Dartmouth College
Campus Energy and Sustainability Management System

Final Report for
New Hampshire Greenhouse Gas Emission Reduction Fund

January 31, 2012

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Appendix

Exhibit 1 - Budget vs. Actual Expenditures Table

Other Exhibits

Dartmouth College
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1. **Program Title:** Campus Energy and Sustainability Management System (CESMS)

2. **Program Type:** The Campus Energy and Sustainability Management system is helping to reduce energy use and associated greenhouse gas emissions at Dartmouth College by using a web-based interface to multiple database platforms to track, report, and optimize building energy performance.

3. Summary of Work Completed:

Work during the 2-year contract period consisted of:

- Planning for deployment of the Campus Energy and Sustainability Management (CESM) System
- Contracting with Rockwell Automation to develop and deliver a packaged VantagePoint solution to meet our requirements
- Automating our 250 building-level energy meters
- Connecting to multiple related energy-monitoring and energy-consuming systems
- Creating reporting structures, content, and activities to use the system to drive down energy use and resultant greenhouse gas (GHG) emissions

A summary of the key elements of the 2-year project follows:

3.1. Planning

3.1.1. **Development of Functional Requirements Specification (FRS)** with the inclusion of the following stakeholder groups:

- Facilities Operations – Building Management System team, Heating/Electric Plant team, Energy Program Team, top-level Planning, Design, Operations and Administrative team
- IT and Networks – Network communications and Administrative Computing Team
- Sustainability Office – Sustainability Manager and sustainability intern
- Financial – Facilities Operations Financial team
- Academic Departments – Faculty representatives from Thayer Engineering School, Tuck School of Business, Dartmouth Medical School, Computer Science Department, Environmental Studies Department and, Dean of Faculty administrative office

3.1.2. **Development of a Meter Automation Plan**– Planning for automation of the greater than 250 building-level energy meters on campus (condensate, electric and chilled water meters). This included ordering approximately 40 IP

addressable electrical meters to replace old analog-style meters and ordering approximately 200 wireless pulse transmitters to connect to existing condensate, chilled water, and some electrical meters.

3.1.3. **Purchasing of Server Equipment and Supporting Software** – Two network servers were ordered and installed in Dartmouth's remote data center. These host several database programs which support the metering and operational software for the CESM system.

3.1.4. **Planning for Connection to BMS Systems** – Plans were made for connection to over 30,000 Building Management System points via Rockwell software connectors to the Honeywell and Johnson Controls building management systems. Minor upgrades were made to some systems to accommodate connections.

3.1.5. **Connection to Heating/Electrical Plant SCADA Systems –** Plans and technical details were developed for connection to the Heating/Electrical plant control systems via a data historian computer and related software.

3.1.6. **Establishment of Energy "Tiger Team"** - A team of internal technical specialists was established to begin development of methods and practices for use of the Campus Energy and Sustainability Management (CESM) System as a tool for building system Retro-Commissioning and persistence Continuous Commissioning, energy system alarming, energy system optimization strategies, and other operational activities that will help drive campus energy usage and GHG emissions downward. The team consists of Building Management System (BMS) specialists, electrical system specialists, mechanical system specialists, and the campus Energy Program Manager. Planning was put into place for creation of new roles within the Facilities Operations department to administer and use the CESM System.

3.1.7. **Establishment of Academic Collaborative** – The beginnings of a Facilities/Academic collaborative was established to develop and execute methods of evaluating the impact of feedback and social networking tools on occupant behavior via use of the CESM System.

3.2. Execution

3.2.1 Task 1 Items:

- **Automated > 250 building-level energy meters** – implemented a metering automation program for condensate, electrical, and chilled water meters. Installed new IP-addressable electrical meters where existing analog meters could not be retrofitted (approx. 50), and installed wireless pulse counters on meters the remainder of meters (approx. 200). All meters report back to an interval data storage database (Rockwell RSEnergyMetrix) and are logged every 15 minutes, providing nearly 3,000 energy demand data points per meter per month. This replaces a manual system of meter reading where only a single consumption value was collected per month per meter. The immense increase in data collection points allows the pattern of daily energy use for each building to be seen very clearly.

Challenges, Problems, Delays: This task took considerably longer than anticipated due to the complexity of program. Each meter had its own particular challenges which could not have been easily determined prior to starting the project. We used a staff of 2 dedicated electricians to complete this task with them staying on the project until it was completed. The cost of materials for the metering program was higher than anticipated, in large part due to the complexity of making the wireless metering infrastructure work reliably. We ended up using more gateway devices and repeaters than originally estimated.

- **Installed approximately 30 additional IP-addressable electrical sub-meters** for monitoring lighting and plug-loads serving student living quarters. This allowed us to conduct research on behavior-based energy usage in dormitory spaces.
- **Connected to Johnson Controls and Honeywell Building Management Systems (BMS)** – Implemented software connectors to connect to the two BMS systems, achieving a greater than >30,000 point visibility. These connections allow us to poll the operations of each energy-consuming HVAC system serving the 130 buildings on the Main Campus. Polling allows us see trend data collected by the host systems in any combinations that we desire. Many recallable trend combinations for the BMS systems have been set up and "published" into the Rockwell VantagePoint system, allowing multiple users to access the data sets.
- **Connected to Heating/Electric plant control systems** using data historian software. This allowed us to retrieve and re-historize Heating/Electric Plant data in the CESM System environment without a direct connection into the Heating/Electric plant SCADA system. We collect approximately 50 points of critical energy consumption and performance data from the Heating/Electric Plant every 15 minutes.

  Challenges, Problems, Delays: This task took somewhat longer and was costlier than anticipated. In order to satisfy the request of the Heating/Electric Plant supervisor that we not connect *directly* into the Plant process control system(s), we established a methodology of making that data visible on the Plant side and then *collecting* and *historizing* the data on the CESM side of the system. This method has proved to be effective in collecting the data and providing operational isolation of the two systems, however it was more costly than originally anticipated.
- **Connected to NOAA weather service** for hourly weather data collection
- **Built baseline energy performance parameters** for each Main Campus building. This was done using historical energy profile data for each meter and the hourly NOAA weather data. Baselines provide predictive calculations of energy use on a continuous 24-hour look-ahead basis. By tracking predictive energy baselines vs actual energy use, we are able to see deviations and investigate why systems may be using more energy than predicted.

  Challenges, Problems, Delays: This task took somewhat longer than anticipated because it was dependent upon meters being automated. Good baseline calculations require a minimum 3 seasons of energy performance data for each meter. The delays in implementing the basic meter automation

program affected this portion of the project, resulting in a 1 to 2 quarter delay in putting the baseline calculations together. As time has moved forward, we have returned to the original baseline calculations and re-run them in a number of cases in order to get better accuracy in the predictive performance. Having greater than one year of energy operating data for all meters now allows us to review these baselines on a regular basis.

- **Set targets for energy alarms** (actual use greater than predicted use for a set period of time)
- **Created Sustainability Indices** for Solid Waste Streams, Water Use, Recycling, #2 Fuel Oil, Propane, and Diesel Fuel
- **Set up parameters for evaluating high-performance Campus buildings** against their original design criteria (BTU/SqFT/Year)

3.2.2 Task 2 Items:

- **Connected energy data from student living quarters** into the Campus Energy and Sustainability Management System.
- **Added additional feedback display systems** in multiple student living quarters.
- **Evaluated impact of feedback on occupant behavior** via separately-funded research project
- **Conducted outreach to students, staff and faculty** about recommended conservation measures
- **Developed case studies** where occupant behavior accounts for a relatively high proportion of total building energy use

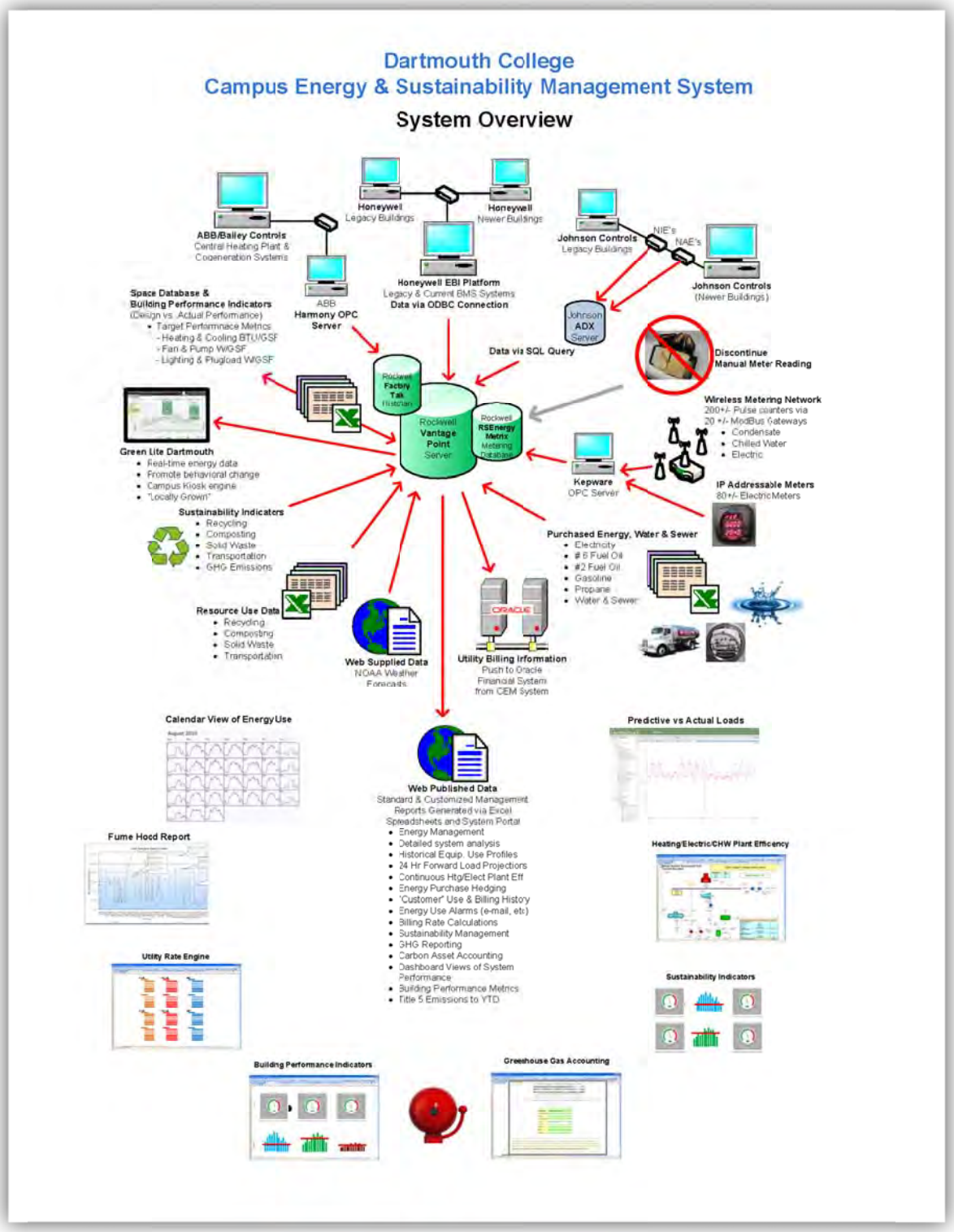
3.2.3 Task 3 Items:

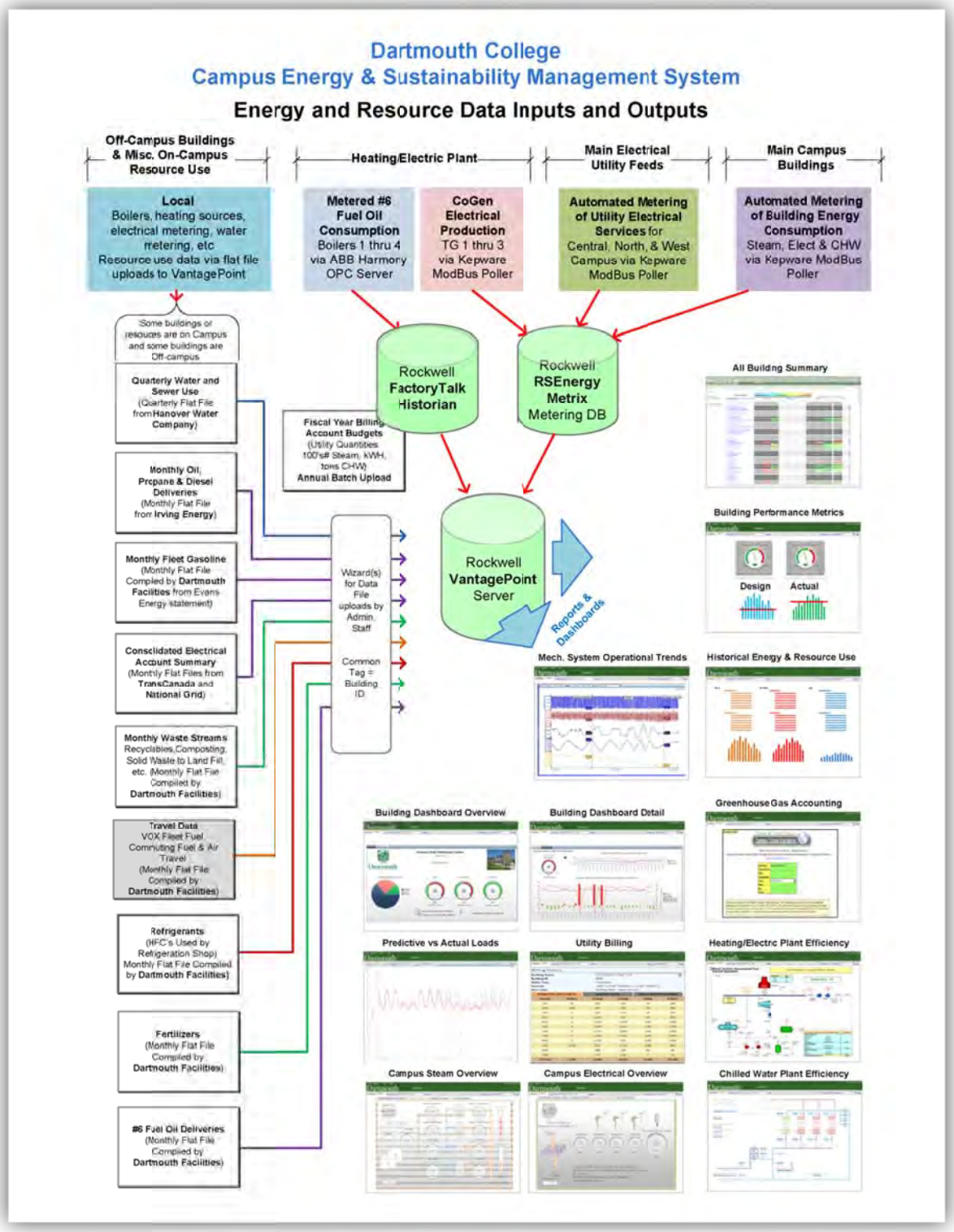
- **Established validation program** to ensure that meter automation results are providing accurate results
- **Established program to verify the polled data** from the Building Management Systems.
- **Set target reductions for top 30 energy-use-buildings** based upon baseline energy performance calculated by CESM System
- **Monitored financial expenditures and performance** of the program
- **Used the system to assess the effectiveness of behavior change** campaigns and social learning experiments
- **Prepared to share the results of the measurement and verification program** in an annual summary report

4. Summary of Overall Project Completed:

Dartmouth's Campus Energy and Sustainability Management (CESM) System consists of a variety of integrated applications and related databases, working together to provide visibility and management of the use of energy and resources on campus. The system vendor is Rockwell Automation. The Rockwell VantagePoint applications and databases were designed to work together to provide a custom

solution for our needs. The system provides the following general capabilities (Please refer to System Block Diagrams for overviews:




Dartmouth College
Campus Energy & Sustainability Management System
Energy and Resource Data Inputs and Outputs
Off-Campus Buildings & Misc. On-Campus Resource Use
Heating/Electric Plant
Main Electrical Utility Feeds
Main Campus Buildings
Local
Boilers, heating sources, electrical metering, water metering, etc
Resource use data via flat file uploads to VantagePoint
Metered #6 Fuel Oil Consumption
Boilers 1 thru 4 via ABB Harmony OPC Server
CoGen Electrical Production
TG 1 thru 3 via Kepware ModBus Poller
Automated Metering of Utility Electrical Services for
Central, North, & West Campus via Kepware ModBus Poller
Automated Metering of Building Energy Consumption
Steam, Elect & CHW via Kepware ModBus Poller
Some buildings or resouces are on Campus and some buildings are Off-campus
Quarterly Water and Sewer Use
(Quarterly Flat File from Hanover Water Company)
Monthly Oil, Propane & Diesel Deliveries
(Monthly Flat File from Irving Energy)
Monthly Fleet Gasoline
(Monthly Flat File Compiled by Dartmouth Facilities from Evans Energy statement)
Consolidated Electrical Account Summary
(Monthly Flat Files from TransCanada and National Grid)
Monthly Waste Streams
Recyclables, Composting, Solid Waste to Land Fill, etc. (Monthly Flat File Compiled by Dartmouth Facilities)
Travel Data
VOX Fleet Fuel, Commuting Fuel & Air Travel
(Monthly Flat File Compiled by Dartmouth Facilities)
Refrigerants
(HFC's Used by Refrigeration Shop)
Monthly Flat File Compiled by Dartmouth Facilities)
Fertilizers
(Monthly Flat File Compiled by Dartmouth Facilities)
#6 Fuel Oil Deliveries
(Monthly Flat File Compiled by Dartmouth Facilities)
Rockwell FactoryTalk Historian
Rockwell RSEnergy Metrix Metering DB
Fiscal Year Billing Account Budgets
(Utility Quantities 100's# Steam, kWH, tons CHW)
Annual Batch Upload
Wizard(s) for Data File uploads by Admin. Staff
Common Tag = Building ID
Rockwell VantagePoint Server
Reports & Dashboards
All Building Summary
Building Performance Metrics
Design
Actual
Mech. System Operational Trends
Historical Energy & Resource Use
Building Dashboard Overview
Building Dashboard Detail
Greenhouse Gas Accounting
Predictive vs Actual Loads
Utility Billing
Heating/Electric Plant Efficiency
Campus Steam Overview
Campus Electrical Overview
Chilled Water Plant Efficiency

4.1. Collection and storage of:

- Automated meter data from Dartmouth's 300+ energy meter infrastructure (approx..130 Buildings; partial listing and examples below)

- Purchased energy resource data (#6 fuel oil, #2 Fuel Oil, Diesel and Propane, Gasoline, etc.)
- Material resource data (trash, recycling, water, etc.)
- Energy and resource use related to Greenhouse Gas Emissions
- Hourly weather data for the Hanover region from connection to the National Oceanographic and Atmospheric Administration (NOAA) website

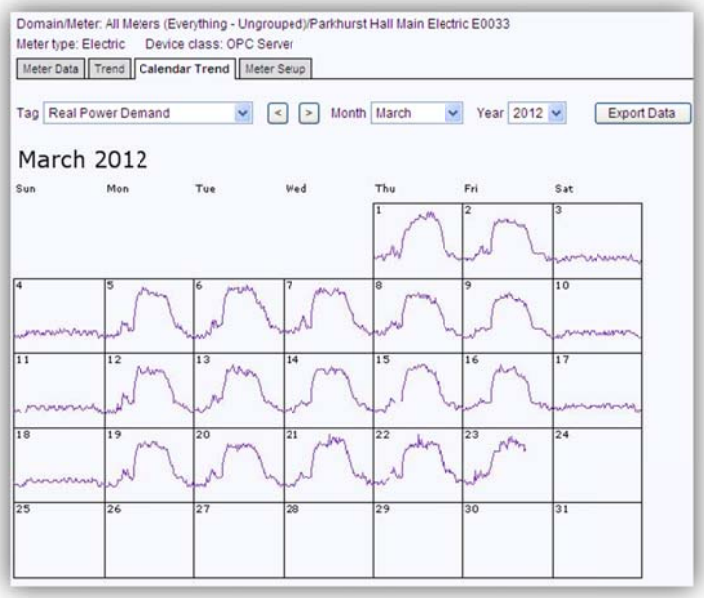
4.2. Connection to:

