.912
Apr	$32.030	$34.017	$38.200	$37.943	$41.642	$42.799
May	$38.039	$41.219	$42.391	$42.084	$45.264	$48.166
Jun	$73.422	$81.045	$91.474	$95.001	$96.574	$104.556
Jul	$75.160	$81.848	$91.717	$95.738	$97.838	$105.491
Aug	$78.174	$86.027	$93.707	$97.346	$99.206	$107.464
Sep	$74.456	$79.876	$89.798	$93.575	$95.296	$103.015
Oct	$59.062	$61.964	$69.762	$72.807	$73.911	$79.957
Nov	$32.877	$35.439	$42.578	$40.428	$41.934	$48.871
Dec	$35.002	$42.941	$49.178	$50.547	$53.170	$60.287

Table 3.1-5 2010 – 2015 Market Power – Electricity Forward Curves (Off Peak Prices)

OffPeak ($/MWh)	2010	2011	2012	2013	2014	2015
Jan	$23.384	$25.410	$28.281	$27.838	$30.503	$31.429
Feb	$23.508	$26.347	$28.215	$28.144	$30.755	$32.509
Mar	$22.520	$24.654	$27.449	$28.598	$29.758	$29.202
Apr	$28.924	$29.504	$30.002	$29.898	$32.073	$32.237
May	$33.348	$35.710	$38.702	$39.597	$42.209	$45.258
Jun	$50.065	$53.247	$58.284	$61.663	$61.018	$63.253
Jul	$50.072	$55.154	$60.170	$63.401	$64.634	$69.070
Aug	$70.484	$73.793	$73.841	$77.289	$79.996	$85.817
Sep	$67.024	$70.371	$70.667	$71.155	$77.750	$83.283
Oct	$34.857	$36.818	$40.091	$41.286	$42.157	$46.135
Nov	$22.314	$23.726	$28.712	$27.117	$28.501	$30.264
Dec	$23.013	$24.955	$28.523	$28.547	$29.490	$30.706

3.2 Plant Operating Costs

Based on the model structure described in chapter 3 of this report the SAIC team developed the plant operating cost based on the inputs for both the fixed and variable cost components (fuel, labor, equipment, maintenance, etc) developing variable and all in costs (including fixed cost allocation) for the outputs of electricity, steam, chilled water produced by the plant. The table below shows the cost per unit.

Table 3.2-1 UIUC Variable Cost

Variable Cost		FY2009	FY2010	FY2011	FY2012	FY2013	FY2014	FY2015	FY2016
Steam (w Electricity credit)	$/Klbs	$5.5760	$6.0165	$6.0026	$7.4419	$8.4404	$8.6847	$9.1853	$9.6839
Electricity from Gas Turbines	$/Kwh	$0.0948	$0.0377	$0.0439	$0.0529	$0.0537	$0.0642	$0.0714	$0.0814
Electricity Purchased	$/Kwh	$0.0516	$0.0637	$0.0688	$0.0642	$0.0641	$0.0654	$0.0684	$0.0737
Blended Electricity	$/Kwh	$0.0530	$0.0505	$0.0558	$0.0592	$0.0601	$0.0650	$0.0694	$0.0761
Chilled Water	$/ton-hr	$0.0425	$0.0425	$0.0460	$0.0496	$0.0514	$0.0547	$0.0582	$0.0633

Variable Cost		FY2017	FY2018	FY2019	FY2020	FY2021	FY2022	FY2023
Steam (w Electricity credit)	$/Klbs	$10.4589	$10.6814	$11.1066	$10.9879	$11.0526	$11.4455	$12.1032
Electricity from Gas Turbines	$/Kwh	$0.0961	$0.0949	$0.1002	$0.0906	$0.0864	$0.0921	$0.0999
Electricity Purchased	$/Kwh	$0.0799	$0.0826	$0.0857	$0.0856	$0.0867	$0.0918	$0.0945
Blended Electricity	$/Kwh	$0.0842	$0.0857	$0.0893	$0.0871	$0.0866	$0.0919	$0.0961
Chilled Water	$/ton-hr	$0.0695	$0.0709	$0.0738	$0.0724	$0.0723	$0.0763	$0.0798

Table 3.2-2 UIUC All in Costs

All in Costs		FY2009	FY2010	FY2011	FY2012	FY2013	FY2014	FY2015	FY2016
Steam	$/Klbs	$13.829	$13.958	$13.102	$14.134	$17.092	$19.385	$18.218	$19.473
Blended Electricity	$/Kwh	$0.061	$0.057	$0.060	$0.063	$0.067	$0.073	$0.073	$0.081
Cooling	$/ton-hr	$0.060	$0.054	$0.050	$0.052	$0.064	$0.077	$0.069	$0.076

All in Costs		FY2017	FY2018	FY2019	FY2020	FY2021	FY2022	FY2023
Steam	$/Klbs	$20.917	$21.481	$22.052	$21.782	$21.666	$22.472	$23.344
Blended Electricity	$/Kwh	$0.089	$0.090	$0.093	$0.091	$0.090	$0.095	$0.099
Cooling	$/Kwh	$0.082	$0.084	$0.086	$0.084	$0.082	$0.086	$0.089

The costs for UIUC are calculated as follows:

- UIUC Steam is the total cost of coal and gas for steam production divided by total amount of steam produced

- UIUC Electricity from Gas Turbines is the total cost of gas used by gas turbines minus the value of the HRSG steam divided by total amount of electricity produced by the turbines (the value of the HRSG steam is equal to the amount of HRSG steam produced times the unit cost of the steam produced by coal and gas boilers)

- UIUC Blended Electricity Costs is the weighted average of all electricity produced and purchased

- UIUC Cooling is the amount of electricity used for cooling times the blended electricity cost plus the amount of steam used for cooling times the cost of steam divided by the total ton hours produced

The all in cost adds the relevant labor and maintenance cost to each of the categories, e.g., the all in cooling costs include the labor and repair costs associated with chilled water production and distribution. In addition the fixed labor cost for plant administration and overall plant cost for labor and maintenance are applied 80% to steam production and 20% to electricity production.

It should be noted that the maintenance contract for the gas turbines of $42,526 per unit per month is assumed to be a fixed cost until the end of FY2013 based on the current binding five year contract. Starting in FY2014 the maintenance cost for the gas turbines is applied as a variable cost, which increases the variable cost and changes the dispatch decision model for the gas turbines. The hourly production costs derived from the hourly market power model are compared to hourly market price to determine the monthly utilization of each asset. After the current maintenance contract expires and assuming that UIUC could enter into a maintenance agreement that would allow it to capture that actual variable production cost of electricity from the gas turbines, it is forecasted by the model that the cost would be higher than market rate at most times. The exception is for periods of peak demand.

The values shown are annual averages and there are brief periods of peak demand in which Market Power forecasts a higher price for electricity in the market than internal production costs. At those times the model dispatches the plant assets. The reason for the utilization of the gas turbines at UIUC is the limit on transmission capability. Due to this limit on transmission the University cannot meet its electricity demand through purchased electricity alone at times of high electricity demand and needs to utilize the, more costly, in house capability instead. The table below shows an example from FY2015 of the various levels of utilization of the assets at UIUC. The high level of utilization of the coal boilers, and to a lesser extend the gas boilers, at UIUC during the winter month is based on the requirement that steam demand needs to be met.

Table 3.2-3 UIUC FY2015 Production Asset Utilization

2015	% of Gas Turbine Capacity	% of Coal Firing capacity	% of Gas Firing capacity
July	90%	78%	55%
August	90%	77%	70%
September	90%	69%	57%
October	90%	50%	56%
November	4%	90%	24%
December	8%	90%	44%
January	14%	90%	48%
February	32%	90%	59%
March	4%	90%	19%
April	5%	50%	42%
May	11%	90%	15%
June	90%	72%	48%

The actual decision to use a given generation asset (dispatch strategy) has to be made on an hourly energy cost basis and take into account any other operating issues with other assets at the time.

3.3 Discounted cash flow analysis

The tables on the following pages show the financial forecasts through FY2023 for operating the UIUC central plant. In the determination of the operating revenue the assumption was made that the plant would recover its cost from the University. Based on this assumption there is no real NPV for the plant as costs are always covered, but rather a total cost of ownership associated with owning the plant. Based on the currently forecasted cost structure for electricity, coal, and natural gas the plant's all in cost for electricity production for the plant are expected to be higher than market price except for times of high peak demand during the summer months. Based on the variable cost only, the cost of electricity production from the gas turbines is lower for a larger amount of time as shown in section 3.2. The actual decision to use a given generation asset has to be made on an hourly energy cost basis. After the current maintenance contract expires and making the assumption that UIUC could enter into a maintenance agreement that would allow it to capture that actual variable production cost of electricity from the gas turbines it is forecasted by the model that the cost would be higher for a greater amount of time. On an annual basis the average variable electricity production cost for electricity from the gas turbines are expected to rise from roughly 7 cents in FY2015 to about 10 cents in FY2023 while the market price is expected to rise from 6 cents to 9 cents over the same time period.

Table 3.3-1 UIUC Financials forecasted through FY2023

UIUC $000	FY 2009	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023
Operating Revenue															
UIUC Revenue from Steam	$45,501	$37,991	$35,779	$38,068	$45,473	$50,994	$47,619	$50,870	$53,802	$55,169	$56,557	$56,709	$56,435	$58,442	$60,705
UIUC Revenue from Electricity	$20,562	$23,048	$23,898	$24,288	$25,747	$27,154	$26,830	$29,195	$30,942	$31,544	$32,571	$32,912	$32,736	$34,362	$35,792
UIUC Revenue from Chillers	$3,727	$3,367	$3,006	$3,036	$3,867	$4,614	$3,997	$4,293	$4,475	$4,615	$4,702	$4,782	$4,756	$4,918	$5,085
Total Revenue	**$69,790**	**$64,405**	**$62,683**	**$65,391**	**$75,087**	**$82,761**	**$78,446**	**$84,358**	**$89,219**	**$91,328**	**$93,830**	**$94,403**	**$93,928**	**$97,722**	**$101,581**
Operating Cost															
Fixed Cost															
Labor	$482	$506	$531	$557	$585	$615	$645	$678	$711	$747	$784	$824	$865	$908	$953
Plant & Equipment	$10,685	$11,006	$11,336	$11,676	$12,026	$12,387	$12,758	$13,141	$13,535	$13,942	$14,360	$14,791	$15,234	$15,691	$16,162
Gas Turbine Maintenance Contract	$1,021	$1,021	$1,021	$1,021	$1,021	$	$	$	$	$	$	$	$	$	$
Reserve Fund	$3,413	$3,528	$1,828	$1,378	$652	$1,197	$1,164	$2,602	$2,495	$2,591	$1,945	$1,864	$358	$269	$99
Total Fixed Cost	**$15,600**	**$16,060**	**$14,715**	**$14,632**	**$14,284**	**$14,199**	**$14,568**	**$16,421**	**$16,742**	**$17,279**	**$17,089**	**$17,478**	**$16,457**	**$16,868**	**$17,214**
Variable Cost															
Fuel															
Cost of Steam Production (Coal)	$13,306	$13,857	$13,928	$15,385	$16,915	$17,013	$17,491	$18,060	$18,653	$19,211	$19,674	$20,154	$20,442	$21,009	$21,680
Cost of Steam Production (Gas)	$10,325	$6,816	$7,525	$8,823	$9,223	$9,346	$10,231	$11,556	$13,163	$13,109	$13,829	$13,102	$12,681	$13,470	$14,555
Cost of Electricity from Gas Turbine	$744	$6,510	$7,442	$7,277	$6,624	$5,927	$6,018	$6,749	$6,306	$6,132	$6,340	$7,306	$7,120	$7,416	$8,004
Cost of Electricity Purchased	$13,635	$9,115	$9,573	$10,399	$11,287	$12,254	$13,258	$14,318	$16,686	$17,363	$18,124	$16,931	$17,099	$18,245	$18,774
Total Fuel Cost	**$38,011**	**$36,299**	**$38,468**	**$41,885**	**$44,049**	**$44,541**	**$46,998**	**$50,683**	**$54,807**	**$55,814**	**$57,967**	**$57,494**	**$57,342**	**$60,139**	**$63,013**
Non-Fuel variable O&M															
Labor	$5,251	$5,514	$5,790	$6,079	$6,383	$6,702	$7,037	$7,389	$7,759	$8,147	$8,554	$8,982	$9,431	$9,902	$10,397
Maintenance	$3,374	$3,475	$3,579	$3,687	$3,797	$4,932	$5,049	$5,170	$5,295	$5,423	$5,555	$5,691	$5,831	$5,975	$6,124
Emissions															
Total Non-Fuel variable O&M Cost	**$8,625**	**$8,989**	**$9,369**	**$9,766**	**$10,180**	**$11,634**	**$12,087**	**$12,559**	**$13,053**	**$13,569**	**$14,109**	**$14,673**	**$15,262**	**$15,878**	**$16,521**
Total Operating Cost	**$62,236**	**$61,347**	**$62,553**	**$66,283**	**$68,514**	**$70,374**	**$73,653**	**$79,663**	**$84,602**	**$86,663**	**$89,165**	**$89,644**	**$89,061**	**$92,885**	**$96,749**
Debt Service	$7,528	$3,355	$511	-$517	$6,886	$12,636	$5,067	$5,067	$5,067	$5,067	$5,067	$5,067	$5,067	$5,067	$5,067
Total Costs	**$69,764**	**$64,703**	**$63,064**	**$65,766**	**$75,400**	**$83,009**	**$78,719**	**$84,730**	**$89,669**	**$91,729**	**$94,231**	**$94,711**	**$94,128**	**$97,951**	**$101,815**

3.4 Sensitivity Analysis

Changes in Demand 20% Increase and 20% Decrease

In order to determine the impact of energy conservation measures to reduce demand for both heat and electricity, as well as the impact of growth in demand, we generated additional cases for a 20% increase in demand and a 20% reduction in demand. Due to the greater cost of electricity production in the plant when compared to the market price the total operating cost of the 15 year operation becomes negative compared to the base case as demand increases. This is due to the import restrictions. Decreased demand has a positive effect on the total operating cost since less electricity generation occurs. The detailed financials are shown in Tables 4.4.1 and 4.4.2 on the following pages.

Table 3.4-1 UIUC Financials forecasted through FY2023 Demand up 20%

UIUC $000	FY 2009	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023
Operating Revenue															
UIUC Revenue from Steam	$51,695	$41,865	$40,007	$43,178	$50,387	$55,709	$52,551	$56,319	$59,975	$61,745	$63,512	$63,783	$63,244	$65,435	$68,214
UIUC Revenue from Electricity	$19,825	$21,258	$22,003	$22,300	$24,910	$27,013	$27,476	$30,552	$32,639	$32,757	$33,558	$33,368	$33,159	$34,635	$35,624
UIUC Revenue from Chillers	$4,349	$3,943	$3,594	$3,724	$4,538	$5,227	$4,589	$4,877	$5,073	$5,198	$5,295	$5,396	$5,381	$5,597	$5,861
Total Revenue	**$75,869**	**$67,065**	**$65,604**	**$69,202**	**$79,836**	**$87,949**	**$84,616**	**$91,749**	**$97,687**	**$99,700**	**$102,365**	**$102,547**	**$101,784**	**$105,667**	**$109,699**
Operating Cost															
Fixed Cost															
Labor	$482	$506	$531	$557	$585	$615	$645	$678	$711	$747	$784	$824	$865	$908	$953
Plant & Equipment	$10,685	$11,006	$11,336	$11,676	$12,026	$12,387	$12,758	$13,141	$13,535	$13,942	$14,360	$14,791	$15,234	$15,691	$16,162
Gas Turbine Maintenance Contract	$1,021	$1,021	$1,021	$1,021	$1,021	$	$	$	$	$	$	$	$	$	$
Reserve Fund	$3,375	$3,490	$1,791	$1,378	$652	$1,197	$1,164	$2,602	$2,455	$2,431	$1,737	$1,655	$150	$100	$50
Total Fixed Cost	**$15,563**	**$16,022**	**$14,678**	**$14,632**	**$14,284**	**$14,199**	**$14,568**	**$16,421**	**$16,702**	**$17,120**	**$16,881**	**$17,269**	**$16,249**	**$16,699**	**$17,165**
Variable Cost															
Fuel															
Cost of Steam Production (Coal)	$14,551	$16,122	$16,205	$17,723	$19,440	$19,552	$20,102	$20,756	$21,436	$22,078	$22,610	$23,162	$23,493	$24,144	$24,915
Cost of Steam Production (Gas)	$16,290	$9,043	$10,001	$12,021	$12,637	$12,808	$14,021	$15,835	$18,038	$17,963	$18,950	$17,955	$17,378	$18,457	$19,946
Cost of Electricity from Gas Turbine	$1,654	$6,540	$7,209	$6,615	$7,512	$7,620	$8,220	$9,112	$8,457	$7,222	$7,200	$7,321	$7,490	$8,212	$8,764
Cost of Electricity Purchased	$11,629	$7,247	$7,961	$9,274	$9,227	$9,797	$10,915	$12,492	$15,500	$17,134	$17,970	$17,398	$17,048	$17,446	$17,551
Total Fuel Cost	**$44,124**	**$38,952**	**$41,376**	**$45,633**	**$48,816**	**$49,777**	**$53,259**	**$58,195**	**$63,432**	**$64,397**	**$66,729**	**$65,836**	**$65,409**	**$68,259**	**$71,176**
Non-Fuel variable O&M															
Labor	$5,251	$5,514	$5,790	$6,079	$6,383	$6,702	$7,037	$7,389	$7,759	$8,147	$8,554	$8,982	$9,431	$9,902	$10,397
Maintenance	$3,374	$3,475	$3,579	$3,687	$3,797	$4,932	$5,049	$5,170	$5,295	$5,423	$5,555	$5,691	$5,831	$5,975	$6,124
Emissions															
Total Non-Fuel variable O&M Cost	**$8,625**	**$8,989**	**$9,369**	**$9,766**	**$10,180**	**$11,634**	**$12,087**	**$12,559**	**$13,053**	**$13,569**	**$14,109**	**$14,673**	**$15,262**	**$15,878**	**$16,521**
Total Operating Cost	**$68,312**	**$63,963**	**$65,423**	**$70,031**	**$73,281**	**$75,610**	**$79,913**	**$87,175**	**$93,187**	**$95,086**	**$97,719**	**$97,778**	**$96,920**	**$100,836**	**$104,863**
Debt Service	$7,528	$3,355	$511	-$517	$6,886	$12,636	$5,067	$5,067	$5,067	$5,067	$5,067	$5,067	$5,067	$5,067	$5,067
Total Costs	**$75,840**	**$67,318**	**$65,935**	**$69,514**	**$80,167**	**$88,245**	**$84,980**	**$92,242**	**$98,253**	**$100,153**	**$102,786**	**$102,845**	**$101,987**	**$105,903**	**$109,929**

Table 3.4-2 UIUC Financials forecasted through FY2023 demand down 20%

UIUC $000	FY 2009	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023
Operating Revenue															
UIUC Revenue from Steam	$37,440	$33,506	$31,229	$33,163	$39,915	$45,073	$41,016	$43,476	$45,230	$46,471	$47,324	$48,065	$48,039	$49,539	$51,224
UIUC Revenue from Electricity	$22,050	$25,155	$25,662	$25,085	$27,015	$29,034	$29,061	$31,597	$33,480	$34,325	$35,552	$35,975	$35,869	$37,824	$39,325
UIUC Revenue from Chillers	$3,622	$3,254	$2,895	$2,922	$3,728	$4,456	$3,814	$4,086	$4,215	$4,341	$4,406	$4,519	$4,502	$4,650	$4,809
Total Revenue	**$63,111**	**$61,916**	**$59,786**	**$61,170**	**$70,657**	**$78,563**	**$73,891**	**$79,159**	**$82,925**	**$85,137**	**$87,282**	**$88,560**	**$88,410**	**$92,013**	**$95,359**
Operating Cost															
Fixed Cost															
Labor	$482	$506	$531	$557	$585	$615	$645	$678	$711	$747	$784	$824	$865	$908	$953
Plant & Equipment	$10,685	$11,006	$11,336	$11,676	$12,026	$12,387	$12,758	$13,141	$13,535	$13,942	$14,360	$14,791	$15,234	$15,691	$16,162
Gas Turbine Maintenance Contract	$1,021	$1,021	$1,021	$1,021	$1,021	$	$	$	$	$	$	$	$	$	$
Reserve Fund	$3,375	$3,490	$1,791	$1,378	$652	$1,197	$1,164	$2,602	$2,455	$2,431	$1,737	$1,655	$150	$100	$50
Total Fixed Cost	**$15,563**	**$16,022**	**$14,678**	**$14,632**	**$14,284**	**$14,199**	**$14,568**	**$16,421**	**$16,702**	**$17,120**	**$16,881**	**$17,269**	**$16,249**	**$16,699**	**$17,165**
Variable Cost															
Fuel															
Cost of Steam Production (Coal)	$13,004	$12,873	$13,167	$14,658	$16,078	$16,171	$16,625	$17,166	$18,041	$18,580	$19,028	$19,157	$19,430	$19,969	$20,606
Cost of Steam Production (Gas)	$2,253	$3,119	$3,144	$3,377	$3,538	$3,586	$3,924	$4,433	$4,512	$4,493	$4,740	$5,026	$4,864	$5,167	$5,583
Cost of Electricity from Gas Turbine	$145	$6,224	$6,159	$4,374	$4,550	$4,611	$5,047	$5,702	$5,143	$5,121	$5,403	$6,464	$6,254	$6,645	$7,181
Cost of Electricity Purchased	$15,901	$11,462	$12,917	$14,952	$15,178	$15,736	$16,608	$17,918	$20,558	$21,300	$22,161	$20,934	$21,212	$22,539	$23,168
Total Fuel Cost	**$31,303**	**$33,678**	**$35,387**	**$37,361**	**$39,344**	**$40,103**	**$42,205**	**$45,219**	**$48,253**	**$49,494**	**$51,333**	**$51,581**	**$51,760**	**$54,320**	**$56,538**
Non-Fuel variable O&M															
Labor	$5,251	$5,514	$5,790	$6,079	$6,383	$6,702	$7,037	$7,389	$7,759	$8,147	$8,554	$8,982	$9,431	$9,902	$10,397
Maintenance	$3,374	$3,475	$3,579	$3,687	$3,797	$4,932	$5,049	$5,170	$5,295	$5,423	$5,555	$5,691	$5,831	$5,975	$6,124
Emissions															
Total Non-Fuel variable O&M Cost	**$8,625**	**$8,989**	**$9,369**	**$9,766**	**$10,180**	**$11,634**	**$12,087**	**$12,559**	**$13,053**	**$13,569**	**$14,109**	**$14,673**	**$15,262**	**$15,878**	**$16,521**
Total Operating Cost	**$55,491**	**$58,690**	**$59,434**	**$61,759**	**$63,808**	**$65,936**	**$68,859**	**$74,200**	**$78,009**	**$80,183**	**$82,322**	**$83,522**	**$83,271**	**$86,897**	**$90,225**
Debt Service	$7,528	$3,355	$511	-$517	$6,886	$12,636	$5,067	$5,067	$5,067	$5,067	$5,067	$5,067	$5,067	$5,067	$5,067
Total Costs	**$63,019**	**$62,045**	**$59,945**	**$61,242**	**$70,694**	**$78,572**	**$73,926**	**$79,266**	**$83,075**	**$85,250**	**$87,389**	**$88,589**	**$88,338**	**$91,963**	**$95,292**

Unconstrained Transmission

To evaluate the cost of the transmission constraint resulting from the limited tie-line capacity into UIUC from the power grid, SAIC analyzed a case in which all transmission constraints would be lifted in FY2014. Lifting this constraint would result in less in house production limited only to the peak demand times in which the gas turbines could produce energy cheaper than market price. At current market price forecasts this increase in electricity imports is predicted to save UIUC an average of approximately $0.5 million annually, producing a net present value of $2 million improvement over the base case.

Table 3.4-3 UIUC Financials forecasted through FY2023 Unconstraint Transmission

UIUC	FY 2009	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023
$000															
Operating Revenue															
UIUC Revenue from Steam	$45,501	$37,991	$35,779	$38,068	$45,473	$52,856	$49,441	$52,779	$55,345	$56,694	$58,075	$58,737	$58,470	$60,508	$62,877
UIUC Revenue from Electricity	$20,562	$23,048	$23,898	$24,288	$25,747	$25,466	$25,310	$26,954	$28,732	$29,614	$30,459	$30,439	$30,528	$32,047	$33,066
UIUC Revenue from Chillers	$3,727	$3,367	$3,006	$3,036	$3,867	$4,684	$4,039	$4,371	$4,535	$4,665	$4,760	$4,870	$4,845	$5,007	$5,179
Total Revenue	**$69,790**	**$64,405**	**$62,683**	**$65,391**	**$75,087**	**$83,007**	**$78,790**	**$84,104**	**$88,613**	**$90,973**	**$93,294**	**$94,047**	**$93,843**	**$97,563**	**$101,121**
Operating Cost															
Fixed Cost															
Labor	$482	$506	$531	$557	$585	$615	$645	$678	$711	$747	$784	$824	$865	$908	$953
Plant & Equipment	$10,685	$11,006	$11,336	$11,676	$12,026	$12,387	$12,758	$13,141	$13,535	$13,942	$14,360	$14,791	$15,234	$15,691	$16,162
Gas Turbine Maintenance Contract	$1,021	$1,021	$1,021	$1,021	$1,021	$	$	$	$	$	$	$	$	$	$
Reserve Fund	$3,413	$3,528	$1,828	$1,378	$652	$1,197	$1,164	$2,602	$2,495	$2,591	$1,945	$1,864	$358	$269	$99
Total Fixed Cost	**$15,600**	**$16,060**	**$14,715**	**$14,632**	**$14,284**	**$14,199**	**$14,568**	**$16,421**	**$16,742**	**$17,279**	**$17,089**	**$17,478**	**$16,457**	**$16,868**	**$17,214**
Variable Cost															
Fuel															
Cost of Steam Production (Coal)	$13,306	$13,857	$13,928	$15,385	$16,915	$17,996	$18,502	$19,104	$19,730	$20,321	$20,810	$21,338	$21,643	$22,243	$22,953
Cost of Steam Production (Gas)	$10,325	$6,816	$7,525	$8,823	$9,223	$8,068	$8,833	$9,976	$11,363	$11,316	$11,938	$11,281	$10,919	$11,598	$12,532
Cost of Electricity from Gas Turbine	$744	$6,510	$7,442	$7,277	$6,624	$326	$357	$403	$459	$457	$483	$383	$371	$394	$426
Cost of Electricity Purchased	$13,635	$9,115	$9,573	$10,399	$11,287	$18,251	$19,499	$20,753	$22,451	$23,186	$24,011	$23,926	$24,140	$25,551	$26,410
Total Fuel Cost	**$38,011**	**$36,299**	**$38,468**	**$41,885**	**$44,049**	**$44,641**	**$47,190**	**$50,236**	**$54,004**	**$55,280**	**$57,242**	**$56,929**	**$57,073**	**$59,785**	**$62,320**
Non-Fuel variable O&M															
Labor	$5,251	$5,514	$5,790	$6,079	$6,383	$6,702	$7,037	$7,389	$7,759	$8,147	$8,554	$8,982	$9,431	$9,902	$10,397
Maintenance	$3,374	$3,475	$3,579	$3,687	$3,797	$4,932	$5,049	$5,170	$5,295	$5,423	$5,555	$5,691	$5,831	$5,975	$6,124
Emissions															
Total Non-Fuel variable O&M Cost	**$8,625**	**$8,989**	**$9,369**	**$9,766**	**$10,180**	**$11,634**	**$12,087**	**$12,559**	**$13,053**	**$13,569**	**$14,109**	**$14,673**	**$15,262**	**$15,878**	**$16,521**
Total Operating Cost	**$62,236**	**$61,347**	**$62,553**	**$66,283**	**$68,514**	**$70,474**	**$73,845**	**$79,216**	**$83,799**	**$86,129**	**$88,440**	**$89,079**	**$88,792**	**$92,531**	**$96,056**
Debt Service	$7,528	$3,355	$511	-$517	$6,886	$12,636	$5,067	$5,067	$5,067	$5,067	$5,067	$5,067	$5,067	$5,067	$5,067
Total Costs	**$69,764**	**$64,703**	**$63,064**	**$65,766**	**$75,400**	**$83,109**	**$78,911**	**$84,283**	**$88,866**	**$91,196**	**$93,507**	**$94,145**	**$93,859**	**$97,597**	**$101,123**
Total Operating Costs Base Case	**$69,764**	**$64,703**	**$63,064**	**$65,766**	**$75,400**	**$83,009**	**$78,719**	**$84,730**	**$89,669**	**$91,729**	**$94,231**	**$94,711**	**$94,128**	**$97,951**	**$101,815**
Total Operating Cost Savings	**$**	**$**	**$**	**$**	**$**	**-$100**	**-$192**	**$447**	**$803**	**$534**	**$725**	**$566**	**$269**	**$354**	**$693**
Net Present Valus	$2,331														
Discount rate	5.00% From OMB Circular A-94														

Implementation of Carbon Tax

The potential impact of a carbon tax was also evaluated as part of this effort. Based on federal budget information a possible carbon tax could range from $12-$15 starting in 2012 and grow to $15-$18 by 2020.[5] Such a tax would add more significantly to the cost of coal fired plants relative to generation from using natural gas. Coal plants emit upward of 200 lbs per MMBTU versus around 120 lbs per MMBTU for natural gas burning units. For the Abbott plant the carbon tax is estimated to be between 1.5 and 2 cents per kWh in added cost for the coal fired plant and between 0.7 and 1 cent per kWh for the gas turbines. At the same time the Market Power model predicts that the carbon tax will increase the annual capacity market price of electricity substantially. While this improves the competiveness of the gas turbines in the market it is not enough at the forecasted fuel prices to make electricity production from the gas turbines cheaper than the price at which electricity can be bought from the grid and hence does not fundamentally change the outcome of the analysis. Market Power forecasts lower production from the coal plants, in total, and the displaced generation will be picked up by new builds of more efficient natural gas combined cycles with lower heat rates and to a smaller extent, from renewables.

In addition to the EPA's forecasted carbon tax, we also ran a scenario with $50 carbon tax. The results are slightly more favorable to the dispatching of the University's gas turbines. However, it does not increase the competitiveness of the gas turbines with respect to other combined cycles, existing and new builds, in the region. Overall, the result of the study that importing electricity is more cost effective than in-house production, most of the time, does not change with a $50 carbon tax.

Outsourcing Operations to Third Party

SAIC analyzed the potential economic benefits of outsourcing plant O&M to a third party provider. Using Worley Parsons' assessment of staffing requirement and needs at UIUC, we updated the fixed labor costs in the Base Case with Worley Parsons' figures. No costs or benefits were considered other than the potential labor cost differential. By outsourcing the UIUC could save on an average of approximately $1.3 million annually, producing a net present value of $13 million improvement over the base case.

This analysis is based on a review of the Organization charts that were provided by UIUC and compared to the charts WorleyParsons developed based on similar technologies. However, due to the limitations of this study and the complexity of plant operations, a more detailed review of staffing and operations would be required before definitive conclusions could be drawn.

[5] * Sources: EPA's Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2007 (2005 Emissions), available at: http://www.epa.gov/climatechange/emissions/usinventoryreport.html; OMB's 2010 Fiscal Year Budget Proposal (Projected Climate Revenues & 2020 Cap Levels), available at: http://www.whitehouse.gov/omb/

Table 3.4-4 UIUC Financials forecasted through FY2023 Outsourced Operations

UIUC $000	FY 2009	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023
Operating Revenue															
UIUC Revenue from Steam	$44,758	$37,211	$34,960	$37,208	$44,570	$50,045	$46,623	$49,825	$52,705	$54,016	$55,347	$55,438	$55,101	$57,041	$59,234
UIUC Revenue from Electricity	$20,376	$22,853	$23,693	$24,073	$25,522	$26,917	$26,581	$28,934	$30,668	$31,256	$32,268	$32,594	$32,403	$34,012	$35,424
UIUC Revenue from Chillers	$3,727	$3,367	$3,006	$3,036	$3,867	$4,614	$3,997	$4,293	$4,475	$4,615	$4,702	$4,782	$4,756	$4,918	$5,085
Total Revenue	**$68,861**	**$63,430**	**$61,659**	**$64,316**	**$73,959**	**$81,576**	**$77,202**	**$83,051**	**$87,847**	**$89,887**	**$92,317**	**$92,814**	**$92,260**	**$95,971**	**$99,743**
Operating Cost															
Fixed Cost															
Labor	$482	$506	$531	$557	$585	$615	$645	$678	$711	$747	$784	$824	$865	$908	$953
Plant & Equipment	$10,685	$11,006	$11,336	$11,676	$12,026	$12,387	$12,758	$13,141	$13,535	$13,942	$14,360	$14,791	$15,234	$15,691	$16,162
Gas Turbine Maintenance Contract	$1,021	$1,021	$1,021	$1,021	$1,021	$	$	$	$	$	$	$	$	$	$
Reserve Fund	$3,413	$3,528	$1,828	$1,378	$652	$1,197	$1,164	$2,602	$2,495	$2,591	$1,945	$1,864	$358	$269	$99
Total Fixed Cost	**$15,600**	**$16,060**	**$14,715**	**$14,632**	**$14,284**	**$14,199**	**$14,568**	**$16,421**	**$16,742**	**$17,279**	**$17,089**	**$17,478**	**$16,457**	**$16,868**	**$17,214**
Variable Cost															
Fuel															
Cost of Steam Production (Coal)	$13,306	$13,857	$13,928	$15,385	$16,915	$17,013	$17,491	$18,060	$18,653	$19,211	$19,674	$20,154	$20,442	$21,009	$21,680
Cost of Steam Production (Gas)	$10,325	$6,816	$7,525	$8,823	$9,223	$9,346	$10,231	$11,556	$13,163	$13,109	$13,829	$13,102	$12,681	$13,470	$14,555
Cost of Electricity from Gas Turbine	$744	$6,510	$7,442	$7,277	$6,624	$5,927	$6,018	$6,749	$6,306	$6,132	$6,340	$7,306	$7,120	$7,416	$8,004
Cost of Electricity Purchased	$13,635	$9,115	$9,573	$10,399	$11,287	$12,254	$13,258	$14,318	$16,686	$17,363	$18,124	$16,931	$17,099	$18,245	$18,774
Total Fuel Cost	**$38,011**	**$36,299**	**$38,468**	**$41,885**	**$44,049**	**$44,541**	**$46,998**	**$50,683**	**$54,807**	**$55,814**	**$57,967**	**$57,494**	**$57,342**	**$60,139**	**$63,013**
Non-Fuel variable O&M															
Contractor Labor	$3,217	$3,378	$3,547	$3,724	$3,911	$4,106	$4,312	$4,527	$4,753	$4,991	$5,241	$5,503	$5,778	$6,067	$6,370
Labor	$1,105	$1,161	$1,219	$1,280	$1,344	$1,411	$1,481	$1,555	$1,633	$1,715	$1,801	$1,891	$1,985	$2,084	$2,189
Maintenance	$3,374	$3,475	$3,579	$3,687	$3,797	$4,932	$5,049	$5,170	$5,295	$5,423	$5,555	$5,691	$5,831	$5,975	$6,124
Emissions															
Total Non-Fuel variable O&M Cost	**$7,697**	**$8,014**	**$8,345**	**$8,691**	**$9,052**	**$10,449**	**$10,842**	**$11,253**	**$11,681**	**$12,129**	**$12,596**	**$13,084**	**$13,594**	**$14,127**	**$14,683**
Total Operating Cost	**$61,307**	**$60,372**	**$61,529**	**$65,208**	**$67,385**	**$69,189**	**$72,408**	**$78,357**	**$83,230**	**$85,222**	**$87,652**	**$88,056**	**$87,394**	**$91,134**	**$94,910**
Debt Service	$7,528	$3,355	$511	-$517	$6,886	$12,636	$5,067	$5,067	$5,067	$5,067	$5,067	$5,067	$5,067	$5,067	$5,067
Total Costs	**$68,836**	**$63,727**	**$62,040**	**$64,691**	**$74,271**	**$81,824**	**$77,475**	**$83,423**	**$88,297**	**$90,289**	**$92,719**	**$93,123**	**$92,460**	**$96,200**	**$99,977**
Total Costs Base Case	**$69,764**	**$64,703**	**$63,064**	**$65,766**	**$75,400**	**$83,009**	**$78,719**	**$84,730**	**$89,669**	**$91,729**	**$94,231**	**$94,711**	**$94,128**	**$97,951**	**$101,815**
Total Cost Savings	**$929**	**$975**	**$1,024**	**$1,075**	**$1,129**	**$1,185**	**$1,244**	**$1,307**	**$1,372**	**$1,441**	**$1,513**	**$1,588**	**$1,668**	**$1,751**	**$1,839**
Net Present Valus	$13,266														
Discount rate	5.00%	From OMB Circular A-94													

Alternative Ownership

In addition to outsourcing the operations of the plant, SAIC also analyzed the alternative ownership of the plant to an outside entity. In the scenario examined the sale/transfer of ownership is really the assumption of the debt and a promise to provide the current level of service in the future. It does not include a valuation of the plant since that is beyond the scope of the present effort, and highly uncertain. The assumptions are as follow:

- The buyer would assume the current debt and provide the current level of service to UIUC and no additional payment would be made for the acquisition of the asset
- Current outstanding debt is a rough estimate of $35 million
- The buyer would refinance this debt at 7.5% for 20 years at level term
- Corporate Tax rate on profits after interest and depreciation is 35%
- The buyer needs to achieve a 6% profit margin to enter into the deal

Based on the above stated assumptions the cost for providing the steam and electricity currently provided by the University run Abbott plant would increase. The cost difference each year would depend on the amount of debt payment the University incurs in a given year (the UIUC debt payment are not uniform over time), but over the 15 year horizon of the analysis the average increase in annual cost under the outside ownership scenario is roughly $2.6 million. The exact numbers depend on the terms of the sale, the level of current debt assumed, the financing terms the new owner can achieve, and the profit margin the new owner needs to achieve in order to enter into the deal.

Table 3.4-5 UIUC Alternative Ownership Model

UIUC $000	FY 2009	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY 2019	FY 2020	FY 2021	FY 2022	FY 2023
Total Revenue	**$68,544**	**$67,498**	**$68,791**	**$72,904**	**$75,339**	**$77,355**	**$80,955**	**$87,605**	**$93,054**	**$95,281**	**$97,998**	**$98,450**	**$97,709**	**$101,890**	**$106,113**
Operating Cost															
Fixed Cost															
Labor	$482	$506	$531	$557	$585	$615	$645	$678	$711	$747	$784	$824	$865	$908	$953
Plant & Equipment	$10,685	$11,006	$11,336	$11,676	$12,026	$12,387	$12,758	$13,141	$13,535	$13,942	$14,360	$14,791	$15,234	$15,691	$16,162
Gas Turbine Maintenance Contract	$1,021	$1,021	$1,021	$1,021	$1,021	$	$	$	$	$	$	$	$	$	$
Reserve Fund	$3,413	$3,528	$1,828	$1,378	$652	$1,197	$1,164	$2,602	$2,495	$2,591	$1,945	$1,864	$358	$269	$99
Total Fixed Cost	**$15,600**	**$16,060**	**$14,715**	**$14,632**	**$14,284**	**$14,199**	**$14,568**	**$16,421**	**$16,742**	**$17,279**	**$17,089**	**$17,478**	**$16,457**	**$16,868**	**$17,214**
Variable Cost															
Fuel															
Cost of Steam Production (Coal)	$13,306	$13,857	$13,928	$15,385	$16,915	$17,013	$17,491	$18,060	$18,653	$19,211	$19,674	$20,154	$20,442	$21,009	$21,680
Cost of Steam Production (Gas)	$10,325	$6,816	$7,525	$8,823	$9,223	$9,346	$10,231	$11,556	$13,163	$13,109	$13,829	$13,102	$12,681	$13,470	$14,555
Cost of Electricity from Gas Turbine	$744	$6,510	$7,442	$7,277	$6,624	$5,927	$6,018	$6,749	$6,306	$6,132	$6,340	$7,306	$7,120	$7,416	$8,004
Cost of Electricity Purchased	$13,635	$9,115	$9,573	$10,399	$11,287	$12,254	$13,258	$14,318	$16,686	$17,363	$18,124	$16,931	$17,099	$18,245	$18,774
Total Fuel Cost	**$38,011**	**$36,299**	**$38,468**	**$41,885**	**$44,049**	**$44,541**	**$46,998**	**$50,683**	**$54,807**	**$55,814**	**$57,967**	**$57,494**	**$57,342**	**$60,139**	**$63,013**
Non-Fuel variable O&M															
Contractor Labor	$3,217	$3,378	$3,547	$3,724	$3,911	$4,106	$4,312	$4,527	$4,753	$4,991	$5,241	$5,503	$5,778	$6,067	$6,370
Labor	$1,105	$1,161	$1,219	$1,280	$1,344	$1,411	$1,481	$1,555	$1,633	$1,715	$1,801	$1,891	$1,985	$2,084	$2,189
Maintenance	$3,374	$3,475	$3,579	$3,687	$3,797	$4,932	$5,049	$5,170	$5,295	$5,423	$5,555	$5,691	$5,831	$5,975	$6,124
Emissions															
Total Non-Fuel variable O&M Cost	**$7,697**	**$8,014**	**$8,345**	**$8,691**	**$9,052**	**$10,449**	**$10,842**	**$11,253**	**$11,681**	**$12,129**	**$12,596**	**$13,084**	**$13,594**	**$14,127**	**$14,683**
Total Operating Cost	**$61,307**	**$60,372**	**$61,529**	**$65,208**	**$67,385**	**$69,189**	**$72,408**	**$78,357**	**$83,230**	**$85,222**	**$87,652**	**$88,056**	**$87,394**	**$91,134**	**$94,910**
Debt Service	$3,433	$3,433	$3,433	$3,433	$3,433	$3,433	$3,433	$3,433	$3,433	$3,433	$3,433	$3,433	$3,433	$3,433	$3,433
Total Costs	**$64,741**	**$63,806**	**$64,962**	**$68,641**	**$70,818**	**$72,622**	**$75,842**	**$81,790**	**$86,664**	**$88,655**	**$91,085**	**$91,489**	**$90,827**	**$94,567**	**$98,343**
Profit	$3,803	$3,693	$3,829	$4,263	$4,520	$4,733	$5,113	$5,815	$6,391	$6,626	$6,912	$6,960	$6,882	$7,323	$7,769
Intrest	$2,625	$2,564	$2,499	$2,429	$2,354	$2,273	$2,186	$2,092	$1,992	$1,884	$1,767	$1,643	$1,508	$1,364	$1,209
Depreciation	$	$	$236	$357	$571	$637	$676	$698	$764	$788	$1,036	$1,064	$1,565	$1,582	$1,599
Taxes	$412	$395	$383	$517	$558	$638	$788	$1,059	$1,272	$1,384	$1,438	$1,489	$1,333	$1,532	$1,737
Net profit	**$3,391**	**$3,298**	**$3,446**	**$3,746**	**$3,962**	**$4,095**	**$4,325**	**$4,757**	**$5,118**	**$5,242**	**$5,474**	**$5,471**	**$5,549**	**$5,791**	**$6,032**
Total Costs Base Case	**$69,764**	**$64,703**	**$63,064**	**$65,766**	**$75,400**	**$83,009**	**$78,719**	**$84,730**	**$89,669**	**$91,729**	**$94,231**	**$94,711**	**$94,128**	**$97,951**	**$101,815**
Cost Delta to Base Case	**$1,221**	**-$2,796**	**-$5,727**	**-$7,138**	**$61**	**$5,654**	**-$2,235**	**-$2,875**	**-$3,385**	**-$3,552**	**-$3,766**	**-$3,738**	**-$3,581**	**-$3,939**	**-$4,297**
Net Present Valus	-$26,062														
Discount rate	5.00%	From OMB Circular A-94													

Appendix I: Market Power Forward Curve Methodology

MarketVision™ Data Sources

February 2009 Release

Through the use of the PowerBase software application, the MarketVision Data is formatted for use in our main simulation programs. The MarketVision data is taken directly from data products created and supported by Ventyx's Energy Velocity Suite (EV). Energy Velocity data is developed by a staff of over 50 professionals dedicated to market research, data analysis and data mining. Details of the data sources are outlined below, along with additional data sources employed specifically for use in PowerBase. Ventyx has a full time staff to complement the EV sourced data, as well as add modeling perspectives based on our experience in the consulting areas of our business.

Any specific details not listed below can be answered directly through our Data Services group at Ventyx.

Sources for Area Network Data

The geographic area structure in our MarketVision Data is based on ISO/RTO/NERC region and sub-region definitions. The smallest geographic entity in PowerBase corresponds roughly to entities which file load data on FERC 714 forms, generally traditional utility companies. Exceptions to this rule exist for tightly integrated pools such as the New York Power Pool where ISO zone definition have become standardized and the ISO provides the needed demand and transfer limit data for the zones. Where applicable, load areas are grouped into transmission areas designed to represent geographic regions that are separated by significant transmission constraints. Transmission areas are assigned to NERC sub-region, which roll up to the standard NERC region definitions. All demands and units are associated with the smallest (market) areas in PowerBase. Regional transfer limits may be modeled between any two individual areas or any two groups of areas.

Sources for Generating Unit Data

MarketVision Data existing generating units is source from Energy Velocity Suite which uses public sources including the EIA-860, EIA-411, EIA-867, EIA-412, EIA-759, FERC Form 1, FERC 423, and REA-12 and other utility and ISO publications. Information from these sources is also used to derive default data for generators that may have missing or incomplete filings. Data items supplied by EV include generator name, location (area assignment), summer/winter capacity, primary and secondary fuels, GADS category, operating & maintenance (O&M) costs, heat rates, projected capacity changes, projected retirement dates, and average monthly hydro energy. Detailed operational data from the Continuous Emissions Monitoring System (CEMS) is used to derive multiple capacity states with associated incremental heat rate data. Values for forced outage rates, forced outage durations, and scheduled maintenance requirements are taken from EV using data the NERC Generating Availability Data Systems (GADS) and supplemented by Ventyx Advisors staff based on generator age. Emission production rates for SO2, NOx, and

CO_2 are sourced from EV and taken from documents published by the Environmental Protection Agency (EPA).

Data for nuclear planned refueling outage schedules and nuclear forced outage rates are developed internally by Ventyx based on publicly filed information from the Nuclear Regulatory Commission. Other operational modeling parameters such as unit minimum runtime, minimum downtime, contribution to spinning reserve, must-run status, etc, needed for simulation accuracy are supplied by Ventyx based on experience and knowledge of our models. Ventyx also provides assignments for all units to buses in the transmission grid for use in detailed LMP studies.

Data for future units modeled in the MarketVision Data is a combination of data supplied by EV and Ventyx consultant's research based on press releases and website information and generation queues. Ventyx supplies source document references for any data used in the MarketVision data to update unit type, capacity, development status, and/or expected on-line date. General defaults are set up for heat rates, emissions rates, variable o&m, etc, based on similar units that have recently come on line and have filing data available, along with manufacturer specifications where available.

Sources for Fuel Data

MarketVision Data contains fuel data for coal, natural gas, oil, and uranium. Forecasted prices for each fuel are developed by the Ventyx fuels group.

The natural gas price forecasts are made up of 3 forecast phases: futures driven, mean reversion and a long-term trend.

To derive the burner-tip forecasts used, Ventyx first examines regional prices and basis swaps at a number of trading hubs. Using this historical data for the first 24 months of the forecast, Ventyx develops a differential price between the appropriate market center nearest to the power plant and the Henry Hub. Gas prices used for the first 24 months are driven by Henry Hub futures market prices plus a basis differential (if any). During the following 24 months of the forecast period, Ventyx imposes a linear mean reversion process on the forecast. This process aligns natural gas prices during the first 24 months back to their long-term, fundamental levels.

To forecast future burner-tip gas prices beyond the initial 48-month period, Ventyx incorporates the RBAC's GPCM gas forecasting model into our modeling methodology for medium- to long-term analysis. The model is a general equilibrium model of gas supply and demand in a competitive environment for the North American natural gas industry.

Another important component in Ventyx's gas forecast is the seasonal or monthly variation in price. To determine the seasonal variation in gas prices, data at individual pricing points are utilized. The appropriate observed seasonal pattern is applied to annual gas price forecasts to derive monthly price forecasts. These seasonal factors represent typical or normalized variation in monthly spot gas prices within a region. A polynomial curve is then fitted to the monthly average. A similar estimation technique is used to forecast monthly fuel oil prices. Fuel oil prices are provided for both heavy and light oil, with a single nation-wide forecast.

Ventyx's long-term coal forecasting model uses numerous factors to come up with a least cost solution for coal delivery on a mine to boiler level. Inputs such as mining costs, emissions price forecasts, transportation routes and pricing, coal quality, boiler specifications, emissions controls and other items interrelate to help determine the source of coal to any given boiler and power plant in the U.S. and the resulting price of that coal on an FOB and delivered basis.

Uranium fuels and associated price forecasts are defined for each NERC sub-region. All price forecasts include seasonal price profiles and extend through at least 2032. Default escalations based on projected GDP rates are applied in later years.

Sources for Demand Data

Demand in the MarketVision Data is derived from a combination of FERC 714 data, data from ISOs and data that acquired directly from contacts at NERC regions. From these we get 10 year peak and energy forecasts and extrapolate those out an extra 20 years. To extrapolate the 10-years for an additional 20 years, the current Advisors Reference Case assumption is to grow the loads at 80% of the average energy growth rate over the last three years of the utility/zonal provided forecast. So for example, if the average energy growth rate for a utility over the last three years was 2%/year, we grow both the energy and peak loads from that point forward at 1.6%/year. (80% of 2%). Hourly load shapes are developed from historical hourly data into a 'synthetic' load shape which is basically an average of several years (currently 2001-2006) load shape that is processed for reasonability (ex: make sure a resulting ISO coincident peak is high enough).

Specifically, for the current release (June 2008 to current (Feb 4, 2009)), load forecasts are updated as follows:

- FRCC – Updated Utility Load Forecasts based upon 2006 10-year Site Plans;
- MRO(MAPP) – Updated traditional MAPP utility load forecasts based upon 2006 MAPP Load & Capability Report;
- MRO(MAIN) – Updated traditional MAIN utility forecasts based upon 2005 FERC 714 Filings;
- NPCC – Updated New York Zonal Load Forecasts based upon 2006 Gold Book;
- NPCC – Updated Ontario Zonal Load Forecasts based upon the 2005 10-Year Outlook adjusted for 2005-2006 actual hourly load data;
- NPCC – Updated New England Utility Load forecasts based upon 2005 FERC 714 and 2006 New England CELT report;
- NPCC – Canadian Eastern Province Updates per 2006 NERC ES&D
- RFC (ECAR/MAAC/MAIN) – Updated Utility load forecasts based upon 2005 FERC 714, PJM 2006 Load Forecast Report, and PJM 2006 actual hourly load data through September;

- SERC – Updated Load forecasts based upon 2005 FERC Form 714 filings;

- SPP – Updated Utility Load Forecasts based upon SPP 2006 EIA-411

- ERCOT loads are based on 2007 actual data published on the ERCOT website (D&E Report) and growth rates in the 2007 LTRA report

- WECC utility load forecasts based upon a variety of sources, including the 2005 FERC 714, Integrated Resource Plans, California Energy Commission documents, and other miscellaneous sources.

Sources for Transmission Data

Data for regional transfer limits between NERC sub-regions is taken from NERC summer/winter assessments, while transfer limits within a sub-region are developed by Platts from FERC 715 filings.

Data to support PROMOD IV detailed powerflow studies is developed by Ventyx based on publicly available powerflow cases (in PTI PSS/E RAW format) published by NERC MMWG, ERCOT, and WECC. Ventyx supplies bus mapping data linking PowerBase generators and loads to powerflow buses. Ventyx also provides monitored line and contingency event data derived from published FERC 715 forms, other public documents, and internal load flow analysis.

Current deliverable powerflows, mappings and constraint sets:

- East: MMWG 2007 Series, 2009 Summer Peak Case, with constraints from NERC, MISO and SPP Books of Flowgates plus other published regional constraints

- ERCOT – 2009 Summer Peak Case (09sum1eco03082008r29.raw released March 8, 2008) with ERCOT published constraints

- WECC – 2008 Summer Peak (08hs4ap.raw released February 8, 2008) with constraints from WECC Path Ratings Catalog (2008) and other published regional constraints.