- Honeywell and Johnson Controls Building Management Systems (BMS) for

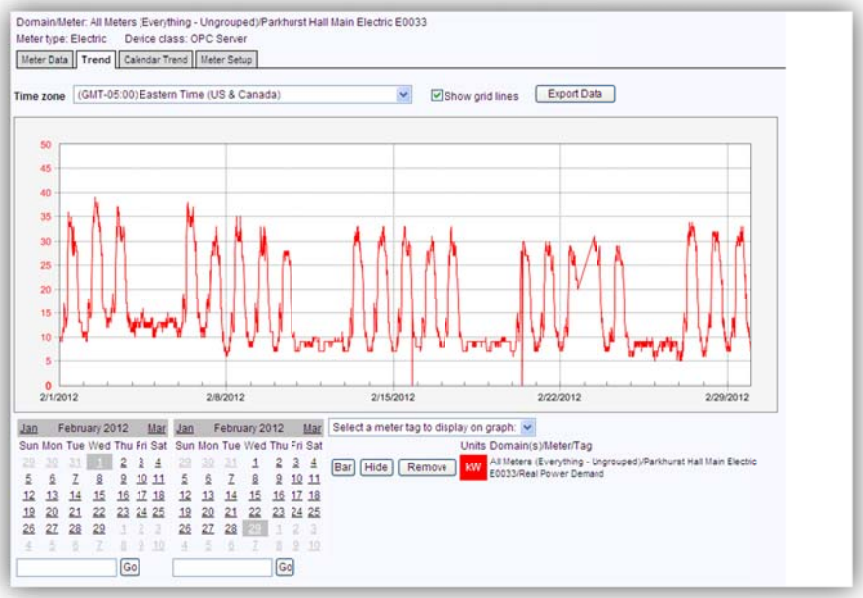
access to their current and historical trend data

- Heating and Electrical Plant process control systems (ABB) for access to their current and historical trend data

4.3. Views of Energy Use in Real and Historical Time



Calendar Trend View

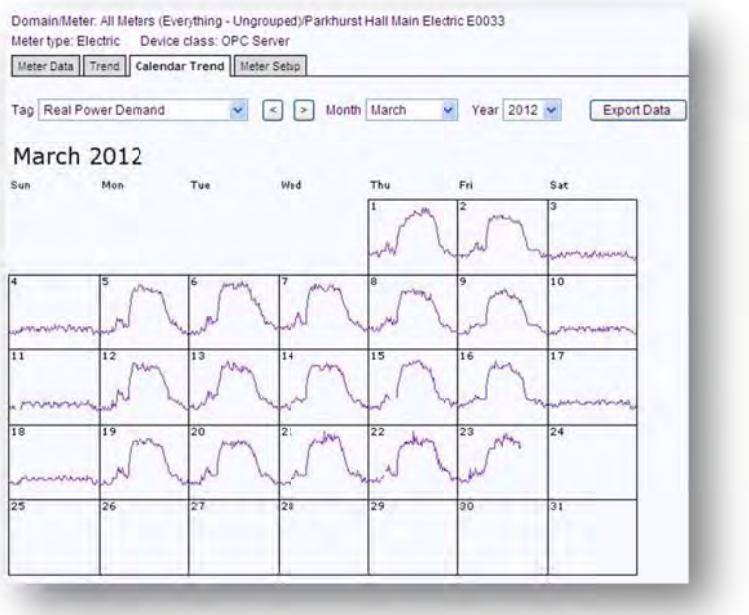


Trend View – Any Time Period

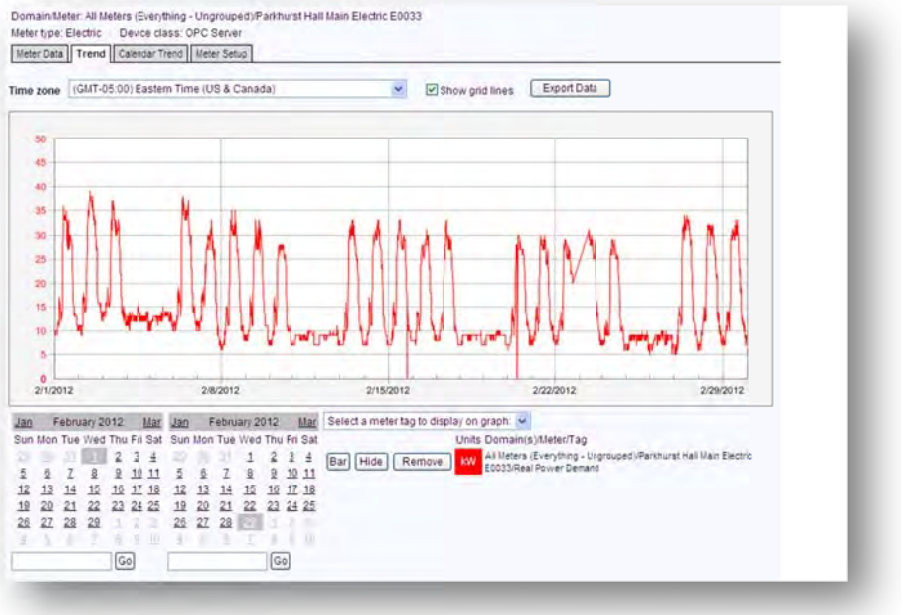
access to their current and historical trend data

- Heating and Electrical Plant process control systems (ABB) for access to their current and historical trend data

4.3. Views of Energy Use in Real and Historical Time



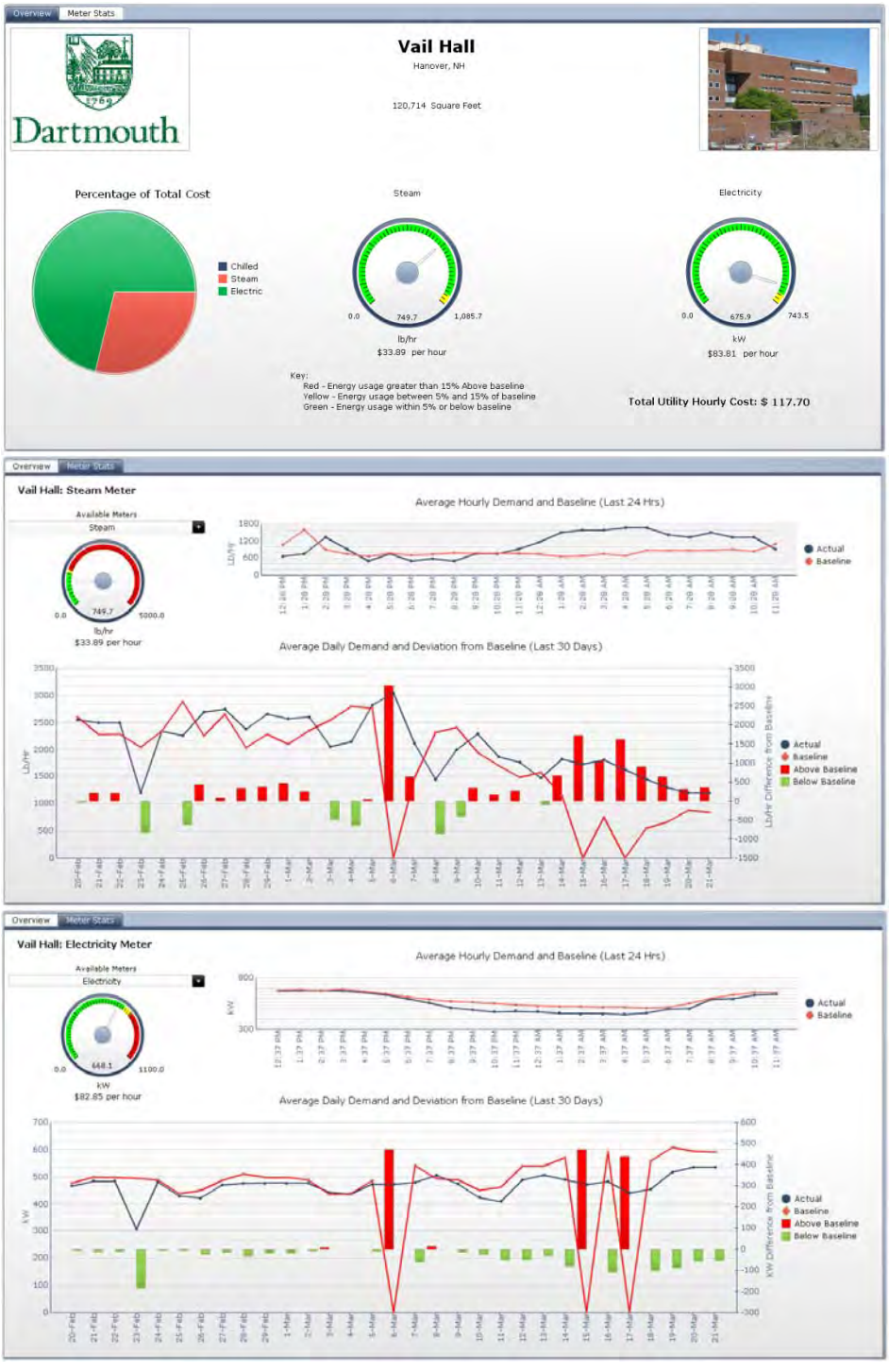
Calendar Trend View



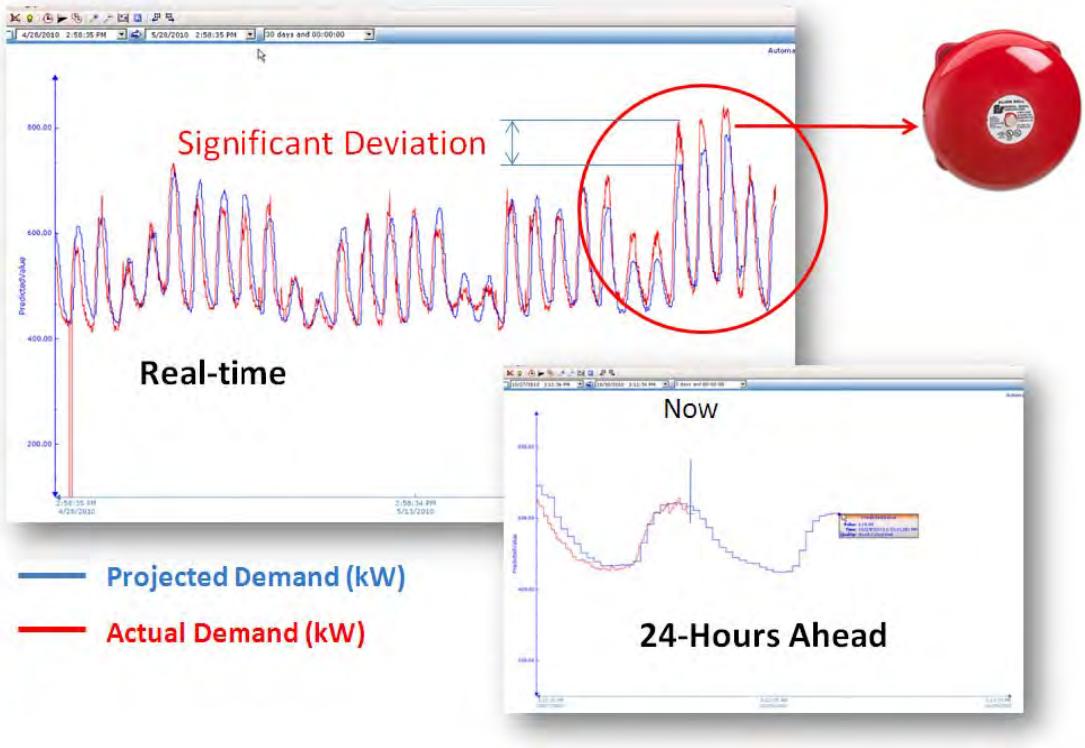
Trend View – Any Time Period

4.4. Predictive Load Analysis and Trends

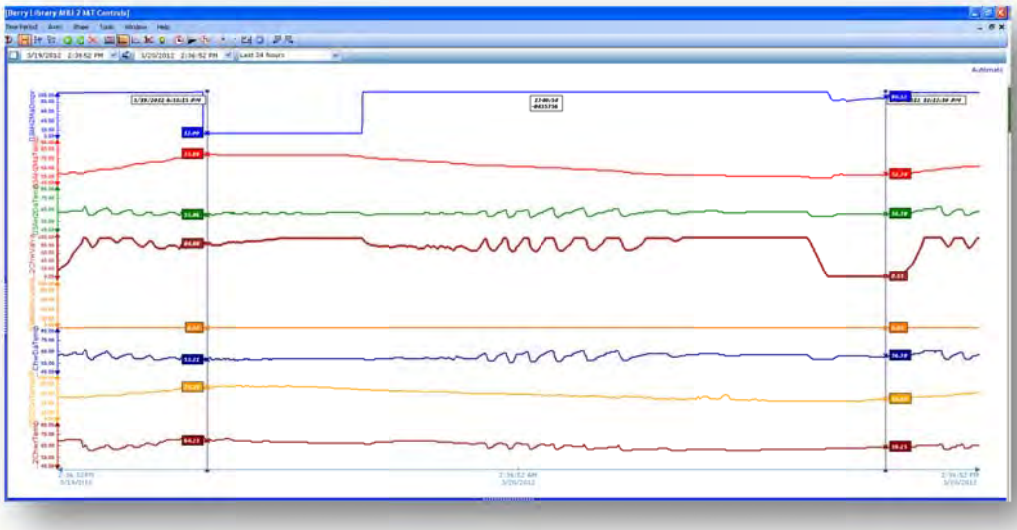
- Dashboard views of each building's energy use vs. predictive energy use



- Predictive load projections of individual meter, building level, or campus level utility usage (24 hour forward load projections)



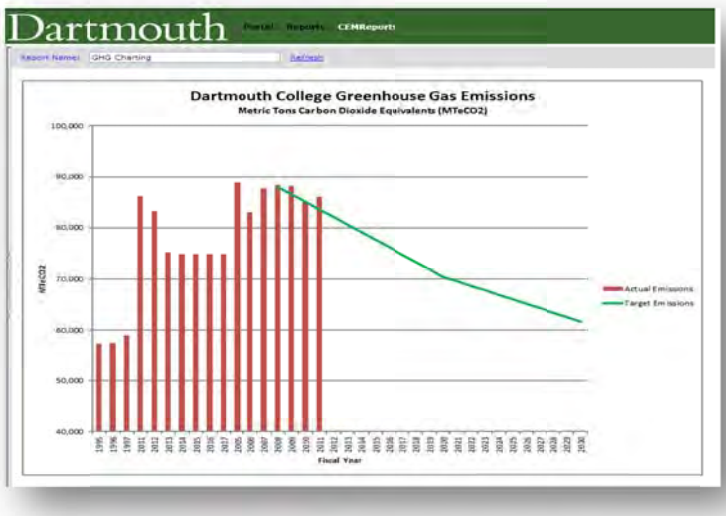
- Pre-configured and ad-hoc trend analysis from any combination of BMS, metering, and Heating Plant points



4.5. Greenhouse Gas Accounting

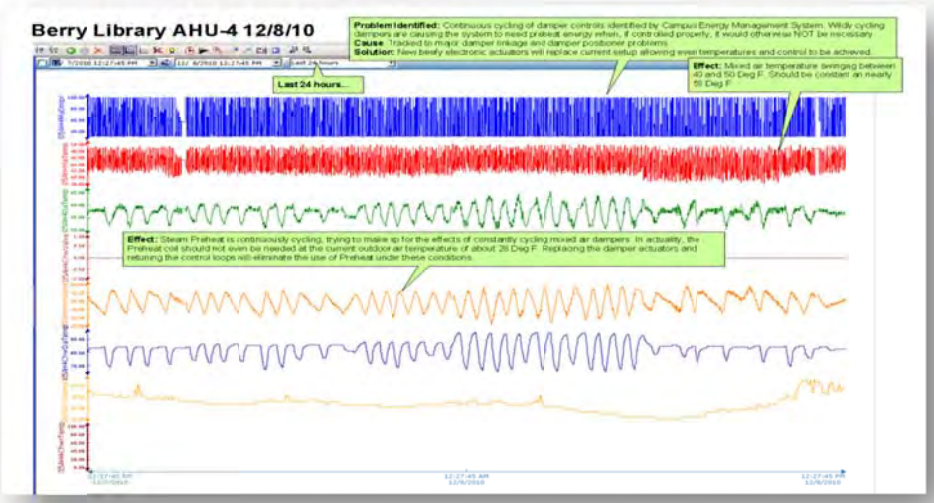
We have configured the CESM System to integrate directly with the Clean Air-Cool Planet (CACP) Campus Carbon Calculator program. The CESM System records units of energy and resource use in its database tables from automated energy metering, manual data sources, and bulk-upload sources, and, on a monthly basis, links this data to the Clean Air Cool Planet Carbon Calculator. The process uses CACP's GHG emissions factors and calculation engine to update the Scope 1, 2, and 3 emissions; any offset values, and produces an updated view of fiscal-year-to-date Net Greenhouse Gas Emissions.

Having a link to the Clean Air Cool Planet GHG calculator allows us to track progress in lowering our GHG emissions and compare this to the reduction trajectory pledged by the College in 2008. An example output graph is shown, below. Our Sustainability Office will continue working with us to add greater content to this feature of the CESM System.

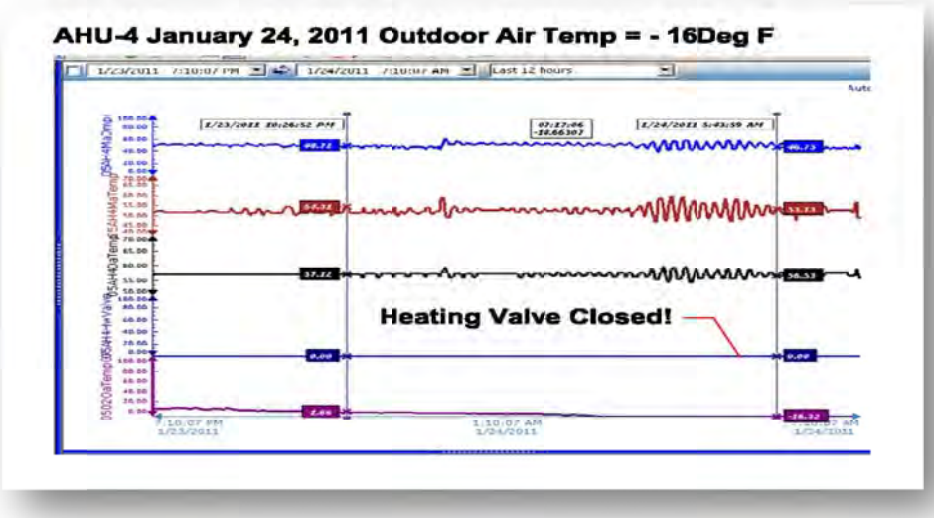


4.6. RetroCommissioning Tool Set

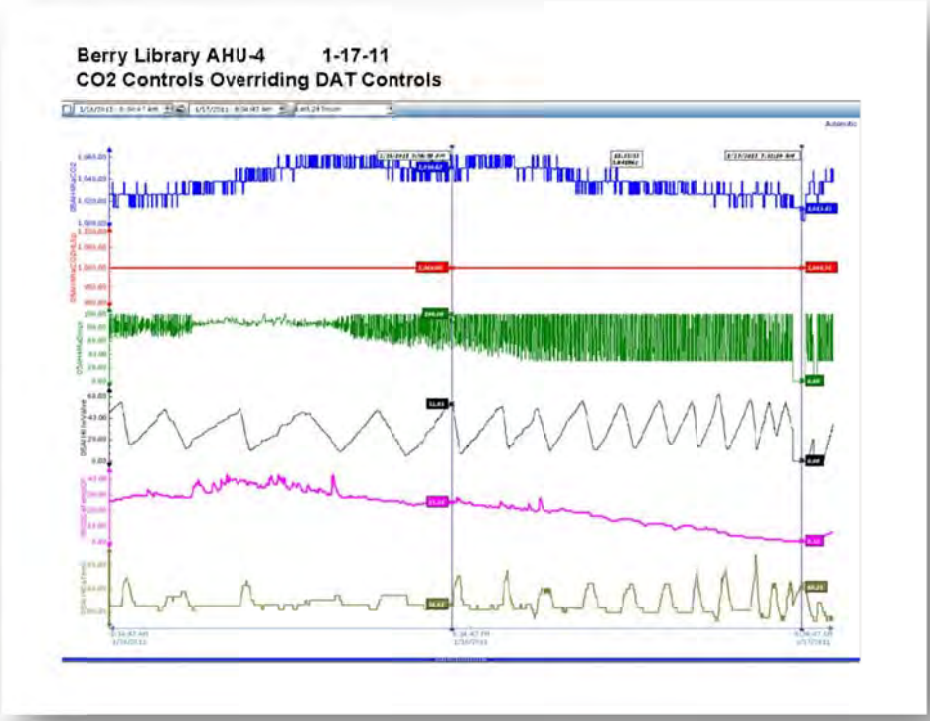
Our new CESM System provides us with excellent tools to detect faults and operational inefficiencies in HVAC and other energy systems. We have used these capabilities in our on-going RetroCommissioning (RCx) programs for the Berry Library complex, our Central Chiller Plant, Alumni Gymnasium complex, and other facilities. Examples of operating issues detected by the CESM System (before) and the fixed systems (after) are shown below. In the examples below, outdoor air dampers were continually cycling during summer and winter, and other ventilation controls and programming issues were causing a large waste of energy. This has since been remedied and is continually checked via the CESM System.



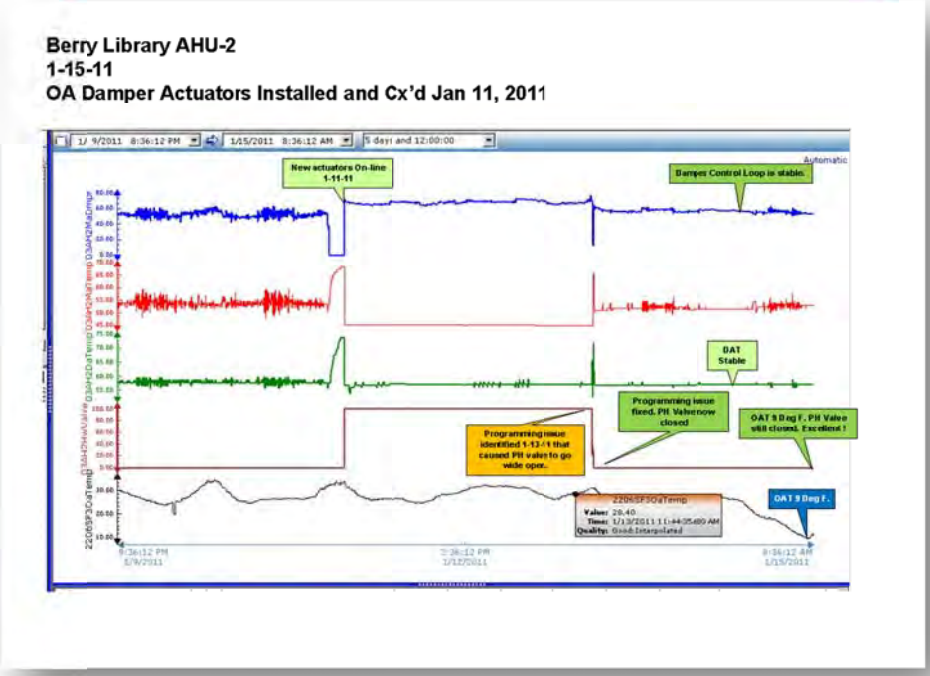
Continuously cycling ventilation dampers causing wasteful heating of outdoor air during winter and wasteful cooling of outdoor air in the summer



Problem Resolved. NO damper cycling and NO heating of outdoor air and it is **Minus** 16 Degrees F Outside!

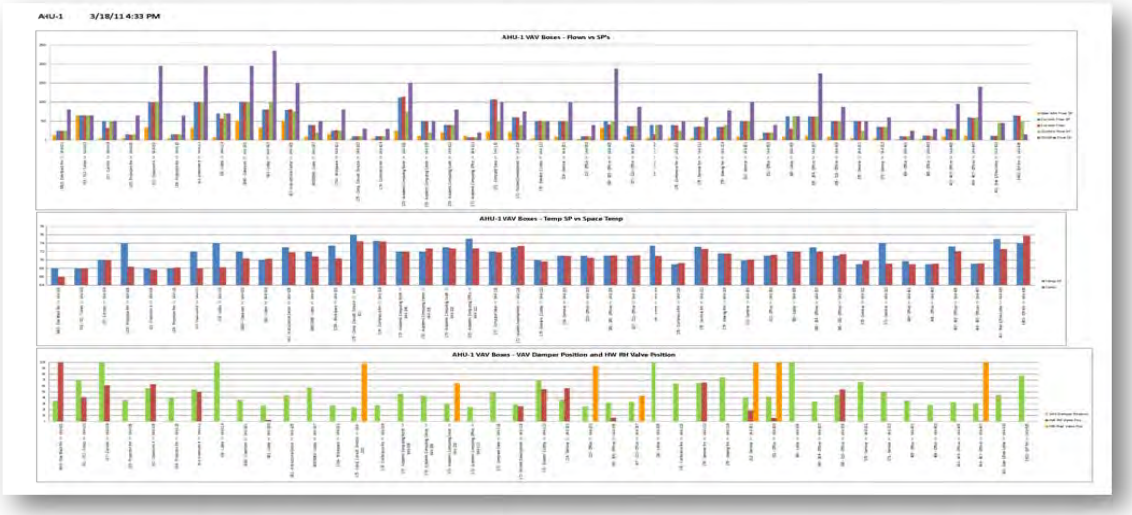


Erroneous CO2 sensor giving bad signal to ventilation dampers and causing winter and summer energy waste.



Damper actuators replaced and control programming issues resolved, resulting in substantial savings.

Multi-dimensional view of results



CESM System is an excellent tool for Persistence Monitoring of Retro-Commissioned buildings. In this example, the CESM System is monitoring conditions for all 40 Variable Air Volume room terminals serving Air Handling Unit-1.

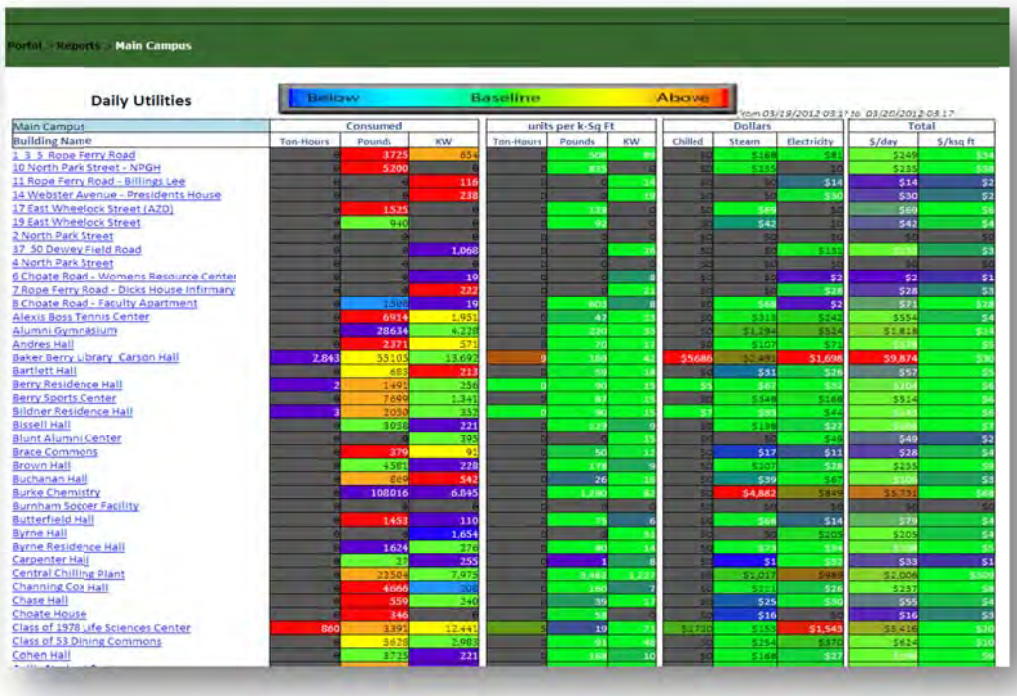
The Berry Library Retro-Commissioning project has yielded excellent results and is continually tracked for performance by the CESM System. Total savings for the first 6 months of operation were greater than $250,000. The table below shows a summary of these savings.

Berry Library Retro-Commissioning Results First 6 Months of Operation						
	6 Months FY'10-'11	6 Months FY'11-'12	Energy Savings	Units	Savings (%)	Savings ($)
Steam	73,454	61,372	12,082	100's #	16.4%	$43,495
Electric	2,829,625	2,533,223	296,402	kWH	10.5%	$38,532
CHW	1,027,430	733,040	294,390	Ton-Hrs	28.7%	$176,634
					Totals	$258,661

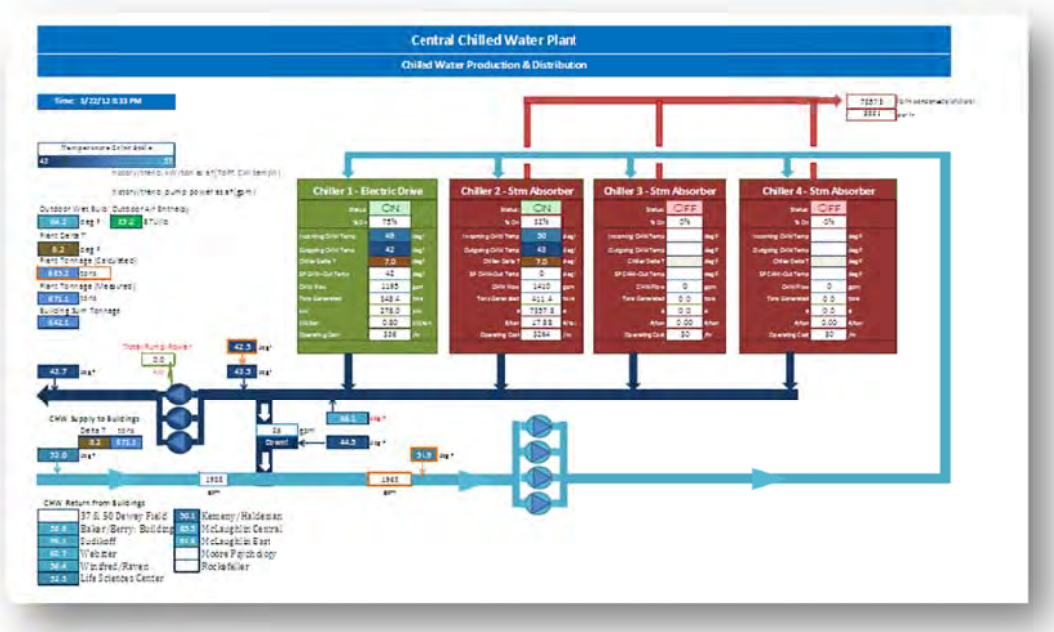
4.7. Reporting

Many reports have been built for the system with more coming on line all of the time. The Rockwell VantagePoint system has an "Add-in" capability to Microsoft Excel which allows us to retrieve live or historical system data from the many sources that we are connected to. Once we bring the data sets into Excel, we can then manipulate the data, performing other functions, including modeling of system performance, calculating system efficiencies, determining rankings, creating statistical views, developing dashboard displays, etc. We can then "publish" the results back into the VantagePoint CESM System model so that other campus stakeholders can see the results via web-based displays, keeping the data fresh and accessible. Some examples are included, below:

- All-Building-Summary of actual energy performance vs. predicted energy performance (green is as predicted, blue is lower than predicted, red is greater than predicted).



- Chilled Water Plant Reports –These reports show our large Central Chilled Water Plant in action. We can see equipment staging, real-time energy use, system cost per hour, calculated efficiencies, chiller loading, and overall performance characteristics.



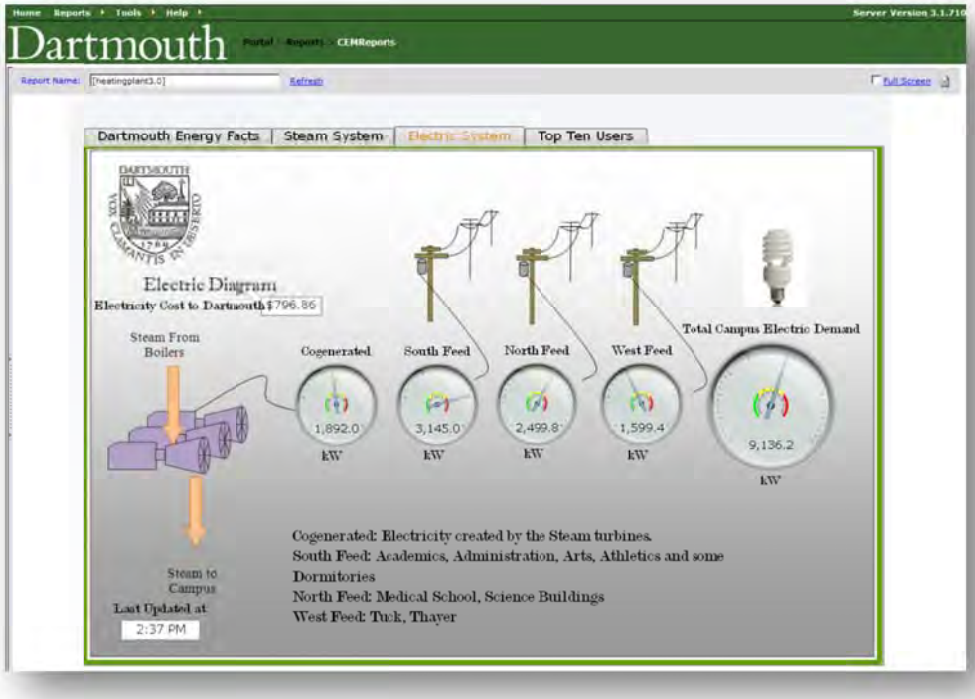
- Chilled Water Delta T Report –This report shows each building's use of chilled water (return temperature minus the supply temperature). A high delta T is good as it means that the building is using the chilled water efficiently and is allowing the chillers to work to their optimal design points and provide substantial cooling loads to the campus.

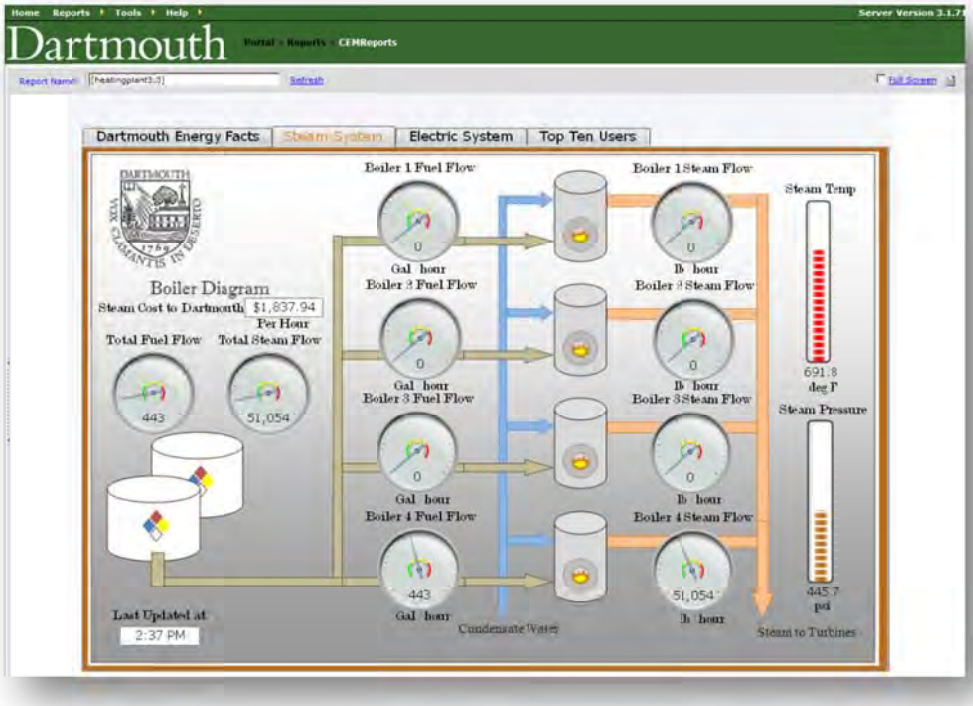
Chilled Water Delta T Summary Report

3/22/12 11:44 AM

	Actual Delta T (Deg F)	Design Delta T (Deg F)	Difference (Deg F)
At Central Chiller Plant			
CHW Delta T at Central CHW Plant	7.4	13	5.6
At Buildings			
Berry Baker Library _ Carson Hall	13.7	13	-0.7
37_50 Dewey Field Road	0.0	13	13.0
Berry, Bildner, Rauner Halls	6.8	13	6.3
Byrne, Thomas, Goldstein Halls	-1.3	13	14.3
Class of 1978 Life Science Center	12.0	13	1.0
Kemeny Haldeman	7.6	13	5.4
Moore Psychology	Null	13	0.0
Rockefeller Center	-0.1	13	13.1
Sudikoff Computer Science	2.2	13	10.8
Webster Hall	17.9	13	-4.9
Winifred Raven House	13.5	13	-0.5

- Heating and Electric Plant Reports – Showing campus-level use of purchased electricity and fuel oil, and production of steam and cogenerated electricity





- Monthly reporting of energy production, purchased utilities, plant efficiencies, peak demand values, billing amounts vs. metered amounts, etc.

Electric Plant Monthly Report

		Monthly Totals									
	Lb Steam per Co-Generated kWH	CoGen Electricity (kWH)	North Electrical Service (kWH)	South Electrical Service (kWH)	West Electrical Service (kWH)	Total Purchased Electricity (kWH)	Total Campus Electrical Use (kWH)	Cogen (%)	Purchased (%)	Total Billed Usage (kWH)	Billed vs. Main Metered (%)
July 2011	22.2	1,562,989	1,768,621	1,803,748	1,048,529	4,620,898	6,183,887	25%	75%	5,719,604	92%
August 2011	22.4	1,350,656	1,724,953	1,825,063	1,044,348	4,594,364	5,945,020	23%	77%	6,072,666	102%
September 2011	23.9	1,261,923	1,589,100	1,007,396	782,455	3,378,951	4,640,874	27%	73%	5,779,449	125%
October 2011	22.4	1,631,775	1,677,767	1,631,004	877,707	4,186,478	5,818,253	28%	72%	5,345,553	92%
November 2011	20.9	1,866,213	1,589,100	1,007,396	782,455	3,378,951	5,245,164	36%	64%	5,693,451	109%
December 2011	22.4	1,834,809	1,501,388	508,489	708,583	1,718,459	4,553,268	40%	60%	4,526,959	99%
	0.0	0	0	0	0	0	0	0%	0%	0	0%
	0.0	0	0	0	0	0	0	0%	0%	0	0%
	0.0	0	0	0	0	0	0	0%	0%	0	0%
	0.0	0	0	0	0	0	0	0%	0%	0	0%
	0.0	0	0	0	0	0	0	0%	0%	0	0%
	0.0	0	0	0	0	0	0	0%	0%	0	0%
TOTAL		9,508,364	9,850,929	7,783,096	5,244,076	12,878,101	32,386,465	29%	71%		

		Peak Values					
		CoGen Peak Demand (kW)	North Peak Demand (kW)	South Peak Demand (kW)	West Peak Demand (kW)	Purch Peak Demand (kW)	Campus Peak Demand (kW)
Jul 11	details	5,212	3,091	7,483	1,999	12,005	14,117
Aug 11	details	2,252	2,940	9,929	1,935	13,699	15,678
Sep 11	details	1,088	2,893	9,435	1,714	13,776	15,824
Oct 11	details	3,288	2,829	3,928	1,636	8,229	9,697
Nov 11	details	3,252	2,792	8,904	1,579	13,054	14,610
Dec 11	details	3,696	2,530	8,867	1,347	12,412	14,467
		0	18	0	0	0	0
		0	0	0	0	0	0
		0	0	0	0	0	0
		0	0	0	0	0	0
		0	0	0	0	0	0
		0	0	0	0	0	0

Peak Electric Demand

September 2011	Peak Demand			Other Values at Peak Time					
	kW	time		North Substation	South Substation	West Feeder	Total Purchased	Total Co-generated	Total Campus
North Substation	2,456	9/26/11 9:00		2,456	3,454	1,388	7,298	1,516	8,814
South Substation	3,454	9/26/11 9:00		2,456	3,454	1,388	7,298	1,516	8,814
West Feeder	1,388	9/26/11 9:00		2,456	3,454	1,388	7,298	1,516	8,814
Total Purchased	7,298	9/26/11 9:00		2,456	3,454	1,388	7,298	1,516	8,814
Total Cogenerated	1,516	9/26/11 9:00		2,456	3,454	1,388	7,298	1,516	8,814
Total Campus	8,814	9/26/11 9:00		2,456	3,454	1,388	7,298	1,516	8,814

Heating Plant Monthly Steam Report

	Heating Deg Days	Total Steam Produced by Boilers (#)	Total Steam to Campus (#)	Heating Units Produced by Boilers (100 #)	Heating Units to Campus (100 #)	Heating Units Billed (100 #)	Billed Heating Units vs. Heating Units to Campus (%)	Makeup Water (#)	Makeup Water (%)	Calc Boiler Eff ASME PTC 4.1	0.5% Sulfur #6 Fuel Oil (Gal)	1.0% Sulfur #6 Fuel Oil (Gal)	Total Fuel Oil Burned (Gal)
Jul-2011	0	40,618,371	34,735,115	406,184	347,351	358,356	103%	4,933,444	12.1%	91.3%	146,885	203,256	350,141
Aug-2011	0	37,872,839	30,312,189	378,728	303,122	309,007	102%	4,183,780	11.0%	91.0%	127,138	200,277	327,415
Sep-2011	115	34,312,308	30,112,189	343,123	301,122	310,303	103%	3,603,397	10.5%	90.7%	128,487	169,067	297,554
Oct-2011	457	41,363,500	36,600,741	413,635	366,007	280,708	77%	4,076,865	9.9%	90.8%	142,001	216,572	358,573
Nov-2011	691	44,651,869	38,997,474	446,519	389,975	379,463	97%	5,742,542	12.9%	87.4%	74,662	327,311	401,973
Dec-2011	1,117	49,180,692	41,186,804	491,807	411,868	405,637	98%	7,287,864	14.8%	87.6%	157,277	284,581	441,858
Jan-2012	1,304	56,733,778	49,333,852	567,338	493,339	505,501	102%	8,107,306	14.3%	86.9%	108,978	405,018	513,996
Feb-2012	1,073	49,221,934	43,206,401	492,219	432,064	465,429	108%	6,215,399	12.6%	87.2%	148,345	295,977	444,322
Mar-2012	0	0	0	0	0	0	0%	0	0.0%	0.0%	0	0	0
Apr-2012	0	0	0	0	0	0	0%	0	0.0%	0.0%	0	0	0
May-2012	0	0	0	0	0	0	0%	0	0.0%	0.0%	0	0	0
Jun-2012	0	0	0	0	0	0	0%	0	0.0%	0.0%	0	0	0
Totals	4,757	353,955,292	304,484,763	3,539,553	3,044,848	3,014,404	70%	44,150,597	12.5%	88.8%	1,033,773	2,102,059	3,135,831

- Sustainability Indicators (fuel oil use, solid waste, recycling, composting, refrigerants, etc.). For these items we are able to track trends in usage and compare values with targets we have set for improvements.