Emissions Markets and Regulatory Drivers

Marketvision Data reflects all major Emissions markets as well as assumptions about presumed developing markets. These include:

- National Clean Air Act Title IV SO2
- Clean Air Interstate Rule NOx*
- Clean Air Interstate Rule SO2*
- SIP Call NOx
- Houston-Galveston NOx
- RECLAIM NOx (Southern California)
- Presumed National Greenhouse Gas Emissions Regulation

Addtionally, effluents not regulated in a certain region or anywhere are reported for the appropriate generator types. These include Mercury (the Clean Air Mercury Rule was overturned in 2008 and thus no penalty is applied in MarketVision data) and NOx in some areas.

*Clean Air Interstate Rule (CAIR) – the CAIR was overturned and subsequently reinstated in 2008. Ventyx Advisors assumes CAIR implementation in 2012 rather than the initially mandated 2009 (for NOX) and 2010 (for SO2). However, for ease of data use and understanding the MarketVision data assumes penalties being in 2009.

Ventyx uses a proprietary Emission Forecast Model (EFM) to simulate emission control decisions and results simultaneously in the three cap-and-trade markets (SO2, NOX, Annual and NOX Seasonal). Ventyx uses a subjective compromise for its CO2 emission forecast based on CO2 price forecasts associated with several legislative proposals.

Cost-Effective Investments in Central Energy Plant and Distribution Facilities
University of Illinois - Urbana-Champaign

Task B and C Final Report

September 2009

Prepared for:

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Summary

This report documents the results of a task to identify cost-effective investments in the existing central energy plant and distribution systems for the University of Illinois Urbana-Champaign (UIUC) campus. The main objective of the task was to identify improvements to the central plants that would result in reduced operation and maintenance costs and improved reliability. This was of particular importance given the age of some of the primary systems and equipment and increasing service demands. The approach involved a condition assessment of the plants at an EPRI level 1 level of detail, an assessment of the plant operations in terms of some key performance indicators or metrics, a determination of the most promising improvements and associated costs/benefits, and a recommended timeframe for the investments, including reserve requirements. The scope covered an investment horizon of 15 years, although the focus was on the next 5 to 10 years.

The major findings of the task are:

1. The Abbott Power Plant is old by industry standards. With the exception of the newer additions of the combined-cycle equipment, the main steam and power generating equipment is well past its original design age. The Abbott operation and maintenance (O&M) staff has done a creditable job of keeping this equipment serviceable over this time period.

2. Plant operation is complex due to the variety of equipment and operating limitations. Compared to comparable plants of this size, the UIUC plant is performing reasonably well. However, additional redundancy is needed to overcome reliability issues with aging equipment.

3. Plant staffing levels appear to be reasonable for a plant of this size. However, separation of operations and maintenance functions and restrictions, on workers in operations from performing maintenance and vice-versa, limit opportunities for optimizing staffing levels. Such restrictions do not exist at the Chicago or Springfield campuses. If such restrictions did not exist, and cross-training of staff was implemented, savings are likely. However, a more detailed staffing analysis would be needed to determine specific savings levels.

4. Consideration should be given to establishing key performance indicators (KPIs) or metrics against which to benchmark plant operations. This would include metrics related to reliability, performance, training, etc. This approach is used in performance contracts with private sector plant operators, as a way to manage risk.

5. In order to maintain reliable operation of the plant, significant investments will be required – on the order of $15 to $20 million per year, over 15 years. Note that this is consistent with the most recent planning budgets provided by Utility Administration. This equates to between $173 million and $234 million in central plant investments and between $51 million and $69 million in thermal distribution systems. This will involve investments in equipment repair/replacement – including major overhauls, but also

increased investments in plant maintenance. Specific priority areas for investment include:

Capital Equipment

- New condensate polishing (cleaning) system to reduce premature corrosion of plant equipment, along with new condensate storage tanks – this will deal with the ongoing boiler water quality issues that are increasing boiler corrosion and tube failures.

- Additional reverse osmosis water treatment capability for makeup water

- Repairs to the coal handling equipment

- Ongoing boiler maintenance and repair to maintain reliability

- Repairs to steam distribution system piping to address concerns with heat loss, structural integrity, and personnel safety, along with reliability

Operation & Maintenance

- Condition based monitoring – this will highlight preventative maintenance required to keep units on line.

- Equipment flow metering – will improve efficiency of operations

6. Environmental regulations on emissions limit the maximum throughput of the flue gas desulfurization equipment (wet scrubber). This in turn limits the generating capacity of the three coal-fired boilers to below their rated capacity. In addition, reliability of the 'Green Fan' for the wet scrubber will need to be addressed. Currently, this is a single point of failure that could force the three coal-fired boilers out of environmental compliance (and hence out of service) at the same time.

7. The distribution systems will require substantial investments in future years. A more detailed assessment of the system is needed to quantify the investment levels with a degree of confidence.

8. Metering of campus utilities has improved, although issues with metering steam to the steam-turbine driven chillers remain. In addition, the output from two of the chiller plants is not presently metered. Metered data from these plants would help more accurately allocate the cost of plant operations.

1. *Overview*

1.1 Introduction/Objectives

The central energy plant and distribution systems of UIUC provide a vital role in meeting the campus needs for heating, cooling, and electricity. Given the increasing cost of providing these services – as a result of higher and increasingly volatile fuel prices – as well as the costs of maintaining equipment, the university is interested in ways of improving operations. The main objective of the task was to identify improvements to the central plants that would result in reduced operation and maintenance costs and improved reliability.

1.2 Approach

The approach to the task involved the following activities:

- *Condition Assessment* – This involved performing an Electric Power Research Institute (EPRI) Level I assessment.[1] This included initial data collection, "walk-throughs" of the central plants and small sections of the distribution systems, and a system by system review.

- O*perations Review*– This involved a review of key plant operating parameters relative to design and good practice, as well as to comparable facilities, to identify opportunities for improvement. As part of this effort, a simplified heat balance was developed (Excel model) for the major systems, to baseline current performance, and to help in evaluating the impacts of investments affecting performance.

- *Prioritized Actions* – This involved prioritizing the opportunities and developing implementation costs assuming an investment horizon of 15 years.

- *Recommended Investments* – Based on the estimated time frame for the investment opportunities a schedule for reserves to cover the costs of the investments was developed.

The information from this task was used as input to a related task to investigate the benefits of producing power at the central energy plant versus purchasing the power.

[1] A Level 1 assessment includes review of plant operations and maintenance records, equipment manuals, and available design drawings; review of design performance versus recorded performance; visual external inspection without non-destructive examination (NDE) or disassembly of equipment; and interviews with plant personnel. If complete or conclusive condition assessment recommendations cannot be made with this type of assessment, then a more detailed, Level 2, condition assessment should be conducted. A Level 2 assessment involves the same activities as in a Level 1 assessment, but in more detail regarding inspections, evaluations of material properties, and evaluation of transient and/or cyclic stresses. Tasks include:
High-wear or high-maintenance-history equipment is disassembled and the internals visually inspected.
Dimensions are taken for such items as remaining material thickness in wear areas.
NDE processes are performed such as taking replicas.
Preliminary calculations are performed to evaluate potential transient and/or cyclic operations effects upon material life.
In most cases, a Level 2 assessment will provide sufficient data to evaluate the condition of all but the most sophisticated equipment items such as steam generators, steam turbines, and electric generators.

2. *Condition Assessment*

2.1 Summary of Condition Assessment

On Thursday and Friday October 30th and 31st, and during a second brief visit on Monday and Tuesday November 17th and 18th of 2008, WorleyParsons Power Plant O&M (Operations and Maintenance) Services employees Jeff White and Joe Andre met with UIUC (University of Illinois Urbana-Champaign) site management personnel and conducted interviews with the O&M staff, and then conducted a visual inspection of the University of Illinois Urbana-Champaign campus utility equipment. Following the site visits, a documentation review was performed to further assess plant condition and O&M practices. Below is a summary of some of the more important observations made during our brief site visit.

- The plant management staff at this site is very cognizant of most of the items necessary for improvement, but is stalled in many areas due to the budgetary constraints imposed upon the Abbott Power Plant and its ancillary campus steam and electrical distribution systems.

- The absence of an integrated O&M staff at Abbott stands out from the other campus plants. At UIS and UIC, campus plant personnel perform both operational and maintenance related tasks. A multi-disciplined staff would allow plant personnel to function more efficiently.

- Staffing concerns due to near future attrition indicate the need for a comprehensive hiring and training program and/or staff augmentation.

- Consideration should be given to establishing key performance indicators (KPIs) or metrics against which to benchmark plant operations. This would include metrics related to reliability, performance, training, etc. This approach is used in performance contracts with private sector plant operators, as a way to manage risk.

- A plant specific Computerized Maintenance Management System (CMMS) is in place at Abbot, but it is not currently being used effectively enough to see the benefits that a CMMS can provide.

- The design and installation of a Condensate Polishing Unit should be prioritized as one of the first Plant Improvement Projects for capital investment by Abbott Station.

- The asbestos abatement program needs more attention than is currently being dedicated, to mitigate possible liability exposure from current open areas (specifically in the distribution tunnels).

- The coal delivery handling system is in need of immediate assessment and repairs to prevent service interruption to university steam and power consumers.

- The coal boilers "Green Fan" is a major redundancy issue requiring a strategy plan to address.

- As-Built drawings do not exist for most systems creating numerous safety concerns and many Operational & Maintenance related issues. Without current as-built drawings documenting new piping and equipment, a lack of operational awareness is the cause for these concerns and issues.

2.2 Plant Assessment

2.2.1 *Fuel and Ash Handling Systems Assessment*

The coal fuel handling system consists of an unloading area with twin drive over grizzly hoppers, conveyer systems A, B, C and D, and the plant coal storage bunkers (see below). The unloading conveyer structure is in poor general condition, from freeze and thaw damage resulting from the inability of the structural angle steel to rid itself of fuel laden and also outside ambient moisture conditions.

Emergency repairs were made as a stop gap measure based on recommendations from a previously performed assessment in May of 2005, but more substantial and permanent repairs remain to be completed.

The following **Level 2 Assessments** are recommended for the Coal Handling System:

- *NDE of structural steel welds on brackets and other cement floor panel supports.*

The following **Plant Improvement Projects** should be considered for the Coal Handling System:

- *Develop corrective action plan formally for budgeting and work planning purposes, and implement necessary repairs.*

The ash handling system was not physically inspected during our site visit due to time constraints and prioritization of assessment issues. However, interviews with plant personnel and documentation review uncovered no issues regarding the system other than ongoing plant initiatives to optimize the ash pipe sizing to reduce system failures and improvement of ash offloading techniques for best efficiency.

The fuel oil system was not inspected during our site visit due to the same reasons that the ash handling system was not physically inspected. Likewise, interviews with plant personnel and documentation review uncovered no major issues.

A visual tour was conducted of the campus fuel gas system. No unusual conditions were visually identified with the system as areas of concern, or requiring further assessment recommendations or plant improvement project considerations at this time. It was reported that there is a continuing problem with the leak detection system on the piping from the fuel oil tanks to the steam tunnel.

2.2.2 *Makeup Water System Assessment*

City water makeup is pumped to the Raw Water Storage Tank, then to RO (Reverse Osmosis) units (see picture below-right), the Prem Tank and finally to the Upstairs Storage Tank. The treated water is then used as makeup for condensate lost from the WSC (Water Steam Cycle) due to venting, leaks, etc. from the system.

Mobile Demin Trailer

RO System

During our site visit it was noted that a mobile demineralized water trailer is being used to augment conditioning of plant makeup water in addition to the installed RO system (see above-left). It was also noted that makeup water use is not currently measured so percent makeup is unknown. An assessment of the wastewater system was not able to be completed due to lack of available time at site. However, it was reported that this area needs attention and a plan to repair the deficiencies was cancelled.

There are currently no **Level 2 Assessments** recommended for the Makeup Water System.

The following **Plant Improvement Projects** should be considered for the Makeup Water System:

- *Design, purchase and install a makeup water flow meter for measuring cycle makeup. This will give a starting point for reducing makeup to the cycle based on a known rate of usage.*

- *Design, purchase and install an additional RO train to eliminate demurrage and rental costs of portable demineralized water trailer.*

- *Document system into As-Built drawings as current site drawings are inaccurate or do not exist.*

- *Incorporate all system equipment into a formal CMMS program listing for maintenance planning and parts inventory control. The current maintenance management software is being used for process only, and equipment lists with nameplate data do not reside in any CMMS.*

- *A CBM (Condition Based Monitoring) vibration program should be implemented on system rotating equipment to gather baseline data and incorporate into the plant CMMS for PM task generation and PDM planning.*

2.2.3 *Condensate System Assessment*

Condensate is returned to (6) different receiver tanks from both campus steam consumers and power plant sources. The condensate is then pumped to (4) direct contact heaters for further heating and deaeration. (see below for condensate system pictures)

The plant was operating at time of this assessment, and therefore no internal inspections or testing was possible. The quality of the condensate returned from campus consumers is ever-changing and has considerable effect on day to day equipment operations. Plant is not currently able to control incoming condensate quality due to lack of ownership of the condensate systems

The following **Level 2 Assessments** are recommended for the Condensate System:

- *NDE such as (UT) or (MT) in addition to visual inspections of existing Condensate Receiver Tanks should be conducted to ensure minimum tank wall thickness and joint weld integrity.*

- *Perform an Eddy Current inspection on all condensers*

- *Conduct a survey to determine percentage of condensate lost from the system piping leak sources, and develop a corrective action plan to address.*

The following **Plant Improvement Projects** should be considered for the Condensate System:

- *Design, purchase and install a properly sized Condensate Polisher skid immediately to alleviate the continued and critical effects of contaminants on plant condensate, feedwater and boiler proper major system assets. The previous boiler tube pluggage, economizer tube failures and need for boiler waterside chemical cleanings are a direct effect of poor water chemistry. The failure rates experienced are higher than most industry standards. The lack of an effective water treatment program has a direct effect on tube failures if left unchecked or untreated. The EFOR (Equivalent Forced Outage Rate) failure rates on similar equipment should be less than 10%.. This percentage may be higher if boilers are operated outside there designed firing temperatures.*

- *Design, purchase and install additional remote monitoring instrumentation as a means for determining source of the out of specification condensate returns. The instrumentation should go close to condensate return sources. This will serve to determine which campus sources are contributing to poor condensate quality and why, and for corrective action plan for elimination of same.*

- *Design, locate, permit and construct two 120 KGAL (based on boiler water usage) Condensate Storage Tank on the Abbott station grounds that would provide approximately 8 hours of retention time in the event of a loss of all makeup. This would allow either correction of the interruption cause, or allow for a controlled plant shutdown. Time to take emergency measures for prevention of freezing of campus buildings and assets during winter months would also be realized. The existing condensate receiver tanks which are inadequate in size and beyond their expected service life and condition should then be decommissioned.*

- *Document system into As-Built drawings as current site drawings are inaccurate or do not exist.*

- *Incorporate all system equipment into a formal CMMS program listing for maintenance planning and parts inventory control. The current maintenance management software is being used for process only, and equipment lists with nameplate data do not reside in any CMMS.*

- *A CBM (Condition Based Monitoring) vibration program should be implemented on system rotating equipment to gather baseline data and incorporate into the plant CMMS for PM task generation and PDM planning.*

2.2.4 *Feedwater Systems Assessment*

Feedwater is pumped from the DC (Direct Contact Heaters) using motor and steam turbine driven pumps (see pictures below), feeding deaerated water through the HP (High Pressure) Heaters and on to the boiler steam drums for drum level control.

Feedwater Pump

Feedwater Pump Repair

Feedwater is also used to attemperate the steam at the boiler superheater outlets, and also as desuperheating water at various PRV (Pressure Reducing Valve) steam conditioning stations throughout the plant main steam system.

The following **Level 2 Assessments** are recommended for the Feedwater System:

- *Internal inspections of DC Heater spray nozzles and tray sections for nozzle condition/tray upset and adjustment and replacement as necessary. Dissolved oxygen testing results of feedwater may assist in determining spray nozzle and tray section condition for priority in planning this inspection.*
- *External NDE inspections of DC Heater storage vessel support pedestal welds should be performed to identify cracking caused by thermal expansion and contraction, and from water hammer events.*
- *NDE such as (UT) or (MT) in addition to visual inspections of existing DC Heater tray and storage sections should be conducted to ensure minimum tank wall thickness and joint weld integrity.*
- *Feedwater Heater tube replacement records should be located and analyzed if existing. HPH (High Pressure Heater) feedwater heaters (FWH) tube failures are a common cause of failure and average lifespan is about 15 years. Excellent performance would be 25-30 years. Generally, retubing/ replacement become necessary when tube pluggage reaches 7-10 % of the total number of tubes.*

The following **Plant Improvement Projects** should be considered for the Feedwater System:

- *Document system into As-Built drawings as current site drawings are inaccurate or do not exist.*
- *Incorporate all system equipment into a formal CMMS program listing for maintenance planning and parts inventory control. The current maintenance management software is being used for process only, and equipment lists with nameplate data do not reside in any CMMS.*

- *A CBM (Condition Based Monitoring) vibration program should be implemented on system rotating equipment to gather baseline data and incorporate into the plant CMMS for PM task generation and PDM planning.*

2.2.5 *Boiler Systems Assessment*

The Urbana-Champaign campus Abbott Power Plant consists of six (6) conventional watertube boilers and two (2) HRSG (Heat Recovery Steam Generator) units.

Boilers #2, #3 and #4 are Erie City OEM gas and fuel oil fired units operating at 350 psig steam pressure at 700 deg F SH outlet steam temperature at 175 KPPH rated steam capacity. It is noted that Boilers #2, #3 are the only gas and fuel oil fired package boilers currently available, as boiler #4 is permitted for restricted operation, but at the present time not operable.

Boilers #5 and #6 are Babcock & Wilcox Company stoker fired coal units operating at 850 psig steam pressure at 760 deg F SH outlet steam temperature at 150 KPPH rated steam capacity each. Flue gas from these units pass through an ESP (Electrostatic Precipitator) for PM (Particulate Matter) removal, and then through a "Green Fan" before entering a Chiyoda Wet Scrubber FGD unit for SO2 abatement, is reheated and then on to the chimney.

Boiler #7 is a Babcock & Wilcox Company stoker fired coal unit operating at 850 psig steam pressure at 760 deg F SH outlet steam temperature at 200 KPPH rated steam capacity. Flue gas from this unit also passes through an ESP (Electrostatic Precipitator) for PM (Particulate Matter) removal, and then through the "Green Fan" before entering a Chiyoda Wet Scrubber FGD unit for SO2 abatement, is reheated and then on to the chimney.

It is noted that emissions limitations imposed on the above coal fired units results in a curtailment in total steam production of 350 KPPH, out of a rated 500 KPPH of installed capacity from the three units, in order to remain below the design limits of the FGD system.

HRSG Units #1 and #2 (see pictures below) are Energy Recovery International OEM utilizing waste heat from two Solar Titan gas and fuel oil fired gas turbine units, operating at 850 psig steam pressure at 760 deg F SH outlet steam temperature at 45 KPPH or 120 KPPH rated steam capacity each using supplemental Duct Burner firing.

HRSG

HRSG

Evidence of overheating was noted on the boiler casing (see pictures below) and requires further assessment as to cause and corrective action. It is noted that a tube leak repair was made to HRSG #2 in August of 2007. The cause appears to have been water quality related but requires further assessment.

Evidence of Overheating

The following **Level 2 Assessments** are recommended for the Boiler Systems:

- *NDE external and internal inspections on all boiler economizer, evaporator section and waterwall tubes and headers should be performed to further assess equipment condition and suitability for continued service, with concentration on the severe service coal fired units to determine tube replacement and other needs in a planned outage mode. Removal of representative samples to assess pitting and chemical deposition should be especially considered given the past water treatment issues, before the current program was being administered. Undertake a representative number of NDT thickness checks on these areas.*

- *Fireside inspection for corrosion and erosion damage caused by improper flue gas distribution due to baffle wall damage, and damage from sootblowers and fly ash especially in coal fired units.*

- *A Steam Drum assessment (fracture mechanical analysis) is required to estimate the remaining life. Note: A similar inspection has been performed on Boiler 7 and an inspection will be performed on 6 when its gen bank is replaced.*

- *Perform an external inspection of Mud Drum to stub and stub to tube nest welds by UT and MT.*

- *Note: A similar inspection has been performed on Boiler 7 and an inspection will be performed on 6 when it's gen bank is replaced.*

- *Visually inspect Mud Drum tubes for corrosion at drum interface.*

- *Further inspections to determine extent of and develop repair plan for boiler fireside casing leaks. Note: Casing on boiler 5 has been replaced/repaired, and boiler 6 will be replaced/repaired in Spring 2009.*

- *Perform a level 2 Assessment on the HRSG casing hotspots as to root cause, and make recommendations as to corrective action.*

- *Perform level 2 stack NDE thickness tests, spalling report and integrity assessment, and develop repair plan.*

- *More frequent and in depth condition based predictive maintenance strategies for the "Green Fan" including fan impeller balancing checks and NDE inspection of welds and bearing maintenance.*

- *An equipment replacement analysis should be based on the Level 2 Assessment recommendations mentioned above.*

The following **Plant Improvement Projects** should be considered for the Boiler Systems:

- *The coal boiler "Green Fan" lacks redundancy and would create a major loss of steam and electricity to campus in the event of either a planned or more importantly, an unplanned forced outage of this critical piece of rotating equipment. Along with more frequent condition based monitoring and preventive and predictive maintenance strategies, a plan needs to be developed to add redundancy to this single fan segment of the system, which can disable the operation of three major boiler assets if the fan is out of service for any reason.*

- *A plan should be developed for reducing total yearly stack emissions from the coal fired units by installing additional flue gas conditioning equipment. This would allow the installed boiler rated steam production capacity to be realized without adding new* *generation assets. Steam production should not be curtailed by future emissions limitations in a plant that can feasibly burn more coal.*

- *Asset Management Services – Initial assessment and then ongoing monitoring of equipment conditions through various NDE and other methods to help prioritize university critical asset replacement based on remaining life. This need is urgent based on the boiler conditions observed in our visual inspection and age of this equipment.*

- *Incorporate all system equipment into a formal CMMS program listing for maintenance planning and parts inventory control. The current maintenance management software if being used for process only, and equipment lists with nameplate data do not reside in any CMMS.*

- *Investigate and remedy reasons for Boiler #4 permit constraints in operating this unit.*

- *A CBM (Condition Based Monitoring) vibration program should be implemented on system rotating equipment to gather baseline data and incorporate into the plant CMMS for PM task generation and PDM planning.*

- *Continued monitoring and diligence by water treatment personnel and water treatment service provider to prevent past tube failures and resulting replacement from recurring. Key progress is noted in this area from past years records, but bypassing of water treatment means was reported (by the in-house water treatment specialist) to still) occurr occasionally.*

- *Continue integration of Boiler Controls into plant DCS for more efficient control and use of assets.*

- *Document system into As-Built drawings as current site drawings are inaccurate or do not exist.*

2.2.6 *Plant Main Steam and Campus Distribution Steam Systems Assessment*

The Plant Main Steam Systems consist of the following main areas:

- *The 350 psig header supplies steam from Boilers #2, #3 & #4 to Steam Turbines #1, #2, #3 & #4. The header also supplies steam to a 350 psig to 150 psig for plant and campus distribution steam use, and to a 350 psig to 50 psig PRV let down station feeding the campus steam consumer distribution system.*

- *One 850 psig header supplies steam from Boilers #5, #6 & #7 to Steam Turbines #6 & #7. The header also supplies an 850 psig to 350 psig PRV let down station, and can be cross-tied to the HRSG steam header using a manual isolation valve in the station.*

- *A second 850 psig header supplies steam from HRSG #1 and #2 to Steam Turbines #8, #9 & #10. The header also supplies an 850 psig to 150 psig PRV let down for plant and campus distribution steam system use, a 150 psig to 50 psig PRV let down station* *supplying campus distribution steam consumers. The 850 psig header can also be cross-tied to Boiler #5, #6 & #7 steam header using a manual isolation valve in the station.*

The Campus Distribution Steam Systems consist of the following:

- *The 50 psig and 150 psig steam headers leave the Plant Main Steam System to supply the campus Distribution Steam System through a system of underground tunnels.*

A tour of the abovementioned steam tunnels was conducted with plant personnel and the following noted:

- **Steam Tunnel Underground Concrete (see pictures below):** The tunnel concrete structural condition varied greatly throughout, with large areas of cement spalling of the roof noted especially near where leaving Abbott Station under the roadway intersection and other areas of the distribution system where traffic travels over. In these areas, overhead roadways where both vehicle weight and road treatment chemicals have made their way through the concrete tunnel roof have caused much spalling and chemical induced damage. Temporary tunnel roof supports were also noted in areas where aboveground campus construction projects are ongoing. It was observed that areas having little roadway traffic above were in far better condition than the aforementioned.


Steam Tunnel Underground Concrete

- **Steam Tunnel Steam Line Support Structure (see pictures below):** Many of the steam line steel supports were wasted away to differing degrees near the base plate of the support from corrosion. The grout under many of the base plates was either completely missing or severely spalled and requires maintenance.

 

Steam Tunnel Steam Line Support Structure

- **Steam Tunnel Electrical Cable Raceway Support Structure:** Cable tray sections were in fair to good condition with some abandoned electrical and cable TV cables still lying loose and could be better determed and disposed of in this area where space is already at a premium.

- **Steam Line Piping (see pictures below):** Many older areas of steam piping still have bolted flanges (bolted flanges do not age well and often rot) and are areas of concern especially with recent line pressure and temperature increases that have been made to satisfy increased usage. A NDE engineering study needs to be conducted to analyze the piping and develop an action plan to replace this piping in the near term.

 

Steam Line Piping

- **Condensate Return Line Piping:** Appears to be in good general condition. Monitoring instrumentation needs to be added to determine source of contamination returning to Abbott Power Plant (See Condensate System assessment for specific Plant Improvement Projects for this area).

- **Steam and Condensate Piping Insulation (see pictures below):** Missing and open friable areas of asbestos insulation are a serious **Safety Issue** that requires immediate correction to avoid liability and fines. Only very small portions of pipe were completely missing insulation.


Steam and Condensate Piping Insulation

The following **Level 2 Assessments** are recommended for the Plant Main & Campus Distribution Steam Systems:

- *Main steam line Creep inspections should be performed on all headers within the system.*
- *NDE assessment of older distribution system steam piping for integrity and safety condition for continued use.*
- *A Level 2 Structural Assessment is recommended on the distributions system.*

The following **Plant Improvement Projects** should be considered for the Plant Main & Campus Distribution Steam Systems:

- *An asbestos abatement program needs to be developed and/or its scope and mission needs to be further refined immediately to address present friable and open areas of asbestos, especially in the campus steam distribution tunnel areas. This is a serious **safety issue**, violation concern and a source of liability for the University.*
- *Campus steam distribution piping is made up of newer welded steam pipe in some areas and very old flanged piping sections in others. A plan needs to be developed to prioritize, coordinate and implement orderly replacement of the older sections of system flanged piping. Delaying action now to replace these older components may well result in catastrophic piping system failure. The entire length of the steam tunnels was not walked down during out assessment so the exact amount of flanged piping is unknown.*
- *Incorporate all system equipment into a formal CMMS program listing for maintenance planning and parts inventory control. The current maintenance management software is being used for process only, and equipment lists with nameplate data do not reside in any CMMS.*

2.2.7 *Steam Turbine Systems Assessment*

The Steam Turbine systems consist of the following (see turbine house pictures below):

- *Steam Turbines #1, #2, #3 & #4 are GE units operating at 350 psig and 660 deg F at the first stage inlet and each have 50 psig extractions, and are nominally rated at 3 MW each. The turbine exhaust from condensing steam turbines #1, #3 & #4 is either used for feedwater heating or is condensed back to the liquid phase. Turbine exhaust from backpressure steam turbine #2 feeds the 50 psig steam header only for plant and campus distribution steam uses.*

- *It is noted that Steam Turbine #5 is also a GE unit nominally rated at 3 MW, but is currently out of commission and considered abandoned in place.*

- *Steam Turbines #6 & #7 are GE units operating at 850 psig and 760 deg F at the first stage inlet and each have 50 psig extractions for campus steam distribution use and are nominally rated at 7.5 MW each. The turbine exhaust from these condensing turbines is either used for feedwater heating, or condensed back to the liquid phase.*

- *Steam Turbines #8 and #9 operate at 850 psig and 760 deg F at the first stage inlet and each have 150 psig extractions for plant and campus distribution steam use and are rated at 12.5 MW in condensing mode or 7 MW in extraction mode. The turbine exhaust from these turbines is either used for feedwater heating or condensed back to the liquid phase.*

- *Steam Turbine #10 operates at 850 psig and 760 deg F at the first stage inlet and has 150 psig and 50 psig extractions for plant and campus distribution steam use and is at 7 MW in 50 psig extraction mode or 4 MW in 150 psig extraction mode.*


Turbine Deck

The following **Level 2 Assessments** are recommended for the Steam Turbine Systems:

- *NDE replica inspections should be performed on all units rotating elements, especially given the vintage of some of the steam turbine assets to determine if repair/replacement is required.*

- *Dielectric insulation breakdown testing inspections should be performed on all turbine electrical generators.*

The following **Plant Improvement Projects** should be considered for the Steam Turbine Systems:

- *A TWIP (Turbine Water Induction Prevention) program should be developed and implemented to preclude a catastrophic plant event resulting from steam turbine water induction. A reported incident involving a perceived possible water induction event led to an expensive turbine internal inspection that may have been avoided had the proper instrumentation and monitoring been installed that give proper indications. The OEM should be consulted regarding TWIP and their recommendations should be followed.*

- *Incorporate all system equipment into a formal CMMS program listing for maintenance planning and parts inventory control. The current maintenance management software if being used for process only, and equipment lists with nameplate data do not reside in any CMMS.*

- *A CBM (Condition Based Monitoring) vibration program should be implemented on system rotating equipment to gather baseline data and incorporate into the plant CMMS for PM task generation and PDM planning.*

- *Asset Management Services – Initial assessment and then ongoing monitoring of equipment conditions through various NDE and other methods to help prioritize university critical asset replacement based on remaining life. This need is urgent based on the age of this equipment observed in our visual inspection.*

2.2.8 *Gas Turbine Systems Assessment*

The Gas Turbine systems consist of the following:

- *GT (Gas Turbine) #1 and #2 (see pictures below) are Solar Titan gas or fuel oil dual fired units nominally rated at 12.5 MW each. The two Gas Turbines exhaust their waste heat into Energy Recovery International HRSG Units #1 and #2 respectively.*

The following **Level 2 Assessments** are recommended for the Gas Turbine Systems:

- *NDE external and internal inspections on all boiler economizer, evaporator section and superheater tubes and headers should be performed especially given the recent tube failure.*

- *The following Plant Improvement Projects should be considered for the Gas Turbine Systems:*

- *Incorporate all system equipment into a formal CMMS program listing for maintenance planning and parts inventory control. The current maintenance management software is being used for process only, and equipment lists with nameplate data do not reside in any CMMS.*

2.2.9 *Electrical Components and Systems Assessment*

The Plant and Campus Electrical incoming and distribution systems consist of the incoming switchyard (See 2nd row pictures below) breaker gear and step down transformers and into the campus electrical distribution switchgear and step down transformers both adjacent to Abbott Power Plant, with the power plant and spread across the campus. Spot checks were made of most plant and campus electrical equipment (see pictures below).

One of the most noted observations is that the electrical utility for the plant imposes a 40 MW import restriction on the University due to the limits of the local transmission system. The University issued a Purchase Order in Spring 2008 to increase this import limit to 60 MW and estimated completion is June 2009.

Switchyard

Cable Vault

A recent switchgear failure had occurred at one of the campus electrical substations resulting in much damage to the 13 KV switchgear and surrounding cabinet. Much of the switchgear in different campus substations range in age and replacement of outdated equipment should be considered.

13KV Switchgear Failure

The following Level 2 Assessments are recommended for the Electrical Components and Systems:

- *An initial Electrical Hot-Spot inspection program is in place and should be expanded to establish baseline data on the entire campus electrical system including transformers and substations.*

- *Protective relays should be calibrated to assure proper operation of switchgear.*

The following Plant Improvement Projects should be considered for the Electrical Components and Systems:

- *Incorporate all electrical system equipment into a formal CMMS program listing for maintenance planning and parts inventory control. The current maintenance management software if being used for process only, and electrical equipment lists with nameplate data do not reside in any CMMS.*

- *An ongoing Electrical Hot-Spot Evaluation program should be developed and implemented on all high voltage electrical system equipment such as transformers and underground cables to gather baseline temperature data and incorporate into the plant CMMS for historical significance, PM task generation and PDM and outage planning.*

- *A Protective Relay Calibration program should be developed and implemented for all electrical protective relaying equipment and incorporated into the plant CMMS program.*

- *Asset Management Services – Initial assessment and then ongoing monitoring of electrical equipment conditions through various NDE and other methods to help prioritize university critical asset replacement based on present condition and remaining life.*

2.2.10 *Instrumentation and Distributed Control Systems Assessment*

The Instrumentation and Control systems consist of the following:

- *Various plant instrumentation and control systems are in place throughout the plant, some analog and some of the digital variety (see pictures below). Plant is in the process of integrating all Abbott Power Plant systems and the newer Oak Street Central Chilled Water Plant into the Plant DCS (Distributed Control System) for central control of most plant systems.*

Control Room

No **Level 2 Assessments** are recommended for the Instrumentation and Distributed Control Systems, as they are currently in a state of flux due to component replacement and this system will need to be re-evaluated once system upgrades and integrations are completed.

The following **Plant Improvement Projects** should be considered for the Instrumentation and Distributed Control Systems:

- *Continue to develop and implement an Instrument Calibration program and manage within the plant CMMS program.*

- *Incorporate all plant instrumentation and DCS system equipment into a formal CMMS program listing for maintenance planning and parts inventory control. The current maintenance management software if being used for process only, and equipment lists with nameplate data do not reside in any CMMS.*

- *Broader use of DCS historian data for plant efficiency gains regarding startup, normal operation and shutdown SOP (Standard Operating Procedure) development and improvements. Preventive and predictive maintenance planning based on hours of operation versus time or "Tribal Knowledge" is another example of how this data can be utilized. A Plant Information software program such as PI could be utilized to help make use of the historian data and assist in the daily plant operational decisions*

- *Asset Management Services – Initial assessment and then ongoing monitoring and management of distributed controls equipment integration with the plant DCS to help* *prioritize which plant assets would be best suited for integration into the DCS, and in what order.*

2.2.11 *Chilled Water System Assessment*

Due to our limited site exposure, most of our assessment regarding chilled water consisted of a visit to the newer Oak Street Central Chilled Water Plant which seemed well maintained and needs little in regards to assessment recommendations or plant improvement project considerations. It is noted that this system is currently being studied for implementation of its control system into the Abbott Power Plant DCS. Four additional satellite chilled water plants were walked through briefly. These other four plants are older than the Oak Street plant and have equipment varying in age and size.

No **Level 2 Assessments** are recommended at this time for the Chilled Water System.

The following **Plant Improvement Projects** should be considered for the Chilled Water System:

- *Incorporate all plant instrumentation DCS system equipment into a formal CMMS program listing for maintenance planning and parts inventory control. The current maintenance management software if being used for process only, and equipment lists with nameplate data do not reside in any CMMS.*

- *Asset Management Services – Initial assessment and then ongoing monitoring and management of distributed controls equipment integration with the plant DCS to help prioritize which plant assets would be best suited for integration into the DCS, and in what order.*

2.2.12 *Cooling Towers and Circulating Water Systems Assessment*

The Abbott Station cooling towers consist of two towers having two cells each seemed to be in fair to good general condition along with the associated circulating water pumps.

General observations were that some cooling tower motor grease fittings seemed to be in need of repair/replacement and or greasing service, fan gearbox sight glasses leaking oil and general housekeeping improvements were necessary both on the topside and on the ground level with proper storage of cooling tower maintenance equipment.

Abbot Station Cooling Towers

We visited the other older campus building cooling towers briefly, and while nothing critical was observed, it was noted that the cooling towers at the Vet Med Facility are nearing the end of their life and the cooling towers at NCCP and Animal Sciences are in need of repair.

The following **Plant Improvement Projects** should be considered for the Cooling Tower and Circulating Water Systems:

- *Develop and implement a plan to repair/replace the cooling towers at the satellite chiller plants. These cooling tower repairs would help improve efficiency of the satellite plants.*

- *Plant Chemistry test results should be tracked for trending purposes and historical data record keeping purposes. The cooling towers at Abbott are equipped with Nalco 3DTrasar units and include real-time monitoring and trending of the tower water chemistry.*

- *Incorporate all system equipment into a formal CMMS program listing for maintenance planning and parts inventory control. The current maintenance management software is being used for work order and preventative maintenance task generation only. Equipment Lists with nameplate data do not reside in any CMMS.*

- *Implement a CBM (Condition Based Monitoring) vibration program on all system rotating equipment to gather baseline data and incorporate into the plant CMMS for PM task generation and PDM planning.*

3. *Operations Assessment*

3.1 Operations and Maintenance Management Program Assessment

Plant Operating Procedures: Our review of plant Standard Operating Procedures indicates that a lot of work has been expended in developing basic procedures that give the operator a basic understanding of major steps in plant evolutions but there are not many procedures that give the operator a detailed understanding.

The procedures should be further refined and include more detail as to what and why certain actions are taken in the procedure. Many procedures at Abbot are vague and too brief in their scope.

The procedures are also missing important date and operator initial blanks. It is not known if the operators follow, use or acknowledge the steps outlined if there is no signature in this spot. This mechanism also helps to prevent mistakes made due to missing important steps when starting or stopping specific plant equipment, systems or entire units. Accountability can also be assigned for correction when mistakes are made. The procedures can then be further improved and revised from the lessons learned and used to train others.

It is also noted that there do not appear to be any normal plant operating procedures, plant shutdown procedures, transient or alarm response procedures (a heading is noted on the SOP index but administrative procedures are contained within). These should be considered for development by Plant.

Plant Operator Training: While a training heading is listed in the index for “New Staff” and “Ongoing Professional Development” of current employees, it was reported that this is an area where more attention is to be given in the near future. It should be considered to contract the services of an O&M Services Training company to develop and administer this training as plant management staff already appears to be heavily tasked. This training will be of paramount importance with the expected loss of a large percentage of highly trained plant personnel within the next five years.

Maintenance Program: Currently Abbot utilizes a Computerized Maintenance Management System (CMMS) to help facilitate corrective maintenance and preventive maintenance work orders only. The software being used is called iMate. Data from Work Orders is being entered on a system level only. No inventory or labor costs are being entered into the system

This system is currently not being utilized to track and trend maintenance and costs on specific pieces of equipment. There are currently no equipment lists in iMate. **It is recommended** that a system be put in place to trend maintenance and costs on an equipment level and also to provide an accurate digital inventory of available spare parts. No comprehensive equipment listing or nameplate data resides in the CMMS. The current CMMS in place is suitable to the plant's needs if the proper information were to be loaded into the system.

3.2 Plant Staffing Assessment

The current plant staffing levels of five operators per shift, a daytime plant chemist and a seven man maintenance crew are not excessive for a power plant of this size and complexity. However, it is unusual in today's power plants to have separate Operations and Maintenance staff. Most power plants cross-train their employees to perform both operational and maintenance tasks within their skill set and then subcontract certain plant area tasks requiring expertise beyond these skill sets. UIUC has both a skilled maintenance staff that could learn operations and a skilled operations staff that could learn maintenance. Maintenance activities that the multi-disciplined staff could perform include regular preventive and corrective maintenance and any major work that falls within the experience level of the Operations and Maintenance staff. Currently, union jurisdictions prevent Abbot from implementing plans for a multi-disciplined Operations and Maintenance staff. If such plans could be implemented it is estimated that staff savings might be possible. However, a more detailed staffing study would be needed. In any event, the recommended incorporation of all equipment and nameplate data mentioned previously in this report will streamline maintenance crew resources with clearly defined and prioritized work tasks. Maintenance Management and staff efficiency gains will be realized.

3.3 Safety Program Assessment

The plant LOTO (Lock Out Tag Out) energy isolation and elimination program was examined briefly and found to be working well with the exception of having to hand write all Lockout tags out manually. A system can be purchased from companies such as the Red Tag Pro system, etc., or an in house program can be created that would print tags automatically when writing clearances for work to be performed. This would increase LOTO accuracy and time savings, resulting in shorter equipment outages for planned and unplanned work.

We did not conduct a LOTO system audit during our short visit, but it is recommended to be performed on a weekly or monthly basis at a minimum for accuracy and adequacy of isolation boundaries. We did not have a chance to conduct an audit of the Confined Space or Hot Work Programs, although no Confined Space Entry Procedure currently appears to exist electronically. The Hot Work Procedure appears satisfactory upon review and if followed will serve Plant well. Other procedures such as Material Safety Data Sheets, Hazard Communication Program, Fire Safety, Hearing Conservation, Respiratory Protection, Chemical Handling, Natural Gas Incident and Steam Incident for some examples appear to be undeveloped and/or in different stages of revision currently.

The plant is to be highly commended on the Abbott Power Plant Control Room Status Board. This helpful tool should be modeled by other Power Plants as an example of efficiency and accuracy for indicating current equipment operational and maintenance status at a glance. This also helps personnel maintain operational awareness of ongoing projects and hazards.

Control Room Status Board

3.4 Performance Assessment and Opportunities for Efficiency Improvement

<u>Central Plant</u>

A simplified plant performance model was developed to establish baseline operations in terms of efficiencies and electric and thermal production capabilities. This was based on monthly data from the Abbott cogeneration facilities and included the major equipment – steam boilers/turbines and gas turbines/heat recovery steam generators. The following table summarizes some of the key performance indicators:

Table 3.4-1. Equipment Performance Characteristics

Equipment	Rated Capacity	As Run Peak Capacity	As Run Average Capacity	Design Efficiency/Heat Rate	As Run Efficiency/Heat Rate
Gas Boilers					
Erie Boiler 2[1]	175 KPPH		160 KPPH	No info Maybe 85%	~ 80%
Erie Boiler 3[1]	175 KPPH		160 KPPH	No info Maybe 85%	~ 80%
Erie Boiler 4[1]	175 KPPH		160 KPPH	No info Maybe 85%	~ 80%
Coal Boilers					
B&W Boiler 5[1]	150 KPPH		140 KPPH	84.1[2]	~88%
B&W Boiler 6[1]	150 KPPH		140 KPPH	84.1[2]	~88%
B&W Boiler 7[1]	200 KPPH		180 KPPH	83.2[2]	~ 70%
Steam Turbines				?	~82 %
Turbine 1	3000 kW	3000 kW	3000 kW	Unknown	
Turbine 2	3000 kW	3000 kW	3000 kW	Unknown	
Turbine 3	3000 kW	Not Operated	Not Operated	Unknown	
Turbine 4	3000 kW	Not Operated	Not Operated	Unknown	
Turbine 5	3750 kW	Decommissioned	Decommissioned	Unknown	
Turbine 6	7500 kW	7500 kW	7500 kW	Unknown	
Turbine 7	7500 kW	7500kW	7500kW	Unknown	
Turbine 8	12,500 kW	8200 kW	6000 kW	Unknown	
Turbine 9	12,500 kW	8200 kW	4000 kW	Unknown	
Turbine 10	7000 kW	7000 kW	5000 kW	Unknown	
Gas Turbines					
Solar 1	13,000		13,000		11300-12400
Solar 2	13,000		13,000		11100-11800
HRSGs each	42 KPPH		42 KPPH		
Duct Burners	78 KPPH		78 KPPH		
Oak Street Chiller Plant					
Chiller 1	5000 tons				
Chiller 2	5000 tons				
Chiller 3	2000 tons			.637 KW/ton	
Chiller 4	2200 tons			.631 KW/ton	
Chiller 5	5000 tons			.615 kW/ton	
North Campus Chiller Plant					
Chiller 1	1200 tons			.653 kW/ton	
Chiller 2	1000 tons			.64 kW/ton	
Chiller 3	1000 tons			.64 kW/ton	
Chiller 4	2000 tons			.645 kW/ton	
Chiller 5	1000 tons			.651 kW/ton	
Chiller 6	2000 tons			.676 kW/ton	
Chiller 7	1200 tons			.653 kW/ton	

Observations:

Boilers - The boiler efficiencies are within a range that is reasonable considering the age of the plant. A large reason for inefficiency with the coal boilers is due to the limitation on steam load that can be achieved as a direct result of permit restrictions on the load of the Wet Scrubber to reduce SOx emissions.

Steam Turbines – It is extremely difficult, due to lack of metering on each individual turbine, as well as the multiple configurations the plant can operate in, to determine the efficiency of the

Steam Turbines. What is evident is that there is derating from the design capacity, and that this is consistent for a plant of this size and age.

Gas Turbines – The GTs are some of the newer equipment on site and have a long-term service agreement (LTSA) in place with the original equipment manufacturer (OEM). As such, they are in good shape and get regular maintenance intervals entered and provided for by the same OEM.

Heat Recovery Steam Generators – On the surface, the HRSGs are similar to the GTs, some of the newest plant equipment. However, water quality issues have led to severe corrosion issues manifesting themselves in the steam drums and generating banks of the HRSGs. This has resulted in a premature re-tubing of both HRSGs. However, the root cause is not this equipment; it is the condensate return quality that is getting sent to the units with little or no treatment.

Chillers – The Oak Street Chiller plant is very new (by campus standards), and at this point in extremely good condition. Likewise, the north campus chillers are also in fine condition for their age.

Opportunities for Plant Efficiency Improvement

- Existing Boilers Efficiency Upgrade – The chief concern of the Abbott Plant boilers is the ongoing life-cycle sustainment maintenance. Overall, direct efficiency improvements are not as effective as replacements of wall tube, generator banks, spray valves, etc. This does not mean there are no opportunities to improve boiler efficiencies, rather that efficiency upgrades will be a byproduct of repairs, as opposed to the justification for same.

- Replacement of Existing Boiler - Given the age of the boilers and general condition it is anticipated that replacing at least one gas boiler is likely. In fact, Boiler #4 is currently retired in place, and would be a likely candidate for such replacement. This is distinct from any requirements due to load growth. Improvement in boiler technology indicates that rather than a built-in-place boiler ‘tacked on’ to the plant; a packaged boiler could be procured to meet this need. In addition, boilers capable of using biofuels should be investigated as a hedge against future carbon taxes and to help meet sustainability goals.

- Pre-Cooling of GT Inlet Air - The performance of the GTs can be improved by providing pre-cooling of the inlet air. This could be accomplished by use of waste heat powering an absorption chiller, or an evaporative cooler. This can usually lead to efficiency gains of two or three percent, with attendant improvement of heat rate. However, the economics of this would need to be evaluated relative to the potential hours of utilization of the equipment, as inlet chilling systems are usually used only for turbines in climates with high average outside temperature or .base-loaded electrical producers.

- Optimization of Chiller Plants – While there are variable speed drives on the secondary distribution system and cooling tower fans, there may be an opportunity for further gains by application of optimization strategies. This includes:

- VSD Chillers – New variable speed drive chillers have the potential to reduce electricity requirements by 30% depending on the chiller load profile. This is most beneficial for operating environments where the chiller is at part power for significant portions of the time. Replacement of older equipment with a new VSD chiller should be evaluated.

- Metering of Chillers – Metering of the chiller plants is needed to establish performance levels and for ensuring efficient operation. This includes metering for the steam turbine driven chiller (suspect meter data) and for the motor-driven chillers, as well as the totalized chilled water flow

Distribution System

Given project limitations, it was not possible to develop an estimate of the thermal integrity of the steam distribution system and associated heat losses. However, a rough estimate of the heat losses can be determined by comparing the send out steam to the steam (condensate) meter data at the buildings, and adjusting for differences between the floor areas of the metered buildings relative to the floor area of the total population of buildings on the steam distribution system. The table below shows the results of this method applied to the calendar year 2008 data. This indicates that the buildings use about 75% of the steam sent out, implying losses of about 25%. However, some of this difference can be attributed to 1) temporary diversion of building condensate before reaching a meter (this occurred in several buildings during the summer), 2) direct use steam applications (e.g., autoclaves) that result in no condensate return (hence lower energy estimates than actual), and the assumption of linearity in the floor area adjustment. Based on this, an annual average estimate of between 15% to 20% loss might be assumed. For a point of comparison a recent benchmarking survey indicated losses ranging from 3% to 20%, with 6 of the 7 respondents indicating a loss of less than 10%.[2] In terms of actual condensate losses, data from the plant indicates that about 84% of the condensate is returned to the plant. The same benchmarking survey indicated a range of 50% to 96.7% for the campuses responding, with an average of 82.9%.

[2] Michigan State University, *Big 10 and Friends Energy Benchmarking Survey, Jul1, 2006-June 30, 200,* April 2008

Table 3.4-2. Comparison of Plant Send-Out Steam (Campus Steam) to Building Steam (Condensate) Meter Data

		Steam Metering, Big 80	Abbott Monthly SO	Projected Total Campus Buildings	Percent Consumed
January	**2008**	168,541	299,934	216,078.21	72.0%
February	**2008**	146,859	284,743	188,280.77	66.1%
March	**2008**	122,889	201,359	157,550.00	78.2%
April	**2008**	104,049	165,084	133,396.15	80.8%
May	**2008**	84,781	132,975	108,693.59	81.7%
June	**2008**	73,777	136,232	94,585.90	69.4%
July	**2008**	69,152	146,980	88,656.41	60.3%
August	**2008**	72,331	155,375	92,732.05	59.7%
September	**2008**	74,070	132,774	94,961.54	71.5%
October	**2008**	98,957	145,982	126,867.95	86.9%
November	**2008**	128,719	206,002	165,024.36	80.1%
December	**2008**	167,797	243,584	215,124.36	88.3%
calendar yr 2008		*1,311,922*	*2,251,024*	1,681,951.28	74.7%

Opportunities for Distribution System Efficiency Improvement

As discussed previously, a more detailed distribution system assessment is needed to identify the specific opportunities for reducing heat losses from the system. These losses are typically due to leaks, faulty traps or malfunctioning valves, and missing or damaged insulation. Ideally, the losses should be reduced to no more than 10% of sendout steam. Another area to investigate is reducing the footprint of the system, once again a byproduct of the recommended additional distribution system detailed study.

4. *Prioritized Actions and Investments for Improving Plants and Distribution Systems*

4.1 Prioritization Approach

The Abbott Power Plant is old by industry standards. With the exception of the newer additions of the Combined-Cycle equipment, the main steam and power generating equipment is well past its original design age. Fortunately, there were sufficient engineering and manufacturing tolerances in the original design of the plant, and this equipment has been able to provide satisfactory service for long past the (approximately 30 yr) ‘life cycle’ of the original design. The Abbott O&M staff has done a creditable job of keeping this equipment serviceable over this time period. However, a plant that has reached this stage of maturity will require more intensive maintenance, just to maintain this status quo. This should include condition-based maintenance, forecasting for equipment overhaul/replacement, and long-term forecasting to ensure that backup means of generation will be available once the equipment inevitably reaches the end of its useful life. Similar plants of this vintage can and do operate with 50-60 year-old equipment, and there is no indication that, given proper maintenance and upgrade programs, Abbott can not do likewise. It is understood, however, that in order to make that happen, significant capital must be placed into both condition assessment and preventative maintenance activities to keep this operating paradigm viable.

The Level 1 Condition Assessment, which was detailed earlier in this document, provides the 'snapshot' of the current plant condition, and is the jumping-off point for further discussion. Using the assessment, and keeping the concept in the preceding paragraphs in mind, the following considerations were used to prioritize investments to the Abbott Power plant:

1. Items which are absolutely necessary to maintain and extend equipment life cycle shall have top priority. This includes not only any new equipment as replacement, but also a condition-based maintenance (CBM) program and necessary overhauls to existing equipment.

2. Studies (of which this is one) that will better refine the need for and scope of capital investments to maintain or replace existing plant equipment hold secondary importance.

3. Upgrades to plant metrics, in the form of metering and data manipulation, will provide a more detailed road map for further plant betterment, in both operational efficiency and predictive maintenance practices.

4. New projects, in order to provide additional plant capacity to handle predicted load growth on campus would follow the above.

It is important to note that the items indicated above are in addition to the currently-planned and ongoing maintenance and overhaul cycles that are being undertaken by Abbott O&M personnel at this time. Such work would be considered to be ongoing, unless need for a certain item is superseded by a project outlined above. Keeping that in mind, the major considerations in prioritizing the possible activities resulting from the condition assessment and operations review are:

- Criticality to reliable operation
- Cost effectiveness
- Savings in operation or maintenance costs

These factors were considered qualitatively.