-

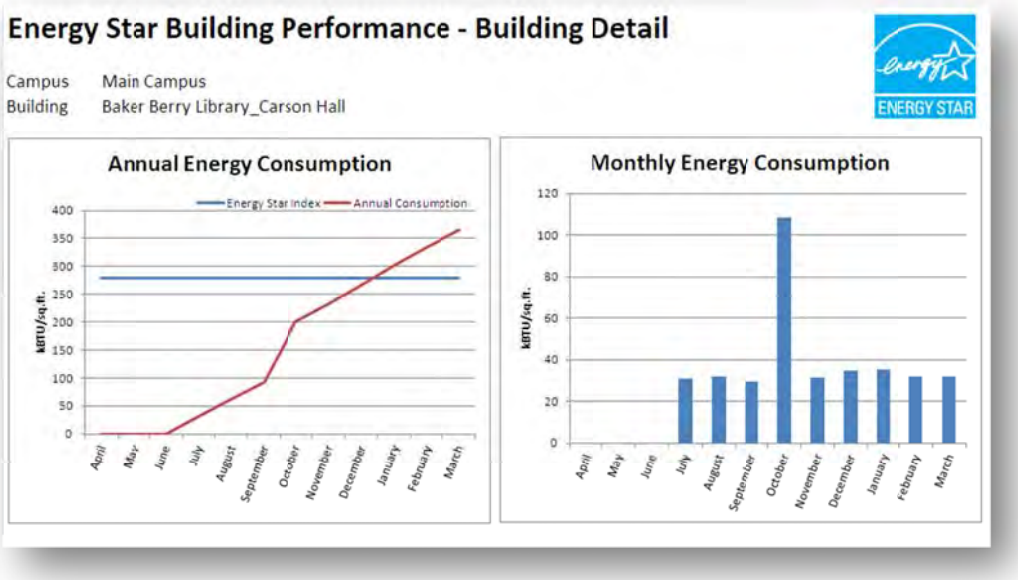
- Building performance metrics (MMBTU, BTU/Sq. ft/Yr, etc)

Dartmouth College

Top Energy User Rankings and Target Reductions

FY11 Rank (MMBTU)	Building	MMBTU (Site)	Sq Ft	BTU/SqFt/Yr (Site)	Energy Use as % of Total Campus Use	Targeted Energy Reduction (MMBTU)	Targeted Energy Reduction (%)
1	Burke Chemistry Laboratory	83,779	83,756	1,000,511	13%	51,943	62%
2	Berry Library	47,373	155,858	303,950	8%	7,106	15%
3	Hopkins Center	36,086	155,114	232,639	6%	7,217	20%
4	Vail Hall	31,196	120,714	258,427	5%	6,239	20%
5	Gilman Life Sciences Laboratory	26,859	62,770	427,902	4%	26,859	100%
6	Moore Psychology Building	22,148	107,091	206,765	4%	2,214	10%
7	Cummings Hall	21,053	129,174	162,978	3%	2,105	10%
8	Alumni Gym	20,425	129,875	157,267	3%	3,064	15%
9	Remsen Hall	19,687	96,418	204,181	3%	1,969	10%
10	Wilder Laboratory	15,335	71,331	214,985	2%	1,534	10%
11	Murdough Center	13,947	73,019	191,010	2%	2,092	15%
12	Hanover Inn	13,325	90,349	147,485	2%	2,665	20%
13	MacLean Engineering Sciences Center	13,061	69,608	187,629	2%	653	5%
14	Steele Hall	12,719	51,428	247,324	2%	1,908	15%
15	Thompson Arena	10,722	83,615	128,230	2%	3,217	30%
16	Class of '53 Commons	9,234	61,611	149,878	1%	462	5%
17	Hood Museum of Art	9,082	37,615	241,440	1%	1,816	20%
18	Leverone Fieldhouse	8,662	91,839	94,320	1%	1,732	20%
19	Fairchild Physical Sciences Center	8,523	82,642	103,129	1%	1,705	20%
20	Byrne Hall	8,085	52,745	153,286	1%	1,617	20%
21	Kemeny/Haldeman	7,785	69,288	112,357	1%	778	10%
22	Webster Hall	7,595	23,910	317,664	1%	380	5%
23	Sudikoff Computer Science	7,352	31,566	232,912	1%	147	2%
24	Collis Student Center	7,110	52,744	134,807	1%	1,067	15%
25	Tuck LLC	7,063	95,000	74,347	1%	353	5%
26	Berry Sports Center	6,305	88,394	71,325	1%	946	15%
27	Whittemore Dormitory	5,960	58,267	102,291	1%	596	10%
28	Floren Varsity Building	5,596	41,300	135,497	1%	839	15%
29	Dana Biomedical Library	5,203	29,691	175,230	1%	5,203	100%
30	37 & 50 Dewey Field Road	4,710	40,708	115,696	1%	471	10%
31	Alexis Bass Tennis Center	4,677	146,855	31,846	1%	468	10%
	Sum of Top Energy Users (31 Bldgs)	500,651	2,484,275	201,528	81%	139,364	
	Totals for All Buildings (122 Bldgs)	621,681	4,221,409	147,269	100%		
				Targeted Energy Savings as % of All Buildings Energy Use >>>			22%

- EnergyStar reporting for each building – The VantagePoint system tracks a rolling 12-month summation of energy use for each building and produces an Annual Energy Consumption graph in KBTU/Sq.Ft. This is compared to an EnergyStar normalized value for peer building types in similar climates.



4.8. Data Sharing and Its Influence on Energy-Use Behavior

As part of the Grant, we explored (and continue to explore) use of energy feedback information to influence energy behavior of building occupants. During the course of the Grant, we had the privilege of working with Dartmouth GreenLite, an academic program run by Professor Lorie Loeb of the Computer Science Department. The GreenLite program uses energy display systems to draw students into behavior change by revealing their use of energy in real-time. The GreenLite program uses animated displays which create an emotional connection between building occupants and their energy-use behaviors.

Because our metering infrastructure allows us to serve data values out to 3rd-party collaborators, we have assisted the GreenLite program in setting up the infrastructure necessary for all of their projects on campus. One such program took place in the spring of 2011 at the Tuck School of Business. The outgoing 2nd year graduate students left a legacy gift to be used for an energy-visibility project. The GreenLite program was chosen by the Tuck School administrators as an effective means of honoring the gift. Our Energy Program Office assisted in design, installation, and setup of the 17-meter infrastructure necessary to support the program.

In the Tuck case, 7 residential floors within two living-learning buildings were outfitted with electrical sub-metering and local touchscreen displays. The displays show live animated images and graphical images of energy-use patterns for the occupants (see below):

A competition was established in the spring, placing residential floors in competition with each other to see who could have the greatest percentage reduction in use of electricity. In addition to the metering infrastructure and displays, a research project was undertaken by the GreenLite project, to determine the motivation of occupants to use the system, and some of the derivative impacts of their interactions with the systems. The results of this research are included in a poster in the Appendix. In general, the students were curious to learn more, and their interaction with the GreenLite displays resulted in them thinking on a broader level about the impacts of their actions on climate change and global use of resources.

Savings based upon behaviorioral impacts typically ranged between 5% and 20%, with most falling in the 5% to 10% range. Additional screenshots of Tuck and other GreenLite installation are shown below:

Competition Mode – One Dormitory Floor vs Other Floors

Graphical View – Now vs Monthly Average + Min/Max Ranges

Campus View Locator Plan for GreenLite Kiosk Locations

GreenLite Energy Tips

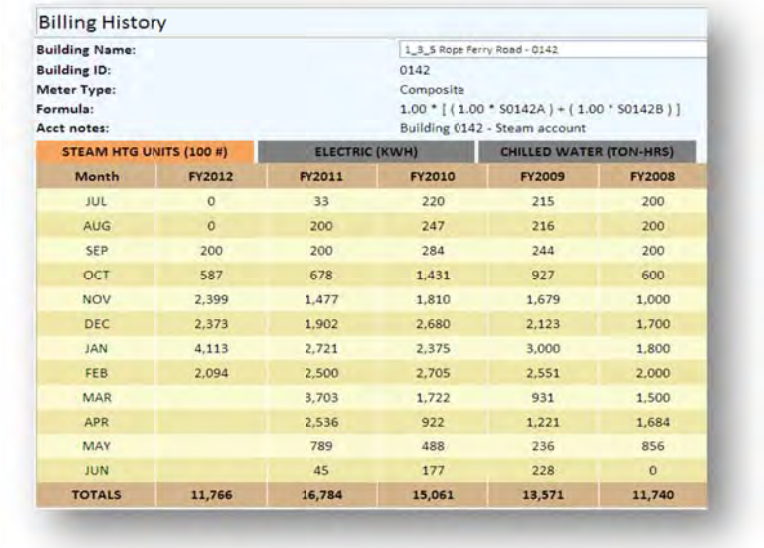
Energy Contextualization – What Are Some Equivalents?

4.9. Alarming

- The VantagePoint system provides the capability of alarming any monitored or calculated system variable when the value falls outside expected performance parameters. We are beginning to make use of this capability to detect faults and provide notification to Facilities Operations and Management staff.

4.10. Utility Billing

- Processing monthly utility billing usage for central campus connected utilities

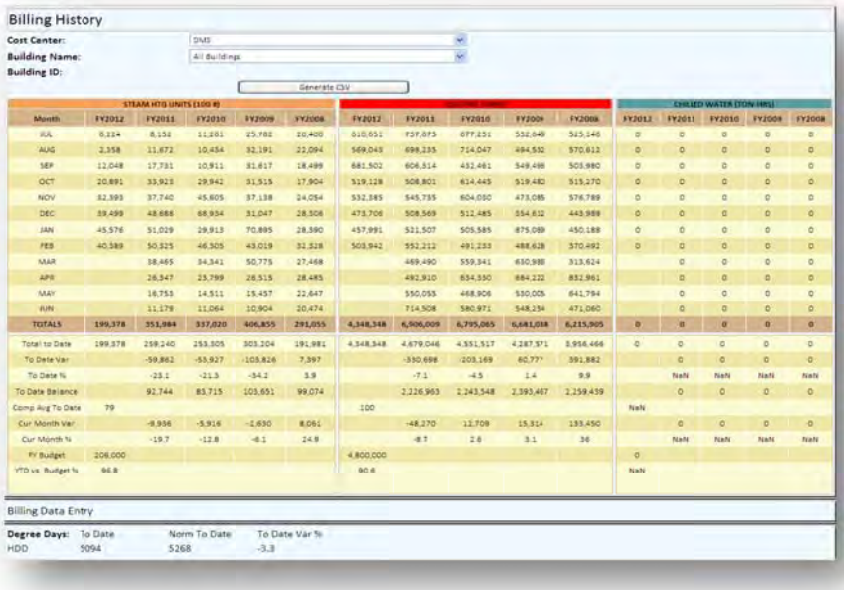


Billing History

Building Name:	1_3_5 Rope Ferry Road - 0142
Building ID:	0142
Meter Type:	Composite
Formula:	1.00 * [(1.00 * S0142A) + (1.00 * S0142B)]
Acct notes:	Building 0142 - Steam account

	STEAM HTG UNITS (100 #)	ELECTRIC (KWH)		CHILLED WATER (TON-HRS)	
Month	**FY2012**	**FY2011**	**FY2010**	**FY2009**	**FY2008**
JUL	0	33	220	215	200
AUG	0	200	247	216	200
SEP	200	200	284	244	200
OCT	587	678	1,431	927	600
NOV	2,399	1,477	1,810	1,679	1,000
DEC	2,373	1,902	2,680	2,123	1,700
JAN	4,113	2,721	2,375	3,000	1,800
FEB	2,094	2,500	2,705	2,551	2,000
MAR		3,703	1,722	931	1,500
APR		2,536	922	1,221	1,684
MAY		789	488	236	856
JUN		45	177	228	0
TOTALS	**11,766**	**16,784**	**15,061**	**13,571**	**11,740**

- Providing detailed historical energy reports by building or cost center



Billing History

Cost Center: DMS
Building Name: All Buildings
Building ID:

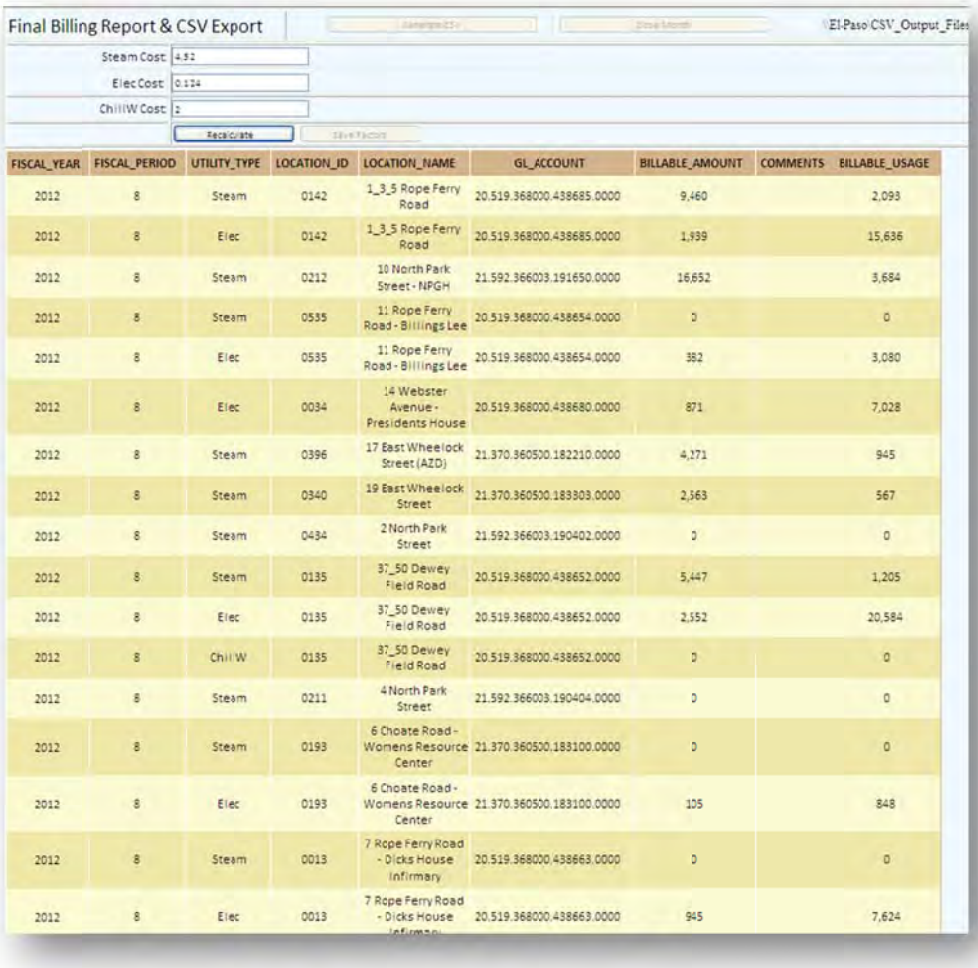
Generate CSV

	STEAM HTG UNITS (100 #)										CHILLED WATER (TON-HRS)				
Month	**FY2012**	**FY2011**	**FY2010**	**FY2009**	**FY2008**	**FY2012**	**FY2011**	**FY2010**	**FY2009**	**FY2008**	**FY2012**	**FY2011**	**FY2010**	**FY2009**	**FY2008**
JUL	8,124	8,152	11,281	25,782	20,400	610,651	737,873	677,251	552,649	525,146	0	0	0	0	0
AUG	2,358	11,672	10,454	32,191	22,094	569,043	698,235	714,047	494,552	570,812	0	0	0	0	0
SEP	12,048	17,731	10,911	31,617	18,499	681,502	606,514	452,481	549,498	503,980	0	0	0	0	0
OCT	20,891	33,923	29,942	31,515	17,904	519,128	508,801	614,445	519,480	515,270	0	0	0	0	0
NOV	32,393	37,740	45,605	37,138	24,054	532,585	545,735	604,080	473,085	576,789	0	0	0	0	0
DEC	39,499	48,686	68,934	31,047	28,508	473,706	508,569	512,485	554,612	443,989	0	0	0	0	0
JAN	45,576	51,029	29,913	70,895	28,390	457,991	521,507	505,585	875,089	450,188	0	0	0	0	0
FEB	40,389	50,325	46,305	43,019	32,328	503,942	552,212	491,233	488,628	370,492	0	0	0	0	0
MAR		38,465	34,341	50,775	27,468		469,490	559,341	630,988	313,624		0	0	0	0
APR		26,347	23,799	28,515	28,485		492,910	634,330	684,222	832,961		0	0	0	0
MAY		16,753	14,511	15,457	22,647		550,055	468,906	530,005	641,794		0	0	0	0
JUN		11,179	11,064	10,904	20,474		714,508	580,971	548,234	471,060		0	0	0	0
TOTALS	**199,378**	**351,984**	**337,020**	**406,855**	**291,055**	**4,348,348**	**6,906,009**	**6,795,065**	**6,681,018**	**6,215,905**	**0**	**0**	**0**	**0**	**0**
Total to Date	199,378	258,240	253,305	303,204	191,981	4,348,348	4,679,046	4,351,517	4,287,571	3,956,466	0	0	0	0	0
To Date Var		-59,862	-53,927	-103,826	7,397		-330,698	-203,169	60,777	391,882		0	0	0	0
To Date %		-23.1	-21.3	-34.2	3.9		-7.1	-4.5	1.4	9.9		NaN	NaN	NaN	NaN
To Date Balance		92,744	83,715	103,651	99,074		2,226,963	2,243,548	2,393,447	2,259,439		0	0	0	0
Comp Avg To Date	79					100					NaN				
Cur Month Var		-8,956	-5,916	-1,630	8,061		-48,270	11,709	15,314	133,450		0	0	0	0
Cur Month %		-19.7	-12.8	-4.1	24.8		-8.7	2.6	3.1	36		NaN	NaN	NaN	NaN
FY Budget	208,000					4,800,000					0				
YTD vs. Budget %	66.8					90.6					NaN				

Billing Data Entry

Degree Days:	To Date	Norm To Date	To Date Var %
HDD	5094	5268	-3.3

- Exporting a monthly billing file to the campus Oracle financial system



Final Billing Report & CSV Export

El-Paso\CSV_Output_Files

Steam Cost: 4.52
Elec Cost: 0.124
ChillW Cost: 2
Recalculate

FISCAL_YEAR	FISCAL_PERIOD	UTILITY_TYPE	LOCATION_ID	LOCATION_NAME	GL_ACCOUNT	BILLABLE_AMOUNT	COMMENTS	BILLABLE_USAGE
2012	8	Steam	0142	1_3_5 Rope Ferry Road	20.519.368000.438685.0000	9,460		2,093
2012	8	Elec	0142	1_3_5 Rope Ferry Road	20.519.368000.438685.0000	1,939		15,636
2012	8	Steam	0212	10 North Park Street - NPGH	21.592.366003.191650.0000	16,652		3,684
2012	8	Steam	0535	11 Rope Ferry Road - Billings Lee	20.519.368000.438654.0000	0		0
2012	8	Elec	0535	11 Rope Ferry Road - Billings Lee	20.519.368000.438654.0000	382		3,080
2012	8	Elec	0034	14 Webster Avenue - Presidents House	20.519.368000.438680.0000	871		7,028
2012	8	Steam	0396	17 East Wheelock Street (AZD)	21.370.360500.182210.0000	4,171		945
2012	8	Steam	0340	19 East Wheelock Street	21.370.360500.183303.0000	2,363		567
2012	8	Steam	0434	2 North Park Street	21.592.366003.190402.0000	0		0
2012	8	Steam	0135	37_50 Dewey Field Road	20.519.368000.438652.0000	5,447		1,205
2012	8	Elec	0135	37_50 Dewey Field Road	20.519.368000.438652.0000	2,552		20,584
2012	8	ChillW	0135	37_50 Dewey Field Road	20.519.368000.438652.0000	0		0
2012	8	Steam	0211	4 North Park Street	21.592.366003.190404.0000	0		0
2012	8	Steam	0193	6 Choate Road - Womens Resource Center	21.370.360500.183100.0000	0		0
2012	8	Elec	0193	6 Choate Road - Womens Resource Center	21.370.360500.183100.0000	105		848
2012	8	Steam	0013	7 Rope Ferry Road - Dicks House Infirmary	20.519.368000.438663.0000	0		0
2012	8	Elec	0013	7 Rope Ferry Road - Dicks House Infirmary	20.519.368000.438663.0000	945		7,624

- Storing and retrieving historical utility consumption data

5. **Jobs Created** – To date, two jobs have been created, directly attributable to the implementation of the CESM System project.

   - *Energy Management Analyst position* – In January of 2012, we hired a full time analyst to manage the day-to-day operations of the CESM System, keeping the system up to date, running specialized reports to determine locations for energy waste on campus, working with the Sustainability Office for additional visibility of our programs, and to provide continuous additional content to the CESM System.

   - *Building Management System Operator position* – In March of 2012, we will hire a new full-time technician to join the Building Management System team. This position was created in response to increased number of work orders generated by energy visibility from the CESM System. Our new hire will assist the Energy Team in tracking down and remedying the energy-waste issues detected by the CESM System.

6. **Obstacles Encountered or Milestones Not Reached**

   Implementation of the Campus Energy and Sustainability Management System was a very complex project. According to our Administrative Computing Department, the CESM System is the second-largest data-integration project undertaken on the Dartmouth campus. Despite the challenges of managing multiple sub-projects over the course of the contract, we have successfully managed to reach each of the milestones, if not always in the estimated time. The greatest obstacles encountered included the following:

   - *Meter Automation Program Complexity* – The sub-project of automating 300 energy meters was a very complex task which ran longer than anticipated and entailed greater capital dollars and labor hours than anticipated. Nonetheless, we stayed the course and were able to complete all work on this sub-task within the timeline of the overall contract.

   - *Validating the CESM System Solution* – Because the CESM System was brought on line piece-by-piece over the course of a 2-year period, it proved difficult to validate that all pieces worked nicely with each other until near the end of the program. When we were able to view all of the pieces together, specific interactions and report components were found to need additional work and documentation (see below) to ensure that they provided the value and repeatable performance promised by the vendor. As the NHGHGER Fund Grant ended, these final pieces were being addressed by Rockwell Automation.

   - *Documenting the CESM System Solution* – In the process of validating the CESM System and ensuring accuracy and repeatability of performance, it became clear that the overall system was not well documented by the vendor. The custom nature of our solution required that the deliverable be fully documented and it was not. Documentation of the solution is ongoing as this Final Report is being prepared. We are confident that we will have a suitable working document, detailing our system operations in the very near future.

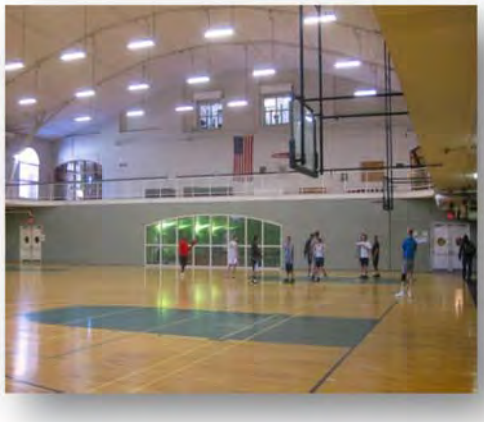
   - *RetroCommissioning (RCx)Program Delays* **–** One of the key benefits of the CESM System is its ability to look into the building HVAC control systems and detect system performance issues. The delays in achieving full functionality of the CESM System, resulted in a somewhat late start on our planned RetroCommissioning program. Although

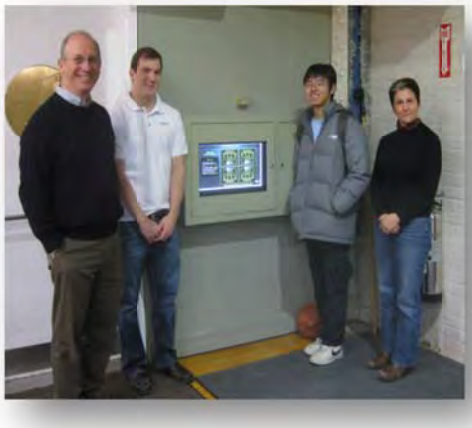
this slowed down initial RCx program activities, we have overcome these issues and are now fully engaged with using the CESM System for our RCx programs.

7. **Beyond the Contract** – *Other Activities, Partnerships, and Synergies*

Implementation of the Campus Energy and Sustainability Management System has allowed us to create a number of productive and rewarding relationships with outside system vendors in the energy control market, various alumni specializing in the fields of energy monitoring, control and data visualization, faculty working on energy visibility and problem solving, and relationships with student interns who have helped us deploy and begin to maximize use of our new CESM System. Examples include:

- **Alumni and Faculty/Student Relationships** - Working with Dartmouth alumnus Marc Josephson, of J+F Labs, developers of CORIS ECS wireless control systems, and Lorie Loeb, Professor in the Computer Science Department, we were able to develop and install a wireless control system and integrated touch screen control system that now directly controls 36 new lighting fixtures in our West Gym facility. The system continuously monitors the energy use of the lighting systems in the West Gym and via our CESM System, we have verified an 82% reduction in lighting energy use for this facility!





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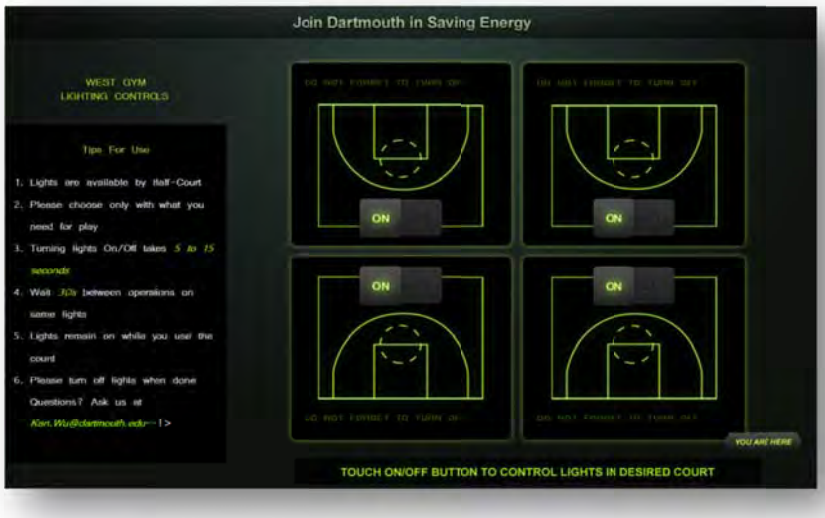

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- **WISP Program Relationships –** More recently, we have worked with Dartmouth's Women in Science Program to highlight our largest energy conservation and efficiency program currently taking place at Burke Chemistry. The WISP Program's mission is to collaborate in creating a learning environment where women can thrive in science, engineering and mathematics. This goal is achieved by enhancing the experiences of Dartmouth women, particularly in their first year, through a comprehensive set of strategies, including mentoring, early hands-on research experience, role models, access to information, and building community in the sciences.

  In our instance, we have created a relationship with Dartmouth WISP students around a $10 million energy retrofit project, involving replacement of Burke's two inefficient steam absorption chillers with two new electric-drive chillers, installation of heat recovery systems and a complete reconfiguration of the laboratory exhaust systems and their associated controls. This project is being undertaken over the course of 1 year and is currently about 50% complete. The project will tie into our CESM System with detailed performance monitoring of the energy use of the renovated systems. The WISP students are documenting the progress of the job with a multi-media website and will also perform energy modeling to show building occupants the impact of controlling use of their fume hoods wisely. The project website link is http://www.cs.dartmouth.edu/~burke/.

8. Grant Promotional Activities

Various promotional activities have taken place over the course of the Grant period to spotlight what we are doing with our CESM System, how the CESM System is helping Dartmouth to better manage its use of energy, and how we are tracking our GHG emissions. Articles, activities and speaking engagements included:

- **Dartmouth News Press Release** – 11/23/09 (see attached Article – PDF)
- **Hanover Rotary Club** - Presentation on "Dartmouth's Energy Initiatives" in January 0f 2010, highlighting Dartmouths energy programs and the Campus Energy and Sustainability Management System
- **Sustainable Design Symposium** – Held at Dartmouth College in April of 2010 and co-sponsored by the New Hampshire AIA. Presentation to gathering of architects, engineers, faculty, students, and campus community, titled, "Energy Innovation at Dartmouth College". Presentation spotlighted Dartmouth's Campus Energy and Sustainability Management System and how it is being used to monitor high performance building operations in its newly designed and built environment.
- **Matariki Institute** – Presentation to gathering of 7 international universities with Dartmouth representing the United States. Held at Queens University, Kingston, Ontario Nov. 2010. Presented "Campus as a Living Laboratory, highlighting Dartmouth's energy programs, its Campus Energy and Sustainability Management System capabilities, and the linkage to academic programs for leaning about energy systems.
- **Energy Supply and Management Conference** at Dartmouth College – Sponsored by Competitive Energy Services – May 2011. Presented a detailed view of Dartmouth's Campus Energy and Sustainability Management System and how it is being used in all facets of energy programs on campus.
- **Tuck Sustains Launches the GreenLite System in Tuck Residence Halls**- Thanks to a gift from the Class of 2010, Tuck Sustains launched the GreenLite system in Whittemore, Achtmeyer, and Pineau-Valencienne residence halls. GreenLite, an energy and sustainability information system where an animated polar bear and penguin serve as a visual indicators of energy use. The GreenLite program was created by Lorie Loeb of the Computer Science Department and a team of undergraduate students. A competition to reduce energy use was held in the spring of 2011 among the Tuck students living on campus.
- **Northern New England Conference/ Eastern Region/Association of Physical Plant Administrators** (NNECERAPPA) Conference - Presentation to gathering of physical plant administrators for Colleges, Universities and Secondary Schools, held at Bates College in Lewiston, ME. Presentation was titled, "Data Driven Building Performance". Presentation high-lighted Dartmouth's use of data systems to monitor performance of its energy-intensive systems.

9. Budget vs. Actual Expenditures

A detailed comparison is presented in Appendix Exhibit 1, showing Budget and Actual Expenditures for the Grant Contract Period. Differences are shown and explained in a comments column. In summary, during the Contract period, the College spent $928,568 for installation, setup, and use of the CESM System. This amounted to 84% of the anticipated 2-year expenditure. We, therefore have requested payments from the Fund in the amount of 84% of the Approved Grant Amount of $330,936, or $278,597.

In summary, expenses were greater during the installation phase than expected, primarily due to the complexity of the meter automation program. During the second contract year, expenses were less than anticipated because our collaborators (academic departments and Office of Sustainability) provided their activities at no cost to the program. We also ran the Retro-Commissioning programs and Continuous Commissioning programs through other funding sources, so these costs were not seen by the Grant.

10. Additional Planned Activities Related to the Grant

Developing, using, and promoting the Campus Energy and Sustainability Management System has allowed us to develop a number of relationships that we might not have encountered if we have not received the Grant. As we end the official Grant phase, there are a number of additional activities that we would like to undertake that would not necessarily have not been in our program, should we have not received the Grant . These include:

- **Behavior feedback** – We plan on continuing to work with the GreenLite program and also Dartmouth's WISP students to develop displays that show fume hood exhaust energy use in real time to researchers in our Lab buildings. We hope that this helps reduce the amount of time that fume hood sashes are left open; a very wasteful practice.
- **Key Performance Indicators** – We would like to develop additional energy visibility projects with academic departments, including the Engineering, Computer Science, and Environmental Science departments. Under these projects, we would create useful key performance indicators (KPI's) for tracking energy use by targeted systems in high-energy-use buildings.
- **Share Building Performance and Resource Use Metrics Data** – We plan on sharing building performance and resource use metrics collected by our CESM System with architectural/engineering design groups, sustainability organizations and with peer institutions. Detailed metered and resource data such as this is not as readily available at many other institutions. Dartmouth is fortunate to have had the metering infrastructure already in place at the time that we received the Grant, and, due to the Grant it is now automated. Sharing the data on energy and resources will help other institutions compare their performance with our performance and will help to building a user database on building energy performance and material and resource usage patterns.
- **Develop Additional Automated Fault Detection Capabilities** – We would like to expand the capabilities of the CESM System to help detect wasteful energy use by means of automated fault detection of key energy-consuming systems. We intend to work with academic departments to pursue this goal. Development of automated fault detection algorithms would make good independent study projects for Dartmouth students.

11. Summary

We are pleased to have been chosen to receive the Grant from the NHGHGER Fund and are appreciative of the opportunity to put our ideas into action. Planning, executing and now using the Campus Energy and Sustainability Management System has been a very rewarding experience for those involved in the project. We have also learned a good deal about energy feedback and behavior from our relationship with the Dartmouth GreenLite project.

During the course of the Grant, our Energy Program Office has grown from one person to five people, with those staff actively using the CESM System. One of the staff is dedicated to management of the CESM System, and we are enlisting our Building Management Shop system into use of the system for fault detection, troubleshooting, and installation of sub-metering for many more energy systems.

The Campus Energy and Sustainability Management System is proving to be an excellent operational, communications, and energy behavior tool. We feel that we are just at the beginning of a journey and look forward to continuing collaborations around the CESM System's many topical areas. We will continue to share our results with the NHGHGER Fund as we move forward.

Respectfully submitted,

Stephen R. Shadford, P.E., LEED AP
Dartmouth College
Energy Manager
Principal Investigator for NHGHGER Fund Grant Project

Dartmouth College
Campus Energy and Sustainability Management System

Final Report for
New Hampshire Greenhouse Gas Emission Reduction Fund

APPENDIX

Exhibit 1

Dartmouth College

Campus Energy and Sustainability Management System

Budget vs Actual Expenditure Comparisons

YEAR 1 COSTS	Original Budget Cost ($)	Actual Expenditures During Grant Period ($)	Difference (+ is Greater than Expected - is Less than Expected)	Comments on Budget vs Actual Expenditures
Installation, Setup and Commissioning of Hardware and Software				
1. Server Hardware & Software	25,000	22,902	-2,098	Complete
2. System Software & Vendor Configuration Services	300,000	225,000	-75,000	Final payment of $75,000 is being held pending completion of remaining project details by system vendor (Rockwell Automation).
3. Vendor Travel and Expenses	10,000	7,132	-2,868	Complete
4. Meter Automation Hardware	133,700	208,730	75,030	Complete. Cost and complexity was greater than originally budgeted
5. Meter Automation Labor (Dartmouth Electrical & Electronics Shops)	70,500	293,200	222,700	Meter Automation Labor was higher than budgeted due degree of difficulty of installations and required addition of some new meters to be able to get an automated signal from them.
6. Upgrades for Connectivity	60,000	102,894	42,894	Data historian was installed during December 2010 to be able to see Heating/Electric plant energy equipment usage trends. Cost of this connectivity was not figured in original estimate.
7. Project Management Labor (Dartmouth Energy Engineer)	70,000	59,224	-10,776	Essentially Complete except for small labor amount for final checkout of system with system vendor (Rockwell) to close out their installation.
Subtotal	**$669,200**	**$919,082**	**$249,882**	The unexpended contingency budget could be assumed to have covered a portion of the meter automation cost overruns or the Upgrades for Connectivity cost overruns.
8. Contingency 10%	66,920	564	-66,356	
Total Installation, Setup and Verification of Hardware and Software	**$736,120**	**$919,645**	**$183,525**	
Labor Using System to Achieve Savings via Continuous Commissioning Process				
9. Continuous Commissioning Labor Using System (Dartmouth Facilities Operations & Management)	52,000	9,013	-42,987	Lower costs due to lag in system installation. Longer meter automation project time and longer-than-anticipated time for system vendor (Rockwell) to bring all aspects of system up on line.
Continuous Commissioning Labor	**$52,000**	**$9,013**	**-$42,987**	
Labor Using System to Leverage Additional Savings via Feedback, Social Learning and Behavior				
10. Social Learning, Individual & Organizational Behavior Collaborative Projects w/Academic Dept's.	45,000	0	-45,000	This work was done in kind by by the Computer Science Department and was funded from other sources.
11. Communication and outreach (Dartmouth Sustainability Manager)	5,000	0	-5,000	Dartmouth's Sustainability Manager left the College in the first Grant year. It was greater than 1 year until the next Sustainability director was hired. During that time communication and outreach on the project was accomplished by Dartmouth;'s Energy Program Manager who assumed the role of Principal Investigator. His costs are included in Project Management costs, under Installation, Setup and Commissioning, above.
Academic Project Labor	**$50,000**	**$0**	**-$50,000**	
YEAR 1 SUBTOTAL	**$838,120**	**$928,658**	**$90,538**	Higher primarily due to the cost of meter automation and a lag in being able to use the system for RetroCommissioning and Continuous Commissioning because the system was not fully tested and verified.
YEAR 2 COSTS				
System Maintenance				
12. System Maintenance Fee	54,000	0	-54,000	As of Grant end date, system was in final stages of acceptance by the College, so Service Agreement was not yet implemented. Estimated start date will be May 2012.
Labor Using System to Achieve Savings via Continuous Commissioning Process				
13. Continuous Commissioning Labor (Dartmouth Facilities Operations & Manag	156,000	0	-156,000	Continuous commissioning labor during 2nd contract year was being done by the Energy Program Manager. This was due to limited personnel resources in the Building Management System shop. Costs of this labor was carried in our Heating Plant operations budget. We hired full time employee in January 2012 to manage Campus Energy and Sustainablilty Management System. His time will be principally spent in using the CESM system to identify energy waste on campus and work with Shop System to remedy the issues.
Labor Using System to Leverage Additional Savings via Feedback, Social Learning and Behavior				
14. Social Learning, Individual & Organizational Behavior Collaborative Projects w/Academic Dept's.	45,000	0	-45,000	This work continued during the 2nd contract year, but costs were picked up by the respective Academic departments under different budgets. No costs were charged to this Grant during the 2nd Contract year.
15. Communication and outreach (Dartmouth Sustainability Manager)	10,000	0	-10,000	New Sustainability Director's time allocated to this task was charged to general overhead on the Provost's side of the Dartmouth organization/
YEAR 2 SUBTOTAL	**$265,000**	**$0**	**-$265,000**	Anticipated expenses did not materialize during this period of the Grant
TOTAL PROJECT COST (YEAR 1 + YEAR 2)	**$1,103,120**	**$928,658**	**-$174,462**	We spent 84% of total estimated budget during the entire Contract Period
MATCHING FUNDS REQUESTED FROM NH GHGER FUND (30%)	**$330,936**	**$278,597**	**-$52,339**	In keeping with our expenditures during the Grant period, our request for payments from GHGER Fund total 84% of Approved Amount

THE STATE OF NEW HAMPSHIRE

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PUBLIC UTILITIES COMMISSION
21 S. Fruit St., Suite 10
Concord, N.H. 03301-2429

July 31, 2009

Kathleen Lambert
Sustainability Manager
Dartmouth College
Office of the Provost
63 South Main Street, Rm. 316
Hanover, NH 03755

Dear Kathleen:

On behalf of the Public Utilities Commission, I am pleased to confirm that Dartmouth College has been awarded funding from the Greenhouse Gas Emissions Reduction Fund in the amount of $330,936. Please be aware that this grant award is contingent upon the approval of Governor Lynch and the Executive Council.

We anticipate bringing your grant award to the Governor and Council (G & C) meeting on September 23. The grant award becomes effective as of the date of G & C approval. Expenses incurred prior to that date are not reimbursable.

We will be working with you to put together a formal grant agreement along with a handful of other documents that are required for all G & C submissions. You will be contacted within the next week or two by a member of our administrative staff to begin this process.

Congratulations, again, on submitting a fine proposal. We are excited to be partnering with you to take on the vital challenge of reducing greenhouse gas emissions in New Hampshire while moving the State toward a clean energy future.