4.2 Prioritized Summary of Improvement Projects

Over the next 15 years, it is estimated that the central plants will require investments between $173 million and $234 million, while the plant thermal distribution systems will require between $51 million and $69 million (see table below). Much of this annually required $15 million - $20 million is for the basic requirements identified as "Capital Costs" and "Preventative Maintenance/Repair. "These requirements were based on the FY 2009 expenditure estimates, escalated by 5% annually over the 15 year period. The line identified as "Additional Capital/Maintenance/Repair" represents costs that are over and above these items, based on Worley Parsons review of plant information. The range is provided due to the uncertainty of the estimates.

Table 4.2-1. Investments in Central Plants and Distribution

	UIUC Annual Investment Costs (in $000)			UIUC 15 Year Investment Costs (in $000)		
Category	**Central Plant**	**Distribution**	**Total**	**Central Plant**	**Distribution**	**Total**
Capital Costs	$6,150	$1,859	$8,009	$92,250	$27,885	$120,135
Preventive Maintenance/Repair	$5,660	$390	$6,050	$84,900	$5,850	$90,750
Additional Capital/Maintenance/Repair	$1,739	$1,750	$3,489	$26,080	$26,250	$52,330
Total	**$13,549**	**$3,999**	**$17,548**	**$203,230**	**$59,985**	**$263,215**
Total +15%	**$15,581**	**$4,599**	**$20,180**	**$233,714**	**$68,983**	**$302,697**
Total -15%	**$11,516**	**$3,399**	**$14,915**	**$172,745**	**$50,987**	**$223,732**

Notes: The Capital Costs and Prevent Maintenance/Repair costs are based on FY 2009 data provided by UA, escalated by 5% over 15 years.
The Additional Capital/Maintenance/Repair cost estimates were based on the Worley Parsons review.

Table 4.2-2 provides more details on the suggested Additional Capital/Maintenance/Repair projects and the 15 year schedule for implementation.

Table 4.2-2. Major Repair and Replacements Above Already Planned Projects

Years 1 through 5	FY2009	FY2010	FY2011	FY2012	FY2013
Major Repairs					
Repairs to Coal Handling Equipment	$0	$0	$223,000	$0	$0
pH Monitoring system	$0	$0	$165,375	$0	$0
Boiler maintenance/repair/replacement of worn equipment	$0	$210,000	$0	$231,525	$85,085
Package Boiler Replacement	$0	$0	$0	$0	$0
Steam Turbine Overhauls	$0	$262,500	$275,625	$289,406	$303,877
Feedwater Pump overhaul/rebuild	$0	$0	$0	$289,406	$0
Total Major Repairs	**$0**	**$472,500**	**$664,000**	**$810,338**	**$388,962**
Replacements					
New Condensate Polishing System	$0	$2,772,000	0	0	$0
New Condensate Storage Tanks/Pumps	$0	$0	$1,233,036	$0	$0
Additional RO Train	$0	$0	$0	$2,274,039	$0
Level 2 Study of Steam/Condensate Distribution System	$0	$262,500	$0	$0	$0
Implementation of full CMMS	$0	$26,250	$0	$0	$0
Implementation of full CBM	$0	$0	$44,100	$0	$0
Full as-built drawings of existing Abbot Plant + steam/condensate distribution system	$0	$0	$0	$115,763	$0
Green Fan Redundancy	$0	$0	$0	$0	$607,753
Total Repacements	**$0**	**$3,060,750**	**$1,277,136**	**$2,389,801**	**$607,753**
Total Major Repairs and Replacements	**$0**	**$3,533,250**	**$1,941,136**	**$3,200,139**	**$996,715**

Years 6 through 10	FY2014	FY2015	FY2016	FY2017	FY2018
Major Repairs					
Repairs to Coal Handling Equipment	$0	$0	$0	$0	$0
pH Monitoring system	$0	$0	$0	$0	$0
Boiler maintenance/repair/replacement of worn equipment	$255,256	$0	$281,420	$0	$3,335,464
Package Boiler Replacement	$0	$0	$0	$0	$0
Steam Turbine Overhauls	$319,070	$335,024	$351,775	$369,364	$387,832
Feedwater Pump overhaul/rebuild	$0	$0	$351,775	$0	$0
Total Major Repairs	**$574,327**	**$335,024**	**$984,970**	**$369,364**	**$3,723,296**
Replacements					
New Condensate Polishing System	$0	$0	$0	$0	$0
New Condensate Storage Tanks/Pumps	$0	$0	$0	$0	$0
Additional RO Train	$0	$0	$0	$0	$0
Level 2 Study of Steam/Condensate Distribution System	$0	$0	$0	$0	$0
Implementation of full CMMS	$0	$0	$0	$0	$0
Implementation of full CBM	$0	$0	$0	$0	$0
Full as-built drawings of existing Abbot Plant + steam/condensate distribution system	$0	$0	$0	$0	$0
Green Fan Redundancy	$0	$0	$0	$0	$0
Total Repacements	**$0**	**$0**	**$0**	**$0**	**$0**
Total Major Repairs and Replacements	**$574,327**	**$335,024**	**$984,970**	**$369,364**	**$3,723,296**

Table 4.2-2. Major Repair and Replacements above Already Planned Projects *(Continued)*

Years 11 through 15	FY2019	FY2020	FY2021	FY2022	FY2023
Major Repairs	$0	$0	$0	$0	$0
Repairs to Coal Handling Equipment	$0	$0	0	0	0
pH Monitoring system	$0	$0	0	0	0
Boiler maintenance/repair/replacement of worn equipment	$0	$342,068	$0	$377,130	$0
Package Boiler Replacement	$0	$6,328,256	$0	$0	$0
Steam Turbine Overhauls	$407,224	$427,585	$448,964	$471,412	$494,983
Feedwater Pump overhaul/rebuild	$0	$427,585	$0	$0	$0
Total Major Repairs	**$407,224**	**$7,525,493**	**$448,964**	**$848,542**	**$494,983**
Replacements					
New Condensate Polishing System	$0	$0	$0	$0	$0
New Condensate Storage Tanks/Pumps	$0	$0	0	0	0
Additional RO Train	$0	$0	0	0	0
Level 2 Study of Steam/Condensate Distribution System	$0	$0	0	0	0
Implementation of full CMMS	$0	$0	0	0	0
Implementation of full CBM	$0	$0	0	0	0
Full as-built drawings of existing Abbot Plant + steam/condensate distribution system	$0	$0	0	0	0
Green Fan Redundancy	$0	$0	0	0	0
Total Repacements	**$0**	**$0**	**$0**	**$0**	**$0**
Total Major Repairs and Replacements	**$407,224**	**$7,525,493**	**$448,964**	**$848,542**	**$494,983**

For ease of understanding and emphasis, we have separated the projects, into two categories: Capital projects which are necessary to prolong the life of the plant, and secondly, O&M projects which will improve efficiency and capabilities of the Abbott O&M staff (and indirectly have a positive impact on the plant life cycle). The projects are described below ranked in order of priority within each category.

Capital Projects

1. **New Condensate Polishing System –** The one common problem identified in the study that would have the largest impact on the most equipment dealt with the water quality issues throughout the plant. This is chiefly due to the current situation of no water treatment being provided to the condensate return from the various campus loads. As a result, inferior quality water has been recycled to the boilers, resulting in increased rate of deterioration of that equipment. The retubing issues of the HRSGs highlight this issue most clearly – to have to retube a HRSG within the first 5 years of its operation is not normal – usual rates are 20-25 years. The plant as designed had a single side-stream softener at 100 gpm, however this equipment has long since fallen into disuse. It is recommended to not only replace this system with a cation/anion/mixed bed replacement polishing system, but to also increase the capacity of this to enable the plant, first for redundancy, secondly to have a treatment capacity for the entire amount of condensate currently returned from the campus. This works out to rates of 100 gpm, 200 gpm, and 400 gpm respectively. The third configuration is recommended as the most prudent, combined with the storage tanks/pumps that will be discussed in the next section. Estimated costs of this system run $2,640,000 for labor and installation, not including any fees for demolition of any existing plant equipment to create room.

2. **New Condensate Storage Tanks/Pumps –** Concurrent with the water quality issue is the ability for the plant to operate with an amount of reserve surge capacity in order to handle an upset condition where little to no condensate is returned from campus. The existing Condensate Storage Tanks are insufficient in capacity to handle this, along with any

maintenance issue inherent, due to their age and accessibility. To alleviate this, it is recommended to add two above ground storage tanks, along with attendant piping and forwarding pumps, to handle this requirement. These would be field-erected tanks of either full stainless steel construction, or carbon-steel construction, lined for corrosion protection. Each tank would have a capacity of 120,000 gallons. This would allow operation of the plant for an approximate 8-hour period without any condensate return, which provides a window of operational reliability and flexibility. Three x 50% capacity forwarding pumps, each rated at 200 gpm are included in this estimate. Depending on whether SS or Carbon Steel/Lined is chosen, approximate equipment and installation cost is $1,118,400 or $902,400, respectively.

3. **Additional RO Train for Makeup –** To eliminate the need for the portable demineralizer on site for makeup flow, it is recommended to procure a second Reverse Osmosis treatment skid. This would be a 100 gpm, two-pass design, similar to the currently-installed plant equipment, and is estimated at $1,964,400 for equipment and installation costs.

4. **Repairs to Coal Handling Equipment –** In order to determine the magnitude of the repair necessary, an additional study would need to be conducted. The order of magnitude for repairs to the structural integrity would be on the order of $100,000, however this number is to be used for planning purposes only as insufficient data was available for an engineering estimate.

5. **Detailed Level 2 Study of Distribution System –** This is necessary, to be performed to evaluate the extent of repairs and replacements that would need to be done to maintain the distribution systems for reliable and safe operation. As is evident in the condition assessment, even from the walk-through of just the major lines, there is need for structural repair, asbestos abatement, insulation repair, and evaluation of any leaks or potentially hazardous line conditions. As the area not walked through is older than the tunnels actually observed, it can be assumed that similar conditions exist therein. The cost of an evaluation study would be on the order of $250,000 depending on the total scope. For planning purposes, and not based on engineering estimates, it would not be unreasonable to assume that repairs to this system could run into the millions of dollars when it is completed. Nevertheless, this is a critical item, and must be addressed at the soonest opportunity in order to determine the overall scope.

6. **Additional NDE (Non-Destructive Examination) of Critical Equipment –** as part of the normal maintenance cycle, and in order to provide a predictive model of future repair/replacement need, it is recommended to continue and accelerate the material evaluation of critical equipment. This will provide an accurate snapshot of the health of items such as boiler tubes and feedwater heaters, feedwater pumps, steam turbine health, etc. This is what is currently supporting the ongoing maintenance budget that is leading to turbine overhauls, repairs to boiler coal feed and traveling grate, wall replacement, etc., and is reflected in the above table as ‘ongoing expenditures’.

7. **‘Green Fan’ Redundancy/Reliability –** as loss of this equipment would mean that the coal boilers would not be able to operate without being in violation of the environmental

permit, this must be addressed (For emergency situations, it could be assumed that running without the fan may be an option, however this must be compared with the penalty for emissions violation). An evaluation should be made as to the prudence of obtaining sufficient spares for the fan motor, VSD, and bearings at the least – they are the highest likelihood items to fail during operation, and having an on-hand spare would minimize down time. Taking these steps may be able to eschew the need for a redundant fan installation, as the current configuration of the breeching, Wet Scrubber, and stack makes locating this item extremely difficult and may in fact alter the permit due to equipment modification. At this time it is recommended to pursue the former strategy.

O&M Projects

1. **Implementation of pH Monitoring System –** This entails adding additional pH monitoring stations at critical points in the steam/condensate distribution/return cycle, as well as into boiler feedwater and cycle condensate monitoring. Each of these stations is roughly $20,000 for equipment, the number of which should be determined by the Abbott O&M crew based on their historical need.

2. **Implementation of Computerized Maintenance Management System –** as referenced in the assessment, this will enable more predictive maintenance as well as consolidating maintenance history on all equipment, and in maximizing efficiency of maintenance tasks. A typical package of software and training in order to set up a system like this would be in the $25,000 range, depending on the software chosen. There are several out there commercially that have been proven to work well in plants such as these. It is assumed that data entry and setup can be implemented into the daily tasks of the O&M crew over time and would not be an additional overhead burden.

3. **Implementation of Condition-Based Monitoring (CBM) Vibration Program –** in addition to the currently installed vibration monitors, the O&M crew can identify additional critical equipment. As a planning number, for order of magnitude, approximately $40,000 per additional monitoring unit would be appropriate.

4. **Full As-Built and Current Drawings for existing Abbott Plant and Steam/Condensate Distribution System –** this is self-explanatory, a reasonable number for planning would be $100,000 for survey/drawing creation, assuming that in-house labor could be utilized for actual data retrieval. It could rise, dependant on how much current drawings are available, two to three times that amount.

4.3 Recommended Investments and Reserves

In order to assess how to progress, we must look at a 5, 10, and 15 year window going forward. For planning purposes, the prioritized items above are what should be addressed in the next 5 years, the top items earliest in that window. Out in the 10 and 15 year windows, it is much harder to predict, based upon the plant data available. However, from similar plant situations, and assuming certain measures are taken (the recommended additional assessments, for example), it should be reasonable to assume that normal wear and tear and replacements will continue.

Table 4.3-1. Reserve Schedule to Fund Major Repair and Replacements Above Already Planned Projects

Years 1 through 5	FY2009	FY2010	FY2011	FY2012	FY2013
Reserve Requirement	$3,413,048	$3,527,913	$1,828,293	$1,378,242	$652,080

Years 6 through 10	FY2014	FY2015	FY2016	FY2017	FY2018
Reserve Requirement	$1,197,396	$1,163,976	$2,602,069	$2,494,868	$2,590,704

Years 11 through 15	FY2019	FY2020	FY2021	FY2022	FY2023
Reserve Requirement	$1,945,041	$1,863,596	$358,498	$268,705	$98,997

This table was developed using the cost shown in Table 4.2-2 and accumulating funds in the 5 years preceding the investment in order to fund these additional outlays. It needs to be noted that the reserve requirements in the final years of the analysis are likely understated as no investment are considered past 2023. Further, one marked note is the inclusion, for planning purposes at the 10-yr mark, of a full-replacement gas-fired boiler. As there are several possible configurations, a nominal 150,000 lb/hr package boiler unit was considered. This budgeted cost only assumes equipment and installation. Demolition of existing equipment is not included (it may be assumed at this time that the boiler could replace the currently-retired Boiler 4).

Facility Energy Consumption Reduction Measures
University of Illinois - Urbana-Champaign

Task D Final Report

September 2009

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Summary

This report documents the results of a study to identify facility energy reduction opportunities for the University of Illinois Urbana-Champaign (UIUC) campus. The main objectives of the study were to identify the most promising areas for building energy reduction, including the types of energy conservation measures (ECMs) and investments required, and priorities and strategic directions for implementation. The approach involved data collection and analysis, including energy surveys (walk-throughs) of representative buildings; a review of baseline energy usage and energy benchmarking based on energy use intensities (EUIs); reviews of the existing UIUC facility energy efficiency programs; identification of representative energy conservation measures (ECMs) and projections of opportunities campus-wide; prioritization of the opportunities based on economics and other criteria; and suggestions for implementation strategies for the facility energy reduction opportunities. As part of the analysis the impacts on the central plant were examined in terms of reduction in steam, chilled water, and electricity outputs.

The major findings of the study are:

1. The potential campus wide annual energy operating cost savings from representative energy conservation measures (ECMs) ranges from $6.5 million assuming only projects with a benefit-cost (B/C) ratio equal to or greater than 1 (Project B/C>1) are considered to $9.8 million assuming the B/C of the entire portfolio of measures is equal to or greater than 1 (Portfolio B//C >1) is considered. The associated annual energy savings are 20% and 32%, respectively. To realize these savings, an investment of $51.7 million to $151.2 million, respectively, would be needed by the university (see table below)

Table ES-1. Facility Investment and Savings Potential

Economic Criteria	Investment Cost ($M)	Annual Savings ($M)	Net Present Value ($M)	Simple Payback (Years)
Project B/C≥1	**51.7**	**6.5**	**41.7**	**8.0**
Portfolio B/C≥1	151.2	9.8	2.1	15.4

It is assumed that annual cost savings are due to fuel reduction, and there is no credit for fixed cost savings or capacity. Table ES-2 summarizes the savings figures by ECM. Table ES-3 shows the financial metrics for the set of measures. The environmental benefits associated with implementing the ECMs for the nominal case (Project B/C>1) is a reduction of 72,234 tons of carbon dioxide, 168 tons of sulfur dioxide, and 202 tons of nitrous oxides annually. For the for the Portfolio B//C >1 case the corresponding reductions are114,572 tons of carbon dioxide, 267 tons of sulfur dioxide, and 202 tons of nitrous oxides annually.

2. Implementation of the ECMs could reduce steam requirements from the central plants by 80,000 to 150,000 pounds per hour (14%-25%), chilled water by 5,000 to 8,000 tons (16%-25%), and electrical loads by 6 to 9 MW (8%-12%) for the nominal case and portfolio case, respectively. While these figures are broad estimates (and dependent on the amount and type of conservation that is implemented) they do indicate that energy conservation efforts can impact equipment operating margins and reserves or defer

capacity additions. Energy conservation measures that reduce the need for new capacity are considered economic if they can be save energy at a cost that is less than the costs of meeting the needs through new plant equipment. For new steam capacity this would be a cost of saved energy of $14.87/MMBtu and for new chilled water capacity this would be a cost of saved energy of $9.19/MMBtu.

3. The suggested priorities for the ECMs are as follows:

   <u>Near Term</u>

   - Lighting and select HVAC energy conservation measures (ECMs) offer the greatest opportunities. Within the lighting category, interior fixture replacements (e.g., T12 to T8 or T5) offer the greatest opportunity in the near-term. While a significant lighting upgrade is in progress, financial constraints have limited its scope and additional opportunities are available.

   - The most cost effective HVAC opportunities in the near-term include retro-commissioning, conversion of constant speed fans to variable speed and expanding the direct digital control (DDC). Expansion of DDC controls will also help facilitate coordinated load management efforts including the ability to strategically reduce loads in response to favorable utility price signals or to internal requirements. While utility-driven demand response incentives are not currently offered, they may be a source for additional savings at some future time. Furthermore, the building automation system/controls capability, together with metering efforts and facilities maintenance are the main components of continuous commissioning or measurement based commissioning – an effective means of locking in the results of the retrocommissioning activities.

   - Weatherization of buildings and judicious use of solar film to reduce heat losses/gains through the building envelope is also a good near-term investment.

   <u>Mid-Longer Term</u>

   - Mid-longer term investments include variable speed drives for pumps, adding economizer capability, and variable air volume controls for laboratory fume hoods. Retrocommissioning of laboratories and daylighting controls have marginal economics, but are worth implementing as part of the overall portfolio of measures

4. Many of the ECMs apply broadly across the various campus building types – classroom/office, research laboratory, etc. The top 100 energy consuming buildings offer the greatest opportunity for savings since they reflect more than 90% of campus energy use. Priority should be given to ECMs that align with the university's deferred maintenance requirements. Deferred maintenance projects with energy savings attributes generally provide better economics while meeting important functional needs. Examples are: incorporating variable air volume controls and/or heat recovery when replacing air handling units; adding roof insulation and/or specifying reflective coatings when replacing roofs.

Table ES-2. Annual Savings for Representative Energy Conservation Measures (ECMs)

ECM Descrip	Annual Energy Savings										
	Energy Usage Savings				Energy Demand Savings			Energy Operating Cost Savings ($/Yr)			
	Elec	CHW	Steam	Total	Elec	CHW	Steam	Elec	CHW	Steam	Total
	kWh	MMBTU	kLbs	MMBTU	kW	Tons	kLbs/hr				
Replace Windows	-	18,077	50,355	68,431	-	574	20	$0	$99,421	$352,484	$451,905
Insulate Roof	-	-	31,592	31,592	-	-	12	$0	$0	$221,145	$221,145
Solar Film	-	9,038	6,859	15,897	-	287	-	$0	$49,710	$48,011	$97,722
Weatherization	-	-	27,992	27,992	-	-	11	$0	$0	$195,941	$195,941
General Lighting Upgrades (Interior, Lam	14,659,600	16,696	(12,418)	54,311	3,080	530	(5)	$1,026,172	$91,825	($86,927)	$1,031,070
Daylighting Controls/Daylight Harvesting	414,772	-	-	1,416	116	-	-	$29,034	$0	$0	$29,034
Occupancy Sensors	400,854	-	-	1,368	458	-	-	$28,060	$0	$0	$28,060
Exterior Lighting - including controls	303,377	-	-	1,035	-	-	-	$21,236	$0	$0	$21,236
Retrocommissioning, Labs	3,680,966	18,714	31,175	62,452	420	594	6	$257,668	$102,928	$218,222	$578,818
Retrocommissioning, General	10,390,527	80,754	116,124	232,341	1,186	2,565	22	$727,337	$444,147	$812,869	$1,984,353
2 Speed Fan Operation, Labs (100% OA)	2,271,510	8,747	16,892	33,392	-	-	3	$159,006	$48,111	$118,245	$325,362
CAVRH to VAVRH Conversion, General (I	5,803,788	128,866	93,592	242,266	1,219	2,256	37	$406,265	$708,760	$655,147	$1,770,172
Eliminate Reheat/Summer Steam	(219,080)	-	6,490	5,742	(46)	-	-	($15,336)	$0	$45,430	$30,094
Redirect Relief Air as Makeup Air	-	-	1,296	1,296	-	-	-	$0	$0	$9,074	$9,074
Heat Recovery, Air to Air	(777,817)	-	12,928	10,273	(89)	-	5	($54,447)	$0	$90,495	$36,048
Use CHW for Preheat	-	-	16,005	16,005	-	-	6	$0	$0	$112,037	$112,037
Add Economizer Capability	-	35,689	-	35,689	-	-	-	$0	$196,291	$0	$196,291
VSD Fans on AHUs (SZ VAV)	2,357,907	13,552	27,115	48,715	495	430	11	$165,053	$74,534	$189,808	$429,396
VSD on Pumps	2,104,146	-	6,792	13,973	442	-	3	$147,290	$0	$47,541	$194,831
Steam System Maintenance (Traps, insul	-	2,869	23,391	26,260	-	91	3	$0	$15,779	$163,735	$179,513
DX to CHW	3,076,202	(9,149)	-	1,351	863	(291)	-	$215,334	($50,317)	$0	$165,017
DeCommission Fume Hood	33,606	583	726	1,423	4	18	0	$2,352	$3,204	$5,084	$10,640
VAV-Phoenix retrofit Labs	1,569,470	7,459	12,064	24,880	179	237	5	$109,863	$41,022	$84,450	$235,335
Install DDC on Central Equipment	5,632,335	61,538	71,301	152,062	-	1,077	15	$394,263	$338,461	$499,105	$1,231,830
Install Motion Sensors for HVAC	127,844	1,216	867	2,519	-	-	-	$8,949	$6,687	$6,068	$21,704
Autoclave Controls	-	-	78	78	-	-	-	$0	$0	$545	$545
Insulate DHW Tanks	-	-	1,573	1,573	-	-	0	$0	$0	$11,011	$11,011
Instantaneous DHW	-	-	325	325	-	-	-	$0	$0	$2,278	$2,278
Solar assist for DHW	-	-	384	384	-	-	-	$0	$0	$2,687	$2,687
Energy Star Computers, printers, etc	2,297,726	-	(5,778)	2,064	644	-	(2)	$160,841	$0	($40,446)	$120,395
Solar PV	986,175	-	-	3,366	277	-	-	$69,032	$0	$0	$69,032
Total	55,113,909	394,648	537,720	1,120,472	9,248	8,370	152	$3,857,974	$2,170,564	$3,764,039	$9,792,576
Baseline Usage	278,185,522	1,039,124	1,527,195	3,515,488				$19,472,987	$5,715,182	$10,690,365	$35,878,534
% Savings	20%	38%	35%	32%				20%	38%	35%	29%
Projects with B/C>=1	41,845,526	235,271	319,328	697,418	6,488	5,145	82	$2,929,187	$1,293,993	$2,235,294	$6,458,473
% Savings - Projects with B/C>=1	15%	23%	21%	20%				15%	23%	21%	18%

Table ES-3. ECM Costs and Financial Metrics

	Financials				
ECM Descrip	ECM Costs	Economic Figure of Merit			
	Net Cost $	SPB Yrs	Benefit/ Cost	CSE ($/MMBtu)	Net Present Value
Replace Windows	$22,792,432	50.4	0.41	$21.67	($11,742,486)
Insulate Roof	$2,967,645	13.4	1.46	$6.67	$1,262,231
Solar Film	$282,941	2.9	3.88	$2.30	$1,313,649
Weatherization	$1,175,972	6.0	1.87	$5.44	$1,651,671
General Lighting Upgrades (Interior, Lam	$6,182,396	6.0	1.79	$14.74	$8,229,330
Daylighting Controls/Daylight Harvesting	$523,702	18.0	0.97	$30.61	($17,989)
Occupancy Sensors	$214,665	7.7	1.47	$20.32	$161,869
Exterior Lighting - including controls	$916,946	43.2	0.42	$71.06	($532,235)
Retrocommissioning, Labs	$8,597,887	14.9	0.99	$13.26	($87,666)
Retrocommissioning, General	$16,577,935	8.4	1.34	$9.24	$9,192,449
2 Speed Fan Operation, Labs (100% OA)	$3,110,881	9.6	1.54	$8.98	$2,068,504
CAVRH to VAVRH Conversion, General (I	$46,143,593	26.1	0.69	$15.28	($14,075,806)
Eliminate Reheat/Summer Steam	$1,102,413	36.6	0.49	$15.41	($557,240)
Redirect Relief Air as Makeup Air	$126,505	13.9	1.06	$9.40	$8,804
Heat Recovery, Air to Air	$2,098,115	58.2	0.25	$19.68	($1,927,146)
Use CHW for Preheat	$87,979	0.8	18.76	$0.53	$1,921,434
Add Economizer Capability	$2,895,068	14.7	1.23	$6.51	$660,860
VSD Fans on AHUs (SZ VAV)	$1,606,324	3.7	3.94	$3.18	$5,803,387
VSD on Pumps	$2,140,605	11.0	1.34	$14.76	$897,064
Steam System Maintenance (Traps, insul	$3,505,353	19.5	0.67	$14.62	($1,583,865)
DX to CHW	$7,273,639	44.1	0.44	$382.13	($3,735,976)
DeCommission Fume Hood	$8,923	0.8	13.38	$0.81	$178,347
VAV-Phoenix retrofit Labs	$4,051,627	17.2	1.05	$13.07	$211,623
Install DDC on Central Equipment	$9,678,146	7.9	1.43	$8.24	$6,695,679
Install Motion Sensors for HVAC	$234,387	10.8	1.04	$12.05	$14,897
Autoclave Controls	$6,781	12.4	0.90	$11.27	($1,065)
Insulate DHW Tanks	$61,649	5.6	2.63	$3.78	$123,651
Instantaneous DHW	$17,691	7.8	2.33	$4.36	$23,582
Solar assist for DHW	$109,598	40.8	0.36	$27.50	($86,095)
Energy Star Computers, printers, etc	$323,399	2.7	2.34	$36.19	$1,250,135
Solar PV	$6,429,093	93.1	0.19	$153.27	($5,178,530)
Total	$151,244,286	15.4	1.01	$11.60	$2,143,068
Baseline Usage					
% Savings					
Projects with B/C>=1	$51,744,736	8.0	2.26		$41,669,167

5. A comparison of the university's energy use intensity (EUI) to benchmark information from comparable institutions indicates the university has higher EUIs than many of the other institutions.

6. The university has done a good job of establishing an energy conservation program. It should accelerate its efforts, particularly in the area of HVAC retrocommissioning and lighting. Resources should be provided to lock-in the results of the retrocommissioning via continuous commissioning/measurement based commissioning in coordination with metering efforts, building automation system activities, and facilities maintenance. Policy guidelines regarding energy reduction goals, building schedules, temperature set points, etc. should be reinforced.

7. The university should establish a funding source for the energy conservation programs. This could be supplemented by a revolving fund that would be replenished from future savings, plus annual additions.

8. Energy awareness campaigns used in conjunction with the university's metering/billing initiative should provide a solid foundation for energy behavioral changes. However this information must be put into context with regard to what occupants can do. Providing building level energy use data and operating parameters (e.g., space temperatures) via web access, including comparisons to previous years and benchmarks would be beneficial. In addition, the campaign could include energy efficiency competitions between buildings/academic units, based on energy use/reduction targets. Providing energy and emissions impact data for behaviors under an occupant's control could help foster some accountability.

9. In addition to requiring new buildings to be LEED certified, an energy master plan and strategy and/or minimum standards should be developed and implemented for new buildings and/or renovations. Items such as use of demand controlled ventilation; use of heat recovery and/or variable flow laboratory hoods; daylighting/dimming controls; peak shaving, etc should be identified.

1. *Overview*

1.1 Introduction/Objectives

The University of Illinois recognizes that managing energy use in its facilities is an important part of any strategy to contain or reduce the costs of utility services. It has undertaken a number of energy consumption reduction initiatives, and has plans to continue or expand some of these efforts. The objective of the work documented in this task report is to provide the university with a strategic direction for these energy consumption reduction efforts. This includes suggestions for investments in energy consumption reduction measures – prioritized investment portfolios - and implementation approaches.

1.2 Approach

The approach to the task involved the following activities:

- *Building Surveys* – This involved performing "walk-throughs" of a small sample of campus buildings to better familiarize the team with facility operations and to identify energy savings opportunities.
- *Baseline Energy Usage* – This involved a review of the energy supply and consumption data to identify trends and operational aspects affecting energy performance and the applicability of energy conservation measures (ECMs).
- *Benchmarking* – This involved the development of Energy Use Intensity (EUI) indicators to serve as a point of reference for building energy performance. This information was also compared to similar data from other research universities.
- *Review of Existing Facility Energy Efficiency Programs* – This was performed to understand efforts currently underway, in order to ensure that 1) our work properly accounted for projects/savings already in-hand or planned and 2)we took advantage of project data based on actual costs/savings achieved by the university.
- *Develop Energy Conservation Measures (ECMs)* – Based on the building surveys, and a review of energy usage/operational information, ECMs were identified and characterized in terms of investment costs and energy savings. The results from the analysis of selected individual buildings were projected to the campus building population through a building categorization process. This included factors that accounted for the percentage of applicable buildings for the specific ECMs.
- *Prioritize Opportunities* – The ECMs were prioritized based on a number of criteria including economic and non-economic considerations.
- *Implementation Strategies* – Implementation strategies for the ECMs were identified including financing and other delivery methods (e.g., in-house, external, etc.).

2. *Facility Overview*

2.1 General Description

The University of Illinois Urbana Champaign (UIUC) campus consists of approximately 500 buildings totaling over 20,000,000 square feet (sq. ft.) and ranging in size from less than 200 sq. ft. to over 500,000 sq. ft. Of the approximately 400 buildings on campus, 290 are designated as academic with the balance designated for other functions such as housing and support. Approximately 20 of the buildings are leased. An estimated 90% of UIUC's energy usage can be attributed to 100 buildings of which 98 are on campus.

All buildings on campus are served by a common electrical system. Steam from the central plant (Abbott Power Plant) is provided to 160 buildings on campus. Chilled water is provided to 93 buildings on campus from one of 5 central chiller plants. Planned expansion of the chilled water distribution system will increase the number of buildings served by the central plants. The remainders of buildings on campus as well as all off campus buildings have electrically operated cooling systems of various types. The off campus buildings are served by the local utility under separate accounts for electric, natural gas, and/or heating oil.

Responsibility for the building operations falls within the purview of the Facilities and Services (F&S) organization. Individual buildings or tenants/academic departments (with the exception of auxiliary buildings) do not currently pay for their utilities service based on the metered usage. This is scheduled to change beginning in fiscal year 2010.

Hours of operation vary based on building occupancy and function. The majority of academic buildings are open from 7 AM to 11 PM, Monday through Saturday. Certain buildings and selected areas of other buildings such as libraries, athletic facilities, performing venues, etc. have restricted hours. Reduced hours are in effect for many buildings on Sunday.

Heating, Ventilating and Air Conditioning (HVAC) Systems

Most of the larger buildings at UIUC rely on central air conditioning systems using chilled water for cooling and steam or hot water for heating. Perimeter heating systems are commonly used to provide comfort in winter. Reheat systems are installed in many buildings to provide zone temperature control and assist with humidity control. Most reheat systems remain active in summer. Most buildings were designed for constant volume air circulation. Variable air volume systems are more common in the newer buildings. A few of the larger buildings use fan coils or other terminal equipment such as heat pumps. Ventilation air and air change rates vary from 100% outside air and 14 air changes per hour (ACH) in research laboratories to 15% outside air and 6 ACH in office/classroom buildings. Most central air systems have air side economizer capability which provides "free" cooling when outside air temperatures permit.

Buildings receiving chilled water from a central plant generally have secondary pumps with variable speed drives to distribute the chilled water within the building to air handling units which generally have 2 way valves. Chilled water is normally supplied at about 40oF from the central plants. Supplemental cooling with air cooled direct expansion (DX) and/or chilled water is common in areas with high internal loading such as computer rooms and certain research laboratory applications.

Most of the larger buildings on campus receive either low (50 pounds per square inch gauge - psig) and/or high (150 psig) pressure steam from the central plant. Many buildings use low pressure steam directly for preheat, reheat, and perimeter heat. The remainder generally have one or more converters (heat exchangers) to create hot water from steam and use it for preheat, reheat, and perimeter heat. Steam condensate is collected at each building with vented condensate receivers and pumped back to the central plant.

Electrical and Lighting Systems

All buildings on campus receive electricity from a campus distribution system which operates at 12,470 volts. Step-down transformers are used to provide 480/277V and/or 208/120V distribution within the buildings.

The majority of interior lighting is provided by fluorescent lamps. The original stock of lighting varies with building age, architectural design, and replacement practice. A major lighting retrofit program is in progress to convert fluorescent lighting to electronic ballasts and T-8 lamps. Interior lighting is generally controlled via manual switches.

Exterior lighting for walkways and parking lots uses a combination of metal halide and high pressure sodium. Control is generally provided by photocell.

Emergency Generators (diesel) and battery backup lights are used extensively for life safety requirements. Uninterruptible power systems are also provided for critical applications such as computer servers.

Process Systems

Domestic hot water (DHW) is generally provided by steam from the central plant using a combination of converters and storage tanks if the steam is available. Buildings without steam rely primarily on electric or gas fired heaters. Capacity and storage volumes vary with the building usage. A few instantaneous steam heaters are in use.

Humidification is limited to central computer rooms (primarily electric) and areas serving animals. The latter typically have clean steam generators and use steam from the central plant, while the former are generally electric. Most of the humidification systems for general building usage (including 100% outside air systems) have been abandoned.

Autoclaves, reverse osmosis (RO) and deionized (DI) water, medical gas, etc are limited to specialized buildings and/or zones within a building – primarily research laboratories and/or veterinary medicine. Steam from the central plant is used for some of these process loads.

Air cooled DX equipment is used for refrigeration in many laboratory areas. The condensing unit and heat rejection locations include in-space, above-ceiling, and in- remote locations. Very little water cooled condensing or outdoor condensing units are used.

Compressed air is used extensively for HVAC controls (pneumatic) and is generally provided by electric reciprocating compressors located in each building. A few specialized buildings and laboratories have independent compressed air systems for research activities. Future plans call for a centralized compressed air system.

As with any large university there are numerous energy using systems and/or loads that are limited in quantity but impact the energy usage and/or energy distribution systems. These range from data centers to swimming pools to kitchens.

2.2 Controls

Automatic temperature control for HVAC systems is provided by a combination of pneumatic and direct digital control (DDC). Pneumatic control is generally limited to room temperature controls (reheat and/or perimeter heat) and actuation of valves and dampers. DDC is used extensively for control of central equipment such as air handling units, steam converters, and pumps. Much of the DDC currently in use displaced pneumatic controls during retrofit upgrades. DDC is a preferred control system due to its ability to readily incorporate energy savings strategies as well as the ability to remotely monitor, adjust, and troubleshoot systems. Pneumatic controls, on the other hand, offer lower cost, high reliability, and adequate functionality in some applications.

DDC systems unfortunately typically use proprietary software (and hardware) which can result in high costs and restricted usefulness. UIUC, like many institutions, has tried to restrict the number of DDC vendors on campus to optimize cost effectiveness and promote system interoperability.

3. *Energy Use*

3.1 Campus Energy

The tables below summarize the annual campus loads (e.g., power or rate of energy use) and energy usage provided by the central plants and purchased electricity for FY08. For electricity, the data includes service to all campus buildings, while for steam it covers 160 buildings, and for chilled water 93 buildings (from all 5 plants). For chilled water, it was necessary to extrapolate from partial data, since only 3 of the plants were metered. Note that the total steam includes campus plus plant steam generated, while campus steam is specifically the steam that goes to the buildings for heating, process, etc.

Table 3.1-1 UIUC Campus Load Summary – FY08

	Electricity (kW)	Steam (lbs/hour) Total/Campus	Chilled Water* (tons)
Summer Peak	**76,530**	**420,000/282,000**	**31,200**
Winter Peak	**58,980**	**656,000/459,000**	**15,500**
Summer Minimum	**44,000**	**250,000/170,000**	**8,300**
Winter Minimum	**36,000**	**350,000/260,000**	**2,900**
Annual Average	**51,692**	**367,360/276,000**	**8,500**
Load Factor**	**63%**	**56%**	**27%**

Note that the peak /minimum values are based on hourly load data. The summer period is assumed to be June - September, while the winter is November - March.
*Data was only available after 8/1/08 and for 3 of 5 plants. This is estimated by extrapolation.
** Ratio of average to peak load

Table 3.1-2 UIUC Campus Energy Requirements – FY08

	Electricity* (MWh)	Steam (klbs)	Chilled Water** (Million-ton-hours)
Summer (June-September)	**173,158**	**669,000**	**49,190**
Winter (November-March)	**166,465**	**1,288,000**	**15,068**
Annual	**453,000**	**2,419,000**	**87,795**

*Usage for all buildings (on and off campus)

**Data was only available after 8/1/08 and for 3 of 5 plants. This is estimated by extrapolation.

Figures 3.1 -1 through 3.1-3 illustrate this information on a monthly basis.

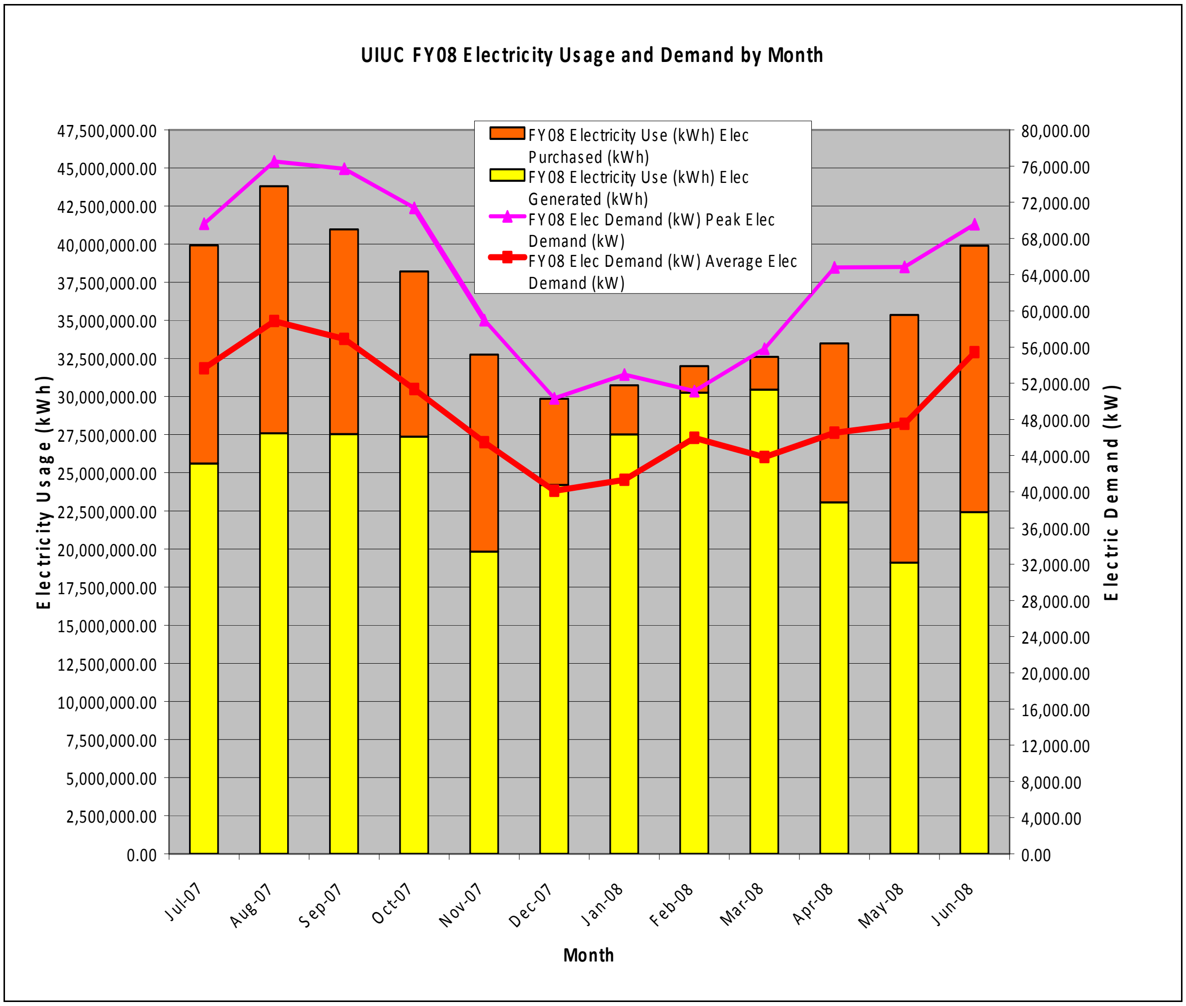

Figure 3.1-1. Monthly Electricity Usage and Demand

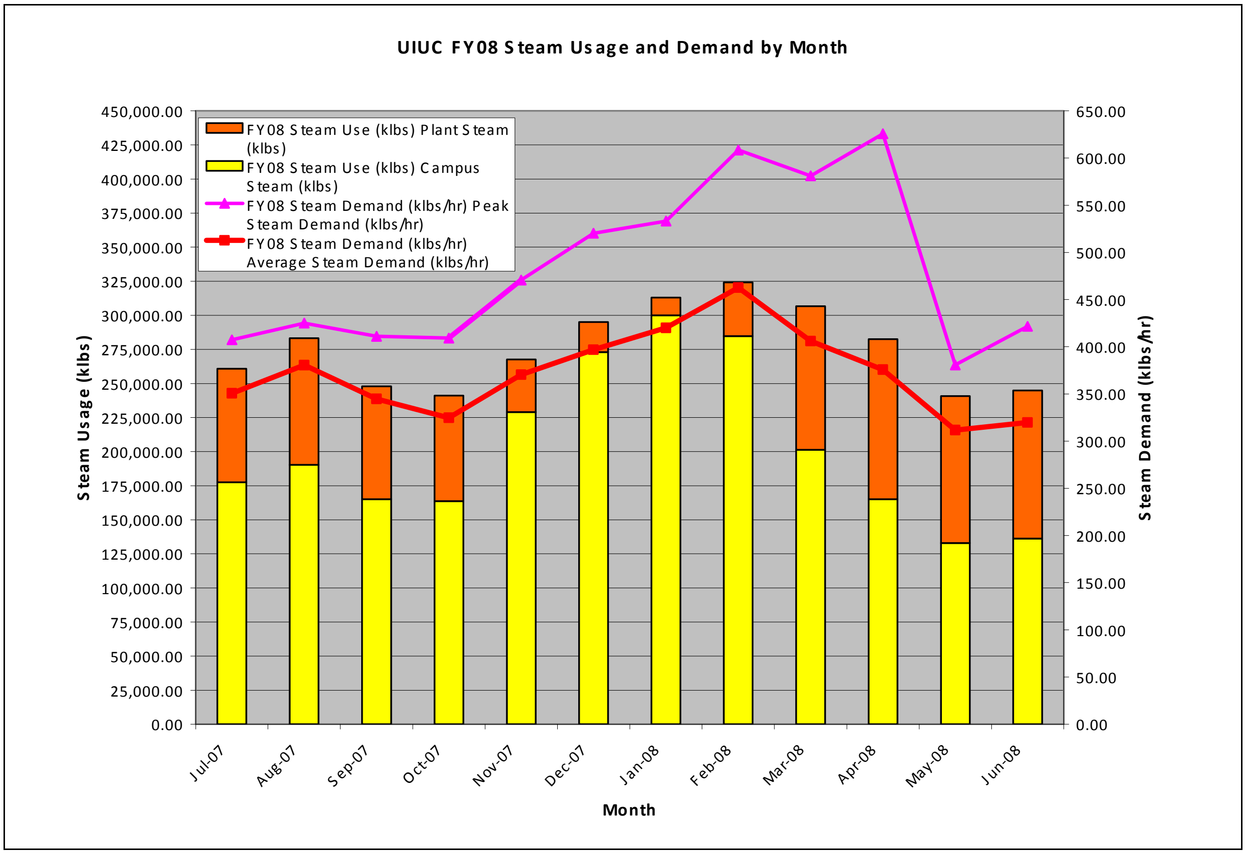

Figure 3.1-2. Monthly Steam Usage and Demand

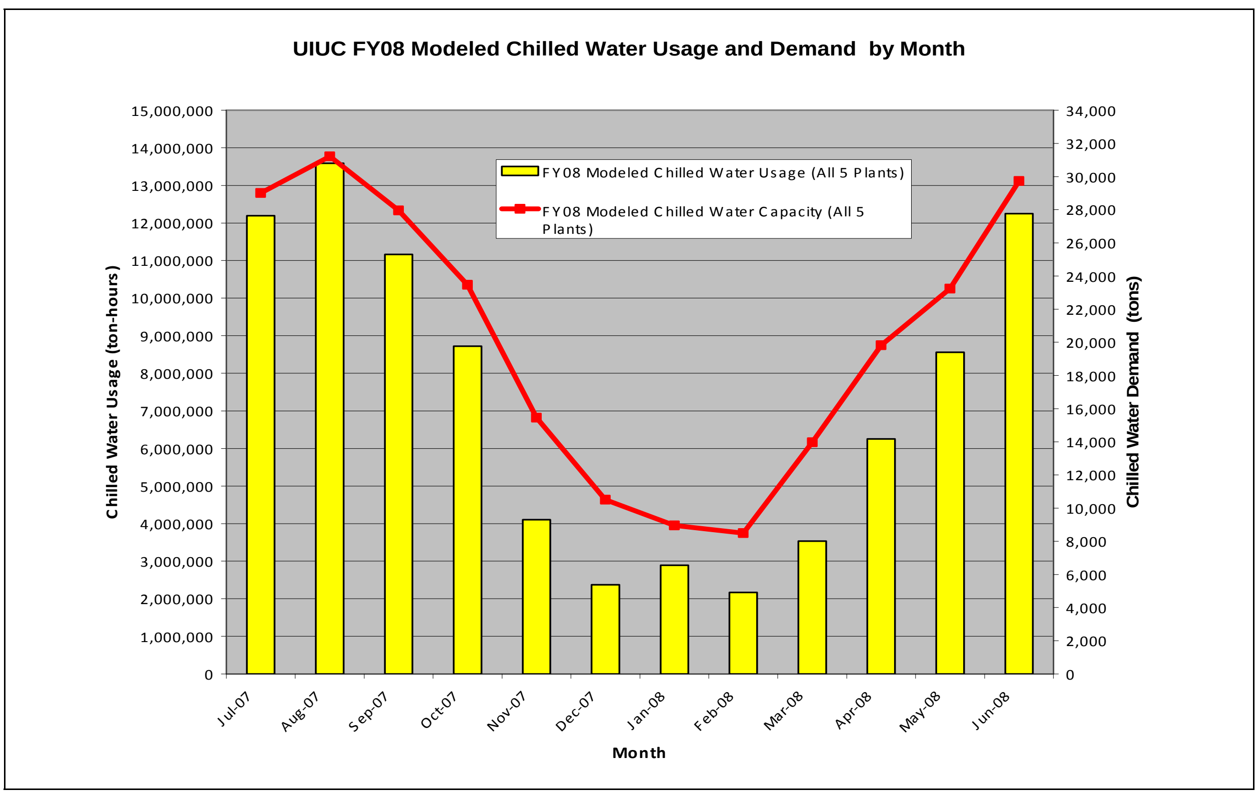

Figure 3.1-3. Monthly Chilled Water Usage and Demand

In addition to the monthly information, hourly data was also analyzed to gain insight into operating profiles. Electric and steam hourly data was available for the main campus for all of 2007 and 2008. Hourly chilled water data was only available for part of 2008 and only for 3 of the 5 plants. Figure 3.1-4 shows the 2008 data set for electricity, chilled water, and steam, while figures 3.1-5 and 3.1-6 show the data for the peak summer week (max electricity usage) and a typical winter week, respectively. This provides more detail. Figures 3.1-7 and 3.1-8 indicate the correlation between steam demand and chilled water demand, respectively, as a function of outside air temperature.