Sincerely,

/s/
Jack K. Ruderman
Director, Division of Sustainable Energy

P.S. A hard copy of this letter will be mailed to you later this week.

Dartmouth College

Dartmouth News

This website is no longer being updated. Visit Dartmouth Now for all news published after June 7, 2010.

Dartmouth News > News Releases > 2009 > November >

Dartmouth receives $330,000 from New Hampshire Green House Gas Reduction Fund for campus energy monitoring project

Dartmouth College Office of Public Affairs • Press Release
Posted 11/23/09 • Media Contact: Susan Knapp *(603) 646-3661*

Dartmouth has received a $330,936 grant from the New Hampshire Green House Gas Reduction Fund to help implement a Campus Energy and Sustainability Management System. This new system, which will measure and monitor energy use around campus, supports Dartmouth's commitment to reduce its greenhouse gas emissions by 30 percent below 2005 levels by the year 2030. The grant award will be matched by funds at Dartmouth.

Lambert (left) and Shadford are working to make the campus more energy efficient (photo by Joseph Mehling '69)

Related Link: Dartmouth's commitment to reducing greenhouse gas emissions celebrates one-year anniversary

"Building energy use currently accounts for approximately 80 percent of Dartmouth's greenhouse gas emissions," says Stephen Shadford, energy engineer with the Facilities Operations and Management Department (FOM). "The new system will continuously monitor the buildings and allow us to ensure that we're being as efficient as possible with the energy-intensive activities on campus -- the heating, cooling, ventilation and lighting of existing buildings."

Shadford and Kathy Lambert, the Dartmouth's sustainability manager, along with a host of other Dartmouth administrators, faculty, and staff, have been working on a variety of fronts to systemize Dartmouth's efforts toward energy efficiency and sustainability.

The Campus Energy and Sustainability Management System at Dartmouth will be implemented over the next several months, starting with the buildings that have the highest energy use. By the end of one year, an array of approximately 250 building energy meters will be tied in to the system, and software will help detect inefficiencies in system operations. With this new tool, FOM will mobilize its internal specialists, called Tiger Teams, to fix the inefficiencies and track the results of many projects that are aimed at reducing energy use on campus.

The new Campus Energy and Sustainability Management System will also be a powerful tool in collecting data for research aimed at promoting individual behavior changes as well as helping campus-wide conservation efforts with real-time building energy feedback data.

"Occupant behavior can often be tied to energy use, especially in buildings with large plug load demand such as campus offices, residence halls, and laboratory buildings," says Lambert. "Through the Campus Energy and Sustainability Management System, we expect to reduce greenhouse gas emissions by 10 to 15 percent for a total reduction of 8,800 to 11,500 MTCDEs per year [metric tons of carbon dioxide equivalent]."

Lambert and Shadford explain that the project will draw on Dartmouth's education and research assets to track the effectiveness of the system, monitor results, distill lessons, and disseminate a case study for other colleges, universities, secondary schools, private corporations, as well as non-profits and municipalities that own and manage multiple buildings. This will be an effective leveraging tool for the New Hampshire GHG Emissions Reduction Fund and its mission.

"Dartmouth College is in the vanguard of large institutions in the state that are working to track, manage, and reduce energy use," said Jack Ruderman, director of the Sustainable Energy Division of the New Hampshire Public Utilities Commission. "The Campus Energy and Sustainability Management program is expected to reduce greenhouse gas emissions by 10 to 15 percent by optimizing building energy use and employing real-time energy feedback to promote behavioral change. As with so many energy efficiency initiatives, not only will there be environmental benefits, but the campus will reduce emissions, and the university will save money."

This project was funded, in part, by the New Hampshire Public Utilities Commission's Greenhouse Gas Emissions Reduction Fund, a program initiated in February 2009 to fund projects throughout New Hampshire to lower greenhouse gas emissions through energy efficiency. GHGERF funding results from carbon allowance auctions from the Regional Greenhouse Initiative (RGGI) an effort by 10 participating Northeastern and Mid-Atlantic states to educe emissions of greenhouse gases from the electric power sector.

Dartmouth has television (satellite uplink) and radio (ISDN) studios available for domestic and international live and taped interviews. For more information, call 603-646-3661 or see our Radio, Television capability webpage.

Recent Headlines from Dartmouth News:

- Dartmouth helps found a global network of universities [06/04/10]
- Dartmouth moves to improve recycling rate [06/02/10]
- Class of 1953 Commons dedicated [05/27/10]
- Dartmouth's Big Green Bus ready for 6th-annual cross-country educational tour [05/26/10]
- Rockefeller Center students to host New Hampshire/Vermont conference on homelessness [05/21/10]
- Sign-up to receive Dartmouth News via email

West Gym Lighting System Upgrade
Celebrating Success

September 2011

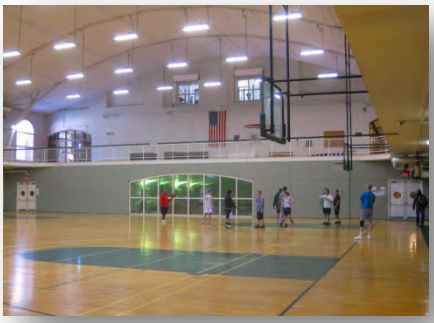
In January of 2011, lighting systems for the West Gym were completely upgraded to provide better lighting quality, user control of lighting levels, and significant energy savings. This project was undertaken by Dartmouth's Energy Team in collaboration with J&F Labs, a wireless energy control system manufacturer, and Dartmouth's Computer Science Department.

Original West Gym lighting system

The project consisted of complete replacement of the lighting systems in the West Gym. The previous lighting system consisted of 48 – 400 watt metal halide fixtures which provided general illumination of the entire gymnasium space. There was no provision for separately lighting the upper level running track. Switches for the lighting fixtures were located behind locked doors, and each fixture each required a long warm up time to achieve full lighting output. As a result, the lights were generally left on 16 to 17 hours each day awaiting the appearance of students or staff to participate in basketball, running, or other fitness activities programmed for the space.

Dartmouth's Energy Program Team worked with a fluorescent lighting manufacturer, a wireless energy control system manufacturer, and our Computer Science department to take an entirely fresh approach to this space. The goals were to:

- Place illumination where it is needed, only when it is needed
- Place control of lighting in the hands of the users
- Improve the quality of lighting for all areas
- Automatically switch lighting off after use
- Provide multiple lighting levels for each fixture
- Provide ability for special event lighting scenes
- Use simple touch-screen interface to control lights
- Save significant energy



New lighing fixtures, each with 3 output levels

Dartmouth's Energy Team is pleased to announce that after the first 6 months of operation, the West Gym lighting system has met all of its goals, including a verified **82% reduction in energy consumption**. The project has far exceeded our expectations of lighting quality, user flexibility, and energy savings. This fall, we will add to our lighting innovation in the West Gym with additional controls designed to make use of natural light which will enter through newly renovated clerestory windows and re-opened high ceiling space.

Wireless control and touchscreen development teams

We are thankful for the continuing collaboration of our innovative partners on this project, including:

- *Marc Josephson – President/CEO, J&F Labs; Dartmouth '72*
- *Kurt Josephson – Chief Technology Officer, J&F Labs*
- *Lorie Loeb – Research Associate Prof., Computer Science Department*

Electrical Savings = 107,400 kWH/Yr	Cost Savings = $14,000/Yr	Project Payback = 4.3 Yrs	Utility Incentive = $36,000

A Case Study: GreenLite Launch at the Tuck School of Business

Jingwei Pan & Doris Pu – Sponsor: Professor Lorie Loeb
Computer Science Department, Dartmouth College

INTRODUCTION

Climate change is a serious issue that all citizens of the world need to recognize and deal with on an individual level. Research has proven that sustainable choices and behaviors are key in combating global warming.

We believe that when people realize there is a direct link between one's actions and their effects on the environment, they will use resources more thoughtfully and responsibly.

With the GreenLite program, we hope to establish both an emotional and intellectually-stimulating connection between consumers and the environment.

GreenLite is unique in that it integrates computer science, animation, environmental studies, psychology, and behavioral economics to promote environmentally friendly actions and attitudes.

HOW THE GREENLITE SYSTEM WORKS

Data Retrieval: We collect data, such as electricity, water, and heat use from meters on every floor of a given building. We then gather and poll the data, which is stored in a database.

Data Aggregation: We gather data from several meters to determine electricity consumption for the entire building and at the campus-wide level. This data is stored for later analysis and generation of graphs and charts.

Data Analysis: We analyze short and long term data to find behavioral trends and identify areas to improve. We compute a "grade" that compares actual energy use to historical data and other key factors, to determine what current energy use ought to be at this time. This grade is recalculated every 5 seconds and drives the suitable animation on screen.

Displays: We display data to tell a meaningful story, demonstrating the impact that our behaviors have on the environment. The main display is of a polar bear, whose welfare depends solely on the "grade" of a given meter. With this emotional connection, we hope that the polar bear's wellbeing will influence people to conserve energy.

Feedback: The primary sources of feedback are the public kiosk displays on each floor and the website (*http://greenlite.dartmouth.edu*), with energy usage data, graphs, and tips on how to conserve energy. We also have a goal-setting page that uses smiles as incentives to conserve energy. "*If your floor/team uses less energy than the goal, you get a smile for that day. If you use more, you get a frown. The daily goal is calculated from a baseline for your floor and a set goal.*"

THE LAUNCH: GREENLITE IN ACTION

The Tuck Class of 2010 gave GreenLite to the Tuck School of Business as a class gift.

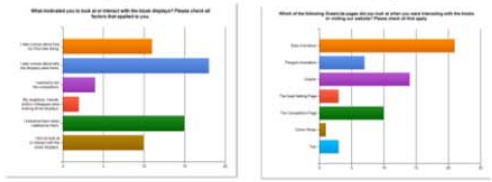
As a result, we worked with Tuck Sustains and other individuals at Tuck to install and implement the GreenLite system in three graduate residence halls, Whittemore, Achtmeyer, and Pineau-Valencienne.

To kick off the launch and spread the word about the program, we decided to hold a floor competition to lower energy use among the students living on campus. Our goal was an 8% reduction.

We were curious if GreenLite would actually produce changes in behaviors or attitudes toward sustainability, so we created two surveys to administer to Tuck students, faculty, and staff members- one prior to the launch and one four weeks later, after the competition.

RESULTS OF OUR USER STUDIES

First, we wanted to gauge individuals' reactions to the GreenLite program at Tuck.



On the goal-setting page, we also found that the floors with the top 2 page views earned the most smiles.

Competition Date Range: 04/11/11 - 05/08/11

Team:	Page Views:	Smiles:
Achtmeyer PV 4th	71	5
Achtmeyer PV 3rd	90	8
Achtmeyer PV 2nd	106	8
Whittemore 1st	309	23
Whittemore 2nd	50	7
Whittemore 3rd	75	10
Whittemore 4th	166	13

We wanted to compare individuals' attitudes towards sustainability and environmental issues before and after the GreenLite Tuck launch.

We asked individuals to rate the statement, "*Climate change is an issue of concern for current and future generations of the world*" on both surveys.

Prior to the launch:	Following the launch:
0.6% Strongly Disagree	0.0% Strongly Disagree
3.9% Disagree	0.0% Disagree
3.9% Neutral	3.7% Neutral
38.1% Agree	25.9% Agree
53.6% Strongly Agree	70.4% Strongly Agree

CONCLUSIONS

There is a significant amount of error because 181 individuals responded to the pre-launch survey, whereas only 33 individuals have responded to the post-launch survey thus far. This dearth in survey respondents has made it challenging for us to properly analyze the effects of GreenLite at Tuck.

Nonetheless, we were still able to draw some conclusions from our user studies. The top 3 pages viewed on the displays were the bear animation, the graphs, and the competition page. This suggests the most significant lures in grabbing attention were the emotional pull of the oft-drowning polar bear, the hard data of energy usage that were presented in the graphs, and the social factor of competition among the floors.

After tracking page views on the goal-setting page, we saw a correlation between page views and the number of smiles that a floor received. While we cannot determine causation, we can surmise a relationship exists between one's concern for the environment and one's choices and behaviors.

THE FUTURE OF GREENLITE

We are always trying to improve the system to keep it fresh, interesting, and effective in promoting change. While the main animation on display is of a cartoon polar bear, the other animated display in the works is of a cartoon penguin, which either saves or wastes money depending on the "grade" of the given meter. In this manner, we are drawing upon behavioral economics, as we remind consumers about the financial ramifications of wasting precious resources.

In the future, we hope to provide the GreenLite program to a broader base, including more buildings on Dartmouth College's campus as well as other schools and universities. Implementing the system in a variety of locations will allow us to better detect patterns of energy usage and determine in what areas and ways we can improve.

ACKNOWLEDGEMENTS

GreenLite received support from the Provost's Office, the Dean of Faculty, NSF Grant #CNS 0708209, Dr. Mary Finegan '86, the students of the Digital Arts Program, the Computer Science Dept., FO&M, the Office of Residential Life, the Sociology Dept., the Sustainability Office, Thayer School of Engineering, and campus student ECO groups.

We would like to acknowledge Tuck School of Business, Tuck Sustains, Rosie Kerr, Becky Rice-Mesec, Kan Wu, and Bernie du Breuil. Most of all, we need to thank WISP; our co-interns Amanda Duchesne, Emily Hoffman, and Sandi Caalim; and our project sponsor, mentor, and fearless leader, Professor Lorie Loeb. Thank you!

Dartmouth College

Energy and Sustainability Management System Overview

Stephen R. Shadford, P.E., LEED AP

May 11, 2011

Energy Inventory

		Units
#6 Fuel Oil	**5,000,000**	**Gallons**
CoGen'd Electricity (~30%)	19,500,000	kWH
Purch'd Electricity (~70%)	45,500,000	kWH
Total Electricity	**65,000,000**	**kWH**

Energy Cost Escalation

Since 2000…Costs UP Dramatically		
#6 Fuel Oil	↑ 500%	~ $12 MM
Purch. Electricity	↑ 130%	~ $5 MM

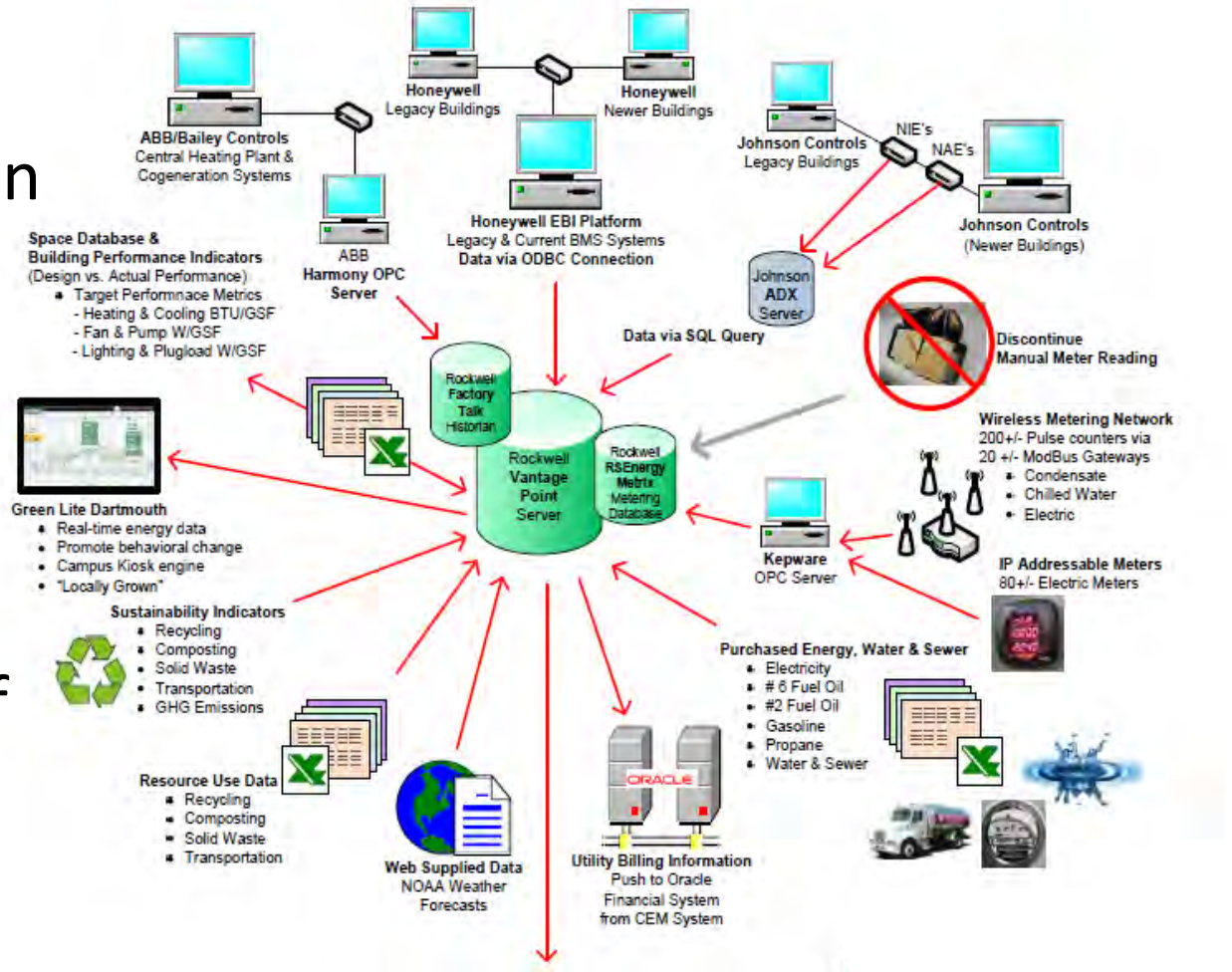
Response…Major Conservation Programs

- Heat Recovery - 100% Outdoor Air Systems
- Ventilation Control Optimization
- Absorption Chiller Replacements
- Campus-wide Lighting Retrofits
- Retro-commissioning - Major HVAC Systems
- Steam-trap maintenance program
- Building renewal programs

Monitoring Our Energy Program

Putting the right tools in place…

- Metering
- Data Integration
- Operations
- Finance
- Metrics
- Data Sharing
- "One Source of the Truth"



Example Outputs

Calendar View of Energy Use

Fume Hood Report

Utility Rate Engine

Web Published Data

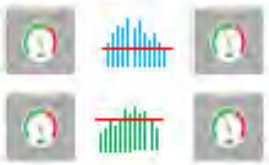
Standard & Customized Management Reports Generated via Excel Spreadsheets and System Portal

- Energy Management
- Detailed system analysis
- Historical Equip. Use Profiles
- 24 Hr Forward Load Projections
- Continuous Htg/Elect Plant Eff.
- Energy Purchase Hedging
- "Customer" Use & Billing History
- Energy Use Alarms (e-mail, etc)
- Billing Rate Calculations
- Sustainability Management
- GHG Reporting
- Carbon Asset Accounting
- Dashboard Views of System Performance
- Building Performance Metrics
- Title 5 Emissions to YTD

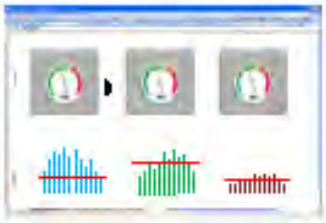
Predictive vs Actual Loads

Heating/Electric/CHW Plant Efficiency

Sustainability Indicators



Building Performance Indicators



Greenhouse Gas Accounting

Metering History

Prior to 2008…

- 250 Meters mainly used to apportion revenue
- Many steam meters were in disrepair
- Only **1 data point** recorded **per month**
- Few meters automated

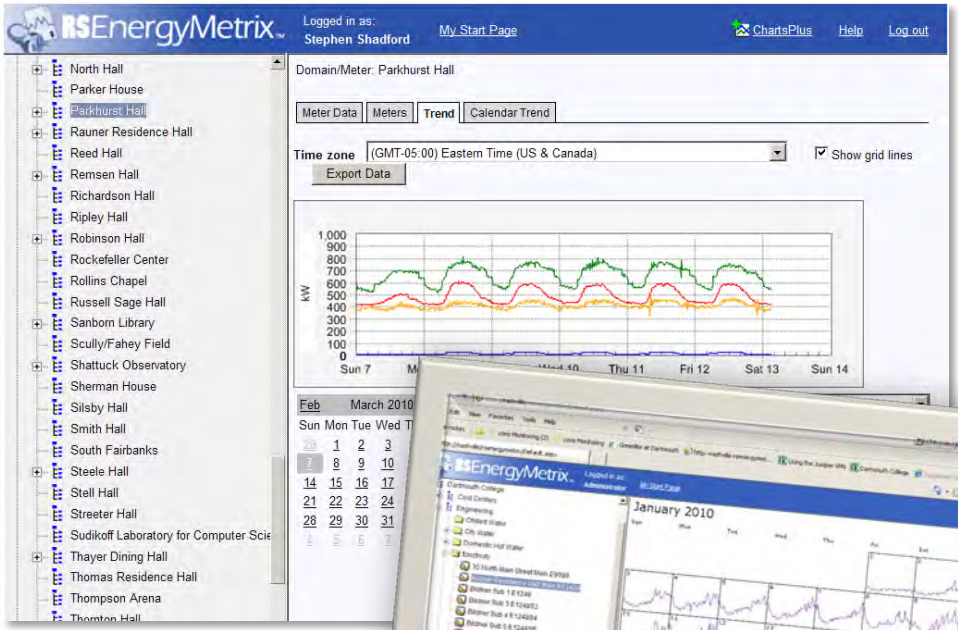
Inability to **MANAGE** energy by this method!