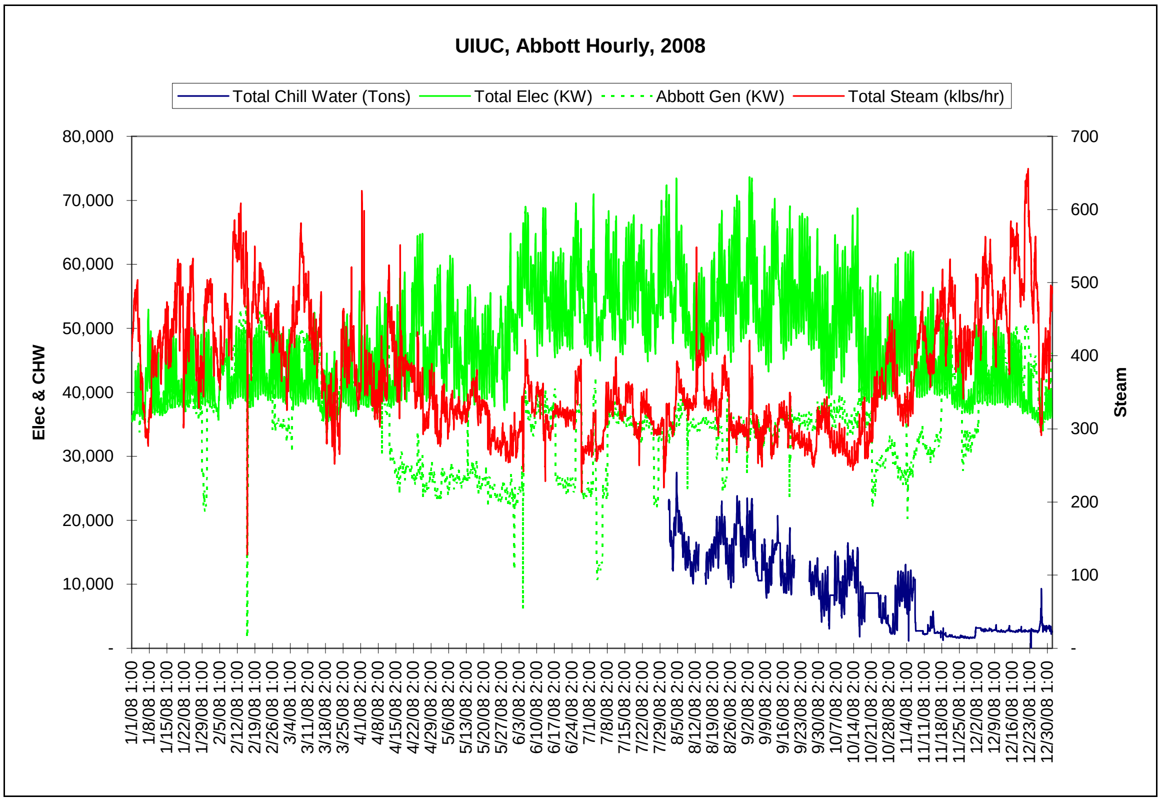

Figure 3.1-4. Hourly Energy Data from UIUC Central Plants - 2008

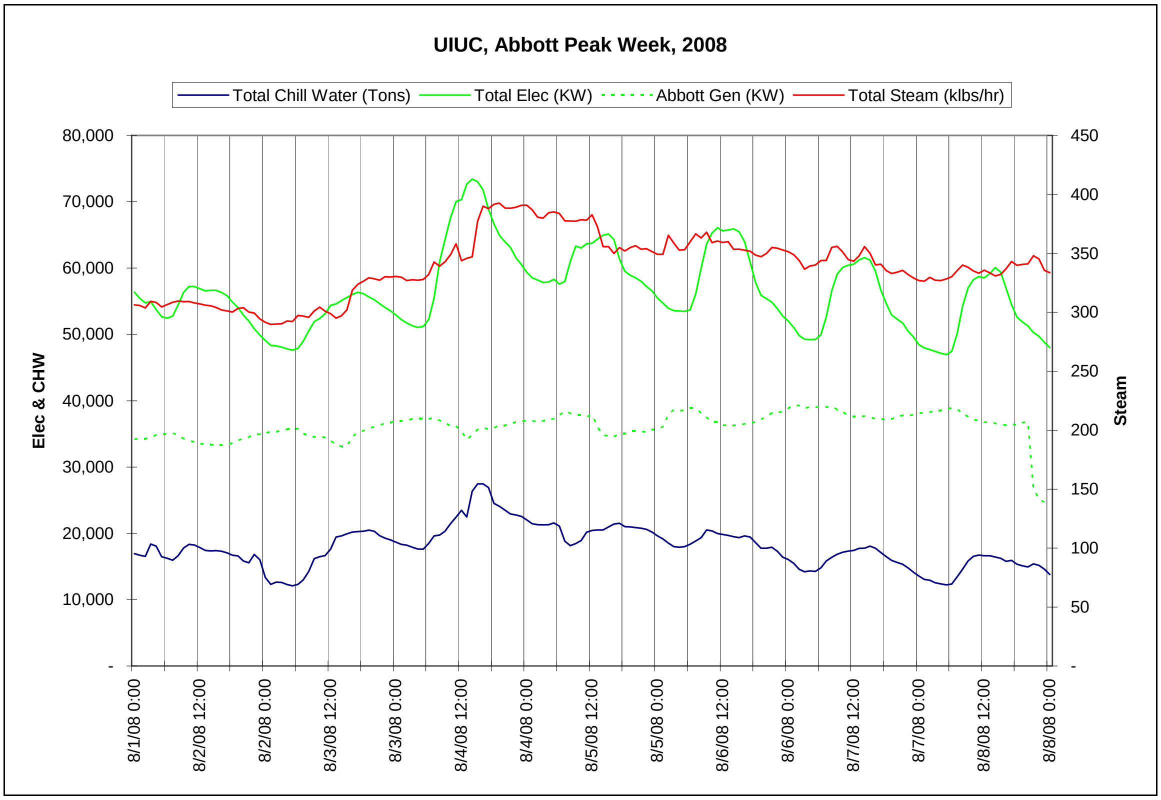

Figure 3.1-5. Electric, Steam, and Chilled Water Load Profiles –August 1 -8, 2008

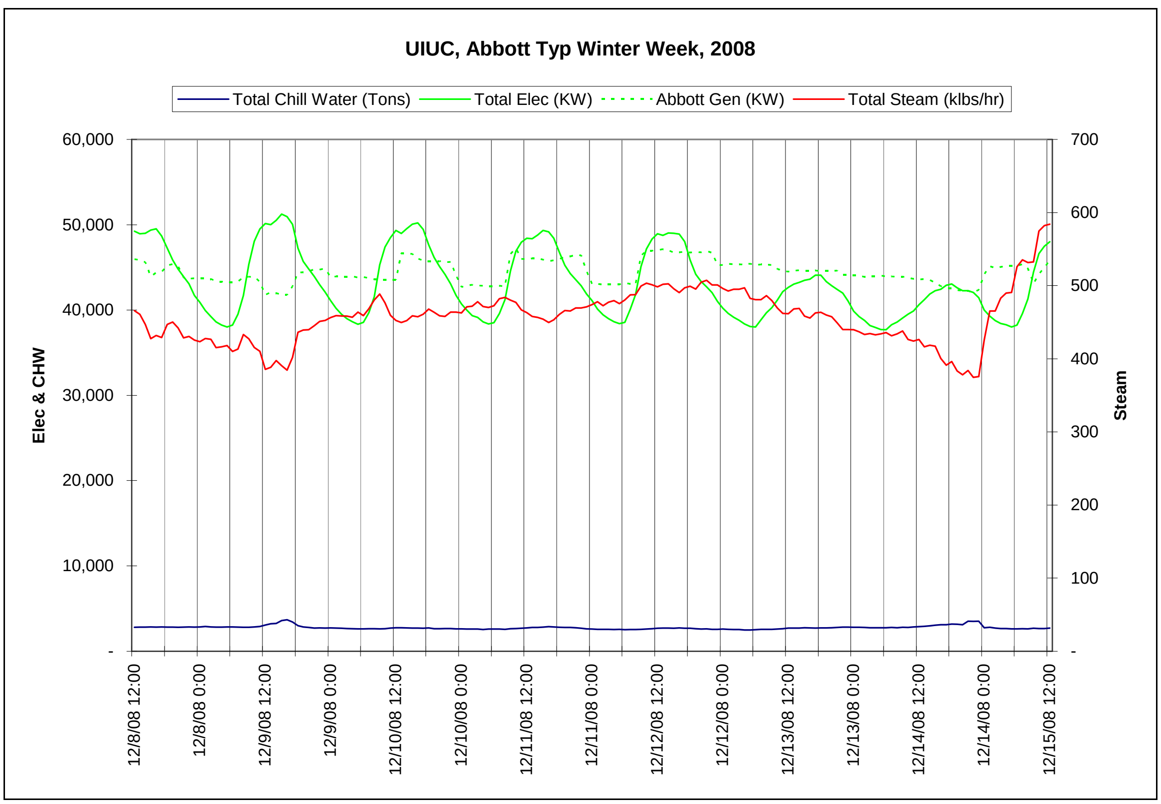

Figure 3.1-6. Electric, Steam, and Chilled Water Load Profiles – Dec. 8-15, 2008

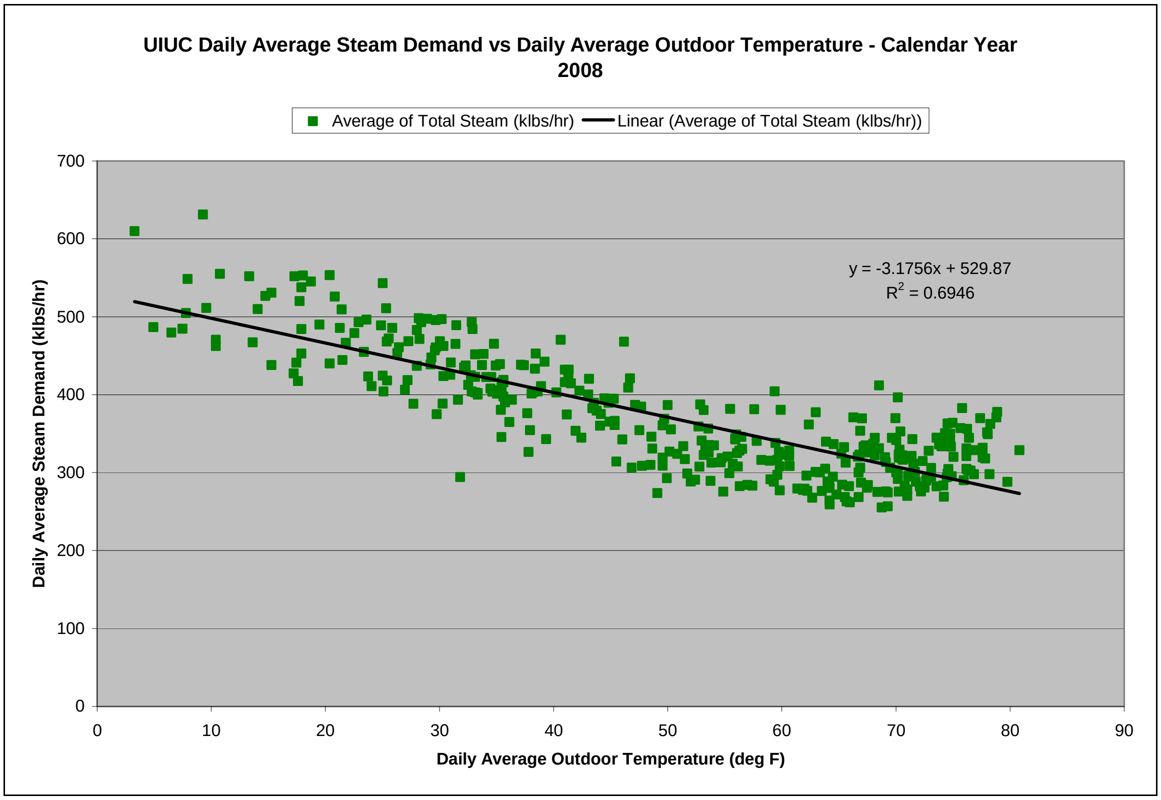

Figure 3.1-7. Average Steam Demand vs. Outside Air Temperature

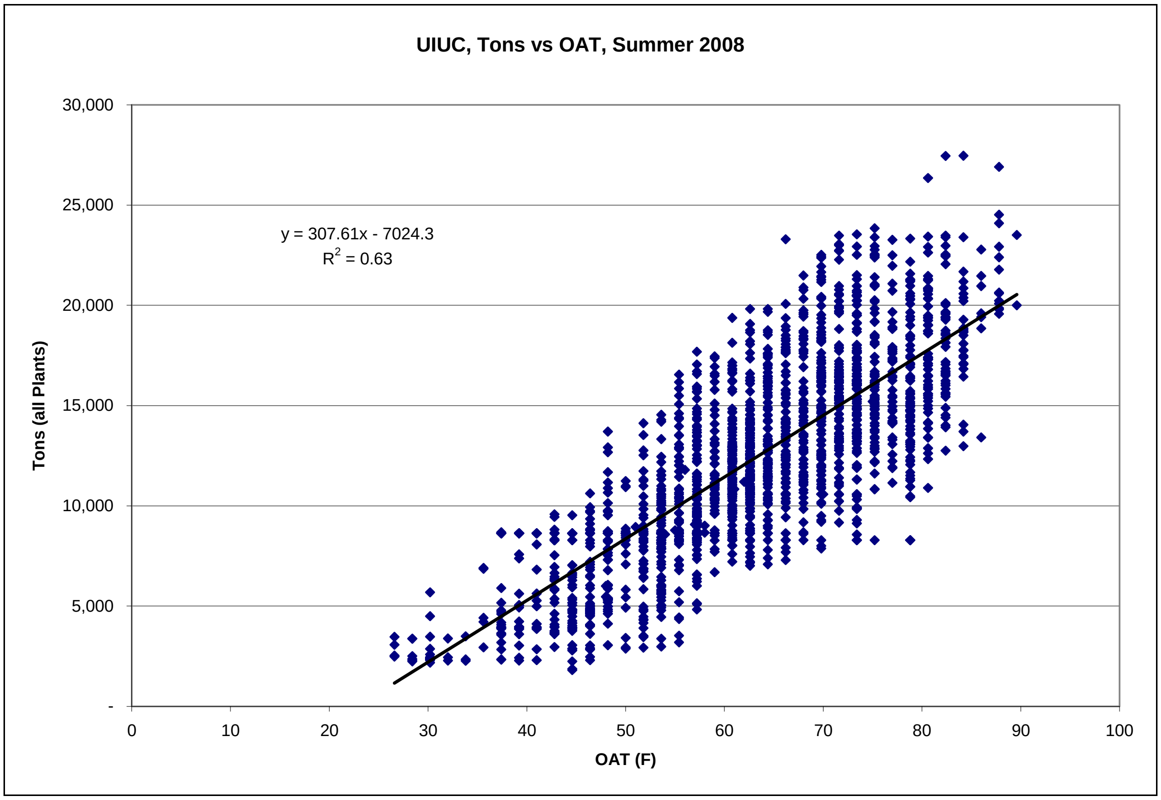

Figure 3.1-8. Chilled Water Demand (Tons) vs. Outside Air Temperature

Some observations based on the analysis of the hourly data include:

Peak Loads

- The peak electric loads (demand) for any given month (winter and summer) occur between Noon and 6 PM
- The peak steam demands in winter tend to occur during morning warm up.
- The chilled water peak loads in summer tend to occur between noon and 6 PM and also tend to coincide with peak electric loads. CHW data is only available after 8/1/08 and the data does not include all chiller plants

Load Profiles

- The electric load typically varies from a minimum between midnight and 6 am to a peak between Noon and 6 PM on any given day.
- Chilled water also varies from a minimum between midnight and 6 AM to a peak between Noon and 6 PM during the summer months. Chilled Water (CHW) has some correlation with both outside air temperature OAT. In winter the CHW profile is very flat with an 80% load factor. This high load factor is likely due to the significant process cooling load as compared to weather driven cooling loads in the winter. The winter CHW increases when the OAT > 50^{o}F.
- Steam correlates reasonably well to OAT in winter, especially if the base load (e.g., water heating, system losses, etc.) are subtracted out. In summer there is no correlation with OAT and the steam consumption has a 78% load factor.
- An analysis of the Electric base load indicates the following:

Time Period	Avg. kW	% Peak
Winter, Weekday, Mid-6AM	39,700	83%
Winter, Weekday, 7-12 AM	44,800	93%
Winter, Weekday, 12-6 PM	48,000	100%
Winter, Weekday, 7-11 PM	42,900	89%

- Comparing the Base Load “Peak” hour (winter, weekday, 12-6, OAT < 50oF) to typical middle of the night base load.

Base Load Peak	51,810 kW
Indicated Switched Load[1]	12,160 kW = 23% = 0.64 W/SF

[1] This includes HVAC, Lights, and Office Equipment. Some offset from Parking Lot Lights needs to be accounted for.

- Weekend usage of all fuel types is generally less than weekday with the exception of winter chilled water usage. It is not clear why the winter chilled water usage on weekends is higher than the weekday average.

Ratio of Weekend/Weekday Average Usage			
	Steam	**CHW**	**Elect**
Summer	**96%**	**95%**	**92%**
Winter	**97%**	**112%**	**93%**

Electric cooling energy can be estimated by comparing summer/winter kW during peak periods (weekday, Noon to 6) and, for energy usage, by assuming that the base load in summer equals the base load in winter.

Average Base Load 41,600 kW

Cooling Energy (Electric) 61,267,000 kWh

Cooling Demand 24,870 kW

Equivalent Full Load Hours (EFLH) 2,480 (Electric Cooling)

If the cooling energy is deducted from the annual electric energy profiles, the following metrics are defined

Annual Peak (No Cooling) 51,800 kW

Annual Load Factor (No Cooling) 80%

<u>Savings and Operational Opportunities Presented from Hourly analysis</u>

- The overall electric load factors of 63% (annual) and 80% (correcting for cooling) are quite high, indicating (or supporting) that turning off HVAC equipment, lights, and office equipment during unoccupied hours is (remains) a valid goal.

- The base loading for steam is also very high. In summer the average consumption of 350 klbs/sq. ft. translates to 17 Btuh/sq. ft. This is the typical heat rate required for a typical building when it's zero degrees F outside. Eliminating reheat systems and reducing distribution losses are the primary measures indicated for this situation.

- The winter time chilled water load, although low, adds up to 15% of the annual chilled water usage. Minimizing energy input required for making winter chilled water by use of water side economizer cycles, strainer cycles or other means should be considered.

- The value of reducing peak demands requires consideration of several factors. Some observations and techniques that should be considered are:

  - *Steam Peaks Summer:* These are generally of very short duration. The possible causes should be investigated (e.g., use of steam driven chillers).

- *Steam Peaks, Winter:* These tend to be of several hours duration and coincident with low OAT although there are several instances of sustained peaks when the OAT was greater than 15^{o} F. It is known that peaks over 600 klbs /hr can result in a need to operate the gas turbine as a steam source. All of the peak demand response strategies below assume DDC controls with feedback loops.

  - Demand Controlled Ventilation could provide a fairly rapid response to lower steam demand by reducing the amount of outside air requiring preheat.

  - Transferring some of the preheat load to chilled water coils (by reducing preheat coil discharge temperatures to 40F) that are flooded and in a freeze protection mode anyway could also provide a quick demand reduction

  - Installing external pilots on some building pressure reducing valves (PRVs) and reducing steam pressure (and probably space temperatures) could provide a method for controlling large and somewhat discretionary steam loads not under control of the existing DDC.

  - Adding DDC override on some "discretionary" loads such as DHW tanks, humidifiers, and possibly even autoclaves could be effective

- *CHW Peaks, Summer:* Not much data is available, but these peaks also tend to be of several hours duration and coincident with high outside temperature and/or humidity.

  - Demand Controlled Ventilation could provide a fairly rapid response by reducing the amount of outside air requiring cooling and dehumidifying.

  - Turning off reheat pumps during hot humid hours will have an indirect impact on CHW demand. But it's a brave individual who calls to complain of being too cold when the OA is greater than 85F. It's a good way to find out who has too much air.

- CHW Peaks, Winter: Not much data is available, but these peaks are typically caused by warm days. No demand response other than DDC override of CHW valve position (and allowing space temperatures to rise) presents itself. Turning off perimeter heat systems in anticipation of a 60 o F+ day could help.

- *Electric Peaks, Summer*: These peaks tend to coincide with high chilled water loads due to the prevalence of electric cooling. Peak shaving strategies over and above the summer cooling strategies are:

  - Global reduction in Fan variable frequency drive (VFD) speeds

  - Global e-mail alert for voluntary reduction in perimeter lights or unused office equipment

  - E-mail alerts to selected departments/staff who have discretionary control of major electrical loads such as earthquake machines, MRIs, electric cooking equipment, etc.

- *Electric Peaks, Winter*: Other than the peaks triggered by electric cooling, these tend to be of several hours duration and a result of general usage of lighting and office equipment. No recommendations are made for reduction

3.2 Baseline Energy Use – Building Level

Compiling and analyzing baseline energy usage is a first step in gauging the energy savings potential within a given building and ultimately the campus as a whole. An understanding of the baseline energy usage also provides a gauge for comparison with other buildings as well as a reference point for projecting future usage. The finer the division of baseline energy usage available (campus vs building, annual vs monthly vs hourly, etc.) the more confidence one can have with regards to conclusions and recommendations about future usage. UIUC is fortunate to have an extensive amount of building-level metered data for electricity, steam, and chilled water. Several years of historical data was made available to SAIC for the purpose of establishing baseline energy usage. FY2008 was selected as since it is the most recent complete fiscal year.[2]

With over 20 million square feet of gross floor space and 500 buildings, it was desirable to find a subset of buildings that would represent the energy usage in UIUC buildings and campus with some degree of accuracy and reasonableness. To this end, a subset of buildings that accounted for 90% (+/-) of the energy usage was identified. This resulted in a list referred to as “the Top 100” since it comprised 100 buildings[3]. The resulting Top 100 building list is shown below.

2 Data from the file “Energy, space_ FY08 Galen 7-08.xls” provided summary energy information on an annual basis for the entire campus (metered and un-metered)

3 UIUC has a list referred to as “Top 80” which has a similar basis. The difference is that the Top 80 excludes auxiliary buildings which are billed separately for energy usage. Since the auxiliary buildings use energy from the central plant and energy savings opportunities similar to the other buildings, they were included in the Top 100 list to provide an accurate portrayal of campus savings impacts on central plants.

Table 3.2-1 Top 100 Buildings Based on Energy Usage

UIUC Top 100 Energy Consuming Buildings					
Loc#	**Building**	**Type Building**	**Annual MMBTU**	**Overall Bldg BTU/GSF**	**Total GSF**
00015	Engineering Hall	CR/Ofc	23,399	251,094	93,188
00026	Altgeld Hall	CR/Ofc	19,786	248,193	79,720
00027	Lincoln Hall	CR/Ofc	12,695	74,187	171,121
00032	Natural History Building	CR/Ofc	17,444	113,804	153,280
00039	Music Building	CR/Ofc	29,166	276,866	105,343
00041	Library	CR/Ofc	60,549	113,682	532,614
00042	Transportation Bldg	CR/Ofc	9,170	178,248	51,445
00043	Gregory Hall	CR/Ofc	20,382	185,218	110,043
00046	Administration Bldg	CR/Ofc	44,372	270,277	164,172
00054	David Kinley Hall	CR/Ofc	12,467	153,877	81,019
00060	Smith Memorial Hall	CR/Ofc	21,257	278,572	76,307
00099	Undergraduate Library	CR/Ofc	36,414	379,688	95,905
00106	Illini Union Bookstore	CR/Ofc	23,335	242,046	96,407
00156	Law Building	CR/Ofc	28,769	151,632	189,729
00159	Wohlers Hall (commerce West)	CR/Ofc	40,143	403,244	99,550
00160	Education Building	CR/Ofc	31,503	334,931	94,058
00172	Foreign Languages Bl	CR/Ofc	43,582	370,233	117,715
00188	Student Service Bldg	CR/Ofc	9,597	232,575	41,264
00210	Digital Computer Lab	CR/Ofc	70,370	362,209	194,280
00219	Art & Design Bldg	CR/Ofc	10,756	143,266	75,077
00324	Grainger Engr Lib Info Center	CR/Ofc	27,923	220,146	126,838
00339	Temple Hoyne Buell Hall	CR/Ofc	10,870	115,400	94,194
00377	Aces Library, Information And Alumni Center	CR/Ofc	30,688	370,887	82,742
00378	Admissions & Records Bldg	CR/Ofc	9,791	297,318	32,931
00564	National Center For Supercomputing Applications	CR/Ofc	33,290	234,919	141,708
01074	"z" Building	CR/Ofc	8,288	126,302	65,620
00001	Davenport Hall	Lab Mix	31,692	285,662	110,942
00008	Agriculture Engr Sci Bldg	Lab Mix	25,976	253,281	102,558
00010	Chemistry Annex	Lab Mix	12,518	294,776	42,466
00012	Noyes Lab Of Chem.	Lab Mix	38,651	209,529	184,466
00013	Talbot Laboratory	Lab Mix	16,991	153,725	110,528
00024	Civil Eng Bldg, N. Newmark	Lab Mix	49,140	266,493	184,395
00029	Mechanical Engineering Lab	Lab Mix	50,644	333,493	151,859
00034	Materials Science And Engineering Building	Lab Mix	12,425	122,050	101,802
00037	Electrical And Computer Engineering, Everitt	Lab Mix	45,101	362,997	124,246
00064	Freer Hall, Louise	Lab Mix	14,245	151,721	93,889
00067	Loomis Lab	Lab Mix	60,686	345,763	175,513
00076	Psychology Lab	Lab Mix	58,164	380,839	152,726
00095	Supercond Cntr Mrl/csl Bridge	Lab Mix	8,158	239,377	34,080
00109	Natural Resources Building	Lab Mix	13,486	95,926	140,587
00112	Mechanical Engineering Bldg	Lab Mix	25,276	250,960	100,717
00124	National Soybean Research Center (nsrc)	Lab Mix	31,314	316,770	98,854
00138	Burrill Hall	Lab Mix	59,399	345,680	171,832
00148	Coordinated Sciences Lab	Lab Mix	56,603	456,450	124,007
00158	Bevier Hall	Lab Mix	42,917	273,757	156,770

Table 3.2-1. Top 100 Buildings Based on Energy Usage *(Continued)*

UIUC Top 100 Energy Consuming Buildings					
Loc#	**Building**	**Type Building**	**Annual MMBTU**	**Overall Bldg BTU/GSF**	**Total GSF**
00165	Animal Sciences Lab	Lab Mix	32,790	219,755	149,211
00174	Engineering Sciences Bldg	Lab Mix	56,498	524,469	107,724
00192	Medical Sciences Building	Lab Mix	51,690	450,324	114,784
00197	Turner Hall	Lab Mix	51,522	286,230	180,002
00228	Beckman Institute	Lab Mix	109,224	305,018	358,090
00242	Morrill Hall	Lab Mix	57,934	340,369	170,209
00563	Siebel Ctr For Computer Sci., Thomas M.	Lab Mix	91,974	344,697	266,825
01095	Enterprise Works At Illinois	Lab Mix	9,719	230,258	42,209
00003	McKinley Health Center	Other	17,763	210,899	84,225
00006	Armory	Other	29,432	114,313	257,468
00007	Auditorium, Foellinger	Other	10,091	194,938	51,765
00014	Skating Rink	Other	18,732	362,496	51,675
00017	Advanced Computation Bldg	Other	126,321	2,785,775	45,345
00023	Illini Union	Other	68,684	225,097	305,130
00052	Krannert Center For Perf Art	Other	57,424	192,508	298,293
00058	Huff Hall	Other	15,038	94,684	158,822
00072	Stadium	Other	23,348	51,276	455,333
00094	Alice Campbell Alumni Center	Other	12,805	185,959	68,859
00108	Computing Applica Bldg	Other	8,381	197,065	42,529
00118	Intramural Physical Educ	Other	32,721	73,990	442,235
00126	Levis Faculty Center	Other	9,101	253,425	35,912
00131	Turner Hall Greenhouse	Other	17,396	258,915	67,188
00166	Assembly Hall	Other	36,262	114,818	315,821
00198	Physical Plant Service Bldg	Other	22,649	139,052	162,881
00217	Housing Food Stores	Other	11,139	217,477	51,219
00220	Krannert Art Museum	Other	10,426	144,386	72,209
00222	Printing & Photographic Services	Other	10,608	178,691	59,365
00256	Plant Sciences	Other	26,628	279,879	95,141
00364	Campus Recreation Cntr-east	Other	31,015	294,340	105,371
00373	Spurlock Museum	Other	20,130	373,323	53,921
00407	Irwin Indoor Football Facility	Other	10,894	143,474	75,930
01094	North Campus Parking Deck	Other	15,916	30,522	521,450
00066	Mat Res Lab, Frederick Seitz	Research Lab	63,020	479,892	131,321
00070	Chem. & Life Science Lab	Research Lab	84,128	363,599	231,376
00116	Roger Adams Lab	Research Lab	126,441	472,339	267,691
00169	Burnsides Res Lab	Research Lab	9,877	412,538	23,942
00237	Micro/Nano Laboratory	Research Lab	105,541	716,275	147,347
00292	Veterinary Teaching Hospital (lac/sac)	Research Lab	107,360	459,388	233,702
00336	Madigan Lab, Edward R.	Research Lab	83,228	486,693	171,007
00350	Vet Med Basic Science Bldg	Research Lab	107,520	414,475	259,412
01080	Institute For Genomic Biology Building	Research Lab	97,803	429,579	227,672
00081	Pdrh Sm-3 Peabody Food Ser	Residential	48,855	141,564	345,109
00085	Gdrh Sm-2 Gregory Food Ser	Residential	34,381	109,588	313,729
00087	Fourth St Clark Hall	Residential	9,798	315,545	31,051
00105	Parh Sw-2 Penn Lounge Bldg	Residential	22,014	81,021	271,707
00141	Lincoln Ave Res Hall	Residential	13,361	87,100	153,397

Table 3.2-1. Top 100 Buildings Based on Energy Usage *(Continued)*

UIUC Top 100 Energy Consuming Buildings					
Loc#	**Building**	**Type Building**	**Annual MMBTU**	**Overall Bldg BTU/GSF**	**Total GSF**
00142	Allen Residence Hall	Residential	11,804	75,603	156,130
00181	Sgrh Daniels Hall, Arthur	Residential	12,998	119,710	108,579
00272	Isrh Wardall Hall	Residential	14,378	139,930	102,751
00273	Isrh Townsend Hall	Residential	15,471	140,306	110,266
00274	Isrh Illinois St Lounge	Residential	13,812	561,349	24,605
00291	Sgrh Sherman Hall	Residential	32,311	264,412	122,199
00297	Farh Food Service	Residential	57,740	181,210	318,636
00675	Airport New Terminal		-	-	-
01206	Business Instructional Facility		-	-	-
	Totals		**3,515,488**	**275,386**	**14,547,277**

With the exception of the Airport, all of the Top 100 buildings are on campus and receive electricity from the central electrical distribution system. All but 3 of the Top 100 buildings receive steam from the central plant and 71 of the Top 100 buildings currently receive chilled water from one of the central chilled water plants. A review of the available information and discussion with UIUC determined that natural gas, oil or other energy types had very limited usage within the Top 100 buildings and it was decided that the baseline consumption and energy savings potential for these auxiliary energy sources were not significant enough to include them in the analysis.

In order to fine tune both the energy savings analysis and provide more insight into energy usage patterns, each building was categorized by major usage and occupancy functions. Building types were established using definitions largely derived from an independent source[4]. As noted in that source "There currently exists no national standard for building types on a university campus." so the validity of the building type definitions and subsequent application to any given building at a UIUC campus is somewhat subjective. The following definitions were used to classify buildings in the Top 100 List.

Table 3.2-2 Building Classification Definitions

Classroom/Office	Containing 20% or greater of both Classroom Space and Office Space, but less than 50% of any other category
Health	Facilities used to provide patient care (human and animal).
Lab Mix	Containing 15% or greater Laboratory and 20% or greater of Office or Classroom Space, but less than 50% of any other category
Research Lab	Containing 40% or greater Research Laboratory Space
Residential	Housing facilities for students, faculty, staff, and visitors to the campus
Other	Computing facilities, food service, athletic, service & support, warehouse, etc

The following chart summarizes the baseline annual energy usage for the Top 100 in terms of these categories, normalized by floor area (gross square feet or GSF). This metric is commonly referred to as the energy use intensity or index (EUI). This analysis is based on FY08 metered data.

[4] Ref. Kunz, Laura, Energy Density Benchmarking, Final Report, Indiana University Sustainability Task Force, 2007, August 31, 2007

Table 3.2-3 Top 100 Buildings Energy Utilization Index

Building Type	GSF	Campus Area (GSF) - Electric	Campus Area (GSF) - Steam	Campus Area (GSF) - Chilled Water	Electric BTU/GSF (UIUC Top 100)	Steam BTU/ GSF (UIUC Top 100)	Chilled Water BTU/ GSF (UIUC Top 100)	Average Annual BTU/GSF (UIUC Top 100)
Classroom/ Office	3,166,270	3,166,270	3,100,650	2,142,559	56,008	91,930	68,723	216,661
Lab Mix	3,751,291	3,751,291	3,709,082	3,415,501	74,548	120,744	101,869	297,161
Research Laboratories	1,693,470	1,693,470	1,693,470	1,438,152	116,360	196,472	150,665	463,497
Residential Facilities	2,058,159	1,845,142	2,058,159	1,796,183	33,920	91,327	14,078	139,325

3.3 Benchmarking

It is useful to compare the energy use intensity (EUI) to other campuses as a means of benchmarking UIUC building energy performance. The table below compares the UIUC Top 100 to buildings from 5 other campuses that were surveyed in the *Energy Density Benchmarking Report.*[5] The results indicate that for all but the residential category UIUC has higher energy use intensity. It should be noted that the survey involved only a small sample of buildings from each campus (e.g., 10 – 38 buildings in each category).

Table 3.3-1 Comparison of UIUC EUI with Energy Density Benchmarking Report

Building Type	Electric BTU/GSF (UIUC Top 100)	Steam BTU/GSF (UIUC Top 100)	Chilled Water BTU/GSF (UIUC Top 100)	Average Annual BTU/GSF (UIUC Top 100)
UIUC Classroom/Office	56,008	91,930	68,723	216,661
Peer Classroom/Office	39,379	45,650	50,881	135,910
UIUC Lab Mix	74,548	120,744	101,869	297,161
Peer Lab Mix	47,493	48,150	42,222	140,816
UIUC Research Laboratories	116,360	196,472	150,665	463,497
Peer Research Laboratories	99,214	120,033	79,463	327,101
UIUC Residential Facilities	33,920	91,327	14,078	139,325
Peer Residential Facilities	38,336	61,830	29,580	136,001

The figure below summarizes the results of another energy benchmarking survey.[6] In this case information about building types was not collected and the EUI information is based on the total population of buildings. Furthermore, the metric – electric EUI - was based on the total electricity use on campus and not on the electricity use of individually metered buildings. The

[5] Ref. Kunz, Laura, *Energy Density Benchmarking, Final Report*, Indiana University Sustainability Task Force, 2007, August 31, 2007. The campuses surveyed included the University of Cincinnati, Purdue University, Iowa State University, Clemson University, and an anonymous university from the Midwest. The University of Indiana is not included in the results, but reported the following EUI (Btu/GSF): Classroom/office: 120,990, Lab Mix: 164,029; Research Labs: 330,201; Residential Facilities: 141,310. This information was reported in Indiana University Task Force on Sustainability Report, Chapter VIII.

[6] Michigan State University, *Big 10 and Friends Energy Benchmarking Survey, Jul1, 2006-June 30, 200*, April 2008

comparison shows that the UIUC campus has a higher electric EUI than all but three of the 13 campuses surveyed.

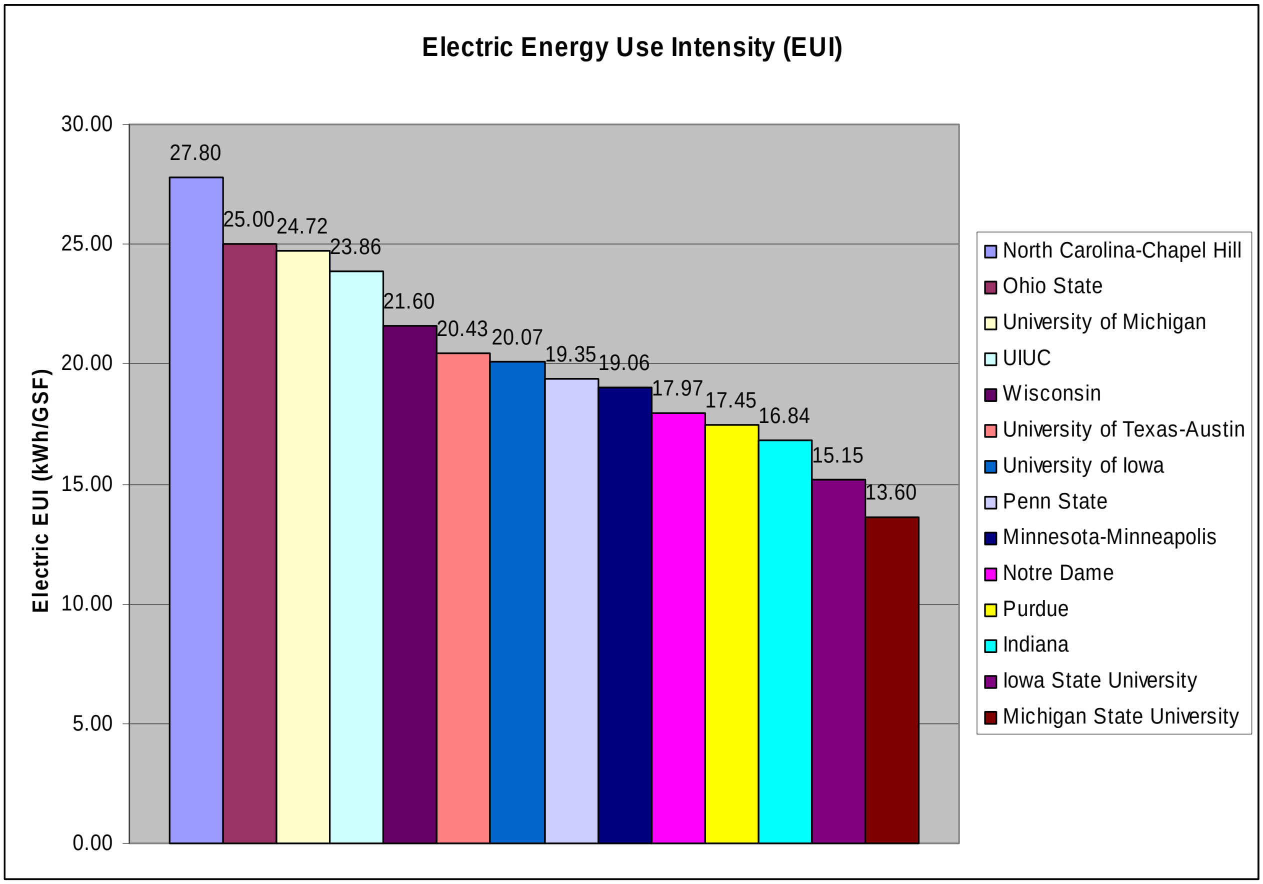

Figure 3.3-1. Campus Level Electric Energy Use Benchmark Comparison

Several caveats need to be considered before drawing any hard conclusions about comparisons with other facilities. The most important (and difficult) factor is making sure that any benchmarking comparison uses the same basis and assumptions. This includes basic definitions about floor area (and buildings to be included), energy type and source (e.g., site vs. source), etc. Nonetheless, campus to campus EUI benchmarking is a useful high level metric to identify areas for further investigation and possible improvement. The available data indicates that UIUC should explore opportunities to reduce its building energy use.

Benchmarking using EUI is also useful for tracking year to year changes in campus energy (see figure below). In this case the EUI includes the campus steam plus electricity (self-generated and purchased) divided by the total campus floor area (exclusive of parking lot structures/non-building structures). Note that the EUI reflects energy used at the campus (site energy) and does not account for the losses associated with the generation, transmission, and distribution of purchased energy (e.g., source energy). The relatively flat EUI in the last two years may be indicative of the progress the university is making in some of its energy conservation efforts. However, other factors may well be involved, and this needs to be explored to understand the actual causes.

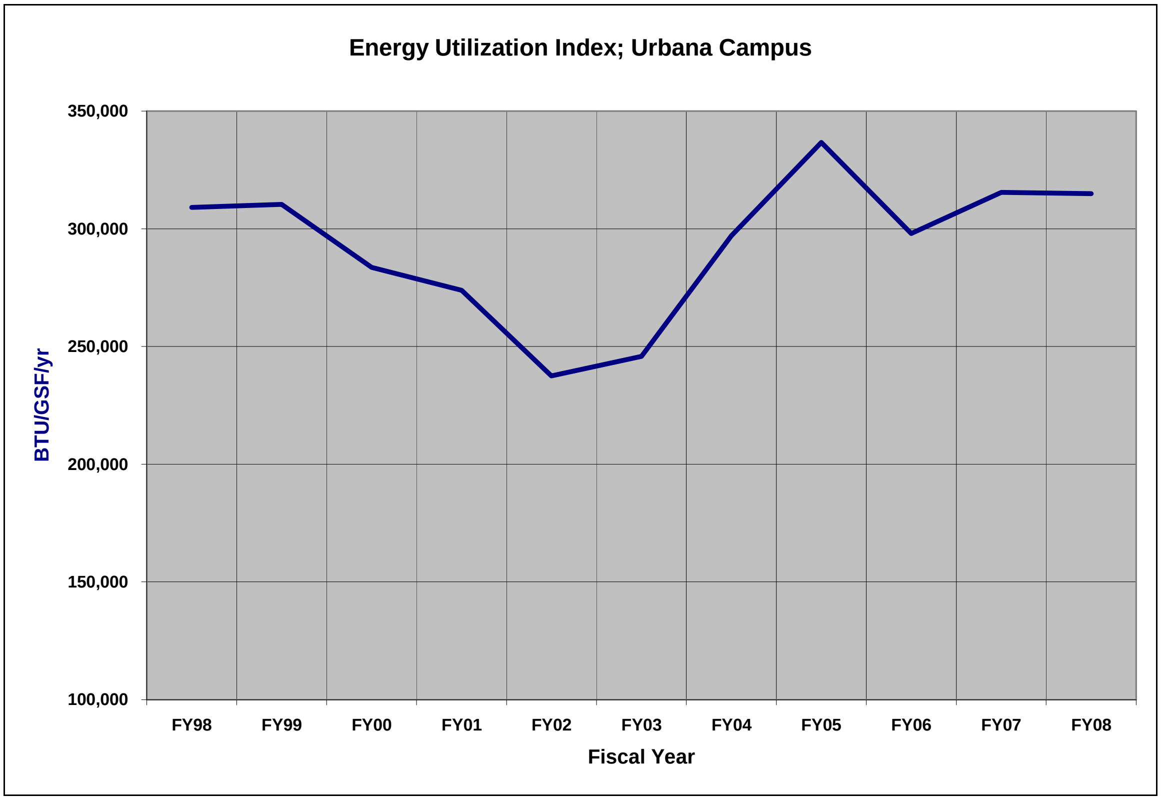

Figure 3.3-2. Historical UIUC Campus Energy Use Intensity

4. *Review of Existing Campus Facility Energy Efficiency Programs*

4.1 Energy Management Policies

The campus has a formal energy use policy that includes incentives, metering, education and awareness as key facility related strategic elements.[7] The policy establishes basic temperature set points for heating and cooling seasons, and encourages practices that reduce unnecessary heating or cooling of spaces or operation of energy consuming equipment during periods of low occupancy/activity. It also establishes energy standards for new facilities. The energy goals of the policy are:[8]

- 10% reduction in energy use intensity (Btu/GSF) relative to FY 2007 achieved by FY 2010

- 25% reduction in energy use intensity (Btu/GSF) relative from FY 2007 achieved by FY 2017

Participation by students and faculty in helping to achieve energy reductions and to introduce more sustainable practices and technologies is an important element of the strategy.

[7] Information on the policies and current energy conservation/energy management can be found at www.energymanagement.uiuc.edu
[8] The energy use intensity is defined as the energy used by the campus central plant and purchased electricity in MMBtu divided by the campus building floor area in gross square feet.

4.2 Current Initiatives

The university has a number of energy use reduction initiatives currently under way including:

Improvement Projects

- Lighting - UIUC has recently undertaken a large scale project to convert existing fluorescent lighting to T-8 lamps and electronic ballasts and exit signs to light emitting diode (LED) types. This work commenced in June 2008 and is expected to be completed by June 2010. This will cover about 50 buildings. Savings projections for included fixtures average 30%.

- Retrocommissioning (RCx) - UIUC has retro-commissioned 12 buildings since June 2007 using an in house approach with dedicated RCx teams. Documented results average 20% savings. The plan is to increase RCx to 8 buildings per year.

- Steam Traps - UIUC has designated a 2 person team to perform steam trap maintenance and repairs on a perpetual basis. A preventative maintenance approach envisions cycling through all buildings at least once every 10 years. This team also repairs steam traps and leaks on a "hot/cold call" basis.

- Deferred Maintenance Projects – UIUC has identified 50 buildings with deferred maintenance projects that will result in improved energy performance when implemented.

Energy Metering

The campus metering initiative, which has resulted in the installation of steam and chilled water meters in the great majority of the largest energy consuming buildings, is the back-bone of energy awareness and energy use benchmarking efforts. Shadow bills based on the meter data have been provided to the various colleges and major academic units. In FY 2010, UIUC intends to bill the departments in an effort to encourage conservation at the grass roots level.

4.3 New Building Initiatives

UIUC has established facilities standards that state that new buildings with a construction value of $5 Million or greater will be LEED Silver Certified and those below this threshold will be LEED Silver certified to the greatest extent possible. The Leadership in Energy and Environmental Design (LEED) rating has gained widespread recognition as the standard for "green" or sustainable building construction. The university has also undertaken projects such as the Business Instructional Facility (LEED gold rating) to demonstrate the use of advanced energy/green design and construction practices.

4.4 Incentives and Grants

UIUC has participated in several programs that provide financial incentives to reduce the cost of various energy conservation measures. This includes the Illinois Department of Commerce and Economic Opportunity (DCEO) *Public Sector Electric Efficiency Program* and the Illinois Clean Energy Foundation's *Energy Efficient Lighting Upgrade Grant Program*. The DCEO program provides up to $100,000 per building for a broad range of ECMs through prescriptive incentives (fixed incentive amounts for particular measures) and custom measures. The university has applied for HVAC custom measures and for lighting measures. The Illinois Clean Energy program provides incentives of $.60/watt. up to $250,000 maximum per campus annually, $500K max for university annually. This was the last year for applications.

5. *Energy Savings Opportunities*

5.1 Energy Conservation Measure Selection

A university campus as diverse and large as UIUC provides many opportunities for reducing energy usage. A comprehensive list of energy conservation measures (ECMs) that are possible in such an environment is equally diverse and large. The challenge is to select a subset of measures that can be analyzed within the resources allocated to this project and then used to reflect the savings achieved on a campus wide basis by various implementation strategies. The approach used to develop the subset was a combination of SAIC staff judgment based on the site surveys of selected buildings and discussions with UIUC staff. The site surveys generally consisted of a walkthrough of the building, interviews of operations staff, a review of the building plans, and a preliminary identification of energy savings opportunities. The selected buildings and their classification type were:

- Davenport Hall - Mixed Lab
- Digital Computing Lab – Classroom Office
- Roger Adams Lab – Research Lab
- Vet Med Basic Science – Research Lab
- Wohlers Hall – Classroom Office

A summary of the surveys for each of these buildings may be found in Appendix B. Based on our review, the following matrix of ECMs was developed.

Table 5.1-1 ECM Analysis Matrix

UIUC- ECM Analysis Matrix								
			Representative Building					
ECM Category		ECM	Wohler's	RAL	DCL	Vet Med	Davenport	Generic Bldg
Envelope	E1	Replace Windows	X					X
	E2	Insulate Roof						X
	E3	Solar Film						X
	E4	Weatherization						X
Lighting	L1	General Lighting Upgrades (Interior, Lamps and Fixtures)						X
	L2	Daylighting Controls/Daylight Harvesting						X
	L3	Occupancy Sensors						X
	L4	Exterior Lighting - including controls						X
	L5	Not Used						
Mechanical	M1	Retrocommissioning, Labs		X		O		
	M2	Retrocommissioning, General	X		X		0	X
	M3	2 Speed Fan Operation, Labs (100% OA)		X		0		
	M4	CAVRH to VAVRH Conversion, General (Mixed Air)	X		X		0	X
	M5	Eliminate Reheat/Summer Steam	X				0	X
	M6	Redirect Relief Air as Makeup Air		X		?		
	M7	Heat Recovery, Air to Air		X		0		
	M8	Use CHW for Preheat		X		?		
	M9	Add Economizer Capability			X		0	
	M10	VSD Fans on AHUs (SZ VAV)						X
	M11	VSD on Pumps		X				
	M12	Steam System Maintenance (Traps, insulation, etc)	X	X				X
	M13	DX to CHW					0	X
	M14	Not Used						
	M15	DeCommission Fume Hood						X
	M16	VAV-Phoenix retrofit Labs		X				
Controls	C1	Install DDC on Central Equipment				0	0	
	C2	Install Motion Sensors for HVAC			O	0		
	C3	Autoclave Controls		X		0	0	
Water Heating	P1	Insulate DHW Tanks						X
	P2	Instantaneous DHW	X	O	O			X
	P3	Solar assist for DHW						X
Equipment								
	EQ1	Energy Star Computers, printers, etc						X
	EQ2	Solar PV						X
	Retro Commission activities							
		Replace Actuators/Dampers/Enthalpy on AS Economizer			X		0	
		Adjust Setpoints (HW,MAT, DAT, Econ, etc) vs OAT			X	?	0	
		Add Space Temp Sensors and/or PB Overrides	X	X	X		0	
		Turn off/slowdown AHUs, Pumps, EFs, & Reheats - unoccupie	X		X		0	
		Turn off reheat systems - Hot days	X	X	X	0	0	
		Rebalance AHUs, Adjust VAV min flow, etc		?	X	0	?	
		Optimize Heat Recovery				0		
		Synchronize Perimeter heat with Airside	X	X	X		0	
		Demand Reduction (electric, steam, etc)	X		X		0	
		Replace/rebuild/recalibrate Reheat Valves & T-stats		X	X	0	0	
		Extend DDC to Campus BAS				0	0	
		Replace/rebuild/recalibrate Reheat Valves & T-stats		X		0		
		Extend DDC to Campus BAS				0		
	X	Analyzed						
	O	Applicable						

Measures that had the broadest impact were selected for analysis. In addition, several measures were included that were generally considered less promising economically, but had other favorable attributes (e.g. renewable energy measures). Note that a "generic building" category is also included in the table. This was done to ensure that measures that could be generally applicable to other campus buildings, but that were not appropriate for the specific buildings analyzed, would be considered. A description of the measures can be found in Appendix A.

5.2 ECM Savings Methodology

The energy savings for ECMs in the selected buildings were derived from a calibrated baseline model that compared the measured annual energy usage of these buildings to the energy model.[9] The baseline model used information gathered from the field and plan reviews for window/wall areas, HVAC system characteristics, lighting and equipment energy densities, operating temperatures, etc. Operations staff provided guidance on operating hours, building/equipment temperature set points, energy system limitations, etc. The typical model included 30 variables which were applied to historical bin temperature profiles and used to "true-up" the model to actual usage values.

Energy savings for the various measures in each building were derived by changing the variable(s) associated with any given measure and subtracting the resulting usage from the baseline model. Since the buildings selected to represent classroom/office occupancy exhibited higher than average energy use intensities the savings potential is also higher. In order to provide savings potential that was more typical of the campus as a whole, a generic building model was created and used as the basis for some of the savings projections. The generic building model uses the same methodology as the calibrated models, but the baseline energy usage was calibrated to an average classroom/office building. This essentially consisted of using more typical HVAC parameters for metrics such as ventilation air requirements, and hours of operation. The generic model was also used to project savings for measures that would not have been strictly applicable to the selected buildings due to physical considerations.

To avoid double counting of savings when multiple measures are involved that address the same loads, two methods were employed. First, it was decided to assume that lighting and retro-commissioning (RCx) measures would likely be implemented in virtually every building due to their broad applicability and favorable economics. The savings for all other measures assume that these 2 measures were installed and use an adjusted building energy consumption baseline (adjusted for the savings attributable to these measures). A separate method to minimize double counting, involved careful selection of measures to avoid (or minimize) applying measures with clearly overlapping savings to the same building/system.

Cost estimates for the measures were developed using data from RS Means, prior experience and, where available, data provided by the University. Costs were developed assuming a traditional design/bid/build scenario in most cases. Costs generally include the following allowances and defaults values;

- Contractor overhead and profit: 20%
- Design engineering: 15%
- Contingency: 10%
- Labor: $61/hour
- $/DDC Point (e.g., : $800 (not including hardware such as valves)[10]

[9] The spreadsheet model uses temperature bin data, along with various assumptions about building operation set points (temperatures), occupancy schedules, ventilation requirements, and building envelope and equipment energy use characteristics.

[10] DDC or Direct Digital Control points include sensors, actuators, or other input/output devices that are used to monitor and/or control the operation of the equipment. There is a fixed cost for the basic energy management and control system and variable costs associated with the number of points that are connected to the system.

Simple measures such as lighting and steam system upgrades have reduced engineering percentages to reflect streamlined design. The costs for hazardous waste abatement and disposal are not included. In a few cases such as roof insulation, the costs reflect only the incremental cost of the energy savings aspects reflecting that these measures will be installed only if a larger project is undertaken, or a replacement at failure.

5.3 Campus Wide Energy Savings Projections and Costs

The results of the building level energy and cost savings calculations were normalized on a unit floor area (square foot) basis for each ECM. These normalized values were assumed to be representative of the savings potential and costs for all similar buildings on campus. There are however limitations as to the applicability of any given measure in any specific building due to physical limitations, existing efficiencies etc. Therefore, a matrix of applicability was constructed to project the percentage of total building area for each of the 5 building types that were applicable for that ECM. Including building types allows a finer method for determining the applicability of measures such as heat recovery (generally limited to laboratories), air side economizers (non laboratories), VFDs, etc. The applicability factors (percentages) were based on SAIC's judgment, and were reviewed with UIUC staff (see table below). They are not based on any statistical sampling/estimation method.