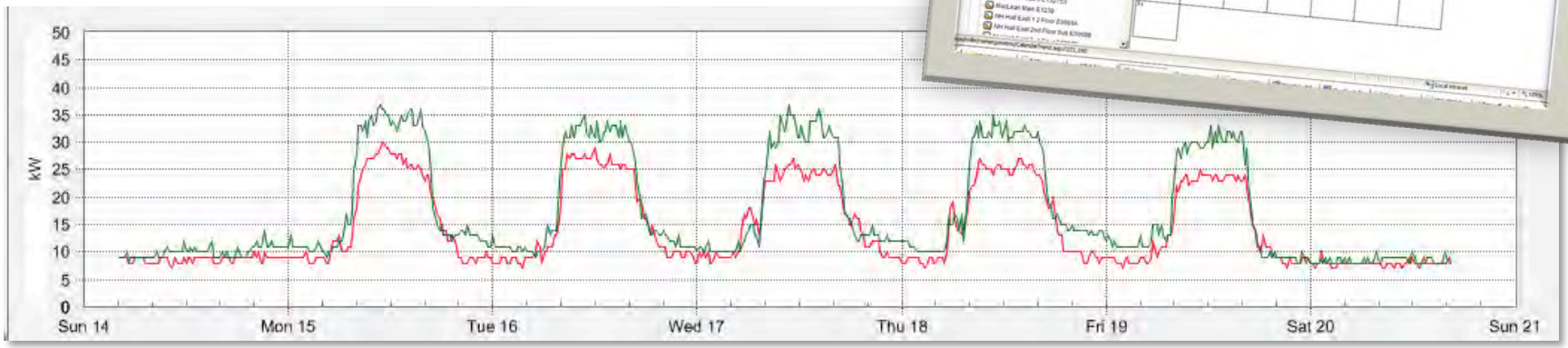
Meter Automation

- Automated existing metering infrastructure (~ 300 meters)
- See energy use in REAL TIME
- 3,000 data points per building per month

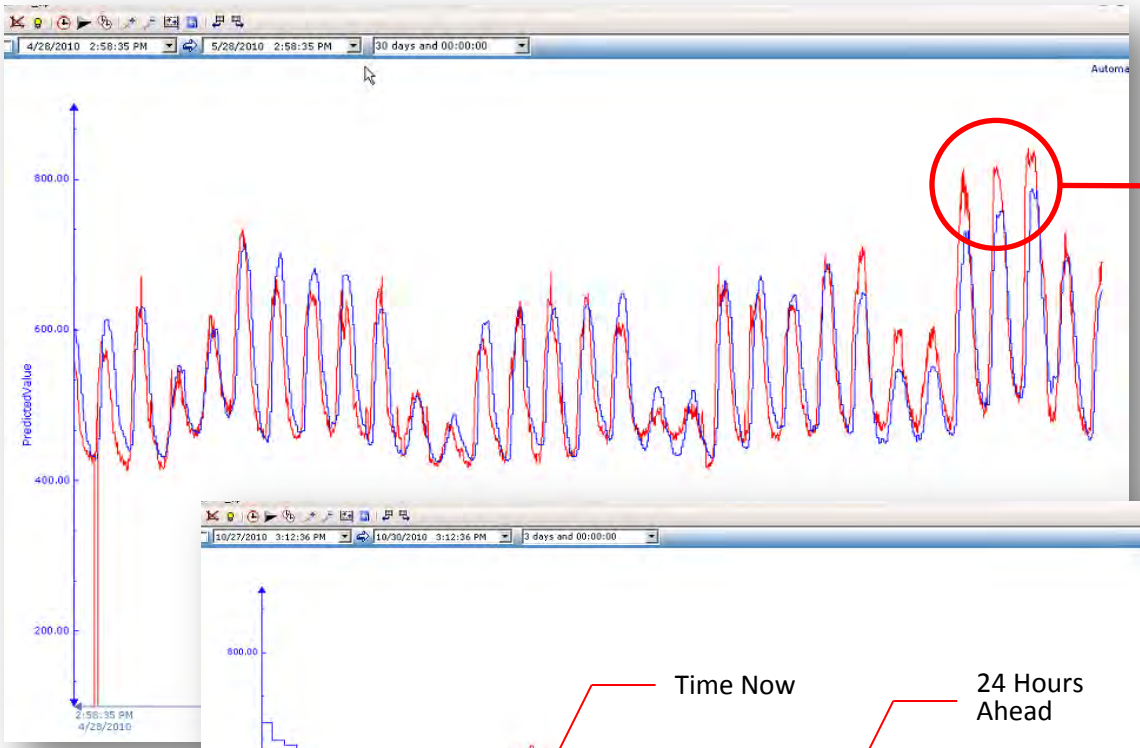
Energy Use Profiles

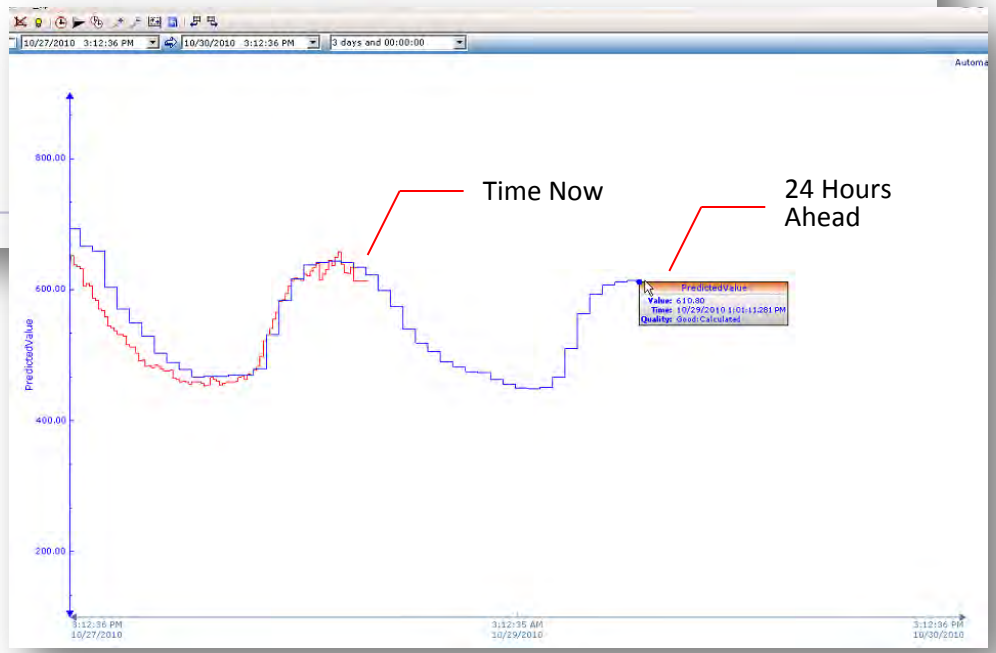
- Each building has an energy-use signature
- We can now see usage, profiles, and costs





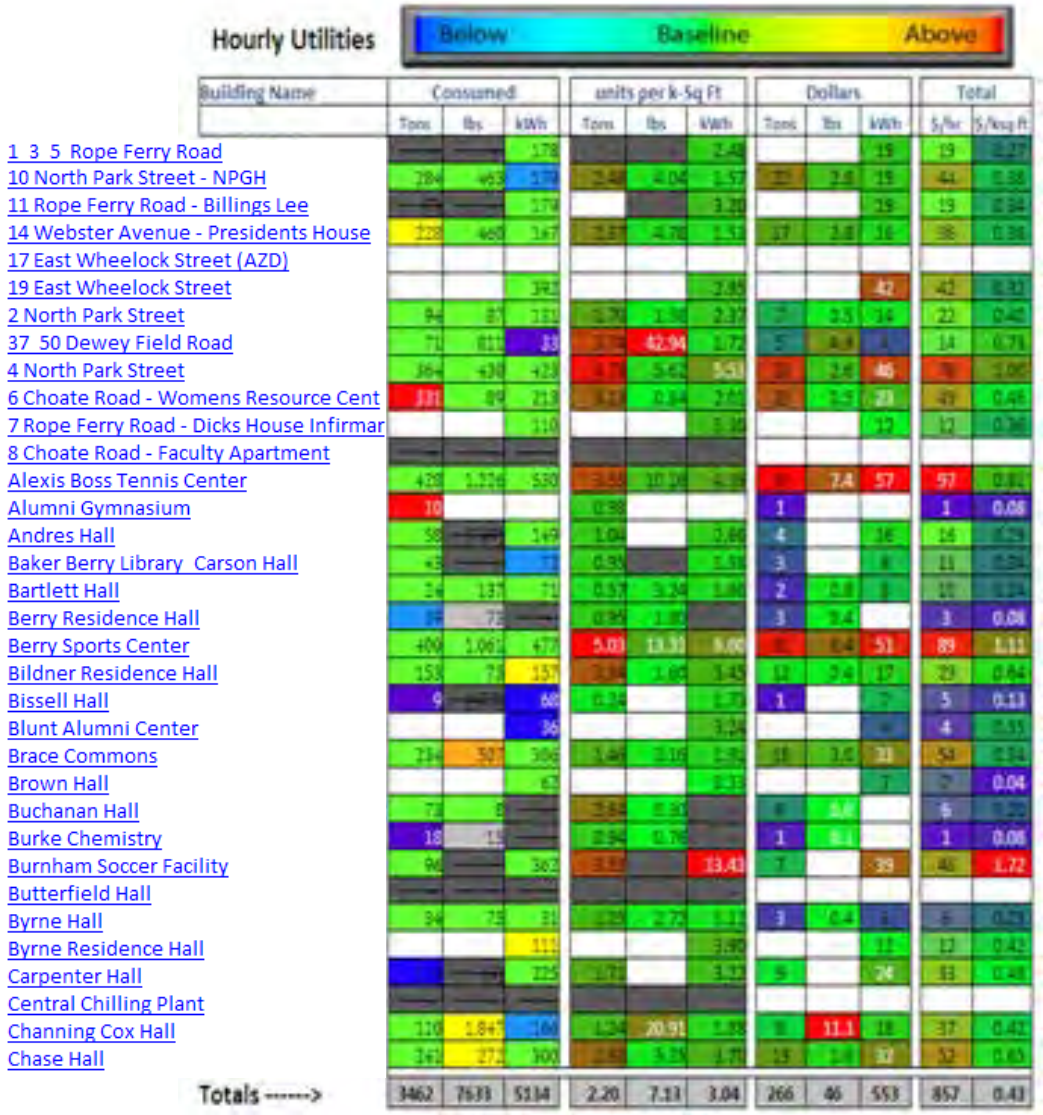
Predictive vs. Actual Use





All-Building Summaries

- Hourly and Daily Summaries
- “Heat Maps” of Actual vs. Predicted Performance



Utility Billing

- Serving our customers with accurate and useful information

Billing History

Cost Center: GPO

Building Name: Baker Berry Library_Carson Hall - 0583

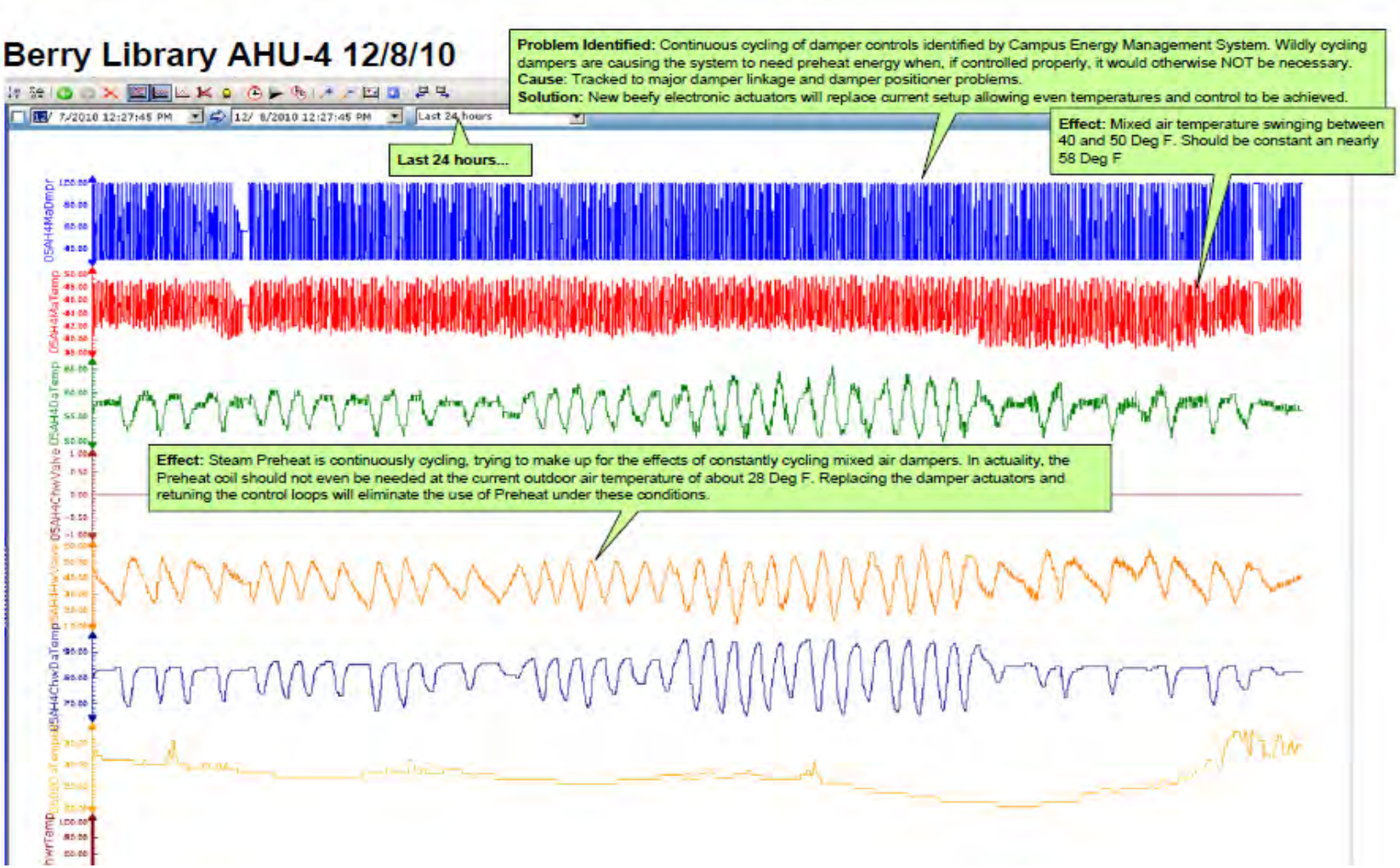
Building ID: 0583

Generate CSV

	STEAM HTG UNITS (100 #)					ELECTRIC (KWH)					CHILLED WATER (TON-HRS)			
Month	FY2011	FY2010	FY2009	FY2008	FY2007	FY2011	FY2010	FY2009	FY2008	FY2007	FY2011	FY2010	FY2009	FY200
JUL	11,140	8,129	9,366	9,064	5,000	543,079	483,844	520,720	467,381	395,257	282,250	191,260	287,637	250,00
AUG	12,795	8,396	9,000	9,000	5,000	479,917	496,986	474,367	506,927	527,931	244,010	233,150	156,150	220,00
SEP	0	7,731	9,000	13,195	5,000	0	376,784	553,569	450,490	416,742	0	97,630	112,160	100,00
OCT	0	15,884	16,000	12,352	8,000	0	498,294	467,996	487,401	537,164	0	48,600	65,280	110,00
NOV	0	19,488	36,000	33,570	15,000	0	533,886	491,989	569,691	412,129	0	38,210	49,000	140,00
DEC	0	24,937	15,493	32,160	21,000	0	441,582	425,116	451,257	439,856	0	28,330	20,400	80,00
JAN	0	22,099	41,313	32,360	47,500	0	397,306	617,141	533,951	491,596	0	24,560	42,730	63,00
FEB	33,333	24,027	27,282	28,900	32,542	0	471,983	430,315	523,663	426,668	0	30,230	29,060	66,55
MAR	30,000	20,799	30,745	23,080	28,258	0	509,799	552,862	434,187	458,238	0	40,050	40,740	100,00
APR	19,693	13,019	20,129	23,000	24,747	383,513	466,938	488,359	575,645	451,361	37,220	63,580	66,360	143,00
MAY		13,605	11,306	10,000	15,475		509,461	467,450	506,224	534,047		135,380	86,040	160,66
JUN		7,236	8,783	7,000	6,330		338,463	478,641	479,869	419,660		110,350	146,850	270,00
TOTALS	**106,961**	**185,350**	**234,417**	**233,681**	**213,852**	**1,406,509**	**5,525,326**	**5,968,525**	**5,986,686**	**5,510,649**	**563,480**	**1,041,330**	**1,102,407**	**1,703,2**
Total to Date	106,961	178,114	225,634	226,681	207,522	1,406,509	5,186,863	5,489,884	5,506,817	5,090,989	563,480	930,980	955,557	1,433,21
To Date Var		-71,153	-118,673	-119,720	-100,561		-3,780,354	-4,083,375	-4,100,308	-3,684,480		-367,500	-392,077	-869,73
To Date %		-39.9	-52.6	-52.8	-48.5		-72.9	-74.4	-74.5	-72.4		-39.5	-41	-60.7
To Date Balance		7,236	8,783	7,000	6,330		338,463	478,641	479,869	419,660		110,350	146,850	270,00
Comp Avg To Date	51					26					58			
Cur Month Var		6,674	-436	-3,307	-5,054		-83,425	-104,846	-192,132	-67,848		-26,360	-29,140	-105,78
Cur Month %		51.3	-2.2	-14.4	-20.4		-17.9	-21.5	-33.4	-15		-41.5	-43.9	-74
FY Budget	217,800					5,875,200					1,041,330			
YTD vs. Budget %	49.1					23.9					54.1			