Table 5.3-1 Campus Level ECM Applicability Factors

UIUC ECM Allocation by Building Type and Percentage of Penetration - Applicability Factors

	Building Type / # Buildings in Category ====>	CR/Ofc	Lab Mix	Research Lab	Residential	Other	Campus Totals	
ECM #	ECM Descrip	29	25	9	7	30	Effective SqFt	# Buildings
E1	Replace Windows	20%	20%	20%	20%	20%	2,909,455	20
E2	Insulate Roof	20%	20%	20%	20%	20%	2,909,455	20
E3	Solar Film	10%	10%	10%	10%	10%	1,454,728	10
E4	Weatherization	70%	70%	70%	70%	70%	10,183,094	70
L1	General Lighting Upgrades (Interior, Lamps and Fixture	70%	70%	70%	25%	56%	8,706,470	N/A
L2	Daylighting Controls/Daylight Harvesting	30%	30%	30%	30%	30%	4,364,183	N/A
L3	Occupancy Sensors	10%	10%	10%	10%	10%	1,454,728	N/A
L4	Exterior Lighting - including controls	20%	20%	20%	20%	20%	2,909,455	N/A
L5	Not Used							
M1	Retrocommissioning, Labs	0%	25%	50%	0%	0%	1,784,558	12
M2	Retrocommissioning, General	75%	50%	25%	5%	75%	7,685,189	53
M3	2 Speed Fan Operation, Labs (100% OA)	0%	10%	20%	0%	0%	713,823	5
M4	CAVRH to VAVRH Conversion, General (Mixed Air)	25%	5%	10%	5%	10%	1,639,196	11
M5	Eliminate Reheat/Summer Steam	10%	0%	0%	0%	0%	316,627	2
M6	Redirect Relief Air as Makeup Air	0%	5%	10%	0%	0%	356,912	2
M7	Heat Recovery, Air to Air	0%	0%	10%	0%	0%	169,347	1
M8	Use CHW for Preheat	0%	5%	10%	0%	0%	356,912	2
M9	Add Economizer Capability	10%	5%	0%	0%	0%	504,192	3
M10	VSD Fans on AHUs (SZ VAV)	20%	10%	2%	0%	2%	1,119,814	8
M11	VSD on Pumps	20%	20%	20%	20%	20%	2,909,455	20
M12	Steam System Maintenance (Traps, insulation, etc)	75%	75%	75%	75%	75%	10,910,458	75
M13	DX to CHW	5%	5%	5%	5%	5%	727,364	5
M14	Not Used							
M15	DeCommission Fume Hood	0%	3%	5%	0%	0%	178,456	N/A
M16	VAV-Phoenix retrofit Labs	0%	0%	10%	0%	0%	169,347	1
C1	Install DDC on Central Equipment	30%	30%	10%	10%	20%	3,226,049	22
C2	Install Motion Sensors for HVAC	2%	2%	0%	0%	2%	215,913	N/A
C3	Autoclave Controls	0%	3%	5%	0%	0%	178,456	N/A
P1	Insulate DHW Tanks	10%	10%	10%	10%	10%	1,454,728	10
P2	Instantaneous DHW	10%	10%	20%	0%	10%	1,418,259	10
P3	Solar assist for DHW	5%	5%	5%	5%	5%	727,364	5
								-
EQ1	Energy Star Computers, printers, etc	40%	20%	20%	5%	20%	3,233,986	22
EQ2	Solar PV	5%	5%	5%	5%	5%	727,364	5

In general, no measure is applicable to all buildings within a category. The highest percentages are Lighting (70%), Retro-commissioning (75%) and steam system upgrades (traps, insulation, leaks, etc) at 75%. The lowest are Autoclave Controls, and de-commissioning of fume hoods because the opportunities are limited both by building type and the suitable areas/systems within the building type. On average the methodology results in a projection of roughly 5 measures in any given building.

The matrix of measures by building types also allows some fine tuning of interaction impacts. For instance, there are four overlapping HVAC ECMs applicable to Research Labs served by constant volume 100% outside air systems. These are: 2 Speed Fans (M-3), Full VAV (M-16), Heat Recovery (M-7), and use of chilled water for preheat (M-8). These will all have significant interactive savings potential and, due to the large energy usage and savings, can lead to potentially significant over-estimation of savings if more than one of these measures was installed on any given system. Careful selection of application minimizes this. So the applicability matrix assigns a combined total of 50% of the Research Lab area to these measures. M-3 is projected for 20% while M-7, 8, and 16 are all projected at 10%. The remaining 50% of Research Lab building area is assumed to be served by mixed air systems where these measures do not apply or are unsuitable due to other constraints.

The savings projection for the Top 100 buildings are arrived at by multiplying the normalized savings projections (each fuel type) by the applicability factor for the given building type by the total area of that building type and summing across the building types. Demand savings for the various fuel types was arrived at by applying the concept of equivalent full load hours (EFLH). The baseline energy consumption of each fuel type was divided by the peak usage to arrive at a baseline EFLH of 3,600 for electric and 2,600 for both steam and chilled water (CHW). This is essentially a load factor metric but can be readily understood by the equation kW * EFLH = kWh or tons * EFLH = ton- hrs. When projecting demand savings the concept is that, for many measures, the savings profile for consumption will be similar to the base consumption profile and the demand profile will also be similar.

The EFLH method, however, has to be tempered by some consideration of the savings mechanisms associated with the particular measure. Demand savings only occur when the savings are coincident with the fuel type peak periods. Analysis of hourly load profiles indicate that electric and chilled water loads tend to peak between the hours of 2 PM and 6 PM on a hot summer weekday. For steam, the peak period was found to be between 6 AM and 9 AM on weekdays when the outside air temperature is below 10^{o}F. When savings occur during these same periods, there will be some demand savings. Measures like 2 speed fan operation in laboratories (M-3), on the other hand, have electric savings occurring outside of the peak hours so there are no coincident demand savings. The savings from some measures are quite difficult to predict but are known to be less than the maximum possible so in some cases the EFLH was adjusted to dilute the demand savings. The campus wide projection of energy savings is shown in the table below, assuming no financial or economic constraints. These are savings in energy at the building.

Table 5.3-2 Campus Level Energy and Demand Savings

		Energy Usage Savings				Energy Demand Savings		
	ECM Descrip	Elec	CHW	Steam	Total	Elec	CHW	Steam
ECM #		kWh	MMBTU	kLbs	MMBTU	kW	Tons	kLbs/hr
E1	Replace Windows	-	18,077	50,355	68,431	-	574	20
E2	Insulate Roof	-	-	31,592	31,592	-	-	12
E3	Solar Film	-	9,038	6,859	15,897	-	287	-
E4	Weatherization	-	-	27,992	27,992	-	-	11
L1	General Lighting Upgrades (Interior, Lamps and Fixtures)	14,659,600	16,696	(12,418)	54,311	3,080	530	(5)
L2	Daylighting Controls/Daylight Harvesting	414,772	-	-	1,416	116	-	-
L3	Occupancy Sensors	400,854	-	-	1,368	458	-	-
L4	Exterior Lighting - including controls	303,377	-	-	1,035	-	-	-
M1	Retrocommissioning, Labs	3,680,966	18,714	31,175	62,452	420	594	6
M2	Retrocommissioning, General	10,390,527	80,754	116,124	232,341	1,186	2,565	22
M3	2 Speed Fan Operation, Labs (100% OA)	2,271,510	8,747	16,892	33,392	-	-	3
M4	CAVRH to VAVRH Conversion, General (Mixed Air)	5,803,788	128,866	93,592	242,266	1,219	2,256	37
M5	Eliminate Reheat/Summer Steam	(219,080)	-	6,490	5,742	(46)	-	-
M6	Redirect Relief Air as Makeup Air	-	-	1,296	1,296	-	-	-
M7	Heat Recovery, Air to Air	(777,817)	-	12,928	10,273	(89)	-	5
M8	Use CHW for Preheat	-	-	16,005	16,005	-	-	6
M9	Add Economizer Capability	-	35,689	-	35,689	-	-	-
M10	VSD Fans on AHUs (SZ VAV)	2,357,907	13,552	27,115	48,715	495	430	11
M11	VSD on Pumps	2,104,146	-	6,792	13,973	442	-	3
M12	Steam System Maintenance (Traps, insulation, etc)	-	2,869	23,391	26,260	-	91	3
M13	DX to CHW	3,076,202	(9,149)	-	1,351	863	(291)	-
M14								
M15	DeCommission Fume Hood	33,606	583	726	1,423	4	18	0
M16	VAV-Phoenix retrofit Labs	1,569,470	7,459	12,064	24,880	179	237	5
C1	Install DDC on Central Equipment	5,632,335	61,538	71,301	152,062	-	1,077	15
C2	Install Motion Sensors for HVAC	127,844	1,216	867	2,519	-	-	-
C3	Autoclave Controls	-	-	78	78	-	-	-
P1	Insulate DHW Tanks	-	-	1,573	1,573	-	-	0
P2	Instantaneous DHW	-	-	325	325	-	-	-
P3	Solar assist for DHW	-	-	384	384	-	-	-
EQ1	Energy Star Computers, printers, etc	2,297,726	-	(5,778)	2,064	644	-	(2)
EQ2	Solar PV	986,175	-	-	3,366	277	-	-
-	Total	55,113,909	394,648	537,720	1,120,472	9,248	8,370	152
-	Baseline Usage	278,185,522	1,039,124	1,527,195	3,515,488			
-	% Savings	20%	38%	35%	32%			

5.4 Energy and Emission Factors

In order to project the energy savings at the building level to impacts on the central plant – reductions in campus steam or electricity requirements or fuel - the following factors (multipliers) can be used:

Plant Output Energy

These factors are used to convert savings at the building meter (kWh or MMBtu of electricity, steam, or chilled water) into savings in the cogeneration plant output (MMBtu of electricity or steam) or purchased electricity in units of million British Thermal Units (MMBtu). Distribution losses are not included. The building level savings are multiplied by the corresponding factor to generate the savings in plant output.

Table 5.4-1 Plant Output Energy Savings Factors

Electricity	Steam	Chilled Water			
MMBtu/ kWh	MMBtu/ klb	Electric MMBtu/ MMBtu	Steam MMBtu/ MMBtu	Weighted Electric MMBtu/ MMBtu	Weighted Steam MMBtu/ MMBtu
.003412	1.03	0.1848	1.25	0.166	0.125

The electric chiller is assumed to use .65 kWh/ton-hr and the steam turbine driven chiller is assumed to use 15 lbs steam/ton chilled water. The usage weighted chilled water factor assumes that 90% of the chilled water is from the electric chillers and 10% is from the steam turbine driven chillers. To estimate savings in plant output (electric and steam in MMBtu) the building level chilled water savings is multiplied by the usage weighted chilled water plant output factor and totaled. The derivation of all the values in the table is provided in Appendix C.

<u>Site Energy (Fuel Savings)</u>

In order to calculate the site energy savings – energy value of fuel savings at the central plant or purchased electricity savings – the following factors can be used. The building level savings are multiplied by the corresponding factor to generate the energy savings at the central plant (e.g., energy value of the fuel used in MMBtu) or purchased electricity.

Table 5.4-2 Site Energy Savings Factors

	Electricity	Steam	Chilled Water			
	MMBtu/ kWh	MMBtu/ klb	Electric MMBtu/ MMBtu	Steam MMBtu/ MMBtu	Weighted Electric MMBtu/ MMBtu	Weighted Steam MMBtu/ MMBtu
Purchased Electric	.003412					
Boiler/Steam Turbine	.023	0.67	1.27	1.56	1.143	.156
Gas Turbine/HRSG	.0120	1.21	.65	1.51	.585	.151
Average Plant	.018	.94	.96	1.54	.864	.154

The steam savings factor for the boiler/steam turbine assumes a reduction of electricity generated by the steam turbine, which is replaced by electricity from the gas turbines. The usage weighted chilled water factor assumes that 90% of the chilled water is from the electric chillers and 10% is from the steam turbine driven chillers. To estimate savings in fuel input, the building level chilled water savings is multiplied by the usage weighted chilled water site energy factor and totaled. The derivation of all the values in the table is provided in Appendix C.

Note that in some cases the factor does not necessarily represent a likely operating scenario. For example, the coal fired boilers/steam turbine generators would not be run simply to generate electricity to run the electric chillers. The actual dispatch strategy will vary depending on the campus loads, operating characteristics of the plant equipment, and economics of generating vs. purchasing electricity.

<u>Emissions Reductions</u>

Environmental benefits were calculated using the following factors:

CO_2: 267.4 lbs CO_2/MMBtu (output)
SO_x: 0.623 lbs SO_x/MMBtu (output)
NO_x: 0.471 lbs NO_x/MMBtu (output)

These emission factors were based on the ratio of fuels input to the Abbott plant (coal and gas) from FY 2008 data and the energy value of campus steam and electricity combined. Changes in these fuel ratios and outputs would change the factors.

5.5 Economic Analysis

The economic analysis of the measures involved the calculation of several economic figures of merit:

- Simple Payback – Capital or investment cost/first year operating cost savings – years to payback the initial investment
- Net Present Value (NPV) – The net life cycle savings or costs based on a discounted cash flow analysis in dollars
- Benefit-Cost (B/C) or Savings to Investment Ratio (SIR) – Ratio of the discounted life cycle savings divided by the capital or investment costs in dollars
- Cost of Saved Energy (CSE) – Annualized capital or investment cost divided by the annual energy savings in dollars per million Btu ($/MMBtu)

The unit energy costs for each energy type assumed in the analysis are:

Table 5.5-1 FY 08 Unit Energy Costs

	Electricity ($/kWh)	Steam ($/klb)	Chilled Water ($/MMBtu)
Total Unit Cost Rate	$.095	$14.96	$10.85
Variable Unit Cost Rate	$.070	$7.00	$5.50

Electricity is a blended rate of site-generated and purchased electricity. The variable cost rate includes primarily fuel and consumables. The total cost rate includes all costs associated with the utility needed to cover plant operations (e.g., fixed labor costs, equipment, debt service, etc.). In general, ECMs reduce fuel use and the variable costs of plant operation and not the fixed costs. However, a portfolio of measures may reduce demand to the extent that investments in plant capacity can be reduced or deferred.[11]

The financial criteria and escalation factors used in the analysis are:

Table 5.5-2 Financial Parameters for Life Cycle Analysis

Nominal Energy Escalation Rate (%)	Nominal Discount Rate (%)	Evaluation Period (Years)
4%	5%	20

The discount rate is based on the U.S. Department of Energy and the federal Office of Management and Budget (OMB) figures (4.9%). The underlying assumption is an inflation rate of about 1.8% and a real discount rate of 3%. Note that for ECMs that had service lives shorter than the study period, replacement costs were included.

[11] The unit energy costs assumed in this analysis are based on the FY 2008 rates obtained from UA and escalated in subsequent analysis years. These costs are generally higher than the costs based on the Market Power model and financial analysis performed under Task A. However, given 1) the uncertainties in the energy outlook and the temporary dip in market prices, 2) the desire to give some credit for the capacity value of the energy conservation measures, and 3) the benefits of building energy conservation measures as a hedge against the price uncertainty, using the higher unit energy costs was considered appropriate.

Campus Level Savings Potential and Economics

Table 5.5-3 below summarizes the campus level investment required and savings assuming benefit-cost is the primary economic figure of merit, and the savings are based on the variable unit cost for utilities. If only ECMs with B/C equal to or greater than 1 are considered (Project B/C≥1 criterion), then the economically justifiable investment is $51.7 million. This yields an annual savings of $6.5 million and a net present value (NPV) $41.7 million and a payback of 8 years. If the B/C criterion is applied to the entire portfolio – that is the total savings and costs associated with all the ECMs are considered (Portfolio B/C≥1 criterion) - then the justifiable investment is $151.2 million. This yields an annual savings of $9.8 million, but an NPV of only $2.1 million and a payback of 15.4 years. The poorer economics is due to the inclusion of individual ECMs that have B/C less than 1. Table 5.5-4 provides details at the ECM level.

Table 5.5-3 Investment and Savings Potential – Variable Unit Cost for Utilities

Economic Criteria	Investment Cost ($M)	Annual Savings ($M)	Net Present Value ($M)	Simple Payback (Years)
Project B/C≥1	**51.7**	**6.5**	**41.7**	**8.0**
Portfolio B/C≥1	151.2	9.8	2.1	15.4

Table 5.5-4 Campus Level Cost Savings and Economics - Assuming Variable Unit Costs for Utilities

		Annual Energy Savings				Financials				
		Energy Operating Costs ($/Yr)				ECM Costs	Economic Figure of Merit			
ECM #	ECM Descrip	Elec	CHW	Steam	Total	Net Cost $	SPB Yrs	Benefit/ Cost	CSE ($/MMBtu)	Net Present Value
E1	Replace Windows	$0	$99,421	$352,484	$451,905	$22,792,432	50.4	0.41	$21.67	($11,742,486)
E2	Insulate Roof	$0	$0	$221,145	$221,145	$2,967,645	13.4	1.46	$6.67	$1,262,231
E3	Solar Film	$0	$49,710	$48,011	$97,722	$282,941	2.9	3.88	$2.30	$1,313,649
E4	Weatherization	$0	$0	$195,941	$195,941	$1,175,972	6.0	1.87	$5.44	$1,651,671
L1	General Lighting Upgrades (Interior, Lamps and Fixtures)	$1,026,172	$91,825	($86,927)	$1,031,070	$6,182,396	6.0	1.79	$14.74	$8,229,330
L2	Daylighting Controls/Daylight Harvesting	$29,034	$0	$0	$29,034	$523,702	18.0	0.97	$30.61	($17,989)
L3	Occupancy Sensors	$28,060	$0	$0	$28,060	$214,665	7.7	1.47	$20.32	$161,869
L4	Exterior Lighting - including controls	$21,236	$0	$0	$21,236	$916,946	43.2	0.42	$71.06	($532,235)
M1	Retrocommissioning, Labs	$257,668	$102,928	$218,222	$578,818	$8,597,887	14.9	0.99	$13.26	($87,666)
M2	Retrocommissioning, General	$727,337	$444,147	$812,869	$1,984,353	$16,577,935	8.4	1.34	$9.24	$9,192,449
M3	2 Speed Fan Operation, Labs (100% OA)	$159,006	$48,111	$118,245	$325,362	$3,110,881	9.6	1.54	$8.98	$2,068,504
M4	CAVRH to VAVRH Conversion, General (Mixed Air)	$406,265	$708,760	$655,147	$1,770,172	$46,143,593	26.1	0.69	$15.28	($14,075,806)
M5	Eliminate Reheat/Summer Steam	($15,336)	$0	$45,430	$30,094	$1,102,413	36.6	0.49	$15.41	($557,240)
M6	Redirect Relief Air as Makeup Air	$0	$0	$9,074	$9,074	$126,505	13.9	1.06	$9.40	$8,804
M7	Heat Recovery, Air to Air	($54,447)	$0	$90,495	$36,048	$2,098,115	58.2	0.25	$19.68	($1,927,146)
M8	Use CHW for Preheat	$0	$0	$112,037	$112,037	$87,979	0.8	18.76	$0.53	$1,921,434
M9	Add Economizer Capability	$0	$196,291	$0	$196,291	$2,895,068	14.7	1.23	$6.51	$660,860
M10	VSD Fans on AHUs (SZ VAV)	$165,053	$74,534	$189,808	$429,396	$1,606,324	3.7	3.94	$3.18	$5,803,387
M11	VSD on Pumps	$147,290	$0	$47,541	$194,831	$2,140,605	11.0	1.34	$14.76	$897,064
M12	Steam System Maintenance (Traps, insulation, etc)	$0	$15,779	$163,735	$179,513	$3,505,353	19.5	0.67	$14.62	($1,583,865)
M13	DX to CHW	$215,334	($50,317)	$0	$165,017	$7,273,639	44.1	0.44	$382.13	($3,735,976)
M14										
M15	DeCommission Fume Hood	$2,352	$3,204	$5,084	$10,640	$8,923	0.8	13.38	$0.81	$178,347
M16	VAV-Phoenix retrofit Labs	$109,863	$41,022	$84,450	$235,335	$4,051,627	17.2	1.05	$13.07	$211,623
C1	Install DDC on Central Equipment	$394,263	$338,461	$499,105	$1,231,830	$9,678,146	7.9	1.43	$8.24	$6,695,679
C2	Install Motion Sensors for HVAC	$8,949	$6,687	$6,068	$21,704	$234,387	10.8	1.04	$12.05	$14,897
C3	Autoclave Controls	$0	$0	$545	$545	$6,781	12.4	0.90	$11.27	($1,065)
P1	Insulate DHW Tanks	$0	$0	$11,011	$11,011	$61,649	5.6	2.63	$3.78	$123,651
P2	Instantaneous DHW	$0	$0	$2,278	$2,278	$17,691	7.8	2.33	$4.36	$23,582
P3	Solar assist for DHW	$0	$0	$2,687	$2,687	$109,598	40.8	0.36	$27.50	($86,095)
EQ1	Energy Star Computers, printers, etc	$160,841	$0	($40,446)	$120,395	$323,399	2.7	2.34	$36.19	$1,250,135
EQ2	Solar PV	$69,032	$0	$0	$69,032	$6,429,093	93.1	0.19	$153.27	($5,178,530)
-	Total	$3,857,974	$2,170,564	$3,764,039	$9,792,576	$151,244,286	15.4	1.01	$11.60	$2,143,068
-	Baseline Usage	$19,472,987	$5,715,182	$10,690,365	$35,878,534					
-	% Savings	20%	38%	35%	27%					
	Projects with B/C>=1	$2,929,187	$1,293,993	$2,235,294	$6,458,473	$51,744,736	8.0	1.55		$41,669,167
	% Savings - Projects with B/C>=1	15%	23%	21%	18%					

If the assumption is made that the energy savings are based on the total unit energy costs, then, the economics are improved considerably, due to the higher value of the saved energy (see table 5.5-5). Table 5.5-6 on the next page provides details at the ECM level.

Table 5.5-5 Investment and Savings Potential –Total Unit Cost for Utilities

Economic Criteria	Investment Cost ($M)	Annual Savings ($M)	Net Present Value ($M)	Simple Payback (Years)
Project B/C≥1	111.6	16.2	154.4	6.9
Portfolio B/C≥1	151.2	17.6	142.9	8.6

Table 5.5-6 Campus Level Cost Savings and Economics - Assuming Total (Fixed Plus Variable) Unit Costs for Utilities

ECM #	ECM Descrip	Annual Energy Savings				Financials				
		Energy Operating Costs ($/Yr)				ECM Costs	Economic Figure of Merit			
		Elec	CHW	Steam	Total	Net Cost $	SPB Yrs	Benefit/ Cost	CSE ($/MMBtu)	Net Present Value
E1	Replace Windows	$0	$196,130	$753,308	$949,439	$22,792,432	24.0	0.86	$21.67	($2,729,347)
E2	Insulate Roof	$0	$0	$472,619	$472,619	$2,967,645	6.3	3.12	$6.67	$5,817,831
E3	Solar Film	$0	$98,065	$102,607	$200,672	$282,941	1.4	7.96	$2.30	$3,178,660
E4	Weatherization	$0	$0	$418,753	$418,753	$1,175,972	2.8	4.00	$5.44	$5,688,059
L1	General Lighting Upgrades (Interior, Lamps and Fixtures)	$1,392,662	$181,146	($185,775)	$1,388,033	$6,182,396	4.5	2.41	$14.74	$14,695,933
L2	Daylighting Controls/Daylight Harvesting	$39,403	$0	$0	$39,403	$523,702	13.3	1.31	$30.61	$169,857
L3	Occupancy Sensors	$38,081	$0	$0	$38,081	$214,665	5.6	1.99	$20.32	$343,412
L4	Exterior Lighting - including controls	$28,821	$0	$0	$28,821	$916,946	31.8	0.57	$71.06	($394,838)
M1	Retrocommissioning, Labs	$349,692	$203,049	$466,372	$1,019,113	$8,597,887	8.4	1.75	$13.26	$7,888,552
M2	Retrocommissioning, General	$987,100	$876,181	$1,737,217	$3,600,498	$16,577,935	4.6	2.44	$9.24	$38,469,935
M3	2 Speed Fan Operation, Labs (100% OA)	$215,793	$94,909	$252,707	$563,410	$3,110,881	5.5	2.67	$8.98	$6,380,898
M4	CAVRH to VAVRH Conversion, General (Mixed Air)	$551,360	$1,398,191	$1,400,143	$3,349,693	$46,143,593	13.8	1.32	$15.28	$14,538,209
M5	Eliminate Reheat/Summer Steam	($20,813)	$0	$97,090	$76,277	$1,102,413	14.5	1.25	$15.41	$279,394
M6	Redirect Relief Air as Makeup Air	$0	$0	$19,392	$19,392	$126,505	6.5	2.26	$9.40	$195,722
M7	Heat Recovery, Air to Air	($73,893)	$0	$193,400	$119,508	$2,098,115	17.6	0.84	$19.68	($415,213)
M8	Use CHW for Preheat	$0	$0	$239,440	$239,440	$87,979	0.4	40.09	$0.53	$4,229,409
M9	Add Economizer Capability	$0	$387,228	$0	$387,228	$2,895,068	7.5	2.42	$6.51	$4,119,807
M10	VSD Fans on AHUs (SZ VAV)	$224,001	$147,036	$405,647	$776,684	$1,606,324	2.1	7.12	$3.18	$12,094,729
M11	VSD on Pumps	$199,894	$0	$101,602	$301,496	$2,140,605	7.1	2.07	$14.76	$2,829,359
M12	Steam System Maintenance (Traps, insulation, etc)	$0	$31,127	$349,925	$381,052	$3,505,353	9.2	1.43	$14.62	$2,067,126
M13	DX to CHW	$292,239	($99,262)	$0	$192,978	$7,273,639	37.7	0.52	$382.13	($3,229,456)
M14										
M15	DeCommission Fume Hood	$3,193	$6,320	$10,864	$20,377	$8,923	0.4	25.63	$0.81	$354,746
M16	VAV-Phoenix retrofit Labs	$149,100	$80,926	$180,482	$410,508	$4,051,627	9.9	1.84	$13.07	$3,384,979
C1	Install DDC on Central Equipment	$535,072	$667,691	$1,066,659	$2,269,422	$9,678,146	4.3	2.63	$8.24	$25,492,318
C2	Install Motion Sensors for HVAC	$12,145	$13,192	$12,967	$38,304	$234,387	6.1	1.83	$12.05	$315,626
C3	Autoclave Controls	$0	$0	$1,166	$1,166	$6,781	5.8	1.93	$11.27	$10,170
P1	Insulate DHW Tanks	$0	$0	$23,531	$23,531	$61,649	2.6	5.62	$3.78	$350,469
P2	Instantaneous DHW	$0	$0	$4,869	$4,869	$17,691	3.6	4.99	$4.36	$70,515
P3	Solar assist for DHW	$0	$0	$5,743	$5,743	$109,598	19.1	0.77	$27.50	($30,735)
EQ1	Energy Star Computers, printers, etc	$218,284	$0	($86,439)	$131,845	$323,399	2.5	2.57	$36.19	$1,457,560
EQ2	Solar PV	$93,687	$0	$0	$93,687	$6,429,093	68.6	0.26	$153.27	($4,731,900)
-	Total	$5,235,821	$4,281,930	$8,044,289	$17,562,040	$151,244,286	8.6	1.82	$11.60	$142,891,786
-	Baseline Usage	$26,427,625	$11,274,495	$22,846,837	$60,548,957					
-	% Savings	20%	38%	35%	29%					
	Projects with B/C>=1	$4,894,967	$4,185,061	$7,091,836	$16,171,865	$111,624,465	6.9	2.62		$154,423,275
	% Savings - Projects with B/C>=1	19%	37%	31%	27%					

In general, the benefit-cost or NPV are excellent metrics to use in evaluating cost-effectiveness of ECMs. The CSE metric is also useful in evaluating the value of energy conservation measures in a way comparable to energy supply systems, such as a power plant. Figure 5.5-1 shows the cumulative savings from the ECMs with the lowest CSE to the highest. The two horizontal lines represent the costs of the energy supply to the campus assuming variable costs only (marginal cost of operation – primarily the cost of fuels and consumables) or total costs (variable and fixed operating costs). The variable unit (energy supply) cost line has a value of $8.74/MMBtu and the total unit (energy supply) cost line has a value of $15.67/MMBtu. These values include the costs of electricity, steam, and chilled water production "blended" in proportion to the energy displaced by the ECMs. The intersection of the line with the CSE curve is the point at which the investments in supply and the investments in energy savings are equal. The ECMs to the left of the curve are economic, whereas those to the right are not. For the variable cost case, this indicates that annual savings of about 331,000 MMBtu in building energy use could be gained cost-effectively through investments in energy conservation. The associated 20 year NPV would be about $20 million. If total costs are assumed, then about 1,000 MMBtu annual savings could be economically justified. This would yield a 20 year NPV of $152 million. Tables 5.5-7 and 5.5-8 show the ECMs prioritized based on CSE, for the variable unit cost cases and the total unit cost case, respectively. The cost-effective ECMs are the ones in the shaded area above the bold horizontal line.

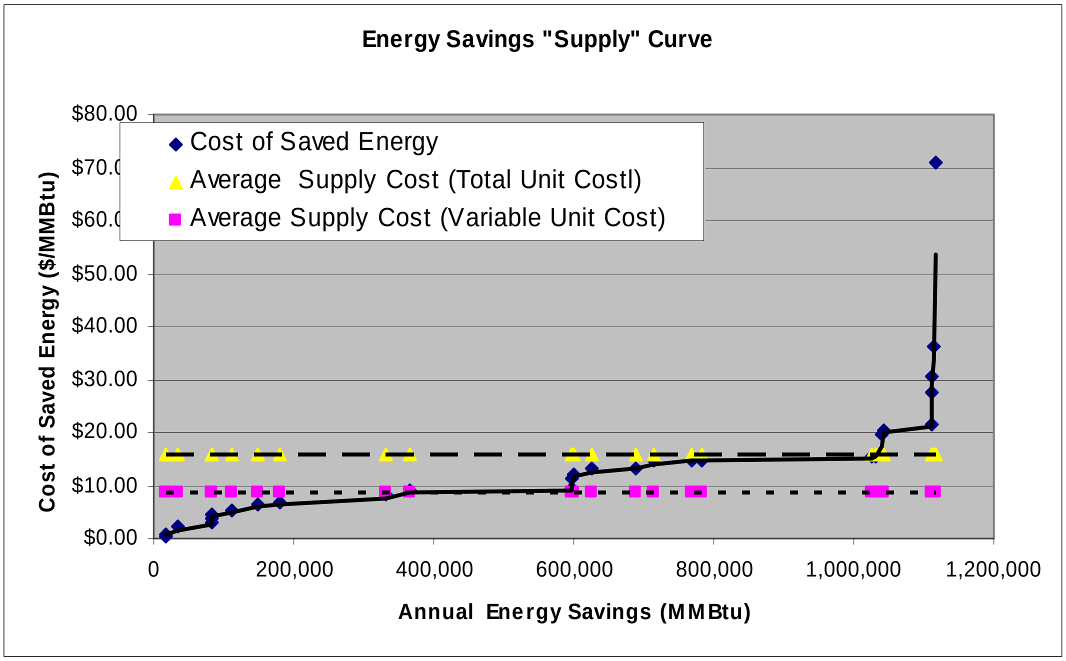

Figure 5.5-1. Energy Savings "Supply Curve"

Table 5.5-7 Projects Ranked Based on Cost of Saved Energy - Variable Unit Energy Costs for Utilities Case

ECM #	ECM Descrip	Total MMBTU	SPB Yrs	Benefit/ Cost	CSE ($/MMBtu)	Net Present Value	Cum MMBtu	Cum NPV
M8	Use CHW for Preheat	16,005	0.8	18.8	$0.53	$1,921,434	16,005	$1,921,434
M15	DeCommission Fume Hood	1,423	0.8	13.4	$0.81	$178,347	17,429	$2,099,781
E3	Solar Film	15,897	2.9	3.9	$2.30	$1,313,649	33,326	$3,413,430
M10	VSD Fans on AHUs (SZ VAV)	48,715	3.7	3.9	$3.18	$5,803,387	82,040	$9,216,817
P1	Insulate DHW Tanks	1,573	5.6	2.6	$3.78	$123,651	83,613	$9,340,467
P2	Instantaneous DHW	325	7.8	2.3	$4.36	$23,582	83,939	$9,364,049
E4	Weatherization	27,992	6.0	1.9	$5.44	$1,651,671	111,930	$11,015,720
M9	Add Economizer Capability	35,689	14.7	1.2	$6.51	$660,860	147,620	$11,676,580
E2	Insulate Roof	31,592	13.4	1.5	$6.67	$1,262,231	179,212	$12,938,811
C1	Install DDC on Central Equipment	152,062	7.9	1.4	$8.24	$6,695,679	331,274	$19,634,490
M3	2 Speed Fan Operation, Labs (100% OA)	33,392	9.6	1.5	$8.98	$2,068,504	364,666	$21,702,994
M2	Retrocommissioning, General	232,341	8.4	1.3	$9.24	$9,192,449	597,007	$30,895,444
M6	Redirect Relief Air as Makeup Air	1,296	13.9	1.1	$9.40	$8,804	598,303	$30,904,248
C3	Autoclave Controls	78	12.4	0.9	$11.27	-$1,065	598,381	$30,903,183
C2	Install Motion Sensors for HVAC	2,519	10.8	1.0	$12.05	$14,897	600,900	$30,918,080
M16	VAV-Phoenix retrofit Labs	24,880	17.2	1.1	$13.07	$211,623	625,780	$31,129,703
M1	Retrocommissioning, Labs	62,452	14.9	1.0	$13.26	-$87,666	688,232	$31,042,038
M12	Steam System Maintenance (Traps, insulation, etc)	26,260	19.5	0.7	$14.62	-$1,583,865	714,491	$29,458,173
L1	General Lighting Upgrades (Interior, Lamps and Fixtures)	54,311	6.0	1.8	$14.74	$8,229,330	768,802	$37,687,503
M11	VSD on Pumps	13,973	11.0	1.3	$14.76	$897,064	782,775	$38,584,567
M4	CAVRH to VAVRH Conversion, General (Mixed Air)	242,266	26.1	0.7	$15.28	-$14,075,806	1,025,041	$24,508,761
M5	Eliminate Reheat/Summer Steam	5,742	36.6	0.5	$15.41	-$557,240	1,030,783	$23,951,520
M7	Heat Recovery, Air to Air	10,273	58.2	0.3	$19.68	-$1,927,146	1,041,057	$22,024,374
L3	Occupancy Sensors	1,368	7.7	1.5	$20.32	$161,869	1,042,425	$22,186,243
E1	Replace Windows	68,431	50.4	0.4	$21.67	-$11,742,486	1,110,856	$10,443,758
P3	Solar assist for DHW	384	40.8	0.4	$27.50	-$86,095	1,111,240	$10,357,663
L2	Daylighting Controls/Daylight Harvesting	1,416	18.0	1.0	$30.61	-$17,989	1,112,656	$10,339,674
EQ1	Energy Star Computers, printers, etc	2,064	2.7	2.3	$36.19	$1,250,135	1,114,720	$11,589,809
L4	Exterior Lighting - including controls	1,035	43.2	0.4	$71.06	-$532,235	1,115,755	$11,057,574
EQ2	Solar PV	3,366	93.1	0.2	$153.27	-$5,178,530	1,119,121	$5,879,044
M13	DX to CHW	1,351	44.1	0.4	$382.13	-$3,735,976	1,120,472	$2,143,068

Table 5.5-8 Projects Ranked Based on Cost of Saved Energy - Total (Fixed Plus Variable) Unit Energy Costs for Utilities Case

ECM #	ECM Descrip	Total MMBTU	SPB Yrs	Benefit/ Cost	CSE ($/MMBtu)	Net Present Value	Cum MMBtu	Cum NPV
M8	Use CHW for Preheat	16,005	0.4	40.1	$0.53	$4,229,409	16,005	$4,229,409
M15	DeCommission Fume Hood	1,423	0.4	25.6	$0.81	$354,746	17,429	$4,584,155
E3	Solar Film	15,897	1.4	8.0	$2.30	$3,178,660	33,326	$7,762,815
M10	VSD Fans on AHUs (SZ VAV)	48,715	2.1	7.1	$3.18	$12,094,729	82,040	$19,857,544
P1	Insulate DHW Tanks	1,573	2.6	5.6	$3.78	$350,469	83,613	$20,208,013
P2	Instantaneous DHW	325	3.6	5.0	$4.36	$70,515	83,939	$20,278,528
E4	Weatherization	27,992	2.8	4.0	$5.44	$5,688,059	111,930	$25,966,587
M9	Add Economizer Capability	35,689	7.5	2.4	$6.51	$4,119,807	147,620	$30,086,394
E2	Insulate Roof	31,592	6.3	3.1	$6.67	$5,817,831	179,212	$35,904,226
C1	Install DDC on Central Equipment	152,062	4.3	2.6	$8.24	$25,492,318	331,274	$61,396,543
M3	2 Speed Fan Operation, Labs (100% OA)	33,392	5.5	2.7	$8.98	$6,380,898	364,666	$67,777,441
M2	Retrocommissioning, General	232,341	4.6	2.4	$9.24	$38,469,935	597,007	$106,247,376
M6	Redirect Relief Air as Makeup Air	1,296	6.5	2.3	$9.40	$195,722	598,303	$106,443,098
C3	Autoclave Controls	78	5.8	1.9	$11.27	$10,170	598,381	$106,453,268
C2	Install Motion Sensors for HVAC	2,519	6.1	1.8	$12.05	$315,626	600,900	$106,768,894
M16	VAV-Phoenix retrofit Labs	24,880	9.9	1.8	$13.07	$3,384,979	625,780	$110,153,873
M1	Retrocommissioning, Labs	62,452	8.4	1.7	$13.26	$7,888,552	688,232	$118,042,425
M12	Steam System Maintenance (Traps, insulation, etc)	26,260	9.2	1.4	$14.62	$2,067,126	714,491	$120,109,552
L1	General Lighting Upgrades (Interior, Lamps and Fixtures)	54,311	4.5	2.4	$14.74	$14,695,933	768,802	$134,805,485
M11	VSD on Pumps	13,973	7.1	2.1	$14.76	$2,829,359	782,775	$137,634,844
M4	CAVRH to VAVRH Conversion, General (Mixed Air)	242,266	13.8	1.3	$15.28	$14,538,209	1,025,041	$152,173,052
M5	Eliminate Reheat/Summer Steam	5,742	14.5	1.3	$15.41	$279,394	1,030,783	$152,452,446
M7	Heat Recovery, Air to Air	10,273	17.6	0.8	$19.68	-$415,213	1,041,057	$152,037,233
L3	Occupancy Sensors	1,368	5.6	2.0	$20.32	$343,412	1,042,425	$152,380,645
E1	Replace Windows	68,431	24.0	0.9	$21.67	-$2,729,347	1,110,856	$149,651,298
P3	Solar assist for DHW	384	19.1	0.8	$27.50	-$30,735	1,111,240	$149,620,563
L2	Daylighting Controls/Daylight Harvesting	1,416	13.3	1.3	$30.61	$169,857	1,112,656	$149,790,420
EQ1	Energy Star Computers, printers, etc	2,064	2.5	2.6	$36.19	$1,457,560	1,114,720	$151,247,980
L4	Exterior Lighting - including controls	1,035	31.8	0.6	$71.06	-$394,838	1,115,755	$150,853,142
EQ2	Solar PV	3,366	68.6	0.3	$153.27	-$4,731,900	1,119,121	$146,121,242
M13	DX to CHW	1,351	37.7	0.5	$382.13	-$3,229,456	1,120,472	$142,891,786

5.6 Environmental Benefits

The table below summarizes the environmental benefits of the investments in the energy conservation or efficiency measures in terms of annual air emissions reductions. The Project B/C≥1 case assumes only ECMs equal to or greater than 1 are implemented assuming variable unit energy costs or total unit energy costs, respectively. The Portfolio B/C≥1 case assumes all ECMs are implemented, since the overall B/C, based on the total benefits and costs of all measures, exceeds 1. The CSE (Variable Unit Energy Costs) case assumes that only ECMs with a CSE less than $8.74/MMBtu are implemented. The CSE (Total Unit Energy Costs) case assumes that only ECMs with a CSE less than $15.67/MMBtu are implemented.

Table 5.2-1 Emissions Reductions from Energy Savings

	CO_2 (tons/year)	SO_X (tons/year)	NO_X (tons/year)
Project B/C≥1 (Variable Unit Energy Costs)	72,234.0	168.3	127.2
Project B/C≥1 (Total Unit Energy Costs)	98,025.7	228.4	172.7
Portfolio B/C≥1 (All ECMs)	114,571.5	266.9	201.8
CSE (Variable Unit Energy Costs)	33,619.6	78.3	59.2
CSE (Total Unit Energy Costs)	97,400.8	226.9	171.6

6. *Portfolio Analysis*

6.1 Overview of Portfolio Based Approach

In addition to economics, other factors may figure significantly in the University's decision in energy efficiency/conservation. To capture these other factors, a portfolio based approach may be used. The basic elements of the portfolio approach are:

- Rating of individual measures by using decision criteria (weighting factors) and a numerical scoring system.
- Grouping of measures in terms of considerations that were not quantitatively reflected in the scoring, but represent desirable features for the portfolio.
- Categorizing measures as short-term and long-term based on economics, investment requirements/financing opportunities, and infrastructure considerations.

6.2 Investment Criteria and Rating of Individual Measures

Proposed decision criteria that could be used to help evaluate energy conservation measures are:

- *Annual Energy Savings* – Magnitude of the annual savings. This accounts for university energy reduction goals.
- *Net Present Value* – Difference in the life-cycle costs of the measure and the baseline.
- *Savings-to-Investment Ratio* – Ratio of the life-cycle savings of the measure to the investment costs (e.g., Benefit/Cost ratio).
- *Maintainability* – The ease with which the measure can be maintained over its life.

- *Environmental Impacts* – The air emissions or other environmental effects of the measure.
- *Improved Infrastructure* – The degree to which the measure represents a needed facility upgrade (e.g., deferred maintenance priority).

Each criterion is assigned a rating (weighting factor) that reflects its importance relative to the other criteria. Table 6.2-1 provides suggested values for the weighting factors.

Table 6.2-1 Criteria Weighting Factors

Criteria	Weighting Factor
Annual Energy Savings	8
Net Present Value	5
Savings to Investment Ratio	5
Maintainability	4
Environmental Impacts	4
Infrastructure Improvement	4

Scoring Guidelines

Each of the measures is scored relative to the criteria on a 1-10 scale, with a 10 representing the highest rated option. The weighting factor for the criterion is then multiplied by the rating for each criterion to obtain a weighted score for the criterion. The sum of the weighted scores for each criterion gives the total score for the option. Guidelines for the scoring are as follows:

Annual Energy Savings – The measure with the greatest savings is assigned the highest score – 10. Each of the measures is compared to the measure with the greatest savings (energy savings of ECM/energy savings of ECM with greatest savings) and the ratio is multiplied by 10. For example if the ratio for the ECM is 0.8 then the score is an 8. This can be modified if necessary to get a greater point spread.

Net Present Value – The measure with the greatest Net Present Value (NPV) is assigned the highest score – 10. Each of the measures is compared to the greatest NPV measure (NPV of ECM/NPV of ECM with greatest NPV) and the ratio is multiplied by 10. For example if the ratio for the NPV is 0.6 then the score is a 6. This can be modified if necessary to get a greater point spread. Measures with an NPV<0 are scored 0.

Savings-to-Investment Ratio - The measure with the highest Savings to Investment Ratio (SIR) is assigned the highest score – 10. Each of the measures is compared to the highest SIR measure (SIR of ECM/SIR of ECM with highest SIR) and the ratio is multiplied by 10. For example if the ratio for the SIR is 0.5, then the score is a 5. This can be modified if necessary to get a greater point spread. Measures with SIR<0 are scored 0.

Maintainability – The highest score should be awarded to ECMs that are the easiest to maintain. This does not relate to a specific vendor's product, but the category of products. Measures that are more difficult to maintain should be given lower scores. For example, a measure that requires frequent adjustment/calibration to maintain a specified level of performance, or that takes specialized skill sets to maintain would be given lower scores.

Environmental Impacts – Measures that improve the environmental conditions at the site are given the highest scores. Measures that maintain the status quo are given scores in the mid-range of the scale, and those that have a negative effect are given the lowest scores.

Improved Infrastructure – Measures that meet an immediate or near-term infrastructure improvement need are given the highest scores. Top scores (8-10) are assigned to those measures that address an infrastructure requirement that needed to be addressed within the next three years. Medium scores are for measures that meet infrastructure requirements within the next four-six years, and the lowest scores (1-3) are for measures addressing infrastructure requirements not needed for seven years or more into the future.

6.3 Portfolio Results

The following table summarizes the results of applying the portfolio analysis method to the representative ECMs characterized in section 5. The results move several measures that were relatively low on the list higher, primarily on the basis of non-economic factors. For example, window replacements move up due to their low maintenance and infrastructure renewal value. This is despite the poor economics.

Table 6.3-1 ECM Ranking based on Total Weighted Score – Variable Unit Energy Cost Case

Measure	Total Weighted Score	Annual Energy Savings (MMBtu)	NPV	B/C (SIR)	PB (yrs)
Retrocommissioning, General	195	232341	$9,192,449	1.3	8.4
CAVRH to VAVRH Conversion, General (Mixed Air)	164	242266	-$14,075,806	0.7	26.1
General Lighting Upgrades (Interior, Lamps and Fixtures)	150	54311	$8,229,330	1.8	6.0
Install DDC on Central Equipment	140	152062	$6,695,679	1.4	7.9
Use CHW for Preheat	132	16005	$1,921,434	18.8	0.8
Replace Windows	124	68431	-$11,742,486	0.4	50.4
VSD Fans on AHUs (SZ VAV)	120	48715	$5,803,387	3.9	3.7
Insulate Roof	118	31592	$1,262,231	1.5	13.4
Decommission Fume Hood	107	1423	$178,347	13.4	0.8
Retrocommissioning, Labs	89	62452	-$87,666	1.0	14.9
DX to CHW	84	1351	-$3,735,976	0.4	44.1
Weatherization	83	27992	$1,651,671	1.9	6.0
2 Speed Fan Operation, Labs (100% OA)	83	33392	$2,068,504	1.5	9.6
VSD on Pumps	82	13973	$897,064	1.3	11.0
Energy Star Computers, printers, etc	82	2064	$1,250,135	2.3	2.7
VAV-Phoenix retrofit Labs	81	24880	$211,623	1.1	17.2
Insulate DHW Tanks	77	1573	$123,651	2.6	5.6
Solar Film	75	15897	$1,313,649	3.9	2.9
Eliminate Reheat/Summer Steam	72	5742	-$557,240	0.5	36.6
Exterior Lighting - including controls	68	1035	-$532,235	0.4	43.2
Solar PV	68	3366	-$5,178,530	0.2	93.1
Add Economizer Capability	66	35689	$660,860	1.2	14.7
Instantaneous DHW	65	325	$23,582	2.3	7.8

Table 6.3-1. ECM Ranking based on Total Weighted Score – Variable Unit Energy Cost Case *(Continued)*

Measure	Total Weighted Score	Annual Energy Savings (MMBtu)	NPV	B/C (SIR)	PB (yrs)
Install Motion Sensors for HVAC	65	2519	$14,897	1.0	10.8
Occupancy Sensors	65	1368	$161,869	1.5	7.7
Steam System Maintenance (Traps, insulation, etc)	64	26260	-$1,583,865	0.7	19.5
Daylighting Controls/Daylight Harvesting	61	1416	-$17,989	1.0	18.0
Heat Recovery, Air to Air	60	10273	-$1,927,146	0.3	58.2
Solar assist for DHW	60	384	-$86,095	0.4	40.8
Redirect Relief Air as Makeup Air	57	1296	$8,804	1.1	13.9
Autoclave Controls	52	78	-$1,065	0.9	12.4

If we look at the rank ordering of the ECMs for the total weighted score, as well as the individual economic indicators we get the following:

Table 6.3-2 ECM Ranking Summary (1-Highest Ranking; 31-Lowest Ranking) – Variable Unit Energy Cost Case

Measure	Total Weighted Score	Annual Energy Savings	NPV	B/C (SIR)	PB (yrs)
Retrocommissioning, General	1	2	1	14	12
CAVRH to VAVRH Conversion, General (Mixed Air)	2	1	31	23	24
General Lighting Upgrades (Interior, Lamps and Fixtures)	3	6	2	9	7
Install DDC on Central Equipment	4	3	3	13	11
Use CHW for Preheat	5	14	6	1	1
Replace Windows	6	4	30	28	29
VSD Fans on AHUs (SZ VAV)	7	7	4	3	5
Insulate Roof	8	10	9	12	17
Decommission Fume Hood	9	23	14	2	2
Retrocommissioning, Labs	10	5	23	20	20
DX to CHW	11	26	28	26	28
Weatherization	12	11	7	8	8
2 Speed Fan Operation, Labs (100% OA)	13	9	5	10	13
VSD on Pumps	14	16	11	15	15
Energy Star Computers, printers, etc	15	21	10	6	3
VAV-Phoenix retrofit Labs	16	13	13	18	21
Insulate DHW Tanks	17	22	16	5	6
Solar Film	18	15	8	4	4
Eliminate Reheat/Summer Steam	19	18	25	25	25
Exterior Lighting - including controls	20	28	24	27	27
Solar PV	21	19	29	31	31
Add Economizer Capability	22	8	12	16	19
Instantaneous DHW	23	30	17	7	10
Install Motion Sensors for HVAC	24	20	18	19	14
Occupancy Sensors	25	25	15	11	9
Steam System Maintenance (Traps, insulation, etc)	26	12	26	24	23

Table 6.3-2. ECM Ranking Summary (1-Highest Ranking; 31-Lowest Ranking) – Variable Unit Energy Cost Case *(Continued)*

Measure	Total Weighted Score	Annual Energy Savings	NPV	B/C (SIR)	PB (yrs)
Daylighting Controls/Daylight Harvesting	27	24	21	21	22
Heat Recovery, Air to Air	28	17	27	30	30
Solar assist for DHW	29	29	22	29	26
Redirect Relief Air as Makeup Air	30	27	19	17	18
Autoclave Controls	31	31	20	22	16

Based on a review of this information the following ECM priorities are suggested.

Near Term Priorities

- Lighting and select HVAC energy conservation measures (ECMs) offer the greatest opportunities. Within the lighting category, interior fixture replacements (e.g., T12 to T8 or T5) offer the greatest opportunity. While a significant lighting upgrade is in progress, financial constraints have limited its scope and additional opportunities are available.

- The most cost effective HVAC opportunities in the near-term include retro-commissioning, conversion of constant speed fans to variable speed and expanding the direct digital control (DDC). Expansion of DDC controls will also help facilitate coordinated load management efforts including the ability to strategically reduce loads in response to favorable utility price signals or to internal requirements. While utility-driven demand response incentives are not currently offered, they may be a source for additional savings at some future time. Furthermore, the building automation system/controls capability, together with metering efforts and facilities maintenance are the main components of continuous commissioning or measurement based commissioning – an effective means of locking in the results of the retrocommissioning activities.

- Weatherization of buildings and judicious use of solar film to reduce heat losses/gains through the building envelope is also a good near-term investment.

Mid-Longer Term Priorities

- Mid-longer term investments include variable speed drives for pumps, adding economizer capability, and variable air volume controls for laboratory fume hoods. Retrocommissioning of laboratories and daylighting controls have marginal economics, but are worth implementing as part of the overall portfolio of measures.

Since the workscope and approach precluded a building-by-building assessment and quantification of ECM opportunities, it is not possible to provide a mapping of the priorities to specific buildings. However, the opportunities by the general categories of buildings were estimated. This is provided in Appendix D for selected categories.

7. *Interaction with Central Plant*

The building level portfolio of ECMs, if implemented, will impact the plant operations to some extent depending on the magnitude of the implementation. In most cases, the central plant output adjusts automatically to any changes to building load so no changes are necessarily required. On the other hand, if the implementation scale is large enough, it may be possible to change the dispatch strategy of equipment in the central plant.

As an example, if the peak chilled water load is reduced by 8,300 tons this may allow a different selection of chillers to operate. If the peak steam load is reduced by 150,000 lbs/hr, it may not be necessary to use a HRSG for supplemental heat. Further, if the summer steam load profile is altered by reducing or eliminating reheat loads and/or if the summer peak electric load is reduced significantly, the operation of steam turbines or gas turbines may be impacted.

This concept can be extended when considering the need for capital improvements as well. The projected peak load reductions could either provide some extra reserve capacity or preclude expanding the plant. To put this into context, it is estimated that the chilled water loads will increase from 33,000 tons to about 42,500 tons by the summer of 2012, and electric loads will increase from 78 MW to 109 MW during this same period. The demand reductions associated with the ECM portfolio could help reduce plant requirements for meeting this load growth.

8. *Implementation Strategies*

Implementation of the energy reduction strategies will require sustained investments on the part of the university, including staff and organizational support. The investments could take several forms:

- Direct Funding - This would involve the university allocating a portion of capital and maintenance funds toward energy efficiency/conservation. The university could contract out for the specific portfolio of measures and provide oversight for project implementation. In-house resources could be used for certain types of projects or aspects of projects if this is advantageous.

- Energy Savings Performance Contracts – An Energy Services Company (ESCO) could be retained to implement energy projects. The advantage to the university would be the risk sharing with the ESCO in terms of energy savings guarantees. The disadvantage is that the savings would not all accrue to the university and the added costs (mark-ups) of the ESCO. The university could use its borrowing authority to obtain financing at the lowest rates.

- Energy Project Revolving Fund – The University could establish a revolving fund that would be replenished based on the energy savings achieved. As with direct funding, initial outlays would be required, but future year requirements would diminish.

A key consideration to which of these avenues to pursue is the university’s staff capabilities and commitment to required staffing levels. For example, the establishment of a dedicated in-house team for retrocommissioning is an excellent strategy. However, given the large number of facilities involved it will take many years for the current teams to complete the work. In order to accelerate this process – to achieve the large campus wide savings results identified - the university will need to further expand its team or to augment staff through contracting for services. A similar consideration holds true for implementation of thermal distribution system savings via insulation, loss reduction, etc. The dedicated in-house team is a good way to attack the problem, since it is closely related to on-going maintenance/preventative maintenance type efforts. However, to capture the benefits in the near-term additional staff/contracting for services would be needed.

In addition to direct project funding, an important strategy for achieving energy reductions is through engagement of the university community at large. The university's metering initiative can provide the accountability aspect to complement the broader message about the benefits of energy reductions. This can be accomplished through a number of activities including:

- Energy Awareness – Information on the energy consequences of various campus activities should be made available through the web site, participation in various campus forums, etc. This should be strongly linked to the sustainability efforts of the university to leverage the energy conservation/"green" message.

- Energy Competitions – The University should encourage competitions to reduce energy consumption. This could involve specific academic units, dormitories, or other facilities.

- Academic Program Links – Student involvement in energy activities (e.g., energy surveys, web-based tools, etc.), should be encouraged. Not only will the activities benefit the student, but the university may be able to undertake certain types of energy projects more cost-effectively.

9. *Summary of Findings*

1. The potential campus wide annual energy operating cost savings from representative energy conservation measures (ECMs) ranges from \$6.5 million assuming only projects with a benefit-cost (B/C) ratio equal to or greater than 1 are considered to \$9.8 million assuming the B/C of the entire portfolio of measures is equal to or greater than 1 is considered. The associated annual energy savings are 20% to 32%. To realize these savings, an investment of \$51.7 million to \$151.2 million, respectively, would be needed by the university. The table below summarizes this information, including the simple payback and net present value associated with these measures.

Economic Criteria	Investment Cost ($M)	Annual Savings ($M)	Net Present Value ($M)	Simple Payback (Years)
Project B/C≥1	51.7	6.5	41.7	8.0
Portfolio B/C≥1	151.2	9.8	2.1	15.4

It is assumed that annual cost savings are due to fuel reduction, and there is no credit for fixed cost savings or capacity credit. The environmental benefits associated with implementing the ECMs for the **nominal case (Project B/C≥1)** is a reduction of 72,234 tons of carbon dioxide, 168 tons of sulfur dioxide, and 202 tons of nitrous oxides annually. For the for the Portfolio B//C $\geq$1 case the corresponding reductions are114,572 tons of carbon dioxide, 267 tons of sulfur dioxide, and 202 tons of nitrous oxides annually.

2. Implementation of the ECMs could reduce steam requirements from the central plants by 80,000 to 150,000 pounds per hour (14%-25%), chilled water by 5,000 to 8,000 tons (16%-25%), and electrical loads by 6 to 9 MW (8%-12%) for the nominal case and portfolio case, respectively. While these figures are broad estimates (and dependent on the amount and type of conservation that is implemented) they do indicate that energy conservation efforts can impact equipment operating margins and reserves or defer capacity additions. Energy conservation measures that reduce the need for new capacity are considered economic if they can be save energy at a cost that is less than the costs of meeting the needs through new plant equipment. For new steam capacity this would be a cost of saved energy of $14.87/MMBtu and for new chilled water capacity this would be a cost of saved energy of $9.19/MMBtu.

3. The suggested priorities for the ECMs are as follows:

Near Term

- Lighting and select HVAC energy conservation measures (ECMs) offer the greatest opportunities. Within the lighting category, interior fixture replacements (e.g., T12 to T8 or T5) offer the greatest opportunity in the near-term. While a significant lighting upgrade is in progress, financial constraints have limited its scope and additional opportunities are available.

- The most cost effective HVAC opportunities in the near-term include retro-commissioning, conversion of constant speed fans to variable speed and expanding the direct digital control (DDC). Expansion of DDC controls will also help facilitate coordinated load management efforts including the ability to strategically reduce loads in response to favorable utility price signals or to internal requirements. While utility-driven demand response incentives are not currently offered, they may be a source for additional savings at some future time. Furthermore, the building automation system/controls capability, together with metering efforts and facilities maintenance are the main components of continuous commissioning or measurement based commissioning – an effective means of locking in the results of the retrocommissioning activities.

- Weatherization of buildings and judicious use of solar film to reduce heat losses/gains through the building envelope is also a good near-term investment.

Mid-Longer Term

- Mid-longer term investments include variable speed drives for pumps, adding economizer capability, and variable air volume controls for laboratory fume hoods. Retrocommissioning of laboratories and daylighting controls have marginal economics, but are worth implementing as part of the overall portfolio of measures

4. Many of the ECMs apply broadly across the various campus building types – classroom/office, research laboratory, etc. The top 100 energy consuming buildings offer the greatest opportunity for savings since they reflect more than 90% of campus energy use. Priority should be given to ECMs that align with the university's deferred maintenance requirements. Deferred maintenance projects with energy savings attributes generally provide better economics while meeting important functional needs. Examples are: incorporating variable air volume controls and/or heat recovery when replacing air handling units; adding roof insulation and/or specifying reflective coatings when replacing roofs.

5. A comparison of the university's energy use intensity (EUI) to benchmark information from comparable institutions indicates the university has higher EUIs. than many of the other institutions.

6. The university has done a good job of establishing an energy conservation program. It should accelerate its efforts, particularly in the area of HVAC retrocommissioning and lighting. Resources should be provided to lock-in the results of the retrocommissioning via continuous commissioning/measurement based commissioning in coordination with metering efforts, building automation system activities, and facilities maintenance. Policy guidelines regarding energy reduction goals, building schedules, temperature set points, etc. should be reinforced.

7. The university should establish a funding source for the energy conservation programs. This could be supplemented by a revolving fund that would be replenished from future savings, plus annual additions.

8. Energy awareness campaigns used in conjunction with the university's metering/billing initiative should provide a solid foundation for energy behavioral changes. However this information must be put into context with regard to what occupants can do. Providing building level energy use data and operating parameters (e.g., space temperatures) via web access, including comparisons to previous years and benchmarks would be beneficial. In addition, the campaign could include energy efficiency competitions between buildings/academic units, based on energy use/reduction targets. Providing energy and emissions impact data for behaviors under an occupant's control could help foster some accountability.

9. In addition to requiring new buildings to be LEED certified, an energy master plan and strategy and/or minimum standards should be developed and implemented for new buildings and/or renovations. Items such as use of demand controlled ventilation; use of heat recovery and/or variable flow laboratory hoods; daylighting/dimming controls; peak shaving, etc should be identified.

APPENDIX A - ECM Descriptions

E - 1, Replace Windows

Windows with single pane glazing will be replaced with more efficient windows consisting of a minimum double pane glazing with argon or krypton gas fill and a low emittance coating. Where aesthetically and architecturally feasible the window frames will also be replaced in order to maximize the efficiency improvement. New windows will be Energy Star® rated with a maximum "U" value of 0.35, a maximum solar heat gain coefficient (SHGC) of 0.55, and a maximum air leakage rating of 0.30. Window tinting and use of triple pane glazing should also be considered on a case by case basis.

In addition to energy savings, window replacement will generally result in improved comfort due to a reduction in temperature differentials and infiltration. Incorporation of UV inhibitors will reduce fading and potentially prolong the life of furnishings. Some consideration needs to given to mechanically (fan) induced infiltration and/or building ventilation rates to achieve all desired benefits. In some cases historic building designations and/or considerations may impact window replacement selection.

Maintenance costs may be reduced by eliminating the need for re-glazing and painting. Lead abatement in older windows may affect the cost significantly. It has been assumed that lead abatement is not necessary in the cost estimates.

The savings projections in this report assume that a rather small percentage of buildings will receive window replacements.

E - 2, Insulate Roof

Adding roof insulation and/or replacing wet insulation is recommended when roofs are replaced. The savings projections are based on adding an average 1" (R-6) of rigid insulation to the existing roof decks for flat roofs.

Adding insulation to flat roofs is cost prohibitive unless the roof is being replaced for other reasons. The cost projection for this measure is for the incremental cost of the insulation only. Additional costs will be incurred to provide the weatherproofing materials. For this reason, the scale of this recommendation is tempered to reflect limited applicability.

E - 3, Solar Film

Solar film can be advantageous in reducing excessive solar heat gain through windows in some buildings. A properly selected and applied film can reduce the heat gain (and air conditioning load) by up to 50% with an estimated useful life of 10 years.

The reduction in solar heat gain can improve comfort dramatically in some situations albeit with a small loss in visibility. The comfort improvements can occur in both summer and winter. Incorporation of UV inhibitors will reduce fading and potentially prolong the life of furnishings.

The areas most suitable for this measure are south and west facing with no external shading from trees and adjacent buildings and where the ratio of glass to floor area exceeds 0.5.

Maintenance needs are minimal during the useful life but the film does have a limited life and will require replacement at some point. Cleaning crews need to be advised that ammonia and/or other harsh chemicals are prohibited. In some cases a highly reflective film may cause objections both externally and internally, the latter at night especially.

E - 4, Weatherization

It is recommended that infiltration be reduced by sealing air gaps in building exterior envelopes. The typical and most visible locations are cracks at doors and windows. In addition to those relatively obvious sources of air leakage, common infiltration paths are found at roof/wall junctions (especially steel decks), soffits, pipe and duct penetrations through exterior walls, dampers at outside and exhaust air openings (especially if the latter consist of gravity type back draft dampers), and elevator shaft vent openings. These sources should also be examined and, if found to be deficient, sealed or, in the case of dampers, refurbished.

In many cases, exhaust fans are the driving force behind "infiltration" due to a lack of adequate makeup or ventilation air. An evaluation of these forces and/or an air balance may be required to achieve the desired effect and ensure adequate indoor air quality.

Reducing infiltration through windows and doors generally results in improved comfort provided that there is adequate ventilation air from other sources. Due to the heavy usage factors at doors, additional maintenance may be required to maintain the projected savings.

L - 1, General Lighting Upgrades (Interior, Lamps and Fixtures)

Energy efficient lighting upgrades can save between 20% and 40% on average in facilities that use primarily fluorescent lighting. The savings are typically achieved by upgrading to more efficient lamps and ballasts and include a broad range of choices. For fluorescent fixtures the typical upgrade consists of changing from T12 lamps and magnetic or electro magnetic ballasts to T5 or T8 lamps and electronic ballasts. The exact selection of lamp and ballast for any given fixture, room, or building can vary based on numerous factors such as fixture and lens type, desired light level, desired light quality, fixture voltage, etc. The savings are dependent on the existing lamp/ballast combinations which will vary significantly depending on age of fixture, previous retrofits, repair/maintenance practices, etc. Savings (and sometimes light quality) can be enhanced by considering de-lamping, use of reflectors, tandem wiring, lens replacement, and fine tuning light levels.

The savings potential for upgrades to non fluorescent lighting can vary tremendously. In general, the savings potential for upgrades to incandescent (and mercury vapor) lighting can be as much as 75%. If these fixtures are dimmable however, the cost may be prohibitive. The savings potential for upgrades to metal halide lighting is similar to fluorescent. There aren't typically many cost effective improvements available for high or low pressure sodium lighting in a university environment.

Based on a combination of prior experience and review of information on current or planned lighting upgrade initiatives at UI campuses, the savings calculations assume a lighting reduction of 30%. Improvements to interior lighting systems generally result in a decrease in cooling energy due to less heat being generated in the conditioned space and an increase in heating energy for the same reason. This interaction has been accounted for in the savings calculations although in Illinois, the cooling credit and heating penalty tend to be about equal.

In addition to energy savings, lighting retrofits typically result in reduced maintenance costs. For large scale projects, wholesale replacement of fluorescent lamps and ballasts provides a "holiday" from the normal replacement cycles due to lamp/ballast failures. After some period of time, the new lamps will start reaching the end of their life and the normal replacement cycles will begin anew. The same will occur for ballasts but at a much later date. Replacement of incandescent lamps with fluorescent provides a long term maintenance benefit due to much longer lamp lives.

L - 2, Day lighting Controls/Daylight Harvesting

Day lighting control may be applicable to as much as 10% of the interior lighting systems. Daylight controls consist of a sensor that monitors light levels in areas with a significant amount of window area and either turn off or dim some portion of the interior lights in response to the varying contribution from sunlight. In many cases this works best when 1 or 2 rows of perimeter lights are controlled independently from rows that are further removed from the windows. Use of dimming ballasts also improves the acceptance factors and smoothes out the changes in light levels.

L - 3, Occupancy Sensors (& Bi-Level Lighting)

Installation of occupancy sensors to reduce the operating hours of lights are recommended in several standard applications:

- Classrooms
- Auditoriums used primarily for lectures
- Libraries (assuming lights are aligned with stacks)
- Corridors (partial)
- Conference Rooms (may need overrides for A/V)
- Restrooms (dual technology)
- Offices (with 4 or more fixtures per sensor)
- Utility Tunnels (timers)
- Mechanical/Electrical Rooms (timers)

In order to be applied successfully, the sensor installation needs to be designed and installed properly with locations, need for multiple sensors, dual technology (infrared & ultrasonic), and commissioning considerations taken into account. In some cases, the occupancy sensor can also be used to control HVAC equipment. This incurs extra costs due to the need for auxiliary contacts, interface with a building automation system, and additional commissioning but can be very cost effective.

Electronic Timers with audible and/or visual cues are recommended for mechanical spaces, utility tunnels and other areas where sensors can't readily "see" the occupants. Cues such as blinking the lights prior to turning them off provide a measure of safety for mechanics who may be working in these spaces. Night lights and/or unswitched lights are recommended (or mandated) in certain applications such as corridors, tunnels, restrooms, and mechanical spaces.

An alternative and/or possible enhancement to installation of occupancy sensors is use of bi-level lighting. In one situation, the occupancy sensors will only control a portion of the lighting whether it is every other fixture or some subset of lamps within a fixture. Another situation is to simply re-circuit the fixtures in a room and provide dual switches with manual control by the room occupants. Other variations are possible but, for the sake of this analysis, the savings have been assumed to be comparable to simple sensor installation.

Installation of occupancy sensors will typically increase maintenance costs. The potential reduction due to increased lamp life is more than offset by the need to repair/adjust/replace sensors over any given period of time.

Potential Energy Savings From Occupancy Sensors: (Estimated Time Unoccupied)		
Type of Space	**U.S. EPA Prediction**	**EPRI Prediction**
Private Offices	13-50%	25%
Classrooms	40-46%	-
Conference Rooms	22-65%	35%
Restrooms	30-90%	40%
Corridors	30-80%	-
Storage Areas	45-80%	-

L - 4, Exterior Lighting - including controls

The primary technology referenced under this measure is converting exterior lighting to LED fixtures and using motion activity sensors. The following excerpt from the California Lighting Technology Center (CLTC) at UC Davis describes the measure as it was applied to a parking structure at that university:

> "The lights and activity-sensing technology provide enhanced nighttime visibility while reducing energy consumption by up to 80 percent compared with the metal halide fixtures that were replaced. Switching to LED lights and adding bi-level activity-sensing technology yields energy savings for the project of 50 percent when the lights are at full power and 80 percent when at half power. UC Davis projects that the maintenance savings will be 42 percent compared with the fixtures that were replaced."

Similar benefits can be had for walkway lighting and parking lots.

L - 5, Re-balance HVAC in CVRH systems

In many buildings with constant volume reheat systems, the reduction in lighting energy requires that the HVAC systems be re-balanced to capture any cooling savings as well as to minimize the heating penalty. The reasons for this are due to the fact that any given room served by these systems receives a fixed amount of cold air at all times when the central air is on. In general, this amount of cold air exceeds the amount needed to offset internal heat gains (from windows, lights, equipment and people) except for peak conditions and a reheat coil heats the air as needed to satisfy the room thermostat setting during part load conditions. When the internal loads are reduced by a reduction in solar gain, turning off the lights, or reducing the lights the reheat coil has to add more heat to compensate.

Variable air volume systems compensate for this automatically by adjusting the air flow but constant air volume systems require rebalancing to match the revised peak load conditions created by a lighting retrofit. For fans with variable speed drives, the simple solution is to simply adjust the maximum VSD down. A 5% reduction is typical but some systems can tolerate more. Fans with fixed speed drives require new sheaves. In both cases it may be necessary to perform a more elaborate room by room adjustment if the macro concept results in too many hot/cold calls. Room by room re-balancing can improve comfort and generate additional savings but generally spills over into a retro-commissioning project as discussed below.

M - 1 & M - 2, Retro-Commissioning, (Labs & General)

Retro –commissioning can be defined in many different ways and incorporate a highly variable scope of work. The following definition is provided by the State of California's Department of General Services:

> *"Retro-commissioning (RCx) is a systematic, documented process that identifies low-cost operational and maintenance improvements in existing buildings and brings the buildings up to the design intentions of its current usage.*
>
> *RCx typically focuses on energy-using equipment such as mechanical equipment, lighting and related controls and usually optimizes existing system performance, rather than relying on major equipment replacement, typically resulting in improved indoor air quality, comfort, controls, energy and resource efficiency.*
>
> *RCx typically includes an audit of the entire building including a study of past utility bills, interviews with facility personnel. Then diagnostic monitoring and functional tests of building systems are executed and analyzed. Building systems are retested and re-monitored to fine-tune improvements. This process helps find and repair operational problems. The identification of more complex problems are presented to the owner as well. A final report, re-commissioning plan and schedule are then given to the owner."*

UIUC provides the following definition of RCx in its August 2008 report:

> *"Retro-commissioning is commissioning, or making sure equipment and mechanical systems work, in existing buildings. It is a systematic approach by a composite team of engineers and tradesmen to analyze a building's systems and maintenance program with a view to restoring the optimal operating conditions while optimizing the control strategies for energy conservation, emission reduction, client comfort satisfaction, and lower utility costs."*

These definitions are consistent and descriptive but the actual opportunities and detailed scope of work will vary significantly in any given building. UIUC has provided the following list of activities commonly evaluated and/or applied to buildings selected for its RCx activities and these were used as the basis for savings projections in this study.

- Replace Actuators/Dampers/Enthalpy on AS Economizer

- Adjust Set points (HW,MAT, DAT, Econ, etc) vs OAT
- Add Space Temp Sensors and/or PB Overrides
- Turn off/slowdown AHUs, Pumps, EFs, & Reheats - unoccupied
- Turn off reheat systems - Hot days
- Rebalance AHUs, Adjust VAV min flow, etc
- Optimize Heat Recovery
- Synchronize Perimeter heat with Airside
- Demand Reduction (electric, steam, etc)
- Replace/rebuild/recalibrate Reheat Valves & T-stats
- Extend DDC to Campus BAS

The savings projections for any one of these activities can vary tremendously depending on the original design, quality of the original equipment/installation, maintenance practices over the intervening years, and current building occupancy/needs.

The distinction in savings and cost projections for Labs vs. General arises from the observation that the savings opportunities in Research Labs are less than other types of buildings. This is driven mostly by the life safety requirements of laboratory spaces and fume hoods that dictate the air flow rates regardless of occupancy, time of day, or outdoor air conditions.

M - 3, Two Speed Fan Operation, Labs (100% OA)

Research labs are commonly designed to be constant volume systems using 100% outside air in order to provide makeup air for the constant volume fume hoods. Fume hood exhaust fans are commonly designed to operate at 100% speed 24/7 for Life Safety considerations.

The recommendation for this measure is to install variable speed drives on both fume hood exhaust fans and the associated air handling unit and institute a night setback strategy that would slow the fans down to 60% during unoccupied periods. The theory is that most governing codes and regulations allow fume hood face velocities as low as 60 FPM and reduced air change rates when the space is unoccupied. Occupied conditions are typically specified as minimum fume hood face velocities of 100 FPM (at a specified sash opening) and an air change rate of 6.0.

Application of this measure will probably be limited to a few select buildings and/or portions of buildings due to occupancy patterns lab types, and cost considerations. The latter is governed by the quantity of exhaust fans and means for determining occupancy. If occupancy sensors are required in each laboratory (as opposed to a written policy) the cost can be prohibitive. Regardless of the means of determining occupancy, override pushbuttons for after hours usage or emergencies should be liberally located and the occupants will require periodic training. Liability concerns may also limit the applicability of this measure.

Since the majority of the savings is attributable to a reduction in heating and cooling the outside air, allowing any given space (or fume hood) to dictate the speed of the AHU (and probably all the other exhaust fans to maintain pressure relationships) may result in a very limited savings opportunity if any given lab is used after hours regularly.

The appeal of this measure is the potentially low cost, high benefit/cost ratio and relative simplicity so that increased maintenance costs are not a significant factor. A more traditional method (M-16) for achieving similar savings is presented below. It should also be noted that there is significant interaction with this measure and any of the heat recovery schemes which are also recommended. In essence, if the energy required to heat or cool the outside air is reduced by heat recovery, the heating and cooling savings attributable to this measure are reduced.

M - 4, CAVRH to VAVRH Conversion, General (Mixed Air)

Many of the HVAC systems serving the campus (es) are constant volume systems with reheat coils for zone temperature control. In these systems, the air volume is selected for the worst case conditions (typically a hot summer day) and remains at that level for the remaining 90% of the time when the building operates at part load. Because some of the spaces served require cooling year around and also due to a lack of space temperature feedback to the central AHU, these AHUs generally supply air at a constant temperature to ensure adequate cooling at all times. Reheat coils are used to temper the air supplied to any given space and a local thermostat governs the amount of reheat energy used. This system provides excellent temperature control (at least in theory) year round and also excellent dehumidification in summer. It is very energy intensive however.

An alternative design which is recommended for some buildings is to allow the air volume for any given to vary in response to the room thermostat. This reduces the amount of air circulated (except on peak days) at any given time and also reduces the amount of reheat energy required. The reduction in air circulation results in a significant reduction in fan energy which tends to be the greatest savings aspect followed closely by the reduction in reheat energy. The reduction in cooling energy is relatively minor.

The scope of work required to achieve the projected savings is rather large, disruptive, and expensive. Each space thermostat represents a location where a new VAV box (and potentially new reheat coil) has to be installed in the ductwork. The thermostats themselves may have to be replaced as well and new control wiring will be extended throughout the building.

Maintenance costs will increase in the long run due to the inclusion of more mechanical devices and extended controls. In the short term there will be a maintenance holiday due to replacement of valves and thermostats which are typically older with a high maintenance factor.

A lower cost alternative (M-10) with lower savings potential is discussed below.

M - 5, Eliminate Reheat/Summer Steam

In some buildings, it may be feasible to eliminate steam usage in the summer months and isolate the steam system accordingly. These buildings are typically those that don't use reheat in the summer and have no process loads. That typically leaves Domestic Hot Water (DHW) as the only summer steam load. For classroom/admin buildings with relatively small DHW loads, the inevitable losses associated with steam systems (leaks and un-insulated pipes and equipment) the recommendation is to convert the DHW heaters to electric using either instantaneous heaters or heat pump water heaters.

The applicability of this measure can be expanded by eliminating summer reheat where it is currently still being used. Some campuses simply institute a policy that limits summer reheat to research areas or other areas with demonstrated need for strict humidity control. HVAC systems with VAV control (M - 4 or M - 10) tend to have fewer problems with this policy so this measure can be a companion measure to a VAV retrofit project. Use of fan powered boxes instead of straight VAV usually also helps eliminate the need for reheat.

The savings from this measure can be amplified if sections of the campus distribution system can be isolated in summer. This could occur where one or more suitable buildings are served by a branch with an isolation valve in a manhole. Shutdown of underground steam lines however requires careful evaluation to avoid problems with wet insulation, excessive expansion/ contraction stresses, and start up problems due to water in the lines.

Maintenance costs are projected to remain the same with this measure. Any reduction due to fewer operating hours on steam system components will be offset by the needs of the new equipment.

M - 6, Redirect Relief Air as Makeup Air

Some 100% outside air systems have mixed air systems with air side economizer controls in relatively close proximity. In these cases, it will usually be feasible to redirect the relief air from economizer operations to the intake of the 100% outside air systems and reduce the heating energy requirements. This is applicable where the use of 100% outside air is driven by a need for makeup air to fume hoods and/or labs that prevent re-circulating the exhaust or room air. Some areas, particularly those in health care situations, may require 100% outside air for other reasons and this measure may not be suitable.

There will be no change in maintenance costs with this measure

M - 7, Heat Recovery, Air to Air

100% outside air systems that operate 24/7 are usually good candidates for heat recovery from the exhaust air. The heat recovery can take various forms such as run around loops, heat wheels, flat plate heat exchangers, and heat pipes depending on the relative proximity and orientations of the air streams as well as the concern for cross contamination between the air streams. In a retrofit situation, run around loops tend to provide the most cost effective configuration due to limitations with building architecture. Heat wheels on the other hand will provide the most energy recovery especially in summer when the latent heat exchange capability of a heat wheel can be very beneficial whereas there is no latent capability with the other types.

All types of heat recovery impose additional pressure drops on the air streams. At a minimum this will result in a fan energy penalty. In some cases it may trigger the need for fan or duct replacement.

Maintenance costs increase when heat recovery systems are installed due to the addition of new filters in the exhaust stream, additional controls, and, for heat wheels and run around loops, added mechanical components.

M – 8, Use CHW for Preheat

In cases where the chilled water coils remain flooded in winter and the chilled water circulating system remains active, it may be possible to use the heat in the chilled water to provide some of the preheat energy for 100% outside air systems.

This concept works best when chilled water temperatures in winter are allowed to be at 50F or higher. Since cooling loads in winter are typically lower than summer, this reset in CHW temperatures is commonly achievable but not always. With CHW temperature of 50F however, and a preheat coil providing air at 30F, most 8 row (or deeper) chilled water coils with full water flow will provide a 3F or closer approach so that the air leaving the CHW coil will be 47F. Since this is colder than the typical supply air temperature, sufficient reheat coil capacity will be needed to make up the difference.

Although the biggest concern in many campuses considering this measure has been providing adequate freeze protection for the chilled water coils, some campuses already circulate CHW through the coils at 100% for freeze protection. Without lowering the preheat coil discharge temp though, they may actually be cooling the air coming off the preheat coil which in effect wastes both preheat energy and chilled water energy. This measure has the added benefit of reducing chiller energy.

Maintenance costs for this measure should not be significantly impacted. Some additional controls are recommended but no new mechanical components are required.

M - 9, Add Economizer Capability

Adding air side economizer capability to HVAC systems serving office and classroom space is recommended to reduce the cooling energy requirements when the outside temperature is below 60F. This measure generally requires adding ductwork for outside and relief air and is generally applicable to systems over 2,000 CFM. For smaller systems without return fans, relief air can generally be free boarded to the building at large with minimal impact on building pressurization.

Air side economizer capability is generally not recommended for systems serving computer rooms.

Maintenance costs will increase slightly due to the addition of dampers and controls.

M – 10, VSD Fans on AHUs (SZ VAV)

This measure consists of installing variable speed drives on the supply and return fans of constant volume systems. The speed of the fan will be based on time of day, outside air temperature and one or two representative space or return air sensors. In essence this creates a single zone variable volume system and has been proven to be an extremely cost effective measure in thousands of systems.

One reason that this works is that that most HVAC systems are oversized and have excess capacity added as a safety factor as part of the design. In these cases, slowing the fan down simply takes the safety factor out of play and can actually improve humidity control in summer and reduce air noise. Another reason that this concept works is that the pressure relationship in the supply duct reacts positively to a slowdown so that the end of the line pressure actually increases relative to the earlier duct takeoffs. So the reduction in the amount of air is pretty much the same at the end of the duct as it is at the beginning. Since fan energy in a constant volume system follows the cube law, a 20% reduction in airflow provides a 50% reduction in fan energy. Because of this, slowing fans down to less than 60% speed isn't recommended due to decreasing savings and increasing potential hot/cold calls.

Some care needs to be taken to maintain adequate ventilation air when slowing down the fans. A simple algorithm to adjust the return fan speed at a different ratio than the supply fan can help with this. CO2 sensors and a demand controlled ventilation strategy can also be used.

Maintenance costs will increase slightly due to the addition of variable speed drives and additional controls.

M – 11, VSD on Pumps

Some chilled water and hot water pumps are suitable for conversion to variable flow by installation of Variable Speed Drives. The distinguishing feature required to achieve the projected savings is the type of control valve(s) used at the coils served by the pump. Systems that use predominantly 2 way control valves are inherently variable flow already and lend themselves to a simple and cost effective conversion. In these cases, there is usually a pressure differential bypass valve that will maintain minimum flow in the system and prevent the pump from dead heading if all the control valves are closed. For these situations the required scope of work is to install VSDs on each pump, close (or modify) the pressure differential valve and add pressure sensors to control the pump. Pressure sensors need to be near the end of the line for successful operation. Locating them near the pumps provides a false signal.

Hydronic systems incorporating 3 way valves at the coils are much more problematic to convert to variable flow. The 3 way valve does provide variable flow to the coil but the system (and pump) sees a constant flow regardless of the load. In some cases it may be possible to close off a balancing valve in the bypass leg of control valve and convert the control valve to 2 way at no significant cost. Unfortunately actuators on many 3 way valves have low shut off pressure ratings and are incapable of keeping a valve closed against the higher pressure differentials they will be exposed to. Replacing the valves can be cost prohibitive unless they are failing and need to be replaced for other reasons.

The savings from this measure usually require that reset schedules be modified to promote as much variable flow as possible within the constraints of the control valve characteristics.

Maintenance costs will increase slightly due to the addition of variable speed drives and additional controls.

M – 12, Steam System Maintenance (Traps, insulation, etc)

While central steam distribution systems offer many advantages to a campus, energy efficiency is not one of their strong suits. The reason for this are many and include: un-insulated piping and equipment (some correctable, some not), failure of traps in an open position, venting of condensate return tanks, venting of flash steam, leaks from failed components, and overall complexity. A telling factor is that just about any room or tunnel with steam PRVs condensate tanks, etc is at least 20F hotter than an equivalent room with hot water equipment.

For optimum efficiency, steam systems demand a continuous and ongoing maintenance program. Failures that are unacceptable in a hydronic system (e.g. leaks, un-insulated piping, and broken returns) are commonly ignored in a steam system. This is especially true for maintenance departments that are short staffed and relying on hot/cold calls for preventative maintenance practices.

This measure projects savings from a continuous maintenance program that includes the following practices in any given building. Similar and/or additional practices apply to the distribution systems:

- Regular testing and replacement of steam traps
- Maintaining insulation on pipes, valves, etc.
- Application of removable jacket insulation for PRVs and other items needing frequent maintenance
- Continuous leak detection and repair
- Maintaining condensate return pumps
- Regular testing of steam control valves to ensure no leak by monitoring for hidden leaks in DHW bundles or AHU coils
- Monitoring steam room temperatures to help detect changes.

In addition to the thermal savings from a reduction in losses, it is likely there will be some reduction in cooling energy since some portion of the steam losses find their way into conditioned space and become a chilled water load.

Insulation of condensate tanks and condensate return piping should be evaluated on a case by case basis. In general, insulation will always reduce energy usage. The concern is that, in some cases the condensate return pumps require relatively cool water to avoid cavitation. If steam trap failure is a common (and undetected) problem the tank temperature can become excessive and an un-insulated tank helps avoid cavitation. A better solution would be to monitor the tank water temperature and send an alarm to the EMCS and lock out the pump if excessive temperatures are detected. Even then though, some CR pumps require lower temperature water for successful operation and a pump replacement will be required to accommodate the higher temperatures resulting from insulating the CR tank and piping.

Maintenance costs will increase significantly with this measure. Some initial capital investment may be required for items such as removable jackets and monitoring controls but the majority of the cost is an ongoing expense for labor and parts.

M – 13, DX to CHW

In addition to high maintenance costs, localized use of packaged direct expansion (DX) equipment is generally less efficient than use of chilled water (CHW) from a central plant. DX equipment can take many forms – window units, split systems, single package (aka rooftops), etc.

This measure, where applicable, assumes that the DX equipment will be eliminated and CHW from the central plant will be used as the primary cooling medium. Due to the need to replace (or add) central air handling equipment, ductwork, and/or chilled water piping, the cost for this measure is very high and this measure has limited applicability as a stand alone concept. It will generally be incorporated in a larger renovation project.

Maintenance costs will generally decrease as a result of this measure due to eliminating mechanical components that have a relatively short life.

M – 14, Not Used

M – 15, Decommission Fume Hood

Fume hoods are very expensive items of equipment to maintain and operate. In addition to the annual balancing requirements and costs there are the costs of maintaining and operating the fume hood exhaust fan. The biggest expense however is providing conditioned air to the space where the fume hood is located especially since most fume hoods operate 24/7 at a constant volume.

Observations and cataloging of fume hoods at any university campus will result in the identification of fume hoods that are not being used at all or used only for storage. In some cases this is a temporary situation but in some cases it is permanent due to occupancy changes or changes in space function.

For the latter situation, this measure recommends that the fume hood(s) be de-commissioned by either removing them or physically modifying them so that they can't be used without re-commissioning. Since the energy savings come primarily from reducing the amount of conditioned air serving the affected space, the scope includes adjustments to the central air system.

Maintenance costs will be reduced due to eliminating the need for an annual inspection and certification of the fume hoods and possibly taking an exhaust fan out of service.

M – 16, VAV with Air Valves - Labs

As discussed in M – 3, converting lab spaces to variable air volume (VAV) can provide tremendous savings. The problem is complying with codes ensuring life safety in spaces with fume hoods. Several manufacturers have developed and offer air valves and related controls that provide the desired energy savings while meeting the code and life safety concerns.

The valves and control systems can take several forms, configurations and sequences of operation. The following is the basis for this recommendation.

Each supply, fume hood exhaust and general exhaust branch duct serving any given space in a laboratory HVAC system will be provided with an air valve. For laboratory spaces, the air valves will be sequenced to maintain the desired pressure relationships in the room and minimum air change rates or fume hood face velocities at all times. An occupancy sensor at the fume hood will toggle the fume hood valve to maintain 100 FPM face velocity when occupied and 60 FPM when unoccupied. Time of day sequences will allow the air change rate in the room to toggle from the occupied maximum to an unoccupied minimum and reset the space temperature accordingly. Override pushbuttons will allow for occasional after hours usage at full flow. Non laboratory spaces served by the same HVAC system will generally use simple VAV controls.

Variable speed drives on the AHUs track the required room air flows and adjust the fan speeds accordingly. Provisions are generally made at the exhaust fans to allow variable exhaust at the room level but constant fan flow to ensure adequate dispersion of the effluents in the exhaust air stream.

The savings achievable from this measure are much greater than those projected in M – 3 due to its' extended hours of savings as well as diversity since any given space can be in a "savings" mode at any given time.

The scope of work required to achieve the projected savings is rather large, disruptive, and expensive. It is a commonly accepted method for Labs though and has general applicability as opposed to M-3.

Maintenance costs will increase significantly with this measure due to addition of mechanical components and complex controls.

C – 1, Install DDC on Central Equipment

Applying direct digital controls (DDC) to central equipment (AHUs, converters, pumps, etc) is a very cost effective method to achieve significant energy savings and is recommended where applicable

Employing interoperability and centralized DDC control would enable the university to consider more advanced control strategies to optimize equipment performance. These strategies would include:

- Lighting control
- Integrated Exhaust/MUA unit control in research areas
- VAV control of fan systems based on zone requirements
- Supply temperature reset of chilled and hot water based on worst case zones
- Seasonal switchover of facilities
- Enthalpy based economizers
- Holiday and Weekly scheduling
- Optimum Start/Stop
- Demand Limiting and Duty Cycling

Modern web-based control systems and operator interfaces allow interoperability of disparate offerings. This centralized control allows the consolidation of building automation to make optimum use of staff through a single point of control and reporting of system faults and facilitates response to non-optimal conditions. The end result is reduced energy consumption and improved occupant comfort. This same interoperability allows energy consumption to be automatically gathered and used to encourage efficient use of facilities while enabling "per site" billing or benchmarking.

C – 2, Install Motion Sensors for HVAC

In some situations, motion sensor control of HVAC systems can be applied with great effectiveness. Especially if the motion sensor cost can be shared with the lighting system upgrades discussed in L – 3, above.

The application provides the most savings by cycling fans or DX units but can be limited to control of outside air dampers or variable volume dampers. The most cost effective applications will generally be large auditoriums served by a single AHU. Other applications can be classrooms and conference rooms served by individual units such as fan coils or heat pumps.

Because these spaces may be used spontaneously by small groups and motion sensors can't distinguish between 1 and 100 people the savings projections are modest. It's also necessary to restrict the temperature swings during the normal occupied hours since the warm up/cool down periods can be lengthy.

Maintenance costs will increase slightly due to the addition of additional controls.

C – 3, Autoclave Controls

Steam fired autoclaves (sterilizers) are often used and required in research/health environments. The observation is that the autoclaves are often energized 24/7 with large heat losses due to un-insulated steam medium pressure internal distribution piping and/or limited insulation. In some cases tempering water for the condensate runs continuously as well.

In situations where the autoclave is used regularly but infrequently, say once a day for a 2 or 4 hour cycle, it is recommended that timers be installed to shut off the steam supply except for the scheduled use period and a warm up period. Override pushbuttons will initiate a warm-up/cleaning cycle for unscheduled or unpredicted usage.

In cases where the tempering water for condensate runs continuously, a solenoid valve and related controls can be added to reduce the water usage.

Maintenance costs will increase slightly due to the addition of additional controls.

C – 4, Demand Response

Demand response refers to strategies that are temporary in nature and designed to reduce peak demand, not necessarily to save appreciable amounts of energy. Several strategies can be employed for demand response. Demand response can either be initiated internally – in which case the university tries to reduce its peak demand to avoid either excessive operating costs (typically signaled by extraordinarily high electric demand costs) and/or the need to dispatch reserve capacity or it can be initiated by the local utility under a formal program in which case there is usually an incentive offered to the university. In either case the actions taken are usually of relatively short duration (6 hours or less) and typically require some cutback in service that is extraordinary. This is in contrast to demand reduction concepts such as more efficient lighting which limit demand inherently.

It is common for Demand Alert levels to be established to help manage a demand response initiative. The following is an example strategy.

Level 1 is a day ahead alert to selected staff. Target loads are:

- Discretionary control of major electrical loads such as earthquake machines, MRIs, electric cooking equipment, decorative lighting, etc
- Voluntary reduction in perimeter lights or unused office equipment

Level 2 are manually initiated events starting an hour or two ahead of the expected demand reduction window. These would be actions not easily (or economically) deployed automatically and/or items with a delayed response. Examples are:

- Reminders on Level 1 targets
- Turning off reheat pumps: This will reduce pumping loads immediately but have an indirect (and somewhat delayed) impact on CHW demand.
- Isolating steam service to selected (typically non research oriented) buildings. Internal losses from steam systems commonly result in a cooling load contribution. A reduction in steam usage can also translate into a reduction in auxiliary loads such as condensate handling, forced draft combustion fans, at the central plant.

Level 3 uses the EMCS to control discretionary loads. These can be initiated automatically when the demand, as monitored at the central plant, approaches a critical point. Examples are:

- Demand Controlled Ventilation. Allowing CO2 levels to creep up to higher levels will reduce the amount of outside air requiring cooling and dehumidifying and provide a fairly rapid load reduction.
- Initial Global reduction in Fan VFD speeds

Level 4 also uses the EMCS to reduce load for critical loads but only in response to a sliding 15 minute interval demand window. Examples are:

- Additional Global reduction in Fan VFD speeds
- Current Limiting on electric chillers
- Turn off selected AHUs, exhaust fans, and other discretionary loads

P – 1, Insulate DHW Tanks

Due to repairs or other factors, some domestic water tanks have damaged or missing insulation. It is recommended that this insulation be replaced. In a few cases the insulation is intact but inadequate. Any surface with a temperature greater than 100F would be indicative of that situation and additional insulation is recommended.

There will no change in maintenance costs as a result of this measure.

P – 2, Instantaneous DHW

Storage type water heaters, even when well insulated, have continuous heat loss. In some situations with limited DHW usage the annual losses approach the energy required for heating. Use of instantaneous water heaters eliminates much of the heat loss by reducing the hot surface area.

In general, the application of domestic water heaters is limited to buildings without showers, laundry, or other large sudden demands. In some cases such as office/classroom buildings, it may be feasible to install electric instantaneous heaters near the end use. In other cases such as labs use of steam fired instantaneous heaters are indicated.

The cost for conversion of storage type heaters to instantaneous type is generally too high to recommend this as a general measure. The recommendation (and cost) for this measure is to convert as the existing water heaters fail. The incremental cost, if any, is relatively minor at that point.

There will no change in maintenance costs as a result of this measure.

P – 3, Solar Assist for DHW

This measure recommends that an indirect solar water heating system be installed on favorable buildings to reduce the energy used for domestic water heating. The system recommended consists of flat plate collectors with electric pumps and controllers to circulate a heat-transfer fluids through the collectors. Heat exchangers will transfer the heat from the fluid to the potable water. Overheat protection is needed to protect the collector and the glycol fluid from becoming super-heated when the load is low and the intensity of incoming solar radiation is high. The heat transfer fluid will be a glycol-water mixture with food-grade propylene glycol. Collector plates will be fixed tilt facing south.

EQ – 1, Energy Star® Computers, printers, etc

This measure is capturing the slow but steady efficiency gains possible by specifying the use of Energy Star® labeled office equipment as the existing equipment fails and gets replaced. The cost represents an incremental cost over and above standard equipment.

EQ – 2, Solar Photovoltaics

Photovoltaic panels will be installed in suitable locations to provide a nominal amount of electricity throughout the year. The panels will be fixed tilt, face south and use polycrystalline silicon cells.

ECM Checklist

Modeled	Considered	N/A	ECM Type	ECM Subtype	ECM Description
		x	Cogeneration	Fuel Cells	Install fuel cells with heat recovery
		x	Cogeneration		Cogeneration - turbine/engine/ HRSG/AbsChiller/TurbChiller/etc.
x			Commissioning		Building Commissioning or Recommissioning
		x	Electric Power	Peak Shaving	Thermal Energy Storage
		x	Electric Power	Peak shaving	Use emergency generators for peak electric load shaving
	x		Electric Power	Transformers	Install energy efficient electric transformers
		x	Envelope	Doors	Install doors/seals in loading dock areas
	x		Envelope	Doors	Place vestibules around exterior entrances
x			Envelope	Insulation	Improve wall or roof insulation - numerous techniques
	x		Envelope	Landscape	Exterior building shading - trees and plants
	x		Envelope	Landscape	Wind protection
	x		Envelope	Roofs	High reflectance roofing material
x			Envelope	Smaller buildings	Blower door test, seal envelope leaks
	x		Envelope	Windows	Exterior window shading devices
x			Envelope	Windows	Improved window thermal performance - replace
x			Envelope	Windows	Install solar window films
	x		Envelope	Windows	Install storm windows
		x	Hot Water	Dishwashers	Water conserving dishwashers
		x	Hot Water	Heat Recovery	Gray Water Heat Recovery
x			Hot Water	Heat Recovery	Hot water using recovered heat (such as from chiller condenser)
x			Hot Water	Instantaneous	Instantaneous hot water heaters (gas or electric)
x			Hot Water	Insulation	Additional insulation on water heaters (heater blankets)
	x		Hot Water	Insulation	Insulate hot water pipes
x			HVAC	Air-side	Convert multizone or dual duct to variable air volume
	x		HVAC	Air-side	Design displacement ventilation system
x			HVAC	Air-side	Exhaust Air Heat Recovery
	x		HVAC	Air-side	Insulate air ducts in unconditioned spaces
		x	HVAC	Boilers	Combustion air preheating
		x	HVAC	Boilers	Improve water treatment to eliminate heat exchanger fouling
		x	HVAC	Boilers	Install multiple high-efficiency condensing boilers
		x	HVAC	Boilers	Isolate off-line boilers
		x	HVAC	Boilers	Preheat feedwater with recovered heat
		x	HVAC	Boilers	Replace and resize boilers for efficiency
		x	HVAC	Boilers	Replace central plant with satellite boilers
		x	HVAC	Boilers	Replace satellite boilers with central plant
		x	HVAC	Boilers	Shut down large boilers in summer and use small ones
		x	HVAC	Chillers	Combine chillers in multiple buildings - run most efficient first
		x	HVAC	Chillers	Isolate off-line chillers and cooling towers
		x	HVAC	Chillers	Replace chillers with more efficient models, size for part loads
x			HVAC	Controls	Air handling unit optimal start/stop
		x	HVAC	Controls	Chiller condenser water temp setback (off outdoor air wetbulb temp)

ECM Checklist *(Continued)*

Modeled	Considered	N/A	ECM Type	ECM Subtype	ECM Description
x			HVAC	Controls	Cold Deck Temp Reset w/ Humidity Override (Constant air volume only)
	x		HVAC	Controls	Duct static pressure reset w/ VAV air system
x			HVAC	Controls	Install programmable zone thermostats
x			HVAC	Controls	Lower zone thermostat heating set point, raise cooling set point
x			HVAC	Controls	Mixed air temperature reset (constant air volume only)
x			HVAC	Controls	Occupancy sensors and VAV system - setback temps, shutoff boxes
		x	HVAC	Controls	Optimize chiller sequencing
x			HVAC	Controls	Outdoor temperature reset - chilled water or hot water
	x		HVAC	Controls	Night precooling
x			HVAC	Controls	CO2 Sensing & Demand-Controlled Ventilation
		x	HVAC	Cooling Tower	Optimize control of multiple towers with multi or variable speed fans
		x	HVAC	Cooling Tower	Oversize cooling tower, lower condenser temps
		x	HVAC	Cooling Tower	Use induced draft (axial fan) over forced draft (centrifugal) when possible
		x	HVAC	Cooling Tower	Use two-speed or variable-speed fan instead of water bypass to modulate capacity
	x		HVAC	Desiccant	Desiccant Dehumidification
x			HVAC	Distribution	Convert constant flow air or water to variable flow, where loads vary
		x	HVAC	Distribution	Oversize ducts and pipes to reduce fan/pump energy
	x		HVAC	Distribution	Reduce flow rates in air and water systems where ever possible
		x	HVAC	Electric Heat	Replace electric resistance heating with other
		x	HVAC	Evaporative	Indirect evaporative cooling
x			HVAC	Free cooling	Air-side economizers
x			HVAC	Free cooling	Waterside economizers
		x	HVAC	Fuel Switching	Gas engine or absorption chillers
		x	HVAC	Furnace	High Efficiency Gas Furnace
	x		HVAC	Heat Pumps	Ground Source Heat Pumps
		x	HVAC	Heat Pumps	Water loop heat pump systems - inside building - simultaneous htg/clg
x			HVAC	Heat Recovery	Heat Recovery - General
x			HVAC	Laboratory	Laboratory Fume Hoods: Low-flow, vav, or heat recovery
		x	HVAC	Low energy cooling	Create air movement with fans
		x	HVAC	Low energy cooling	Install roof-spray cooling systems - need low wetbulb temps
	x		HVAC	Motors	Install or replace with premium efficiency
	x		HVAC	Motors	Replace significantly under-load motors with correct motor size
x			HVAC	Packaged	Specify or replace high efficiency packaged equipment
	x		HVAC	Pumps	Pump impellor trimming

ECM Checklist *(Continued)*

Modeled	Considered	N/A	ECM Type	ECM Subtype	ECM Description
x			HVAC	Steam	Fix steam condensate being dumped to drain
x			HVAC	Steam	Install or improve insulation on steam lines
x			HVAC	Steam	Investigate lowering steam system pressures
x			HVAC	Steam	Survey and fix any steam leaks
x			HVAC	Steam	Survey and replace failed steam traps
x			HVAC	Window ACs	Replace window air conditioners with central system
x			Lighting	Controls	Occupancy Sensors
x			Lighting	Controls	Rewire lighting to allow portions of circuit to be shut off
x			Lighting	Daylighting	Daylighting and dimming systems
	x		Lighting	Exit Signs	LED Exit Signs
	x		Lighting	Exterior	Exterior/Parking Lot Lighting
	x		Lighting	High Bay	High Bay Metal Halide to T8 or T5 conversion
x			Lighting	Interior	Incandescent to Compact Fluorescents
	x		Lighting	Light levels	Reduce illumination levels in overlit areas
		x	Lighting	Sky lights	Install skylights and light dimming system
x			Lighting	T8/Electric	T8 Lamps and Electronic Ballasts - specify or replace T12/magnetic
	x		Lighting	Task lighting	Use task lighting with low ambient illumination
	x		Office Equipment		Computers - power management systems
x			Office Equipment		Office Equipment - purchase energy efficient
			Office Equipment		Plug load occupancy sensors
	x		Process Equipment	Compressed Air	Plug leaks, reduce system pressure
		x	Process Equipment	Compressed Air	Recover waste heat from compressor cooling system
		x	Refrigeration		Insulate floors of walk in coolers if slab extends beyond cooler
		x	Renewable Energy		Install wind turbines where feasible
x			Renewable Energy		Photovoltaics
	x		Renewable Energy		Solar wall to preheat air for high-bay type buildings
x			Renewable Energy		Use solar thermal systems for heat loads
	x		Small Equipment	Vending Machines	Vending Misers
	x		Swimming Pools		Install covers on swimming pools
x	x		Turn off	Turn off	Shut anything off when not in use.
			Water	Dishwashers	Water conserving dishwashers
			Water	Irrigation	Heat recovery from/to irrigation water
			Water	Irrigation	Use soil water sensors and/or efficient distribution systems
			Water	Water use reduction	Faucet Aerators
			Water	Water use reduction	Install automated faucets and flush valves
			Water	Water use reduction	Low Flow Shower Heads

ECM Checklist *(Continued)*

Modeled	Considered	N/A	ECM Type	ECM Subtype	ECM Description
			Water	Water use reduction	Rainwater harvesting
			Water	Water use reduction	Waterless Urinals

APPENDIX B - Field Survey Summaries

Digital Computer Lab

General:

The Digital Computer Laboratory (DCL) was the original home of the Computer Science department. It was originally constructed in 1958 as a two-story building. It received its first addition in 1963 and a second addition in 1965. By the early 1980's the department had outgrown the available space. A third addition was completed in 1989 which added a third floor and wrapped the old building on three sides creating an open space flooded with natural light. In late Fall 2003 the department moved to its new home in the Thomas M. Siebel Center for Computer Science. The department continues to use the two large classrooms and the instructional labs. Numerous faculty offices are located in DCL and the university’s central computer system is housed in DCL.

The building is used year round. Most of the student and faculty building usage occurs during the hours of 7 AM to 10 PM, M-F. Labs are available to graduate students at any hour and many of the computing resources remain operational 24/7.

Envelope:

The exterior walls are composed of face brick and masonry with a gypsum interior finish. The walls in the 1989 addition have 1” of rigid insulation while the remaining exterior walls from the 1950s and 1960s have no insulation. The roof is a built up composite of ballast, bitumen and insulation (average 3”) over a metal deck. Windows in the 1989 addition are primarily fixed, double pane. Windows in the 1950s and 1960s sections are single pane. A large skylight is located over the central atrium.

Mechanical Systems:

Approximately 60% of the building (the 1989 addition) is served by a Variable Air Volume Reheat (VAVRH) system relying on seven central station air handling units, ranging from 20 to 40 HP in size. These AHUs have variable speed drives, humidification, and air side economizer controls. Cooling is provided by chilled water while preheating is provided by low pressure steam. Pneumatic controls are provided for the zone VAV boxes and reheat coils which use hot water. Perimeter finned tube radiation (FTR) also uses hot water and pneumatic controls. Minimum ventilation amounts are estimated at 15%.

Much of the remainder of the building (original and 1960s additions) is served by multiple constant volume reheat systems using a combination of four pipe air handling units, large fan coil units, and one multizone unit. These units range in size from 2 to 15 HP. Much of this equipment is original and is in fair to poor condition. Cooling is provided by CHW and steam is generally used for the preheat coils installed on some units. Outside air quantities are fixed with no ASE capability and estimated at 15%. Perimeter heat is provided in the 1960s sections of the building but not the original.

Several supplemental cooling units are provided to serve computer rooms. These units use chilled water for cooling and are assumed to have electric reheat and humidification.

High pressure steam is provided from the central plant and reduced to low pressure (10 psig) for distribution to preheat coils, domestic water heaters, clean steam generators, and HW converters. Condensate return is collected at a central location and pumped back to the central station. The original building and 1960 additions use a vacuum steam system for FTR. Steam is used year round.

Separate steam to HW converters and piping systems are provided for FTR and reheat coils in the 1989 addition. The earlier sections of the building rely on separate steam to HW converters for reheats (one for original building plus one for addition), fan coil units, and FTR.