Retro-commissioning

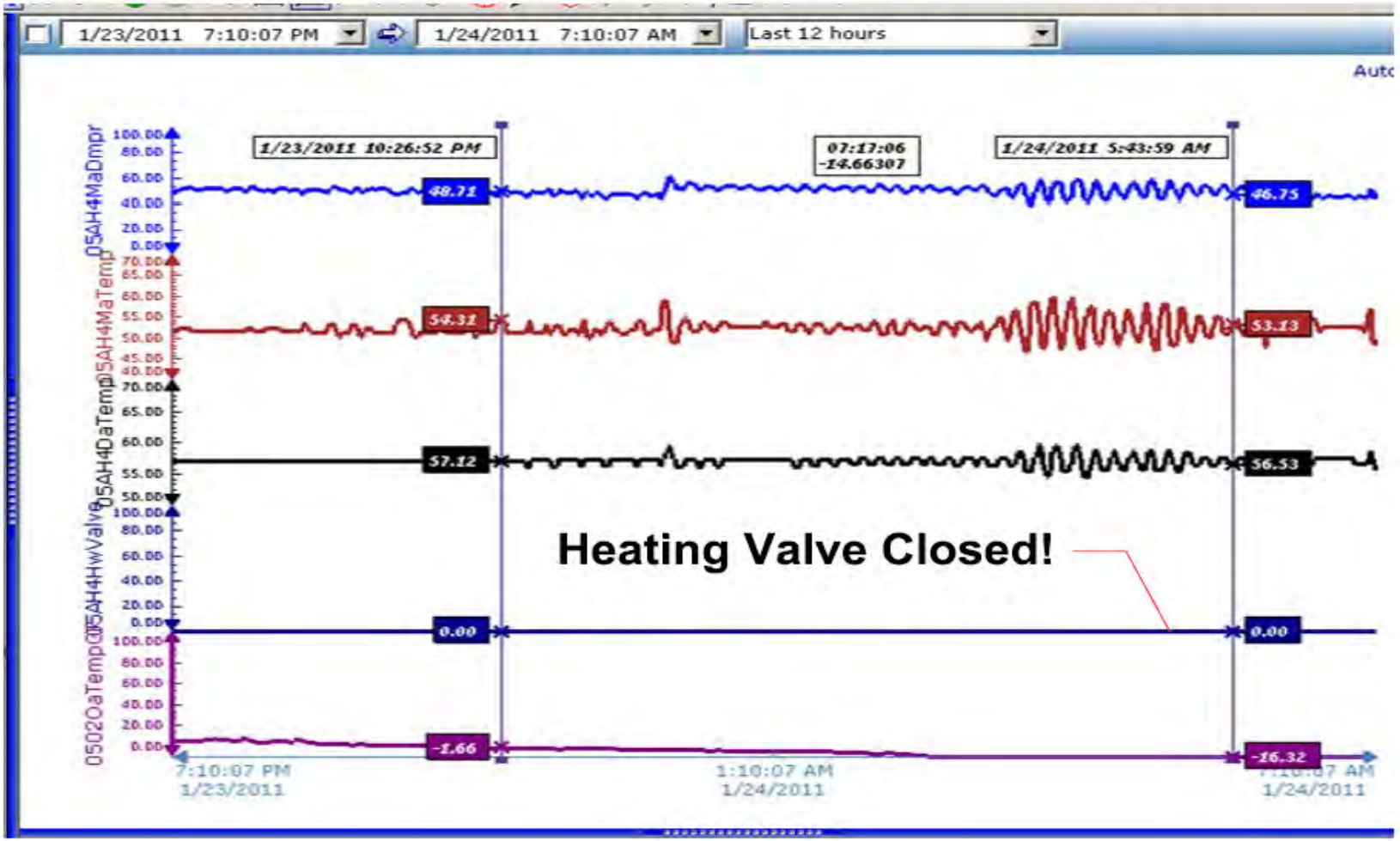
- Tools for identifying problems



Retro-commissioning

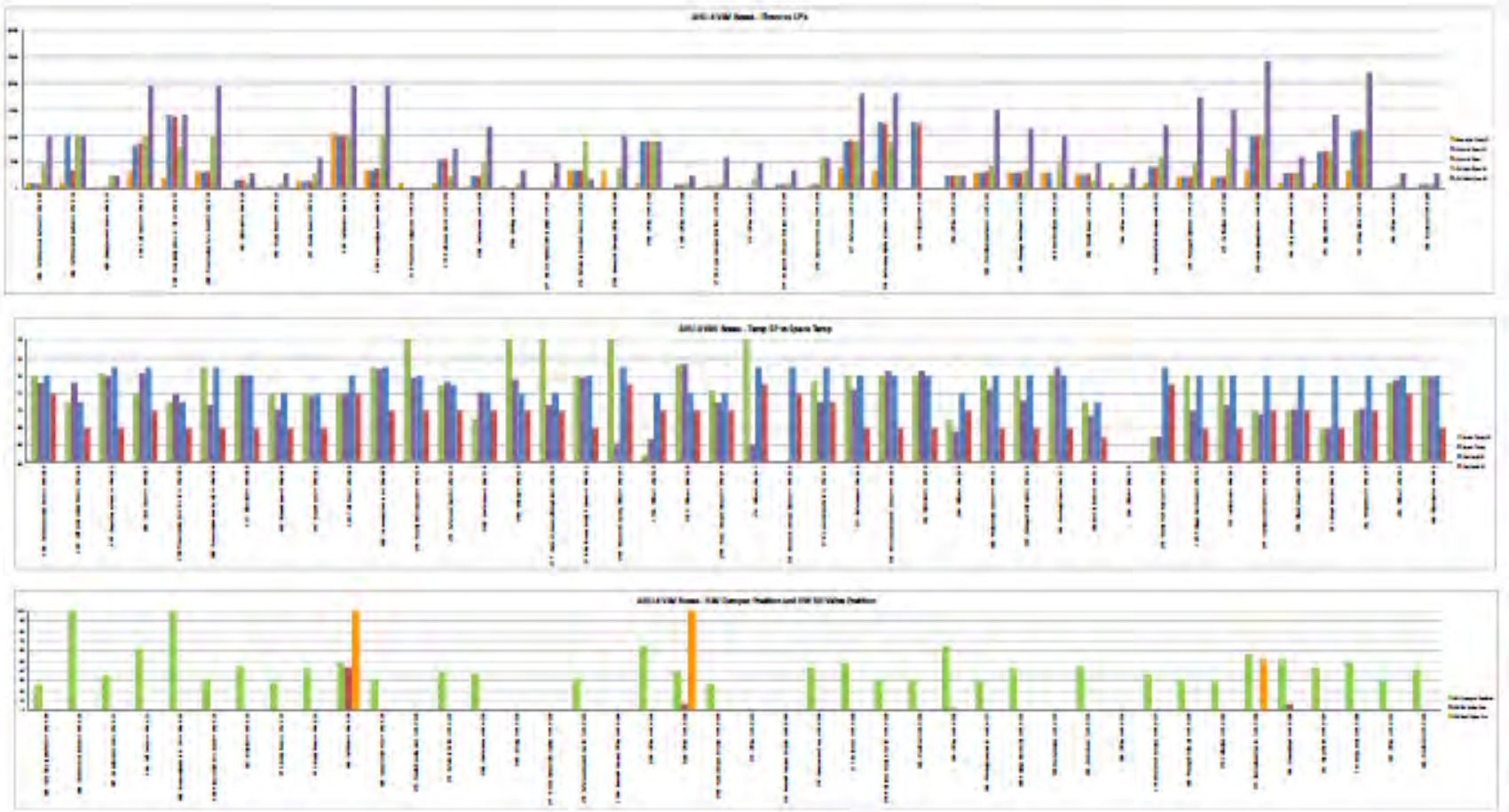
- Tools for validating effectiveness of fixes

AHU-4 January 24, 2011 Outdoor Air Temp = - 16Deg F



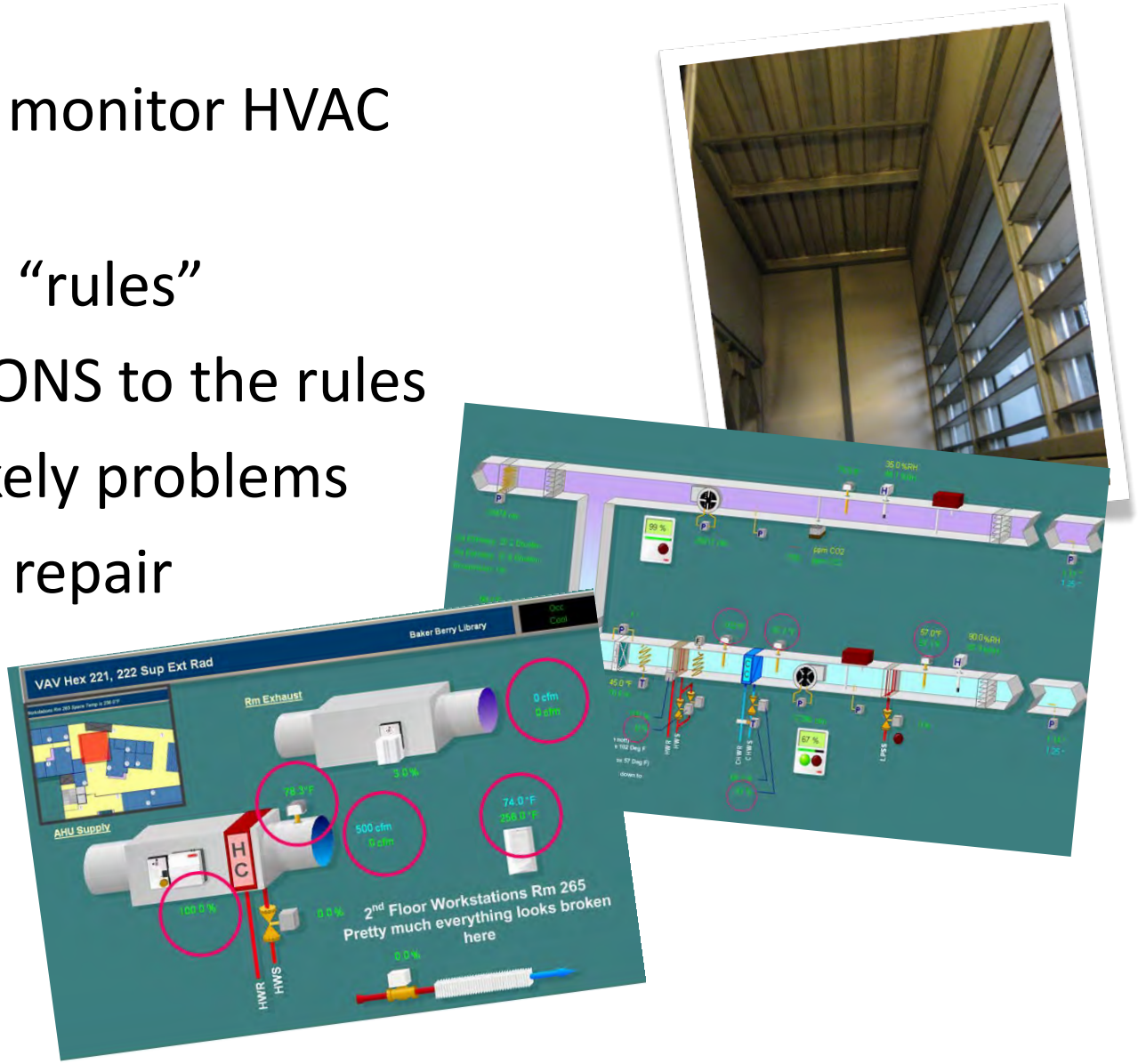
Continuous Commissioning

- Tools for continuously monitoring for persistence of savings



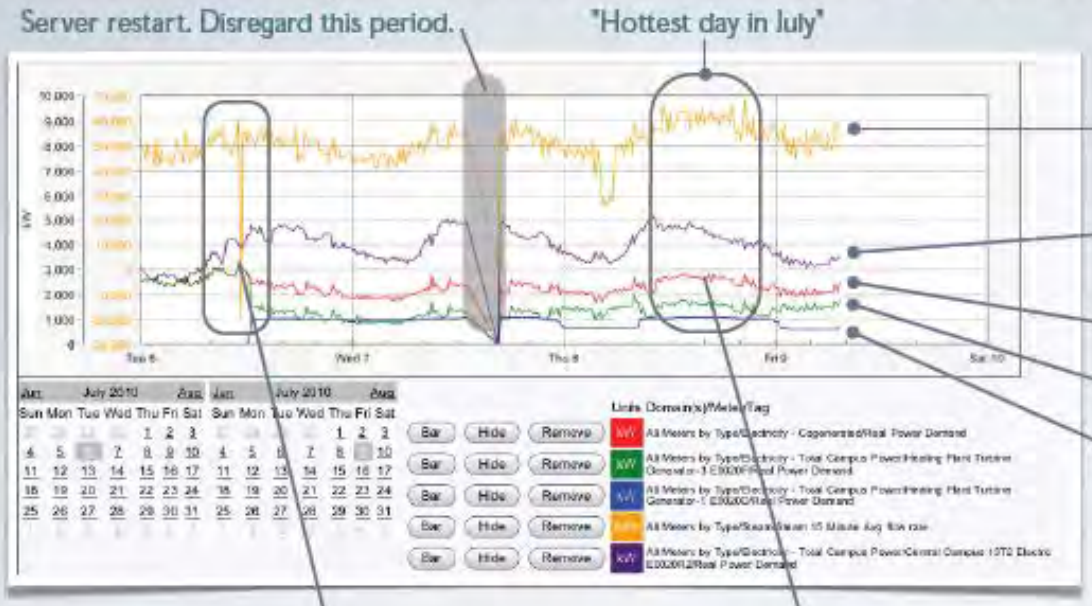
Exception Reporting

- Continuously monitor HVAC systems
- Evaluate with “rules”
- Find EXCEPTIONS to the rules
- Report the likely problems
- Prioritize and repair the systems



Optimization

Efficiency Comparison:
Running 2 Turbines in Parallel vs 1 Turbine Alone



> 3 mW Output on Turbine 3 operating independently (RSEM metered steam load ~ 55,000 #/hr)

2.7 mW Output with Turbine 3 and Turbine 1operating in parallel (RSEM metered steam load ~ 65,000 #/hr)

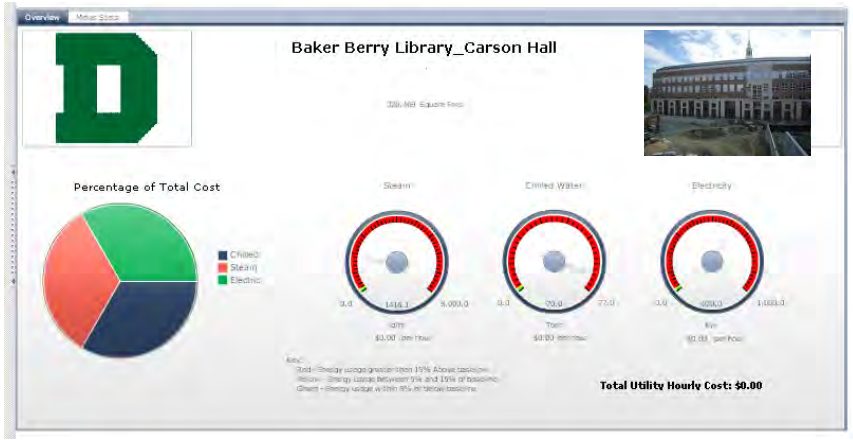
Conclusion:

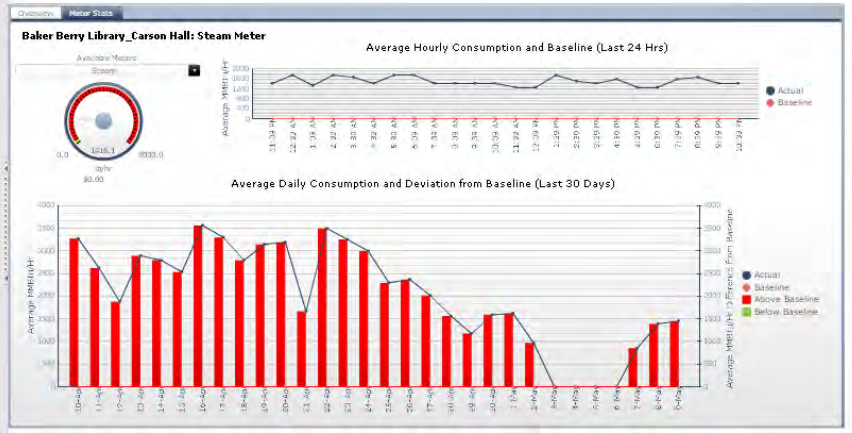
Turbine 3 is the most efficient and should be run independently through the summer. It appears to be capable of making 400 - 500 kW MORE than the combination of two turbines on line together during very high load periods.. Savings during such high load periods is > $1,500 per day plus demand charge savings.

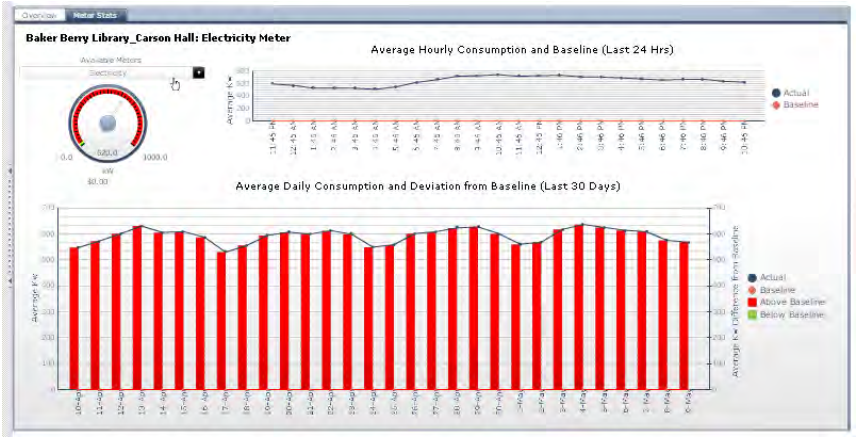
FRIDAY JULY 9, 2010

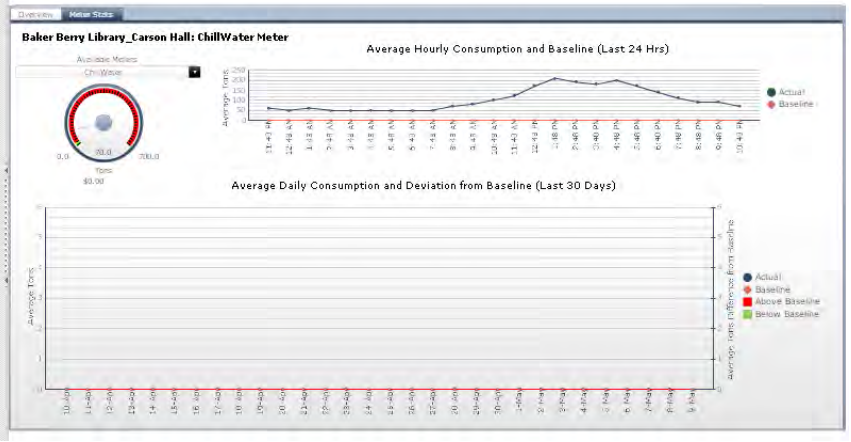
Building Dashboards

- For Op's Management and Building Occupant Awareness

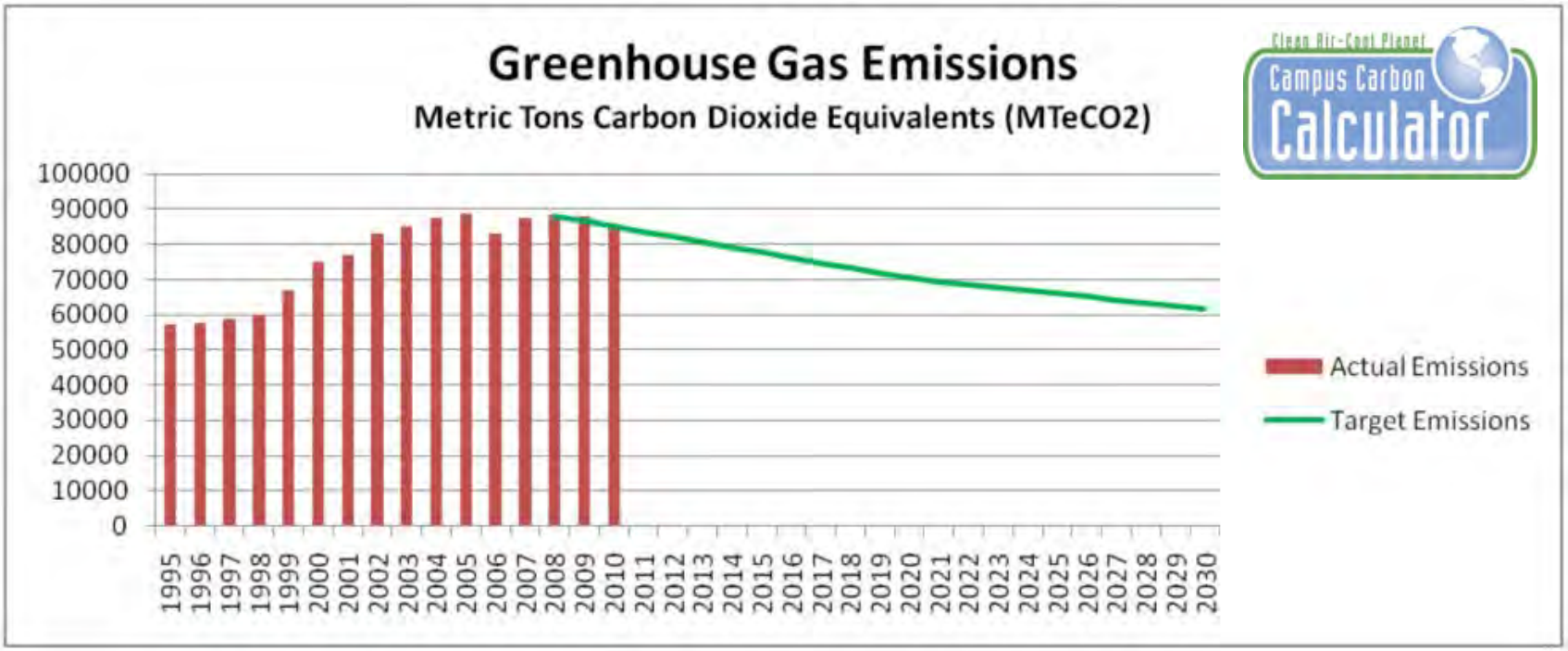








Sustainability Indicators



Also …

- Solid Waste
- Recycling
- Water

Continuing Development…

- Collaboration with Academic programs
- Automated Fault Detection and reporting
- Heating/Electric Plant Optimization
- Campus-wide Demand Control
- Integration with supply-side changes
- Ability to do real-time electrical purchasing

Campus Energy Management System

Questions…

Thank You!