Chilled water is provided from a central plant at 40F. CHW is used year round for both supplemental cooling and for AHU/FCUs without air side economizer capability.

DHW is provided by 3 steam to hot water units using steam bundles in storage tanks.

Controls:

The central equipment (converters, pumps, and 1989 AHUs) are controlled by a Barber Coleman (aka Seibe or Invensys) DDC system. The remainder of the HVAC equipment uses pneumatic controls. The DHW uses self contained temperature regulators. Most of the equipment currently operates 24/7. The perimeter heating systems incorporate an OA reset schedule and are manually turned off in summer

The VAVRH systems use standard sequences to maintain a constant discharge air temperature by sequencing the chilled water valve, steam valve and mixed air dampers Duct pressures is maintained by modulating the fan speed(s). The constant volume systems operate similarly except that most have a fixed amount of outside air. Zone thermostats are single set point type.

Perimeter heat in the 1989 addition is generally controlled by self contained (danfoss valves). Perimeter Heat

Lighting Systems:

Observed areas fluorescent lighting at about 1.5 Watts/sq. ft. based on T12 lamps. (see UIUC lighting project summary sheet for equivalent fixture counts)

Process Systems:

The following process systems are used in this building

Steam Humidification

Computer Room Cooling Units

ECMs:

1. Retrocommisioning (RCx): The following measures should be evaluated and incorporated as a retro-commissioning measure.

   - Convert remaining pneumatic controls on central systems to DDC. This includes:
     - MZ Unit serving original bldg
     - HW converters serving Original Bldg, 1962 and 1964 additions
   - Confirm need for humidification. On units serving areas where Humidifiers will remain active, optimize ASE set points and lockouts
   - Confirm that VAV boxes are functioning properly.
   - Provide unoccupied modes on select AHUs as follows
     - Use PB overrides to allow aggressive scheduling of fan speed (or duct static) and/or fan shut off.
     - Shut off EFs and reduce OA accordingly
     - Turn off reheat pumps and/or add solenoid valves to allow large sections of building to setback
     - Setback perimeter heat by turning off pumps (add space temp sensors)
     - Add solenoid valves to pneumatic branch lines to force VAV boxes closed (run new main air for selected areas). Or convert VAV to DDC.
   - Install CO2 sensors and implement DCV. Re-balance min OA
   - Add motion Sensors in auditorium to shut off S-3
   - Add discharge air and reheat supply temp reset control based on Oat and time of day (coordinate with Fan VFD energy)
   - Convert HW & CHW Valves from 3W to 2W in 1989 section
   - Replace Danfoss valves on perimeter FTR (1989) with pneumatic and sequence with reheats
   - Trim Pump Impellors (some TD valves are 20% open)
   - Where multiple computer room units serve same area, add controls to synchronize heat/cool, dehumidify and humidify controls.
   - Add monitoring of condensate tank and/or CR pumps

2. Use alternative humidification (atomization or ultrasonic)

3. Install heat recovery chiller and use condenser water for reheat and/or perimeter heat. May need to replace coils and/or FTR to utilize max 125F water. There should be enough heat in the building from all the electrical energy usage to eliminate the need for steam.

4. Allow CHW to reset up to 50F supply in winter and use Lydell cycle to use CHW as preheat

5. Replace 1957 multi-zone unit with new AHU and convert to VAV

6. Add ASE capability to 1957, 1962, and 1964 sections (may need to replace AHUs too)

7. Add supplemental cooling to critical rooms to allow AHU shutdown

8. Convert Steam FTR to HW and synchronize FTR heat with reheat valve (1957 and 1964 sections)

9. Steam System Insulation (steam room mostly)

10. Replace fan coil units on perimeter of 1962 addition with low temp HW ftr

11. Add big ass fans to destratify atrium in winter.

12. Add insulated window shades (?) to minimize heat loss from atrium skylight in winter.

13. Use heat pump water heaters and/or instantaneous electric for DHW

14. Replace Windows in original bldg and 1960s addition

Roger Adams Lab

General:

This facility houses the Chemistry and Chemical Engineering Laboratory and dates from 1947. The building had a major addition in 1964 and a series of renovations in the mid 1990's. Most recently the 3rd and 4th floors were renovated to provide laboratory and office space for researchers in biochemistry. This space includes some energy efficiency features including waste heat recovery from laboratory exhaust hoods.

Mechanical Systems: HVAC & DHW

The HVAC systems serving the original 1947 section of the building (much of which remains unaltered) rely on steam radiators for perimeter heat, constant volume heating and ventilating systems for air circulation, and constant volume exhaust for labs and fume hoods. The H&V units were sized at roughly 1 CFM per sf or 7 ACH based on gross area with over 50% outside air. The H&V units use a combination of steam preheat (with face and bypass damper control) and steam reheat (again with face and bypass control). There are approximately 20 H&V units and 40 zones which are arranged by exposure and occupancy. Cooling is provided by window air conditioning units to a great extent. There are numerous fume hoods served by dedicated exhaust fans. Approximately 30% of the 1947 building has had modern HVAC systems installed. By and large these are constant volume reheat systems, some using 100% outside air. The steam perimeter heat is generally left in place.

The HVAC system serving the 1963 addition is also a constant volume reheat system. The bulk of the building is served by 3 large dual duct AHUs operating with 100% OA. Offices and other ancillary areas are served by some smaller constant volume reheat systems with return air capability. The AHUs were sized at roughly 2 CFM per sf in this portion of the building. Cooling is provided by CHW coils using chw from the central plant. Steam from the central plant is used for preheat and reheat. There are approximately 90 fume hoods, each served by a dedicated fan. General exhaust from conditioned areas is also provided. Perimeter heat in the 1963 building is provided by HW finned tube.

Domestic hot water is created using steam from the central plant and stored in large tanks. There are two systems – one each for the 1947 and 1963 sections.

Controls:

The control systems in use vary with the age of the system.

The original HVAC systems in the 1947 section generally use local pneumatic control. The AHUs modulate the mixed air dampers and face and bypass dampers to maintain a fixed discharge temperature. Zone thermostats modulate the reheat coil bypass dampers. Perimeter heat in the 1947 section uses pneumatic valves presumably controlled by the same zone thermostat. The perimeter heat was originally designed as a vacuum system with OAT reset but it is not known if it is still functional at this point. There are 5 master steam zone control valves (radiation, reheat, preheat, process, and ?) that are presumed to enable/disable steam service based on OAT. Window air conditioning units use self contained controls.

The newer AHUs in the 1947 section have standalone DDC control systems.

The central systems in the 1963 addition have Barber Coleman (Siebe) DDC controls. The dual duct systems modulate the preheat and chilled water valves to maintain a fixed discharge temperature (58F at time of visit) and the reheat valve modulates to maintain a fixed DAT as well (90F at time of visit). Pneumatic thermostats in each lab and/or each zone modulate the hot and cold deck dampers in individual mixing boxes to maintain room temperature. S-4 serving the office area incorporates mixed air damper control for economizer operation.

Perimeter heat in the 1963 section runs wild. The HW temperature is reset based on OAT. There are no provisions for zoning.

Domestic hot water in both sections use self contained regulating valves.

Lighting Systems:

T12 lamps (see UIUC lighting project summary sheet for equivalent fixture counts)

Process Systems:

Both the 1947 and 1963 sections have steam humidifiers installed in the AHUS. It is not known if these are still active or functional. The 1963 addition uses a clean steam boiler to isolate the central plant steam from ventilation air.

Both sections have laboratory services such as gas, compressed air, vacuum, and RO and/or distilled water provided from central distribution points. It is probable that some autoclaves are installed and in use.

Supplemental cooling as well as research coolers and freezers are generally air cooled. Condensing units for split systems are located in mechanical spaces.

ECMs:

1947 Section

- Replace AHUs & perimeter heat.
    - AHUs: CHW from central plant, air side economizer, zoning to match occupancy and allow office areas and classrooms to be shut off (VAV/RH with DDC and shutoff boxes)
    - VAV or Occ/Unocc Lab Exhaust
    - Heat Recovery

- Perimeter Heat: HW with zone valves
- Note: Savings may be offset by code required upgrades (Lab ACH, 100% OA, etc)

- Replace DHW with Instantaneous
- AHU-405 (2002): Add Heat recovery. Close off bypass and balance with VFD

1963 Section

- Heat recovery (owner initiated)
- Add VAV or Occ/Unocc to Lab Exhaust
- RCx
    - CHW pump VFDs
    - HW Pump VFDs (wild coils but reverse return)
    - Optimize perimeter heat control (zone valves?)
    - Reduce ACH ?
- Replace DHW with Instantaneous

Global

- Dedicated water loop and convert DX equip (refrig, freezers, ice machines) to water cooled. Add autoclave discharge?. Reduction in A/C plus heat recovery.
- Steam Pipe Insulation
- Steam Traps
- EE Motors
- EMCS

Davenport

General:

Davenport Hall currently houses the Anthropology and Geology departments. It was originally built prior to 1950 to house the College of Architecture and has had numerous remodeling and renovation projects to transform it into it's current occupancy of labs, classrooms, auditoriums and offices. The building renovations appear to be piecemeal with mechanical systems installed and modified as needed to serve the renovated areas.

Mechanical Systems:

Davenport Hall has a steam perimeter heating system which has been modified throughout the years. It appears that most of the building uses convectors and/or finned tube radiation. At least one section had a vacuum system installed as part of a renovation. Many sections of the heating system have been replaced over the years with irregular documentation. The building has both a low pressure (15 psig) and a high pressure steam service. The high pressure line is used for process. Steam service is also provided to 2 separate locations. There is a condensate return system but it is not clear how robust it is.

Air conditioning and ventilation is provided by numerous air handling units that have been installed piecemeal for small scale renovations. The earliest available set of plans for these renovations is 1951. Not all plans are available and key information (CFM, HP, etc) is lacking on many of the plans that are available. Based on the information available it appears that there are at least 15 AHUs. The size, age and configuration of these units range from 1,000 CFM to approx 20,000 CFM; 10 to 55 years; and include window units, constant volume, variable volume, and multi zone units. Some units are 100% OA while others are 10% outside air. Most use steam for pre heat and reheat but there is at least one HW converter. Cooling is provided by a variety of sources including DX (including split systems) and chilled water. There are several small (25-40 ton) air cooled chillers still in service, some with glycol. It is believed that about 50% of the building is served by chilled water from the central plant. The variations seem to reflect both the diverse occupancy (wet labs, offices, classrooms), HVAC technology at the time of the design, and designer preferences.

There are numerous fume hoods scattered around in Davenport Hall. Most are served by individual exhaust fans.

DHW service is provided by two steam heat exchangers with integral storage tanks.

Controls:

The control systems used in Davenport vary widely. The perimeter heat uses a combination of pneumatic and self contained (danfoss) valves. The latter appear to be in fair to poor condition). Sections of the steam system are manually isolated in summer although reheats are left active.

Some AHUs have JCI DDC controls. These appear to be stand alone and are not networked in to the campus systems. Other (especially older) AHUs use distributed pneumatic controls. Most of the room level controls (for VAV, mz dampers, reheat coils, etc) are pneumatic, even. A similar situation exists for the few central mechanical systems (HW & CHW pumps, converters, chillers).

Domestic hot water heaters use self contained steam regulating valves.

Lighting Systems:

T12 lamps and ballasts (see UIUC lighting project summary sheet for equivalent fixture counts) and candidates for T8 upgrades with electronic ballasts.

Process Systems:

At least one autoclave is present in the building.

Several of the labs are wet labs with a complement of gas and medical air service.

Some AHUs have humidifiers although it is not known if they are functional. No clean steam systems were observed.

ECMs:

- RCx

  Add DDC control to steam zones (PRV pilot and space temp sensors)

  ASE (chiller on with OAT = 55) optimization

  Get perimeter heat in synch with overhead air (simultaneous heat & cool)

  Convert pneumatic to DDC (on/off, ef control, DCV)

  Network for scheduling etc.

- Replace select AHUs

  - 1951 SZCV serving Rm 139 ➔ Add economizer
  - 1956 CVRH units serving center section ➔ VAV/RH (offices and CRs)
  - 1964 MZ units serving NW & SW wings in original building ➔ VAV/RH (offices & CRs)
  - 1964/69 CVRH units serving SE wing ➔ VAV/RH (offices)

- Add AHUs

  - Get rid of window A/C and add economizer

- Try summer steam shutdown
  - Need summer steam for: DHW, Reheat, & Autoclave
  - Autoclaves ?
  - Backfeed LP from HP and isolate LP only
- Replace windows (sp to dp)
- Use electric autoclaves and isolate HP steam?
- Add time of day and/or water controls to autoclaves

Global

- Repair steam leaks and traps
- Insulate steam and CR pipes

Vet Med Basic Sciences

General:[12]

The VMBSB was first occupied in 1981 and has not undergone any major renovations or additions although some areas that were left unfinished in the original occupancy have been finished out in the intervening years. Many of these were anticipated in the original design. A major exception was an area on the 2nd and 3rd floors in which a major re-modeling project in 2003 required additional air handling equipment.

The VMBSB includes research laboratories, classrooms, teaching labs, a library, a café, and administrative/faculty offices.

The VMBSB is described as follows:

- 3–story structure (2-story at southern portion).
- Basement under the 3-story portion.
- Exposed aggregate, pre-cast concrete with ribbon windows; rust from fasteners/reinforcing is visible on face of concrete.
- Rooftop mechanical equipment and exhaust fans.
- Programs include: research laboratories, vivarium, diagnostic lab, incinerator, classrooms, teaching labs, administrative offices, café, and library.
- Atrium on second and third floors in research area.

Organization

- Research labs at the north.
- Classrooms at the south.
- Administration in laboratory space on the third floor.
- Library/Café on the south end of the first floor.
- Diagnostic Lab and vivarium at the north end of the first floor.

Steam

The Veterinary Medicine Campus is located on Lincoln Avenue south of Florida Avenue. This area of the UIUC campus is supplied with high-pressure steam from the campus steam loop. A 10” steam main extends from the north to the existing buildings as shown in the drawing below. The existing 10” diameter high-pressure steam main will supply

[12] The general information is taken largely from descriptions found in the UIUC website.

approximately 80,000 lbs/hr, which can support more than 450,000 square feet of building area.

Chilled Water

Chilled water is produced at a Chiller Plant located between the Small Animal Clinic and the Basic Sciences Building instead of from the campus loop. The Chiller Plant has the capacity to produce 3,220 tons of cooling for eight months a year. The chiller plant currently serves approximately 450,000 square feet of building. There is also an adsorption chiller at the plant that is not currently used. This chiller could be used, however, if there were a situation that called for additional chilled water.

UIUC Facilities and Services plans to move a 1,500-ton chiller into the Veterinary Medicine Campus Chiller Plant. This will result in an additional capacity capable of supporting approximately an additional 400,000 square feet. This addition will give the Veterinary Medicine Campus adequate capacity to serve the proposed additions to the Campus and leave excess capacity for redundancy. Significant energy savings are realized during the cold winter months when the plant is offline and many pieces of equipment are not operated. On warm days when the plant is offline, however, occupants experience uncomfortable conditions. This could be remedied by keeping one of the chillers active during winter for minor cooling loads.

Electrical

The electrical system currently supplying the Veterinary Medicine Campus is supplied from Distribution Center 11 (DC11) part of the UIUC campus electrical distribution system. DC 11 has a firm capacity of 15 megawatts at 12.47kV. UIUC has stated that there is adequate capacity in DC 11 for the proposed expansion. Existing buildings are supplied from a single 5,000kVA transformer owned by UIUC. The primary of this transformer is supplied from DC 11.

Basic Sciences Building

The HVAC system capacity in the Basic Sciences Building is adequate to support the proposed renovation project, as air-handling units are currently operating at approximately 65% of full load.

Small Animal Clinic

Many of the building systems in the Small Animal Clinic are currently running at, or near, 100% of their capacity. Future renovation work should include system upgrades to achieve better energy efficiency, maintenance access, and higher performance equipment.

Mechanical Systems:

Approximately 10 central station air handling units ranging in size from 8,700 to 74,000 CFM serve this building. Most of the AHUs are 100% outside air. A few of the smaller units are zoned for office/admin occupancy and have provisions for reducing the amount of OA to 25%. The AHUs use steam for heating and chilled water for cooling with return air units having economizer capability. The six 100% OA units located in the basement use the chilled water coils as preheat coils when the CHW system is manually changed over into a heat recovery mode. All of the original 8 AHUs located in the basement were originally provided with in flight adjustable vane axial fans. Most of these have been modified to use variable frequency drives. The two roof mounted units installed in 2002 use steam preheat and have VSDs. Many of the AHUs never exceed 70% capacity even on peak days but a few operate at 100% consistently.

The air handling systems are all variable volume with the odd constant volume box as needed. Laboratory's use a combination of air valves and 2 speed exhaust fans to provide an un-occupied cycle for exhaust with supply air tracking. Many of these 2 speed fans have had variable speed drives installed as a retrofit. All VAV boxes, including those serving offices, classrooms and support areas have a 50% minimum setting. There is no exterior/interior zoning. AHUs more or less serve areas with similar programmatic needs but there are many exceptions. In addition to dedicated fume hood exhaust fans, there are several general exhaust fans which incorporate heat recovery coils for use in a run around loop.

Steam is provided from the central plant through a high pressure line and reduced to medium and low pressure for end use. Low pressure steam is used directly for preheating in most of the central station air handling units. Low pressure steam is used as the heat source in separate converters to create hot water for perimeter heat and reheat, each of which have their own distribution systems and pumps. Condensate is collected via a gravity return system in the building and returned to the central plant via a pumped return system. Steam is available all year.

Cooling is primarily provided by chilled water which is produced in a central plant adjacent to the VMBSB. This plant has both absorption and electric water cooled centrifugal chillers. The former are reported to be abandoned in place. A secondary chilled water pump serves this building with a crossover bridge link to the primary system. The secondary CHW pump has a VSD and all large AHUs have two way valves. Chilled water is available as needed between April 1 and Dec 1. There is a heat recovery system in VMBSB that uses chilled water piping and coils via some manual changeover valves.

Supplemental cooling is provided by a combination of air cooled and water cooled systems. Condensing units are located in various locations including mechanical rooms, roof, and above ceilings. Water cooled systems are one pass using domestic water.

Domestic hot water is provided by steam bundles in storage tanks at a central location.

Controls:

The HVAC control systems are pneumatic and generally original. AHU control is very basic with steam and chilled water valves modulating to maintain a fixed discharge air temperature and fan speed (or vane position) modulated to maintain a fixed static pressure. Return fans (where they are used) track the supply fan.

VAV boxes and reheat coils use direct acting thermostats to modulate the air valve and HW valves in response to room set point and temperature. Rooms with general exhaust valves track the supply air valve. Switches allow for reduced air flow during unoccupied hours.

Perimeter heat runs wild with no control valves. The supply temperature is reset based on OAT. Reheat supply temperature is fixed. The heat recovery system is semi-automatic with manual switches positioning pneumatic valves. Domestic hot water uses self contained steam regulating valves.

All of the AHUs and the reheat pumps run continuously. Perimeter heat pumps and secondary chilled water pumps run seasonally based on manual operation.

Lighting Systems:

Primarily 2 lamp fixtures with 34 Watt fluorescent lamps and magnetic ballasts.

Process Systems:

Steam humidification is provided at the room level for several critical areas such as animal rooms.

Autoclaves, sterilizers, and cage washing systems are located in the building.

ECMs:

- Add Heat Recovery to AHU-2 (2002 Lab Unit)
- Optimize Existing Heat Recovery
    - Automatic Switchover
    - Gang Fume Hood Exhaust and add more exhaust CFM
- Modify AHU zoning to allow AHU shutdown at night (owner initiated)
- Convert once through water on env chambers to closed loop.
    - Convert Air cooled split systems to water cooled
    - Use process cooling loop for heat recovery
- RCx
    - Decommission fume hoods and/or convert to biological type with no exhaust
    - Decommission some env chambers?
    - Convert Pneumatic controls to DDC

- Automate Unoccupied sequence
- Add isolation valves to Reheat loop and isolate sections at night, during hot days, etc
- Add isolation valves to perimeter heat (South facing glass) & labs (with lots of internal heat)
- Perimeter Heat setback
- Reset SAT, SP
- Split mixed air damper control
- DCV
- Convert Office/support/admin VAV to DDC and add unoccupied setting (10% flow)

• Convert Fume Hoods to Low flow and re-balance

• Combine AHUs (3 @ 65% = 2@ 95%)

Wohlers

General:

The structure was originally built in 1963 and extensively renovated in 2000. It includes primarily classrooms and offices, and lecture halls.

Mechanical Systems: HVAC & DHW

Wohlers Hall is served by a constant volume reheat system with perimeter heat. Eight package air handling units, ranging from 10,000 to 16,000 CFM, serve floors 1 through 4. A field fabricated unit rated at 42,000 CFM serves the Ground floor and auditorium. All of the AHUs have steam preheat, chilled water and economizer controls with approximately 10% minimum outside air damper position. All AHUs also have variable speed drives which are used only for reduced air flow during unoccupied hours.

Reheat is provided by approximately 220 hot water reheat coils, each with their own pneumatic thermostat. Perimeter heat is provided by a combination of HW convectors, cabinet unit heaters and finned tube radiation. Reheat and perimeter heat use 2 way valves.

Chilled water is provided from a central plant. A secondary chilled water pump with VSD is used. Chilled water valves are 2 way.

Steam is provided from the central plant and separate converters are used for the reheat and perimeter heat systems.

DHW is provided by steam bundles in a storage tank.

Controls:

Control for the central equipment (AHUs, converters, and pumps) is provided by a JCI Metasys DDC system. AHU control is very basic with steam, chilled water and mixed air damper actuators modulating to maintain a fixed discharge air temperature. VFDs are used solely to reduce fan speed during unoccupied hours and the return fan speed tracks the supply fan.

Each room has a pneumatic thermostat to control the reheat coil and perimeter heat.

CHW, Reheat, and perimeter heat pumps vary speed as needed to maintain line pressures. Bypass valves are used to prevent pump dead heading

Process Systems: humidification, reverse osmosis (ro) water, autoclaves, etc

There are no process systems

ECMs:

- Replace windows (sp-dp, historic?)

- RCx

  Shut off AHUs at night (pb overrides) or at least shut off reheats and OA damper

  Shut off EF at night

  Chw pumps on with oat = 50F?

  DCV

  Optimize reset schedule with VFD operation

  SAT reset

  Add dampers to isolate auditorium (Occ sensor?) and adjust AHU-1 speed accordingly

  Confirm on campus DDC network

- Steam system insulation

APPENDIX C - Energy Savings Factors

Information for Tables 5.4-1 and 5.4-2 Energy Savings Factors

Table 5.4-1 Plant Output Energy Savings Factors

These factors are used to convert savings at the building meter (kWh or MMBtu of electricity, steam, or chilled water) into savings in the cogeneration plant output (MMBtu of electricity or steam) or purchased electricity in units of million British Thermal Units (MMBtu). Distribution losses are not included.

Electricity Savings: Each kWh of electricity saved is equal to .003412 MMBtu (e.g., 3412 Btu/kWh)

Steam Savings: Each klb of steam equates to 1.03 MMBtu (1030 Btu/lb – from Terry Ruprecht data)

Chilled Water:

- Electric Chillers: Each MMBtu of chilled water reduction at the building saves .1848 MMBtu of electricity at the chilled water plant, assuming the chilled water is supplied by electric chillers performing at .65 kW/ton (.65 kW/ton x 3412 Btu/kWh)/(12000 Btu/ton-hr) = .1848 MMBtu electricity/MMBtu chilled water saved)

- Steam driven chillers: Each MMBtu of chilled water reduction at the building saves .1848 MMBtu of steam at the chilled water plant, assuming the chilled water is supplied by steam driven chillers requiring 15 klb steam to generate 12 MMBtu of chilled water (15 klb x 1.0 MMBtu/klb/12 MMBtu chilled water) = 1.25 MMBtu steam/MMBtu chilled water saved

- Weighted Electric: .9 x .1848 MMBtu electricity/MMBtu chilled water saved = .166 MMBtu electricity/MMBtu chilled water saved

- Weighted Steam: .1 x 1.25 MMBtu steam/MMBtu chilled water saved.

Table 5.4-2 Site Energy Savings Factors

These factors are used to calculate the energy value of the fuel into the cogeneration plant or purchased electricity, in units of million British Thermal Units (MMBtu). Distribution losses are not included. Since there are different types of steam and electricity generating equipment, the factors assume various operating scenarios or cases. **Note that this is not used to develop energy costs, but to help in determining energy use at the campus boundary.**

Electricity Savings:

- Purchased Electricity Savings: Each kWh of purchased electricity saved is equal to .003412 MMBtu (e.g., 3412 Btu/kWh)

- Boiler/Steam Turbine: Each kWh reduction in electricity generated by the steam turbines results in a savings of **.023** MMBtu of boiler fuel. This assumes about 56.1 kWh electricity generated/klb of plant steam required per plant data. Fuel savings =

(electricity savings in kWh/ (56.1 kWh electricity/klb)) x (enthalpy of boiler steam out – enthalpy of boiler feedwater)/**boiler efficiency**. This results in (1/(56.1 x 1000)) x (1370 – 355)/.783) = **.023**.

- Gas Turbine/HRSG: Each kWh reduction in electricity generated by the gas turbine generators results in a net savings of .012 MMBtu of gas turbine fuel. This is based on gas turbine heat rate data – 12,000 Btu/kWh.

Steam Savings

- Boiler/Steam Turbine: Each klb in steam savings results in a net savings of .67 MMBtu in boiler fuel. This is a net savings since the reduction in boiler operation results in a reduction in electricity generated by the steam turbine generators. This electricity must be made up by purchased electricity or electricity generated by the gas turbine generator. This case assumes the electricity is made up by the gas turbine generator. The boiler fuel savings are: steam savings in klb x (enthalpy of boiler steam out – enthalpy of boiler feed water)/efficiency of boiler. The additional fuel required by the gas turbine generator is calculated from the additional electricity required times the gas turbine heat rate.

- Gas Turbine/HRSG: Each klb reduction in steam generated by the HRSG generators results in a net savings of 1.21 MMBtu of duct burner fuel. This is based on plant data.

Chilled Water Savings:

- Electric Chillers with Electricity Provided by the Boiler/Steam Turbine Generators: Each MMBtu of chilled water reduction at the building saves 1.27 MMBtu of boiler fuel. This is based on: ((.023 MMBtu boiler fuel/kWh electricity x .1848 MMBtu electricity/MMBtu chilled water saved))/.003412 MMBtu/kWh electricity

- Electric Chillers with Electricity Provided by the Gas Turbine Generators: Each MMBtu of chilled water reduction at the building saves .65 MMBtu of fuel. This is based on: ((.0120 MMBtu boiler fuel/kWh electricity x .1848 MMBtu electricity/MMBtu chilled water saved))/.003412 MMBtu/kWh electricity

- Steam Driven Chillers with Steam Provided by the Boilers: Each MMBtu of chilled water reduction at the building saves **1.56** MMBtu of fuel. This is based on: (1.25 MMBtu steam/MMBtu chilled water saved)/boiler efficiency, where the boiler efficiency is **80%**.

- Steam Driven Chillers with Steam Provided by the HRSGs: Each MMBtu of chilled water reduction at the building saves **1.51** MMBtu of fuel. This is based on: (1.25 MMBtu steam/MMBtu chilled water saved)/boiler efficiency, where the duct burner efficiency is **82.6**%.

- Weighted Electric with Electricity Provided by the Boiler/Steam Turbine Generators: .9 x **1.27** MMBtu boiler fuel saved/MMBtu chilled water saved = **1.143** MMBtu boiler fuel saved/MMBtu chilled water saved.

- Weighted Electric with Electricity Provided by the Gas Turbine Generators: .**9 x .65** MMBtu boiler fuel saved/MMBtu chilled water saved = **.585** MMBtu boiler fuel saved/MMBtu chilled water saved

- Weighted Steam with Steam Provided by the Boilers: **.1 x 1.56** MMBtu boiler fuel saved/MMBtu chilled water saved = **.161** MMBtu fuel saved/MMBtu chilled water saved.

- Weighted Steam with Steam Provided by the HRSGs: .**1 x 1.51** MMBtu boiler fuel saved/MMBtu chilled water saved = **.151** MMBtu fuel saved/MMBtu chilled water saved.

APPENDIX D - ECM Savings by Building Category

Classroom-Office – ECM Energy and Demand Savings

ECM #	ECM Descrip	Energy Usage Savings				Energy Demand Savings		
		Elec kWh	CHW MMBTU	Steam kLbs	Total MMBTU	Elec kW	CHW Tons	Steam kLbs/hr
E1	Replace Windows	-	3,934	10,960	14,894	-	125	4
E2	Insulate Roof	-	-	6,876	6,876	-	-	3
E3	Solar Film	-	1,967	1,493	3,460	-	62	-
E4	Weatherization	-	-	6,092	6,092	-	-	2
L1	General Lighting Upgrades (Interior, Lamps and Fixtures)	3,731,866	4,250	(3,161)	13,826	784	135	(1)
L2	Daylighting Controls/Daylight Harvesting	90,277	-	-	308	25	-	-
L3	Occupancy Sensors	87,247	-	-	298	100	-	-
L4	Exterior Lighting - including controls	66,031	-	-	225	-	-	-
M2	Retrocommissioning, General	3,210,645	24,953	35,882	71,793	367	792	7
M4	CAVRH to VAVRH Conversion, General (Mixed Air)	2,802,649	62,229	45,196	116,990	589	1,089	18
M5	Eliminate Reheat/Summer Steam	(219,080)	-	6,490	5,742	(46)	-	-
M9	Add Economizer Capability	-	22,412	-	22,412	-	-	-
M10	VSD Fans on AHUs (SZ VAV)	1,333,394	7,663	15,334	27,548	280	243	6
M11	VSD on Pumps	457,975	-	1,478	3,041	96	-	1
M12	Steam System Maintenance (Traps, insulation, etc)	-	624	5,091	5,715	-	20	1
M13	DX to CHW	669,547	(1,991)	-	294	188	(63)	-
M14								
C1	Install DDC on Central Equipment	1,658,391	18,119	20,994	44,773	-	317	4
C2	Install Motion Sensors for HVAC	37,496	357	254	739	-	-	-
P1	Insulate DHW Tanks	-	-	342	342	-	-	0
P2	Instantaneous DHW	-	-	73	73	-	-	-
P3	Solar assist for DHW	-	-	84	84	-	-	-
EQ1	Energy Star Computers, printers, etc	899,846	-	(2,263)	808	252	-	(1)
EQ2	Solar PV	214,645	-	-	733	60	-	-
-	Total	15,040,928	144,519	151,215	347,068	2,695	2,721	44
-	Baseline Usage - All Campus Buildings	278,185,522	1,039,124	1,527,195	3,515,488			
-	% Savings	5%	14%	10%	10%			
	Projects with B/C>=1	11,416,860	79,722	83,394	202,082	1,879	1,550	21
	% Savings - Projects with B/C>=1	4%	8%	5%	6%			
	CR/Ofc - Energy Usage	51,974,209	291,075	217,595	686,006			
	CR/Ofc - %Savings - Projects with B/C>=1	22%	27%	38%	29%			

Classroom-Office – ECM Cost Savings and Economics

ECM #	ECM Descrip	Elec	CHW	Steam	Total	Net Cost $	SPB Yrs	Benefit/ Cost	CSE ($/MMBtu)	Net Present Value
E1	Replace Windows	$0	$21,639	$76,719	$98,359	$4,960,859	50.4	0.41	$21.67	($2,555,797)
E2	Insulate Roof	$0	$0	$48,133	$48,133	$645,919	13.4	1.46	$6.67	$274,729
E3	Solar Film	$0	$10,820	$10,450	$21,270	$61,583	2.9	3.88	$2.30	$285,921
E4	Weatherization	$0	$0	$42,647	$42,647	$255,955	6.0	1.87	$5.44	$359,492
L1	General Lighting Upgrades (Interior, Lamps and Fixtures)	$261,231	$23,376	($22,129)	$262,478	$1,573,841	6.0	1.79	$14.74	$2,094,924
L2	Daylighting Controls/Daylight Harvesting	$6,319	$0	$0	$6,319	$113,986	18.0	0.97	$30.61	($3,915)
L3	Occupancy Sensors	$6,107	$0	$0	$6,107	$46,723	7.7	1.47	$20.32	$35,231
L4	Exterior Lighting - including controls	$4,622	$0	$0	$4,622	$199,577	43.2	0.42	$71.06	($115,843)
M2	Retrocommissioning, General	$224,745	$137,240	$251,174	$613,160	$5,122,537	8.4	1.34	$9.24	$2,840,442
M4	CAVRH to VAVRH Conversion, General (Mixed Air)	$196,185	$342,260	$316,371	$854,816	$22,282,738	26.1	0.69	$15.28	($6,797,206)
M5	Eliminate Reheat/Summer Steam	($15,336)	$0	$45,430	$30,094	$1,102,413	36.6	0.49	$15.41	($557,240)
M9	Add Economizer Capability	$0	$123,268	$0	$123,268	$1,818,072	14.7	1.23	$6.51	$415,013
M10	VSD Fans on AHUs (SZ VAV)	$93,338	$42,149	$107,336	$242,823	$908,375	3.7	3.94	$3.18	$3,281,810
M11	VSD on Pumps	$32,058	$0	$10,347	$42,406	$465,911	11.0	1.34	$14.76	$195,249
M12	Steam System Maintenance (Traps, insulation, etc)	$0	$3,434	$35,638	$39,072	$762,953	19.5	0.67	$14.62	($344,734)
M13	DX to CHW	$46,868	($10,952)	$0	$35,917	$1,583,135	44.1	0.44	$382.13	($813,149)
M14										
C1	Install DDC on Central Equipment	$116,087	$99,657	$146,957	$362,701	$2,849,643	7.9	1.43	$8.24	$1,971,482
C2	Install Motion Sensors for HVAC	$2,625	$1,961	$1,780	$6,366	$68,744	10.8	1.04	$12.05	$4,369
P1	Insulate DHW Tanks	$0	$0	$2,396	$2,396	$13,418	5.6	2.63	$3.78	$26,913
P2	Instantaneous DHW	$0	$0	$509	$509	$3,949	7.8	2.33	$4.36	$5,265
P3	Solar assist for DHW	$0	$0	$585	$585	$23,854	40.8	0.36	$27.50	($18,739)
EQ1	Energy Star Computers, printers, etc	$62,989	$0	($15,840)	$47,149	$126,651	2.7	2.34	$36.19	$489,584
EQ2	Solar PV	$15,025	$0	$0	$15,025	$1,399,316	93.1	0.19	$153.27	($1,127,127)
-	Total	$1,052,865	$794,853	$1,058,503	$2,906,222	$46,390,152	16.0	1.00	$11.36	($53,324)
-	Baseline Usage - All Campus Buildings	$19,472,987	$5,715,182	$10,690,365	$35,878,534					
-	% Savings	5%	14%	10%	9%					
	Projects with B/C>=1	$799,180	$438,471	$583,761	$1,821,413	$13,961,320	7.7	2.36		$12,280,426
	% Savings - Projects with B/C>=1	4%	8%	5%	5%					
	CR/Ofc - Energy Usage	$3,638,195	$1,600,913	$1,523,165	$6,762,272					
	CR/Ofc - %Savings - Projects with B/C>=1	22%	27%	38%	27%					

Laboratory Mix – ECM Energy and Demand Savings

ECM #	ECM Descrip	Energy Usage Savings				Energy Demand Savings		
		Elec	CHW	Steam	Total	Elec	CHW	Steam
		kWh	MMBTU	kLbs	MMBTU	kW	Tons	kLbs/hr
E1	Replace Windows	-	4,661	12,985	17,646	-	148	5
E2	Insulate Roof	-	-	8,147	8,147	-	-	3
E3	Solar Film	-	2,331	1,769	4,099	-	74	-
E4	Weatherization	-	-	7,218	7,218	-	-	3
L1	General Lighting Upgrades (Interior, Lamps and Fixtures)	4,421,390	5,035	(3,745)	16,380	929	160	(1)
L2	Daylighting Controls/Daylight Harvesting	106,957	-	-	365	30	-	-
L3	Occupancy Sensors	103,368	-	-	353	118	-	-
L4	Exterior Lighting - including controls	78,232	-	-	267	-	-	-
M1	Retrocommissioning, Labs	1,934,425	9,835	16,383	32,820	221	312	3
M2	Retrocommissioning, General	2,535,910	19,709	28,341	56,705	289	626	5
M3	2 Speed Fan Operation, Labs (100% OA)	1,193,726	4,597	8,877	17,548	-	-	2
M4	CAVRH to VAVRH Conversion, General (Mixed Air)	664,097	14,745	10,709	27,721	140	258	4
M6	Redirect Relief Air as Makeup Air	-	-	681	681	-	-	-
M8	Use CHW for Preheat	-	-	8,411	8,411	-	-	3
M9	Add Economizer Capability	-	13,277	-	13,277	-	-	-
M10	VSD Fans on AHUs (SZ VAV)	789,881	4,540	9,083	16,319	166	144	4
M11	VSD on Pumps	542,594	-	1,751	3,603	114	-	1
M12	Steam System Maintenance (Traps, insulation, etc)	-	740	6,032	6,772	-	23	1
M13	DX to CHW	793,257	(2,359)	-	348	222	(75)	-
M14								
M15	DeCommission Fume Hood	17,661	306	382	748	2	10	0
C1	Install DDC on Central Equipment	1,964,806	21,467	24,873	53,046	-	376	5
C2	Install Motion Sensors for HVAC	44,423	422	301	875	-	-	-
C3	Autoclave Controls	-	-	41	41	-	-	-
P1	Insulate DHW Tanks	-	-	406	406	-	-	0
P2	Instantaneous DHW	-	-	86	86	-	-	-
P3	Solar assist for DHW	-	-	99	99	-	-	-
EQ1	Energy Star Computers, printers, etc	533,054	-	(1,340)	479	149	-	(1)
EQ2	Solar PV	254,304	-	-	868	71	-	-
-	Total	15,978,084	99,306	141,489	295,329	2,452	2,057	37
-	Baseline Usage - All Campus Buildings	278,185,522	1,039,124	1,527,195	3,515,488			
-	% Savings	6%	10%	9%	8%			
	Projects with B/C>=1	12,146,812	71,684	95,241	208,382	1,768	1,390	24
	% Savings - Projects with B/C>=1	4%	7%	6%	6%			
	Lab Mix - Energy Usage	81,961,313	452,946	382,139	1,114,737			
	Lab Mix - %Savings - Projects with B/C>=1	15%	16%	25%	19%			

Laboratory Mix – ECM Cost Savings and Economics

ECM #	ECM Descrip	Elec	CHW	Steam	Total	Net Cost $	SPB Yrs	Benefit/Cost	CSE ($/MMBtu	Net Present Value
E1	Replace Windows	$0	$25,638	$90,895	$116,532	$5,877,460	50.4	0.41	$21.67	($3,028,022)
E2	Insulate Roof	$0	$0	$57,026	$57,026	$765,263	13.4	1.46	$6.67	$325,490
E3	Solar Film	$0	$12,819	$12,381	$25,199	$72,962	2.9	3.88	$2.30	$338,749
E4	Weatherization	$0	$0	$50,527	$50,527	$303,247	6.0	1.87	$5.44	$425,915
L1	General Lighting Upgrades (Interior, Lamps and Fixtures)	$309,497	$27,695	($26,217)	$310,975	$1,864,634	6.0	1.79	$14.74	$2,481,997
L2	Daylighting Controls/Daylight Harvesting	$7,487	$0	$0	$7,487	$135,046	18.0	0.97	$30.61	($4,639)
L3	Occupancy Sensors	$7,236	$0	$0	$7,236	$55,356	7.7	1.47	$20.32	$41,741
L4	Exterior Lighting - including controls	$5,476	$0	$0	$5,476	$236,452	43.2	0.42	$71.06	($137,247)
M1	Retrocommissioning, Labs	$135,410	$54,091	$114,680	$304,181	$4,518,371	14.9	0.99	$13.26	($46,070)
M2	Retrocommissioning, General	$177,514	$108,398	$198,389	$484,301	$4,046,007	8.4	1.34	$9.24	$2,243,507
M3	2 Speed Fan Operation, Labs (100% OA)	$83,561	$25,283	$62,140	$170,984	$1,634,833	9.6	1.54	$8.98	$1,087,043
M4	CAVRH to VAVRH Conversion, General (Mixed Air)	$46,487	$81,100	$74,965	$202,552	$5,279,969	26.1	0.69	$15.28	($1,610,621)
M6	Redirect Relief Air as Makeup Air	$0	$0	$4,768	$4,768	$66,481	13.9	1.06	$9.40	$4,627
M8	Use CHW for Preheat	$0	$0	$58,878	$58,878	$46,235	0.8	18.76	$0.53	$1,009,754
M9	Add Economizer Capability	$0	$73,022	$0	$73,022	$1,076,996	14.7	1.23	$6.51	$245,847
M10	VSD Fans on AHUs (SZ VAV)	$55,292	$24,968	$63,584	$143,844	$538,106	3.7	3.94	$3.18	$1,944,090
M11	VSD on Pumps	$37,982	$0	$12,259	$50,241	$551,996	11.0	1.34	$14.76	$231,325
M12	Steam System Maintenance (Traps, insulation, etc)	$0	$4,069	$42,222	$46,291	$903,922	19.5	0.67	$14.62	($408,430)
M13	DX to CHW	$55,528	($12,975)	$0	$42,553	$1,875,646	44.1	0.44	$382.13	($963,392)
M14										
M15	DeCommission Fume Hood	$1,236	$1,684	$2,672	$5,591	$4,689	0.8	13.38	$0.81	$93,725
C1	Install DDC on Central Equipment	$137,536	$118,070	$174,110	$429,716	$3,376,162	7.9	1.43	$8.24	$2,335,747
C2	Install Motion Sensors for HVAC	$3,110	$2,324	$2,108	$7,542	$81,445	10.8	1.04	$12.05	$5,176
C3	Autoclave Controls	$0	$0	$287	$287	$3,564	12.4	0.90	$11.27	($559)
P1	Insulate DHW Tanks	$0	$0	$2,839	$2,839	$15,897	5.6	2.63	$3.78	$31,886
P2	Instantaneous DHW	$0	$0	$603	$603	$4,679	7.8	2.33	$4.36	$6,237
P3	Solar assist for DHW	$0	$0	$693	$693	$28,262	40.8	0.36	$27.50	($22,201)
EQ1	Energy Star Computers, printers, etc	$37,314	$0	($9,383)	$27,931	$75,026	2.7	2.34	$36.19	$290,021
EQ2	Solar PV	$17,801	$0	$0	$17,801	$1,657,863	93.1	0.19	$153.27	($1,335,382)
-	Total	$1,118,466	$546,185	$990,426	$2,655,077	$35,096,568	13.2	1.13	$10.55	$5,586,313
-	Baseline Usage - All Campus Buildings	$19,472,987	$5,715,182	$10,690,365	$35,878,534					
-	% Savings	6%	10%	9%	8%					
	Projects with B/C>=1	$850,277	$394,263	$666,684	$1,911,224	$14,580,013	7.6	2.37		$13,142,876
	% Savings - Projects with B/C>=1	4%	7%	6%	5%					
	Lab Mix - Energy Usage	$5,737,292	$2,491,203	$2,674,973	$10,903,468					
	Lab Mix - %Savings - Projects with B/C>=1	15%	16%	25%	18%					

Research Laboratory – ECM Energy and Demand Savings

ECM #	ECM Descrip	Energy Usage Savings				Energy Demand Savings		
		Elec kWh	CHW MMBTU	Steam kLbs	Total MMBTU	Elec kW	CHW Tons	Steam kLbs/hr
E1	Replace Windows	-	2,104	5,862	7,966	-	67	2
E2	Insulate Roof	-	-	3,678	3,678	-	-	1
E3	Solar Film	-	1,052	798	1,851	-	33	-
E4	Weatherization	-	-	3,259	3,259	-	-	1
L1	General Lighting Upgrades (Interior, Lamps and Fixtures)	1,995,977	2,273	(1,691)	7,395	419	72	(1)
L2	Daylighting Controls/Daylight Harvesting	48,284	-	-	165	14	-	-
L3	Occupancy Sensors	46,664	-	-	159	53	-	-
L4	Exterior Lighting - including controls	35,317	-	-	121	-	-	-
M1	Retrocommissioning, Labs	1,746,541	8,880	14,792	29,632	199	282	3
M2	Retrocommissioning, General	572,401	4,449	6,397	12,799	65	141	1
M3	2 Speed Fan Operation, Labs (100% OA)	1,077,783	4,150	8,015	15,844	-	-	2
M4	CAVRH to VAVRH Conversion, General (Mixed Air)	599,595	13,313	9,669	25,029	126	233	4
M6	Redirect Relief Air as Makeup Air	-	-	615	615	-	-	-
M7	Heat Recovery, Air to Air	(777,817)	-	12,928	10,273	(89)	-	5
M8	Use CHW for Preheat	-	-	7,594	7,594	-	-	3
M10	VSD Fans on AHUs (SZ VAV)	71,316	410	820	1,473	15	13	0
M11	VSD on Pumps	244,947	-	791	1,627	51	-	0
M12	Steam System Maintenance (Traps, insulation, etc)	-	334	2,723	3,057	-	11	0
M13	DX to CHW	358,105	(1,065)	-	157	100	(34)	-
M14								
M15	DeCommission Fume Hood	15,946	276	345	675	2	9	0
M16	VAV-Phoenix retrofit Labs	1,569,470	7,459	12,064	24,880	179	237	5
C1	Install DDC on Central Equipment	295,662	3,230	3,743	7,982	-	57	1
C3	Autoclave Controls	-	-	37	37	-	-	-
P1	Insulate DHW Tanks	-	-	183	183	-	-	0
P2	Instantaneous DHW	-	-	78	78	-	-	-
P3	Solar assist for DHW	-	-	45	45	-	-	-
EQ1	Energy Star Computers, printers, etc	240,640	-	(605)	216	67	-	(0)
EQ2	Solar PV	114,802	-	-	392	32	-	-
-	Total	8,255,633	46,866	92,139	167,181	1,236	1,121	28
-	Baseline Usage - All Campus Buildings	278,185,522	1,039,124	1,527,195	3,515,488			
-	% Savings	3%	5%	6%	5%			
	Projects with B/C>=1	6,130,806	23,300	46,083	90,308	853	562	14
	% Savings - Projects with B/C>=1	2%	2%	3%	3%			
	Research Lab - Energy Usage	57,752,638	332,720	255,146	784,918			
	Research Lab - %Savings - Projects with B/C>=1	14%	14%	36%	21%			

Research Laboratory – ECM Cost Savings and Economics

ECM #	ECM Descrip	Elec	CHW	Steam	Total	Net Cost $	SPB Yrs	Benefit/Cost	CSE ($/MMBtu)
E1	Replace Windows	$0	$11,574	$41,033	$52,607	$2,653,301	50.4	0.41	$21.67
E2	Insulate Roof	$0	$0	$25,744	$25,744	$345,468	13.4	1.46	$6.67
E3	Solar Film	$0	$5,787	$5,589	$11,376	$32,938	2.9	3.88	$2.30
E4	Weatherization	$0	$0	$22,810	$22,810	$136,897	6.0	1.87	$5.44
L1	General Lighting Upgrades (Interior, Lamps and Fixtures)	$139,718	$12,502	($11,836)	$140,385	$841,764	6.0	1.79	$14.74
L2	Daylighting Controls/Daylight Harvesting	$3,380	$0	$0	$3,380	$60,965	18.0	0.97	$30.61
L3	Occupancy Sensors	$3,266	$0	$0	$3,266	$24,990	7.7	1.47	$20.32
L4	Exterior Lighting - including controls	$2,472	$0	$0	$2,472	$106,743	43.2	0.42	$71.06
M1	Retrocommissioning, Labs	$122,258	$48,837	$103,542	$274,637	$4,079,516	14.9	0.99	$13.26
M2	Retrocommissioning, General	$40,068	$24,467	$44,780	$109,316	$913,258	8.4	1.34	$9.24
M3	2 Speed Fan Operation, Labs (100% OA)	$75,445	$22,828	$56,105	$154,377	$1,476,047	9.6	1.54	$8.98
M4	CAVRH to VAVRH Conversion, General (Mixed Air)	$41,972	$73,223	$67,684	$182,878	$4,767,142	26.1	0.69	$15.28
M6	Redirect Relief Air as Makeup Air	$0	$0	$4,305	$4,305	$60,024	13.9	1.06	$9.40
M7	Heat Recovery, Air to Air	($54,447)	$0	$90,495	$36,048	$2,098,115	58.2	0.25	$19.68
M8	Use CHW for Preheat	$0	$0	$53,159	$53,159	$41,744	0.8	18.76	$0.53
M10	VSD Fans on AHUs (SZ VAV)	$4,992	$2,254	$5,741	$12,987	$48,584	3.7	3.94	$3.18
M11	VSD on Pumps	$17,146	$0	$5,534	$22,681	$249,191	11.0	1.34	$14.76
M12	Steam System Maintenance (Traps, insulation, etc)	$0	$1,837	$19,061	$20,897	$408,063	19.5	0.67	$14.62
M13	DX to CHW	$25,067	($5,857)	$0	$19,210	$846,735	44.1	0.44	$382.13
M14									
M15	DeCommission Fume Hood	$1,116	$1,520	$2,412	$5,048	$4,234	0.8	13.38	$0.81
M16	VAV-Phoenix retrofit Labs	$109,863	$41,022	$84,450	$235,335	$4,051,627	17.2	1.05	$13.07
C1	Install DDC on Central Equipment	$20,696	$17,767	$26,200	$64,663	$508,041	7.9	1.43	$8.24
C3	Autoclave Controls	$0	$0	$259	$259	$3,218	12.4	0.90	$11.27
P1	Insulate DHW Tanks	$0	$0	$1,282	$1,282	$7,177	5.6	2.63	$3.78
P2	Instantaneous DHW	$0	$0	$544	$544	$4,225	7.8	2.33	$4.36
P3	Solar assist for DHW	$0	$0	$313	$313	$12,758	40.8	0.36	$27.50
EQ1	Energy Star Computers, printers, etc	$16,845	$0	($4,236)	$12,609	$33,869	2.7	2.34	$36.19
EQ2	Solar PV	$8,036	$0	$0	$8,036	$748,420	93.1	0.19	$153.27
-	Total	$577,894	$257,761	$644,970	$1,480,625	$24,565,053	16.6	0.97	$12.62
-	Baseline Usage - All Campus Buildings	$19,472,987	$5,715,182	$10,690,365	$35,878,534				
-	% Savings	3%	5%	6%	4%				
	Projects with B/C>=1	$429,156	$128,148	$322,584	$879,888	$8,780,076	10.0	1.82	
	% Savings - Projects with B/C>=1	2%	2%	3%	2%				
	Research Lab - Energy Usage	$4,042,685	$1,829,960	$1,786,022	$7,658,667				
	Research Lab - %Savings - Projects with B/C>=1	14%	14%	36%	19%				

Facility Energy Metering
University of Illinois - Urbana-Champaign

Task E Final Report

September 2009

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Summary

This task report contains a review of the facility energy metering needs of the University of Illinois at Urbana-Champaign (UIUC) and metering recommendations. The determination of additional metering needs was based on a comparison of the current metering program, including its extent of coverage of campus buildings and energy use, in comparison to the university's metering objectives. The university provided information on the energy usage, a list of the existing meters, and a portion of the internal college shadow billings. This information was used to identify "gaps" in metering coverage. The gap analysis examined the cost effectiveness of adding new meters. It also analyzes upgrading the existing electric meters and putting the remaining steam meters into the existing direct digital control (DDC) system.

The UIUC campus has concentrated its recent metering efforts on the top 80 academic (e.g., state funded) energy consuming buildings, since these buildings account for an estimated 90% of campus energy usage. A total of 90 steam condensate, and 21 chilled water meters were installed in the past two and one-half years. This analysis looks at expanding the metering coverage to the top 120 academic locations, representing 96% of campus energy usage.

A simplified economic analysis was performed to determine if additional metering or upgraded metering could be justified on an energy/operational cost savings basis. The assumption was that where no metering existed, 6% of the building's estimated energy use could be saved. For situations where upgrading an existing meter was considered or connecting the existing metering into a campus energy management system, a savings figure of 2% of the building's energy use was assumed.

Overall, the existing metering system at the UIUC campus provides excellent coverage of buildings that use the vast majority of campus energy. From the perspective of ESPC projects the existing metering should be adequate for developing average energy use baselines at the whole building level. For projects where peak demand reductions are an important component of the cost savings guarantees, additional metering may be required. However, investments in this type of monitoring are best made after the decision to move forward with specific types of projects.

Nonetheless, there are opportunities to improve the benefits of metering, as well as to expand the metering on campus. Based on our review we suggest that:

- Bring the total number of fully metered academic buildings to 120 which accounts for 96% of campus energy use. This would require installing a total of 5 steam condensate meters and 4 chilled water meters.

- Existing meters that are not already linked to the energy management systems be connected to the system, where practical. Connecting the existing meters to the system would automate the process of meter reading, and with the appropriate software, enable energy use data to be evaluated at much finer time intervals. This would enhance the ability to identify inefficient energy use through load profiling and enhance diagnostic

and troubleshooting capabilities. To benefit from this additional staff time/resources would be needed.

- A meter calibration program should be established. This would help maintain the accuracy of the readings, and establish confidence for billing purposes. Electrical meters should be calibrated once every three to four years. Steam condensate and chilled water meters should be calibrated annually. In addition, consideration should be given to using short-term steam measurements as a means of checking energy estimates based on the condensate meters in selected buildings. This could be used to develop adjustment factors to apply to the condensate meter based energy values to get them closer to a true steam usage value.

UIUC has embarked on a course to raise awareness through its billing system. In order for a metering system to be successful it needs trained users, management buy-in/leadership, campus wide awareness and it needs to be maintained. Furthermore, if the potential of the metering system is to be fully realized, there need to be staff resources to review the energy use data on an ongoing basis and be in a position to act on the information.

1. *Introduction*

The objective of this task report is to identify metering improvements to support facility energy management and related objectives (e.g., diagnostics, cost allocation, billing, performance benchmarking). This solution includes improvements to the existing metering that enhance the building system diagnostics as well as create consumer incentives.

The SAIC approach involved a structured process that mapped the current metering situation to information objectives of the metering. SAIC obtained meter lists/inventories provided by the university and interviewed facilities staff to gain an understanding of the metering program and plans. SAIC assessed necessary data elements based on metering objectives – whether the data is being used to support billing, energy management, or condition/status monitoring (diagnostics, maintenance management, power quality, etc.). SAIC also reviewed existing and proposed metering in the context of Measurement & Verification (M&V) of future Energy Saving Performance Contracts (ESPC). A gap analysis was used to determine additional metering that may be needed or is desirable. This was based, in part, on the estimated magnitude of the energy usage of the facility. SAIC also investigated alternative monitoring approaches where appropriate. The criteria for the analysis included the elements identified under data needs, accuracy and granularity of the data, extent of coverage, and data collection/communication needs.

2. *Campus Metering Overview*

Historically, UIUC campus energy usage and billing was based on metering at the central heating and power plant and chilled water plants, along with utility meters for purchased electricity and fuels, as well as selected meters at a number of buildings. These buildings generally fell under the classification of housing and auxiliary buildings – buildings excluded from state support of utility expenditures (housing, Illini Union, commercial food service, etc.). Beginning in 2007, the campus launched an extensive metering program, with the following objectives:

- Provide data to enable billing of academic departments and units in state funded buildings
- Provide information to the facility occupants/operators to raise awareness and encourage energy conservation,
- Benchmark energy usage for targeting energy reduction opportunities

The approximately $2.5 million dollar program resulted in the installation of 90 steam condensate and 21 chilled water meters in the Top 80 energy consuming academic (e.g., state funded) buildings. These buildings account for 90% of campus energy use. Beginning in FY2010 (July 1, 2009) the meter data will be used as the basis for billing each academic unit for their energy use.

3. *Existing Metering*

Information on existing building meters was provided by the university in the form an Excel spreadsheet named "*TR_01_14_09_meterlist.xls*". The characteristics and capabilities of the existing meters organized by electric, steam, or chilled water follows. In addition, information on the communications method, and meter data management software is identified. Note that the general comments made on each type of meter are from the information based on the manufacturer or model number provided.

In order to ensure meter accuracy a calibration program is desirable. Typically, electrical meters should be calibrated once every three to four years. Steam and chilled water meters should be calibrated annually. At the present time, there is not a formal meter calibration program at the university. Meter problems are identified through review of the meter data (monthly readings), and corrective action is taken, as necessary. A recent review of three months of actual readings indicated approximately 17 out of 720 readings (combined electric, steam condensate, and chilled water monthly data) that had to be edited/estimated due to a metering related problem.[1]

3.1 Electric Meters

There are 1171 electric meters distributed across 526 locations (total campus). Most of the top 80 academic buildings have multiple electrical meters in use. These meters are located per the electrical distribution, and not aligned with specific tenants. There are a variety of meters in use as shown in the following table:

Table E-1. Summary of Existing Electric Meters

Manufacturer/ Model	Quantity	Type	Communication Option
Duncan	7	analog	No
General Electric	315	analog	No
Sangamo	25	analog	No
Westinghouse	80	analog	No
AB PM3000	42	digital	Yes
Itron	186	digital	Yes
LANDIS & GYR	6	digital	Yes
Schlumberger	56	digital	Yes
Siemens	99	digital	Yes
Unspecified	355		

The electric meters measure cumulative electricity usage in kilowatt hours (kWh) and are read once a month by facilities staff. Meters that are identified as digital also have the capability to record data during specified time intervals, which can be useful for developing time differentiated electricity use profiles. Other features, such as harmonics detection can be used to identify power quality problems, etc. However, these features are currently not being used.

[1] Per discussion with Terry Ruprecht. Related problems include improperly functioning check valves that result in erroneous steam condensate flow measurements.

Communications

Meters with communications options are capable of automated reading. However, this feature is not used.

Meter Data Management

The meter data is read manually via Palm Pilot device and is loaded into the CHAMPS system, which calculates the electricity consumption. Allocation of electricity use below the building level is accomplished by a combination of floor area allocation and modeling, depending on building usage characteristics (e.g., laboratory vs. office/administrative, etc.). Specifically, the impact of fume hoods is modeled using the Trace computer program. The energy associated with the laboratory fume hoods (electricity, as well as steam and chilled water) is subtracted from the whole building use, and the balance of the energy use is apportioned on a floor area basis. The energy bills based on this usage allocation and defined unit energy costs. Data errors are identified by observation (review by the Energy Manager) and trending is accomplished by comparing, month to month variations or year over year variations.

3.2 Steam Condensate Meters

Steam usage is measured indirectly, through the use of steam condensate meters, rather than direct measurement of steam via steam meters. The advantages of steam condensate meters are that they are less expensive, easier to maintain, and easier to calibrate than steam meters. The primary disadvantage is that the condensate measurement reflects the net amount of water, after losses in the building, and not the actual amount of steam used. This loss can vary in each building. The steam condensate meters at the buildings measure the quantities of condensate returned from the building's steam system in thousands of pounds per hour. There are 177 steam condensate meters distributed across 138 buildings (includes academic and auxiliary). These meters measure all but 14% of the total campus facility steam use.

There are a variety of meters in use as shown in the following table:

Table E-2. Summary of Existing Steam Condensate Meters

Manufacturer/ Model	Quantity	Type	Communication Option	Accuracy
ABB	48	magnetic	4-20mA Hart, Profibus	+/- 0.2 to 0.5%
Badger	87	Pos Displ.	Contact	NA
Cadillac	39	magnetic	4-20mA	+/-0.5%
Krohne	6	magnetic	4-20mA Hart, Profibus	+/-0.15%
Yokogawa	2	vortex	4-20mA	+/-0.75%

Communications

About 60% of the steam condensate meters are on the direct digital control (DDC) system (Siemens or in a few cases Andover systems). The other meters must be read manually.

Meter Data Management

The data from meters that are linked to the energy management systems (flow measurements) is combined with associated thermal data to develop energy (Btu) data. The software package with the system generates steam usage reports. The data that is read manually via Palm Pilot is also entered into the report. Allocation of steam use below the building level is accomplished by a combination of floor area allocation and modeling, depending on building usage characteristics (e.g., laboratory vs. office/administrative, etc.). Specifically, the impact of fume hoods is modeled using the Trace computer program. The energy associated with the laboratory fume hoods (steam, as well as electricity and chilled water) is subtracted from the whole building use, and the balance of the energy use is apportioned on a floor area basis. The energy bills based on this usage allocation and defined unit energy costs. Data errors are identified by observation (review by the Energy Manager) and trending is accomplished by comparing, month to month variations or year over year variations.

3.3 Chilled Water Meters

There are 90 chilled water meters distributed across 87 (includes academic and auxiliary) buildings. These meters measure all but 13% of the total campus facility chilled water use. The existing chilled water meters determine the energy content of the water in British Thermal Units (Btu). There are a variety of meters in use as shown in the table below:

Table E-3. Summary of Existing Chilled Water Meters

Manufacturer/ Model	Quantity	Type	Communication Option	Accuracy
ABB	58	magnetic	RS232, HART, PROFIBUS	+/- 0.2 to 0.5%
ES Pro	2	Diff Press.	NA	+/- 0.2 to 0.5%
Rosemount Pro-Bar	10	annubar	HART	+/- 1.1%
Veris Verabar	1	annubar	yes	+/- 1.1%

Communications

All of the chilled water meters are linked to the energy management systems.

Meter Data Management

The data from meters (flow measurements) is combined with associated temperature data to develop energy (Btu) data. The software package with the system generates chilled water usage reports. Allocation of chilled water use below the building level is accomplished by a combination of floor area allocation and modeling, depending on building usage characteristics (e.g., laboratory vs. office/administrative, etc.). Specifically, the impact of fume hoods and animal rooms is modeled using the Trace computer program. The energy associated with the laboratory fume hoods (chilled water, as well as electricity and steam) is subtracted from the whole building use, and the balance of the energy use is apportioned on a floor area basis. The energy bills based on this usage allocation and defined unit energy costs. Data errors are identified by observation (review by the Energy Manager) and trending is accomplished by comparing, month to month variations or year over year variations.

4. *Metering Analysis*

The existing campus metering has the capability to meet the billing and energy information objectives of the campus for buildings that represent the large majority of campus energy use. This is summarized in the table below:

Table E-4. Summary of Existing Metering Capabilities vs. Objectives

Meter System	Billing	Benchmarking	Diagnostics	ESPC Projects
Utility Meters				
Analog read manually	Good	Adequate	Poor	Adequate
Digital w/real-time data	Good	Adequate	Very Good	Adequate
Meter Data Management	Excellent	Excellent	Excellent	Excellent

While there are a wide variety of meters in use, so long as they remain functional, and are properly maintained and calibrated, their replacement must be driven by economics or other policy considerations. The same holds true for additional metering (whole building or sub-metering within the building) or alternative meters. For example, if certain energy savings projects are planned that will affect major building energy systems (e.g., specific ESPC projects); it may be useful to perform baseline metering of these systems.

4.1 Economic Analysis of Adding Meters

The economics of additional or alternative metering is not straight forward from an energy standpoint given that the metering itself does not save energy. The meter information must be acted on by the facility energy staff and the building occupants, in order to effect energy reductions and cost savings. However, a number of studies have indicated that such actions do occur once a metering program is in place, with savings estimates ranging from a few percent to as much as ten percent or more.[2] Given this, we performed a simplified analysis to determine the economics of adding meters to unmetered buildings, or in some cases upgrading meters or linking them to the DDC system.

The analysis involved the identification of buildings that were unmetered and in some cases "partially metered" - lacking either steam or chilled water meters. The assumption was that where no metering existed, 6% of the building's estimated energy use could be saved. In addition, we analyzed situations where connecting the existing metering into a campus Direct Digital Control (DDC) systems or upgrading an existing meter could be beneficial. In this case, a savings figure of 2% of the building's energy use was assumed. A simple payback period of 10 years was used as the cutoff for economic feasibility.[3] The unit energy costs assumed were: $ 0.0954/kWh for electricity, $14.96/MMBtu for steam, and $10.85/MMBtu for chilled water. Note that the meter costs used in the analysis did not include periodic maintenance/calibration or

[2] The article "Submeters: The Best-Kept Secret" by School Construction News stated reduced energy consumption of 5 percent to 15 percent from sub metering. The document *Sub-Metering Energy Use in Colleges and Universities: Incentives and Challenges* from the U.S. Environmental Protection Agency's ENERGY STAR, December 2002, stated two case studies with at least 10-percent reduction in costs.

[3] Simple Payback Period is the number of years required to recover the installed cost of the meters, based on the annual energy cost savings attributed to the meters.. This is calculated by dividing the installed cost by the annual energy cost savings.

costs of staff that would be required if meter data was to be reviewed on a daily basis for diagnostic purposes.

4.1.1 ***Electrical Meters***

Adding New Meters

There are no buildings with significant electricity use that are not already metered. Therefore, no new meters are required to be added.

Linking Existing Electric Meters to the Energy Management System

Connecting the existing meters to the energy management system would automate the process of meter reading, and with the appropriate software, enable energy use data to be evaluated at much finer time intervals. This would enhance the ability to identify inefficient energy use (load profiling) and enhance diagnostic and troubleshooting capabilities. For existing meters with pulse capability, the connection would involve wiring costs and potentially adding booster relays for long runs. For meters that do not have pulse capability, a special relay would first need to be installed (KYZ relay), to add this functionality. Typical installed costs are $350 -$500 in buildings that already have a state-of-the-art, expandable BAS. For buildings that do not, such as many of the campus buildings, the cost for BAS connection is much higher for this modification. Once connected data transfer would be ongoing, and provide the capability for near real time reporting and associated decision making capabilities. An alternative option would be to install a low cost data recorder/logger with communications capabilities to record the pulses with a date and time stamp associated. Retrieval of the interval data could then be conducted at a later time. The cost of data logger/recorders varies from a low of $100 to $1,000. The cost differential is based on whether the unit includes a display, the amount of memory, and communication modules. However, this option would not provide the ready access to the data as would the connection the automated system. Furthermore, it would still require staffing for data reduction/analysis to reap the benefits.

Upgrading with Advanced Meters

Replacement of existing analog meters with new solid state digital meters is an alternative means of obtaining interval data. One of the main benefits of utilizing a meter versus a data logger/recorder is that meter installation is much quicker and easier and can typically be accomplished in less than an hour. While installation costs are much lower, the cost of the meter can be much higher. Cost ranges for solid state meters, purchased in low volume, are typically between $1,000 and $7,500. Even at the low end of the cost range basic interval data recording with multiple data channels is possible. The cost differential is based on the meter functionality (4 quadrant recording, power quality capability, alarming and events, etc.), mode of communications (frame relay, fiber optics, radio, phone, microwave, etc.), and physical characteristics (display type, durable construction, etc.).

Another consideration in solid state meter deployment is how the interval data will be retrieved. Multiple communication methods are possible, but more importantly to the actual communication mode (phone, radio, etc.) is ensuring the capability to retrieve the data from the meter. While there is ANSI standards associated with solid state metering and how the data is stored there is an issue with each meter vendor utilizing a proprietary communications protocol. There are two solutions to this issue. The first is to purchase all the meters from the same vendor and then utilize their, typically no or low cost, communications software to retrieve and store the interval data. The second is to purchase a multi-vendor capable communications and translation software. This option allows you to purchase meters from various vendors while eliminating the need to utilize vendor specific communication software.

Note that when replacing older electric meters with new solid state meters, and particularly meters that have not been calibrated, energy usage will appear to increase. This is due to the under-recording of energy usage with the older meters, as they wear (slow down). For situations where the existing metering had been used for billing, this would require educating the tenant.

The analysis of upgrading the existing electric meters with advanced solid state interval meters and tying them into an energy management system assuming a $7,000 meter cost and 2% savings in electricity use.

Table E-5. Economic Analysis of Upgrading Existing Electrical Meters

Locations	Quantity to Upgrade	Percent Upgraded	Annual Savings	Cost	Simple Pay Back
Top 80	202	95%	$468,823	$1,414,000	3.0
Top 120	230	63%	$535,247	$1,610,000	3.0

4.1.2 *Steam Condensate Meters*

Adding New Meters

An analysis was done for adding steam meters where none exist. This includes the top 80 locations that were the focus of the recent metering initiative, as well as 40 additional academic buildings that do not have complete metering coverage. This analysis resulted in the following:

Table E-6. Economic Analysis of Upgrading Adding Steam Meters

Locations	Quantity	Annual Savings	Cost	Simple Pay Back
Top 120	5	$11,917	$45,000	3.8

The new meters are assumed to cost $9,000 each. The savings estimates are assumed to be 2% of annual steam energy when locations have at least some existing meters and 6% if no meters currently exist. The lower savings estimate assumes that tenants in buildings that already have received bills (even if partially estimated), will have already made some savings adjustments. A list of the candidate buildings for the steam meters is provided in the following table. Note that magnetic type flow meters are good choices for measuring steam condensate.

Table E-7. Candidate Buildings for New Steam Condensate Meters

Location#	Building Name
00108	Computing Applic Bldg
00209	Speech & Hearing Cl

00050	Architecture Bldg
00171	Meat Science Lab
00056	Vivarium, Victor E S

Linking Existing Steam Condensate Meters to the Energy Management System

The table below shows the economics of linking an estimated 71 of the 177 existing steam condensate meters, which are not already on the energy management system to it. This is based on a cost of $30,000 per meter and an annual cost savings of 2% of annual steam energy use.

Table E-8. Economic Analysis of Connecting Remaining Steam Meters

Location	Quantity to Add	Annual. Savings	Cost	Ave. Pay Back
Total Campus	71	$573,108	$2,136,000	3.73

4.1.3 *Chilled Water Meters*

The gap analysis identified 5 academic buildings that did not have chilled water meters among the top 120 academic buildings. The table below provides the economic analysis of installed the five meters based on a cost of $20,000 for each meter. The achieved savings of the estimated usage is 2% when locations have at least one existing meter and 6% if no meters currently exist.

Table E-9. Economic Analysis of New Chilled Water Meters

Locations	Quantity to Add	Annual. Savings	Cost	Ave. Pay Back
Top 120	4	$7,466	$80,000	10.7

The lower savings estimate assumes that tenants in buildings that already have received bills (even if partially estimated), will have already made some savings adjustments. A list of the candidate buildings for the steam meters is provided in the following table. The achieved savings of the estimated usage is 2% when locations have at least one existing meter and 6% if no meters currently exist. The savings comes from quicker response to inefficient energy use by tenants, improved operations and equipment efficiency diagnostics and troubleshooting. We recommend using more of the ABB MAGMASTER flow meters for measuring chilled water flow.

Table E-10. Candidate Buildings for New Chilled Water Meters

Location #	Building Name
00273	Isrh Townsend Hall
00274	Isrh Illinois St Lounge
00111	Busey Hall
00275	Isrh Illinois St Food Ser

4.2 ESPC Project Metering Considerations

Metering for the purposes of establishing energy use baselines in anticipation of energy savings performance contracts (ESPC) can be accomplished at the whole building level or at the system level. Guidelines for establishing baselines and measurement and verification protocols are contained in the documents developed by the U.S. Department of Energy's Federal Energy

Management Program (FEMP) and the Efficiency Valuation Organization (EVO).[4] For UIUC, the existing metering system should provide reasonable data for estimating average energy use baselines. However, the electric meters are not able to capture peak building demands. For projects where peak demand reductions are an important component of the cost savings guarantees, additional metering may be required. For example, cool storage projects, which are designed primarily to shift loads from peak periods to off-peak periods, would need to have separate metering/monitoring. However, investments in this type of monitoring are best made after the decision to move forward with specific types of projects. Other types of information that are generally applicable to ESPC projects are operating schedule information and equipment run times. Some of this information may be captured by the energy management systems, but a combination of metering/building survey might be required.

4.3 Submetering (Within Buildings)

Metering of specific areas within a building or loads (e.g., lighting, HVAC) is desirable to gain more accuracy in tenant billing or when there is a desire to establish the usage of large loads. In the case of tenant billing, this would be most appropriate if there is a very different usage within a building (e.g., energy intensive laboratory/research equipment vs. general office space) that is paid for by different occupants/departments. The choice of metering is similar to that for the whole building, although it may be possible to install shorter-term monitoring equipment and develop a calibrated energy use model for the area. The model could then be used in lieu of metering to calculate the usage. Note that at UIUC the modeling approach is used for determination of fume hood energy as described under the meter data management subsections. However, these are not calibrated by measurements, and it would be useful if such calibration could be implemented. For buildings that are already metered, the number of meters needed would be one less than the number of loads of interest. The unmetered load would be calculated by subtracting the sum of the individually metered loads from the whole building load. While, potentially not as accurate as metering all the loads, this method will save metering costs.

4.4 Alternative Metering Options

As an alternative to permanent meters for long-term monitoring, it is possible to determine energy use using alternatives such as clamp-on meters for electricity and chilled or hot water. These devices can provide temporary performance checks/verification and load profiles for non-metered energy sources. This would suffice for non-changing loads. An example of an electric clamp-on meter is the CW120 Clamp-on Power Meter by YOKOGAWA. The max voltage is 450V and the max current range is 1000Amps. It has clamp on probes and flash memory. An example hot/cold water meter is the Sitrans FUE1010 clamp-on ultrasonic Check Metering Kit from Siemens. This portable metering kit measures energy (Btu), has an option for electric power (kW) usage to and can log data. It is applicable for chilled water, condenser water or heating water. Wireless communications can provide less costly networking by eliminating the need to run wires. Virtual sub-meters can be calculated when the primary and the other branch circuit(s) are metered. This method can be used to reduce the cost of metering.

[4] *M&V Guidelines: Measurement and Verification for Federal Energy Projects Version 3.0,* FEMP, April 2008 (http://www1.eere.energy.gov/femp/pdfs/mv_guidelines.pdf) *and International Performance Measurement and Verification Concepts and Options for Determining Energy and Water Savings Volume 1*, Efficiency Valuation Organization, April 2007 (www.evo-world.org)

5. *Conclusions and Recommendations*

Overall, the existing metering system at the UIUC campus provides excellent coverage of buildings that use the vast majority of campus energy. From the perspective of ESPC projects the existing metering should be adequate for developing average energy use baselines at the whole building level. For projects where peak demand reductions are an important component of the cost savings guarantees, additional metering may be required. However, investments in this type of monitoring are best made after the decision to move forward with specific types of projects.

Nonetheless, there are opportunities to improve the benefits of metering, as well as to expand the metering on campus. Based on our review we suggest that:

- Bring the total number of fully metered academic buildings to 120 which accounts for 96% of campus energy use. This would require installing a total of 5 steam condensate meters and 4 chilled water meters.

- Existing meters that are not already linked to the energy management systems be connected to the system, where practical. Connecting the existing meters to the system would automate the process of meter reading, and with the appropriate software, enable energy use data to be evaluated at much finer time intervals. This would enhance the ability to identify inefficient energy use through load profiling and enhance diagnostic and troubleshooting capabilities.

- A meter calibration program should be established. This would help maintain the accuracy of the readings, and establish confidence for billing purposes. Electrical meters should be calibrated once every three to four years. Steam condensate and chilled water meters should be calibrated annually. In addition, consideration should be given to using short-term steam measurements as a means of checking energy estimates based on the condensate meters in selected buildings. This could be used to develop adjustment factors to apply to the condensate meter based energy values to get them closer to a true steam usage value.

UIUC has embarked on a course to raise awareness through its billing system. In order for a metering system to be successful it needs trained users, management buy-in/leadership, campus wide awareness and it needs to be maintained. Furthermore, if the potential of the metering system is to be fully realized, there need to be staff resources to review the energy use data on an ongoing basis and be in a position to act on the information.

Appendix – Gap Analysis

The primary emphasis of the gap analysis is to analyze new metering on the campuses. This is done through a comparison of the 2008 usage data “Energy, space_FY08 Galen 7-08.xls“and the existing meter data “TR_01_14_09_meterlist.xls“received from the university. In general static data has black text.

All savings projections in this report are based on 2008 usage data and the energy rates from the college billing report “2008-JUN_Bills.pdf” received from the university and updated for the latest rates. The cost used for electricity consumption is $0.0954 per kWh, steam production cost is $14.96 per klbs, and chilled water production cost is $10.85 per MMBTU.

The gap analysis is illustrated in the spreadsheet “U of I Urbana Champaign Gap analysis.xls”.

The “FY08 Rank” column is the ranking of the locations set by the university from the greatest energy consumers to the least.

Three groups of columns under the headings “New (Electric, Steam, Chilled Water) Meters Pay Back from Estimated usage” analyze adding meters where the pay back of eliminating the estimated usage is less than 10 years. For further analysis the following inputs (yellow highlight) can be changed in the gap analysis spreadsheet for each meter type; utility rate, percent savings achieved, new meter cost and payback period.

This analysis uses a savings of 6% of the estimated energy usage from new metering and 2% savings to increase metering coverage. This value was derived from several sources. The article “Submeters: The Best-Kept Secret” by School Construction News stated reduced energy consumption of 5 percent to 15 percent from sub metering. The document “Sub-Metering Energy Use in Colleges and Universities: Incentives and Challenges” from the U.S. Environmental Protection Agency’s ENERGY STAR, stated two case studies with at least 10-percent reduction in costs. These savings are viable if; the data is communicated to the users so informed decisions can be made, energy/cost reduction programs are developed and a calibration program is implemented. Also see Advantages of Sub-metering above.

An estimated cost of $7,000 for electric, $9,000 for steam and $20,000 for chilled water was used for new metering points. This includes the cost of the new meter, installation and tie into an existing system. This cost estimate will require a more detailed estimation before implementation.

Table E-11. New Steam Meters Pay Back from Estimated Usage

			New Steam Meters Pay Back from Estimated usage					
FY08 Rank	**Loc#**	**Building**	**Estim. Steam klbs**	**Estim. Annual Steam Cost**	**Annual Savings from new Meters**	**Qty of Meters to Add**	**Cost of new Metering**	**Steam PayBack Period**
1	**00116**	Roger Adams Lab	**4,637**	**$69,369.52**	**$1,387.39**	**0**	**$0**	**0.0**
2	**00017**	Advanced Computation Bldg	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.0**
3	**00228**	Beckman Institute	**2,987**	**$44,685.52**	**$893.71**	**0**	**$0**	**0.0**
4	**00350**	Vet Med Basic Science Bldg	**1**	**$14.96**	**$0.30**	**0**	**$0**	**0.0**
5	**00292**	Veterinary Teaching Hospital (lac/sac)	**2**	**$29.92**	**$0.60**	**0**	**$0**	**0.0**
6	**00237**	Micro/Nano Laboratory	**4,811**	**$71,972.56**	**$1,439.45**	**0**	**$0**	**0.0**
7	**00563**	Siebel Ctr For Computer Sci., Thomas M.	**1,246**	**$18,640.16**	**$372.80**	**0**	**$0**	**0.0**
8	**00070**	Chem & Life Science Lab	**6,423**	**$96,088.08**	**$1,921.76**	**0**	**$0**	**0.0**
9	**00336**	Madigan Lab, Edward R.	**81**	**$1,211.76**	**$24.24**	**0**	**$0**	**0.0**
10	**01080**	Institute For Genomic Biology Building	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.0**
11	**00210**	Digital Computer Lab	**2,543**	**$38,043.28**	**$760.87**	**0**	**$0**	**0.0**
12	**00023**	Illini Union	**1,526**	**$22,828.96**	**$456.58**	**0**	**$0**	**0.0**
13	**00066**	Mat Res Lab, Frederick Seitz	**2,688**	**$40,212.48**	**$804.25**	**0**	**$0**	**0.0**
14	**00067**	Loomis Lab	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.0**
15	**00041**	Library	**7,603**	**$113,740.88**	**$2,274.82**	**0**	**$0**	**0.0**
16	**00138**	Burrill Hall	**2,637**	**$39,449.52**	**$788.99**	**0**	**$0**	**0.0**
17	**00076**	Psychology Lab	**20**	**$299.20**	**$5.98**	**0**	**$0**	**0.0**
18	**00242**	Morrill Hall	**4,340**	**$64,926.40**	**$1,298.53**	**0**	**$0**	**0.0**
19	**00297**	Farh Food Service	**1,506**	**$22,529.76**	**$450.60**	**0**	**$0**	**0.0**
20	**00052**	Krannert Center For Perf Art	**3,697**	**$55,307.12**	**$1,106.14**	**0**	**$0**	**0.0**
21	**00148**	Coordinated Sciences Lab	**135**	**$2,019.60**	**$40.39**	**0**	**$0**	**0.0**
22	**00174**	Engineering Sciences Bldg	**8,906**	**$133,233.76**	**$2,664.68**	**0**	**$0**	**0.0**
23	**00192**	Medical Sciences Building	**12,453**	**$186,296.88**	**$3,725.94**	**0**	**$0**	**0.0**
24	**00197**	Turner Hall	**7,593**	**$113,591.28**	**$2,271.83**	**0**	**$0**	**0.0**
25	**00029**	Mechanical Engineering Lab	**5,698**	**$85,242.08**	**$1,704.84**	**0**	**$0**	**0.0**
26	**00024**	Civil Eng Bldg, N. Newmark	**285**	**$4,263.60**	**$85.27**	**0**	**$0**	**0.0**
27	**00081**	Pdrh Sm-3 Peabody Food Ser	**3,600**	**$53,856.00**	**$1,077.12**	**0**	**$0**	**0.0**
28	**00037**	Electrical And Computer Engineering, Everitt	**19**	**$284.24**	**$5.68**	**0**	**$0**	**0.0**
29	**00046**	Administration Bldg	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.0**

Table E-11. New Steam Meters Pay Back from Estimated Usage *(Continued)*

			New Steam Meters Pay Back from Estimated usage					
FY08 Rank	Loc#	Building	Estim. Steam klbs	Estim. Annual Steam Cost	Annual Savings from new Meters	Qty of Meters to Add	Cost of new Metering	Steam PayBack Period
30	00172	Foreign Languages Bl	1,111	$16,620.56	$332.41	0	$0	0.0
31	00158	Bevier Hall	10	$149.60	$2.99	0	$0	0.0
32	00159	Wohlers Hall (commerce West)	239	$3,575.44	$71.51	0	$0	0.0
33	00012	Noyes Lab Of Chem	13,606	$203,545.76	$4,070.92	0	$0	0.0
34	00099	Undergraduate Library	0	$0.00	$0.00	0	$0	0.0
35	00166	Assembly Hall	496	$7,420.16	$148.40	0	$0	0.0
36	00085	Gdrh Sm-2 Gregory Food Ser	0	$0.00	$0.00	0	$0	0.0
37	00564	National Center For Supercomputing Applications	759	$11,354.64	$227.09	0	$0	0.0
38	00165	Animal Sciences Lab	0	$0.00	$0.00	0	$0	0.0
39	00118	Intramural Physical Educ	16,985	$254,095.60	$5,081.91	0	$0	0.0
40	00291	Sgrh Sherman Hall	1,555	$23,262.80	$465.26	0	$0	0.0
41	00001	Davenport Hall	1,015	$15,184.40	$303.69	0	$0	0.0
42	00160	Education Building	61	$912.56	$18.25	0	$0	0.0
43	00124	National Soybean Research Center (nsrc)	2,242	$33,540.32	$670.81	0	$0	0.0
44	00364	Campus Recreation Cntr-east	0	$0.00	$0.00	0	$0	0.0
45	00377	Aces Library, Information And Alumni Center	1,263	$18,894.48	$377.89	0	$0	0.0
46	00006	Armory	130	$1,944.80	$38.90	0	$0	0.0
47	00039	Music Building	0	$0.00	$0.00	0	$0	0.0
48	00156	Law Building	0	$0.00	$0.00	0	$0	0.0
49	00324	Grainger Engr Lib Info Centr	0	$0.00	$0.00	0	$0	0.0
50	00256	Plant Sciences	7,436	$111,242.56	$2,224.85	0	$0	0.0
51	00008	Agriculture Engr Sci Bldg	0	$0.00	$0.00	0	$0	0.0
52	00112	Mechanical Engineering Bldg	9,365	$140,100.40	$8,406.02	0	$0	0.0
53	00015	Engineering Hall	0	$0.00	$0.00	0	$0	0.0
54	00072	Stadium	6,518	$97,509.28	$1,950.19	0	$0	0.0
55	00106	Illini Union Bookstore	875	$13,090.00	$261.80	0	$0	0.0
56	00198	Physical Plant Service Bldg	0	$0.00	$0.00	0	$0	0.0
57	00105	Parh Sw-2 Penn Lounge Bldg	13,381	$200,179.76	$4,003.60	0	$0	0.0
58	00060	Smith Memorial Hall	653	$9,768.88	$195.38	0	$0	0.0

Table E-11. New Steam Meters Pay Back from Estimated Usage *(Continued)*

			New Steam Meters Pay Back from Estimated usage					
FY08 Rank	**Loc#**	**Building**	**Estim. Steam klbs**	**Estim. Annual Steam Cost**	**Annual Savings from new Meters**	**Qty of Meters to Add**	**Cost of new Metering**	**Steam PayBack Period**
59	**00043**	Gregory Hall	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.0**
60	**00373**	Spurlock Museum	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.0**
61	**00026**	Altgeld Hall	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.0**
62	**00014**	Skating Rink	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.0**
63	**00003**	Mckinley Health Center	**1,480**	**$22,140.80**	**$442.82**	**0**	**$0**	**0.0**
64	**00032**	Natural History Building	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.0**
65	**00131**	Turner Hall Greenhouse	**1,559**	**$23,322.64**	**$466.45**	**0**	**$0**	**0.0**
66	**00013**	Talbot Laboratory	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.0**
67	**01094**	North Campus Parking Deck	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.0**
68	**00273**	Isrh Townsend Hall	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.0**
69	**00058**	Huff Hall	**459**	**$6,866.64**	**$137.33**	**0**	**$0**	**0.0**
70	**00272**	Isrh Wardall Hall	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.0**
71	**00064**	Freer Hall, Louise	**10**	**$149.60**	**$2.99**	**0**	**$0**	**0.0**
72	**00274**	Isrh Illinois St Lounge	**1**	**$14.96**	**$0.30**	**0**	**$0**	**0.0**
73	**00109**	Natural Resources Building	**761**	**$11,384.56**	**$227.69**	**0**	**$0**	**0.0**
74	**00141**	Lincoln Ave Res Hall	**81**	**$1,211.76**	**$24.24**	**0**	**$0**	**0.0**
75	**00181**	Sgrh Daniels Hall, Arthur	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.0**
76	**00094**	Alice Campbell Alumni Center	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.0**
77	**00027**	Lincoln Hall	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.0**
78	**00010**	Chemistry Annex	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.0**
79	**00054**	David Kinley Hall	**103**	**$1,540.88**	**$30.82**	**0**	**$0**	**0.0**
80	**00034**	Materials Science And Engineering Building	**3,598**	**$53,826.08**	**$1,076.52**	**0**	**$0**	**0.0**
81	**00142**	Allen Residence Hall	**1,120**	**$16,755.20**	**$335.10**	**0**	**$0**	**0.0**
82	**00217**	Housing Food Stores	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.0**
83	**00407**	Irwin Indoor Football Facility	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.0**
84	**00339**	Temple Hoyne Buell Hall	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.0**
85	**00219**	Art & Design Bldg	**775**	**$11,594.00**	**$231.88**	**0**	**$0**	**0.0**
86	**00222**	Printing & Photographic Services	**243**	**$3,635.28**	**$72.71**	**0**	**$0**	**0.0**
87	**00220**	Krannert Art Museum	**543**	**$8,123.28**	**$162.47**	**0**	**$0**	**0.0**
88	**00007**	Auditorium, Foellinger	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.0**
89	**00169**	Burnsides Res Lab	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.0**
90	**00087**	Fourth St Clark Hall	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.0**

Table E-11. New Steam Meters Pay Back from Estimated Usage *(Continued)*

			New Steam Meters Pay Back from Estimated usage					
FY08 Rank	Loc#	Building	Estim. Steam klbs	Estim. Annual Steam Cost	Annual Savings from new Meters	Qty of Meters to Add	Cost of new Metering	Steam PayBack Period
91	00378	Admissions & Records Bldg	0	$0.00	$0.00	0	$0	0.0
92	01095	Enterprise Works At Illinois	0	$0.00	$0.00	0	$0	0.0
93	00188	Student Service Bldg	0	$0.00	$0.00	0	$0	0.0
94	01206	Business Instructional Facility	0	$0.00	$0.00	0	$0	0.0
95	00042	Transportation Bldg	0	$0.00	$0.00	0	$0	0.0
96	00126	Levis Faculty Center	3,638	$54,424.48	$3,265.47	1	$9,000	2.8
97	00108	Computing Applic Bldg	6,808	$101,847.68	$6,110.86	0	$0	0.0
98	00675	Airport New Terminal	0	$0.00	$0.00	0	$0	0.0
99	01074	"z" Building	0	$0.00	$0.00	0	$0	0.0
100	00095	Supercond Cntr Mrl/csl Brdge	0	$0.00	$0.00	0	$0	0.0
101	00044	English Building	51	$762.96	$15.26	0	$0	0.0
102	01071	Early Child Development Laboratory	0	$0.00	$0.00	0	$0	0.0
103	00069	Mumford Hall	2,183	$32,657.68	$653.15	0	$0	0.0
104	00176	Rehabilitation Ctr	1,789	$26,763.44	$535.27	0	$0	0.0
105	00111	Busey Hall	1,182	$17,682.72	$353.65	0	$0	0.0
106	01140	Gregory Place	164	$2,453.44	$49.07	0	$0	0.0
107	01103	Z-2	0	$0.00	$0.00	0	$0	0.0
108	00115	Evans Hall	1,102	$16,485.92	$329.72	0	$0	0.0
109	00073	Agriculture Bioprocess Lab	3,906	$58,433.76	$1,168.68	0	$0	0.0
110	00275	Isrh Illinois St Food Ser	0	$0.00	$0.00	0	$0	0.0
111	00071	Student Services Arcade Building	61	$912.56	$18.25	0	$0	0.0
112	00287	Vet Med Surgery & Obstet Lab	251	$3,754.96	$75.10	0	$0	0.0
113	01075	Motorola Building	0	$0.00	$0.00	0	$0	0.0
114	00331	Library & Information Sci	0	$0.00	$0.00	0	$0	0.0
115	00209	Speech & Hearing Cl	1,789	$26,763.44	$1,605.81	1	$9,000	5.6
116	00025	Harker Hall	0	$0.00	$0.00	0	$0	0.0
117	00152	Hydrosystems Lab C E	46	$688.16	$13.76	0	$0	0.0
118	00376	Campbell Hall	0	$0.00	$0.00	0	$0	0.0
119	00360	Atkins Tennis Center	0	$0.00	$0.00	0	$0	0.0
120	00218	Instit Of Labor & Indus Rel	51	$762.96	$15.26	0	$0	0.0

Table E-11. New Steam Meters Pay Back from Estimated Usage *(Continued)*

			New Steam Meters Pay Back from Estimated usage					
FY08 Rank	**Loc#**	**Building**	**Estim. Steam klbs**	**Estim. Annual Steam Cost**	**Annual Savings from new Meters**	**Qty of Meters to Add**	**Cost of new Metering**	**Steam PayBack Period**
121	**00206**	Waste Management And Research Laboratory	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.0**
122	**00136**	Student Staff Apts	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.0**
123	**00050**	Architecture Bldg	**3,481**	**$52,075.76**	**$3,124.55**	**1**	**$9,000**	**2.9**
124	**00065**	Illini Hall	**1,263**	**$18,894.48**	**$377.89**	**0**	**$0**	**0.0**
125	**00089**	Flagg Hall	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.0**
126	**01073**	Forbes Natural History Bldg	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.0**
127	**00061**	University High School	**1,431**	**$21,407.76**	**$428.16**	**0**	**$0**	**0.0**
128	**00379**	Bielfeldt Athletic Admin Bldg	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.0**
129	**00110**	Nuclear Physic Lab	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.0**
130	**00091**	Fourth St Van Doren Hall	**1,635**	**$24,459.60**	**$489.19**	**0**	**$0**	**0.0**
131	**00040**	Stock Pavilion	**632**	**$9,454.72**	**$189.09**	**0**	**$0**	**0.0**
132	**00005**	Gym Annex	**1,101**	**$16,470.96**	**$329.42**	**0**	**$0**	**0.0**
133	**00018**	Art-east Annex Studio 1	**81**	**$1,211.76**	**$24.24**	**0**	**$0**	**0.0**
134	**00140**	Biomedical Imaging Center	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.0**
135	**00171**	Meat Science Lab	**1,789**	**$26,763.44**	**$1,605.81**	**1**	**$9,000**	**5.6**
136	**00062**	Child Dev, Home Ec	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.0**
137	**00117**	Nuclear Engineering Lab	**1,856**	**$27,765.76**	**$555.32**	**0**	**$0**	**0.0**
138	**00321**	Natural Res Studies Annx	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.0**
139	**00056**	Vivarium, Victor E S	**2,579**	**$38,581.84**	**$2,314.91**	**1**	**$9,000**	**3.9**
140	**00021**	Kenney Gym	**1,101**	**$16,470.96**	**$329.42**	**0**	**$0**	**0.0**
141	**02105**	I-cyt	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.0**

Table E-12. New Chilled Water Meters Pay Back from Estimated Usage

			New Chilled Water Meters Pay Back from Estimated usage					
FY08 Rank	**Loc#**	**Building**	**Estim. Chilled Water MMBTU**	**Estim. Annual Chilled Water Cost**	**Annual Savings from new Meters**	**Qty of Meters to Add**	**Cost of new Metering**	**Chilled Water PayBack Period**
1	**00116**	Roger Adams Lab	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
2	**00017**	Advanced Computation Bldg	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
3	**00228**	Beckman Institute	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
4	**00350**	Vet Med Basic Science Bldg	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
5	**00292**	Veterinary Teaching Hospital (lac/sac)	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
6	**00237**	Micro/Nano Laboratory	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
7	**00563**	Siebel Ctr For Computer Sci., Thomas M.	**38,306**	**$415,620.10**	**$24,937.21**	**0**	**$0**	**0.00**
8	**00070**	Chem & Life Science Lab	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
9	**00336**	Madigan Lab, Edward R.	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
10	**01080**	Institute For Genomic Biology Building	**25,400**	**$275,590.00**	**$16,535.40**	**0**	**$0**	**0.00**
11	**00210**	Digital Computer Lab	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
12	**00023**	Illini Union	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
13	**00066**	Mat Res Lab, Frederick Seitz	**1,789**	**$19,410.65**	**$388.21**	**0**	**$0**	**0.00**
14	**00067**	Loomis Lab	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
15	**00041**	Library	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
16	**00138**	Burrill Hall	**2**	**$21.70**	**$0.43**	**0**	**$0**	**0.00**
17	**00076**	Psychology Lab	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
18	**00242**	Morrill Hall	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
19	**00297**	Farh Food Service	**216**	**$2,343.60**	**$46.87**	**0**	**$0**	**0.00**
20	**00052**	Krannert Center For Perf Art	**6,714**	**$72,846.90**	**$1,456.94**	**0**	**$0**	**0.00**
21	**00148**	Coordinated Sciences Lab	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
22	**00174**	Engineering Sciences Bldg	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
23	**00192**	Medical Sciences Building	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
24	**00197**	Turner Hall	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
25	**00029**	Mechanical Engineering Lab	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
26	**00024**	Civil Eng Bldg, N. Newmark	**4,136**	**$44,875.60**	**$897.51**	**0**	**$0**	**0.00**
27	**00081**	Pdrh Sm-3 Peabody Food Ser	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
28	**00037**	Electrical And Computer Engineering, Everitt	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**

Table E-11. New Chilled Water Meters Pay Back from Estimated Usage *(Continued)*

			New Chilled Water Meters Pay Back from Estimated usage					
FY08 Rank	Loc#	Building	Estim. Chilled Water MMBTU	Estim. Annual Chilled Water Cost	Annual Savings from new Meters	Qty of Meters to Add	Cost of new Metering	Chilled Water PayBack Period
29	**00046**	Administration Bldg	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
30	**00172**	Foreign Languages Bl	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
31	**00158**	Bevier Hall	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
32	**00159**	Wohlers Hall (commerce West)	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
33	**00012**	Noyes Lab Of Chem	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
34	**00099**	Undergraduate Library	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
35	**00166**	Assembly Hall	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
36	**00085**	Gdrh Sm-2 Gregory Food Ser	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
37	**00564**	National Center For Supercomputing Applications	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
38	**00165**	Animal Sciences Lab	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
39	**00118**	Intramural Physical Educ	**518**	**$5,620.30**	**$112.41**	**0**	**$0**	**0.00**
40	**00291**	Sgrh Sherman Hall	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
41	**00001**	Davenport Hall	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
42	**00160**	Education Building	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
43	**00124**	National Soybean Research Center (nsrc)	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
44	**00364**	Campus Recreation Cntr-east	**11,252**	**$122,084.20**	**$2,441.68**	**0**	**$0**	**0.00**
45	**00377**	Aces Library, Information And Alumni Center	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
46	**00006**	Armory	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
47	**00039**	Music Building	**9,131**	**$99,071.35**	**$1,981.43**	**0**	**$0**	**0.00**
48	**00156**	Law Building	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
49	**00324**	Grainger Engr Lib Info Centr	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
50	**00256**	Plant Sciences	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
51	**00008**	Agriculture Engr Sci Bldg	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
52	**00112**	Mechanical Engineering Bldg	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
53	**00015**	Engineering Hall	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
54	**00072**	Stadium	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
55	**00106**	Illini Union Bookstore	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
56	**00198**	Physical Plant Service Bldg	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**

Table E-11. New Chilled Water Meters Pay Back from Estimated Usage *(Continued)*

			New Chilled Water Meters Pay Back from Estimated usage					
FY08 Rank	Loc#	Building	Estim. Chilled Water MMBTU	Estim. Annual Chilled Water Cost	Annual Savings from new Meters	Qty of Meters to Add	Cost of new Metering	Chilled Water PayBack Period
57	00105	Parh Sw-2 Penn Lounge Bldg	0	$0.00	$0.00	0	$0	0.00
58	00060	Smith Memorial Hall	0	$0.00	$0.00	0	$0	0.00
59	00043	Gregory Hall	0	$0.00	$0.00	0	$0	0.00
60	00373	Spurlock Museum	6,698	$72,673.30	$4,360.40	0	$0	0.00
61	00026	Altgeld Hall	0	$0.00	$0.00	0	$0	0.00
62	00014	Skating Rink	0	$0.00	$0.00	0	$0	0.00
63	00003	Mckinley Health Center	0	$0.00	$0.00	0	$0	0.00
64	00032	Natural History Building	0	$0.00	$0.00	0	$0	0.00
65	00131	Turner Hall Greenhouse	0	$0.00	$0.00	0	$0	0.00
66	00013	Talbot Laboratory	0	$0.00	$0.00	0	$0	0.00
67	01094	North Campus Parking Deck	0	$0.00	$0.00	0	$0	0.00
68	00273	Isrh Townsend Hall	5,568	$60,412.80	$3,624.77	1	$20,000	5.52
69	00058	Huff Hall	4,121	$44,712.85	$894.26	0	$0	0.00
70	00272	Isrh Wardall Hall	5,188	$56,289.80	$3,377.39	0	$0	0.00
71	00064	Freer Hall, Louise	5	$54.25	$3.26	0	$0	0.00
72	00274	Isrh Illinois St Lounge	1,241	$13,464.85	$807.89	1	$20,000	24.76
73	00109	Natural Resources Building	0	$0.00	$0.00	0	$0	0.00
74	00141	Lincoln Ave Res Hall	0	$0.00	$0.00	0	$0	0.00
75	00181	Sgrh Daniels Hall, Arthur	0	$0.00	$0.00	0	$0	0.00
76	00094	Alice Campbell Alumni Center	0	$0.00	$0.00	0	$0	0.00
77	00027	Lincoln Hall	0	$0.00	$0.00	0	$0	0.00
78	00010	Chemistry Annex	0	$0.00	$0.00	0	$0	0.00
79	00054	David Kinley Hall	0	$0.00	$0.00	0	$0	0.00
80	00034	Materials Science And Engineering Building	3,309	$35,902.65	$718.05	0	$0	0.00
81	00142	Allen Residence Hall	0	$0.00	$0.00	0	$0	0.00
82	00217	Housing Food Stores	0	$0.00	$0.00	0	$0	0.00
83	00407	Irwin Indoor Football Facility	0	$0.00	$0.00	0	$0	0.00
84	00339	Temple Hoyne Buell Hall	0	$0.00	$0.00	0	$0	0.00
85	00219	Art & Design Bldg	0	$0.00	$0.00	0	$0	0.00
86	00222	Printing & Photographic Services	0	$0.00	$0.00	0	$0	0.00

Table E-11. New Chilled Water Meters Pay Back from Estimated Usage *(Continued)*

			New Chilled Water Meters Pay Back from Estimated usage					
FY08 Rank	**Loc#**	**Building**	**Estim. Chilled Water MMBTU**	**Estim. Annual Chilled Water Cost**	**Annual Savings from new Meters**	**Qty of Meters to Add**	**Cost of new Metering**	**Chilled Water PayBack Period**
87	**00220**	Krannert Art Museum	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
88	**00007**	Auditorium, Foellinger	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
89	**00169**	Burnsides Res Lab	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
90	**00087**	Fourth St Clark Hall	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
91	**00378**	Admissions & Records Bldg	**4,357**	**$47,273.45**	**$2,836.41**	**0**	**$0**	**0.00**
92	**01095**	Enterprise Works At Illinois	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
93	**00188**	Student Service Bldg	**3,441**	**$37,334.85**	**$2,240.09**	**0**	**$0**	**0.00**
94	**01206**	Business Instructional Facility	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
95	**00042**	Transportation Bldg	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
96	**00126**	Levis Faculty Center	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
97	**00108**	Computing Applic Bldg	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
98	**00675**	Airport New Terminal	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
99	**01074**	"z" Building	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
100	**00095**	Supercond Cntr Mrl/csl Brdge	**2,426**	**$26,322.10**	**$526.44**	**0**	**$0**	**0.00**
101	**00044**	English Building	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
102	**01071**	Early Child Development Laboratory	**468**	**$5,077.80**	**$101.56**	**0**	**$0**	**0.00**
103	**00069**	Mumford Hall	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
104	**00176**	Rehabilitation Ctr	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
105	**00111**	Busey Hall	**2,233**	**$24,228.05**	**$1,453.68**	**1**	**$20,000**	**13.76**
106	**01140**	Gregory Place	**106**	**$1,150.10**	**$23.00**	**0**	**$0**	**0.00**
107	**01103**	Z-2	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
108	**00115**	Evans Hall	**2,233**	**$24,228.05**	**$1,453.68**	**0**	**$0**	**0.00**
109	**00073**	Agriculture Bioprocess Lab	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
110	**00275**	Isrh Illinois St Food Ser	**2,426**	**$26,322.10**	**$1,579.33**	**1**	**$20,000**	**12.66**
111	**00071**	Student Services Arcade Building	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
112	**00287**	Vet Med Surgery & Obstet Lab	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
113	**01075**	Motorola Building	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
114	**00331**	Library & Information Sci	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
115	**00209**	Speech & Hearing Cl	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**

Table E-11. New Chilled Water Meters Pay Back from Estimated Usage *(Continued)*

			New Chilled Water Meters Pay Back from Estimated usage					
FY08 Rank	**Loc#**	**Building**	**Estim. Chilled Water MMBTU**	**Estim. Annual Chilled Water Cost**	**Annual Savings from new Meters**	**Qty of Meters to Add**	**Cost of new Metering**	**Chilled Water PayBack Period**
116	**00025**	Harker Hall	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
117	**00152**	Hydrosystems Lab C E	**234**	**$2,538.90**	**$50.78**	**0**	**$0**	**0.00**
118	**00376**	Campbell Hall	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
119	**00360**	Atkins Tennis Center	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
120	**00218**	Instit Of Labor & Indus Rel	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
121	**00206**	Waste Management And Research Laboratory	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
122	**00136**	Student Staff Apts	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
123	**00050**	Architecture Bldg	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
124	**00065**	Illini Hall	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
125	**00089**	Flagg Hall	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
126	**01073**	Forbes Natural History Bldg	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
127	**00061**	University High School	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
128	**00379**	Bielfeldt Athletic Admin Bldg	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
129	**00110**	Nuclear Physic Lab	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
130	**00091**	Fourth St Van Doren Hall	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
131	**00040**	Stock Pavilion	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
132	**00005**	Gym Annex	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
133	**00018**	Art-east Annex Studio 1	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
134	**00140**	Biomedical Imaging Center	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
135	**00171**	Meat Science Lab	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
136	**00062**	Child Dev, Home Ec	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
137	**00117**	Nuclear Engineering Lab	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
138	**00321**	Natural Res Studies Annx	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
139	**00056**	Vivarium, Victor E S	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
140	**00021**	Kenney Gym	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**
141	**02105**	I-cyt	**0**	**$0.00**	**$0.00**	**0**	**$0**	**0.00**