



NCBC

Tracking the Benefits of Retro-Commissioning: M&V Results from Two Buildings

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QUANTUM ENERGY SERVICES & TECHNOLOGIES, INC.



Tracking the Benefits of Retro-Commissioning: M&V Results from Two Buildings

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Overview

This presentation will discuss:

- **Current Situation**
- **Basic M&V Requirements**
- **M&V Results for Two Campus Buildings**
- **Discussion & Conclusion**



Situation

- RCx is a means to improve a building's energy efficiency
 - Owners
 - Energy Efficiency Programs
- “RCx Measures”
 - Correct and optimize system operations
 - Operational changes
 - Control system changes
 - Justification provided by measure cost-effectiveness
- RCx measure recommendations based on savings estimates



Situation

- RCx measure savings estimates are based on:
 - Design documentation
 - Equipment specifications
 - Monitored operational data
 - Independent data loggers
 - Control system trends
 - Bin models, engineering models, computer simulations, etc.
- Savings estimates = “real” savings?
 - Model errors
 - Incomplete or inaccurate data
 - Incorrect assumptions
 - Etc.



Situation

Risks to Owner:

- Savings not delivered, no return on investment
- No ability to track actual savings
- Savings do not last:
 - “Soft” measures that can be and often are defeated

EE Program Risks:

- Program’s claimed savings do not stand up to third party review
- Savings lifetimes are short
- Negative impact on program realization rates

Risk to Regulatory Agencies (e.g. PUCs, PSCs)

- Unreliable basis for program planning and accurate forecasting



Need for Robust M&V in RCx Projects

Needs:

- **Demonstrate actual, verified energy savings benefits of RCx**
- **Provide a mechanism to determine measure savings persistence**
- **Smooth process of third party EM&V in public-goods funded RCx programs**

Opportunities:

- **Standardization of M&V processes for RCx**
- **Provide information tools for operators and owners to maintain measure savings, and further improve energy performance**

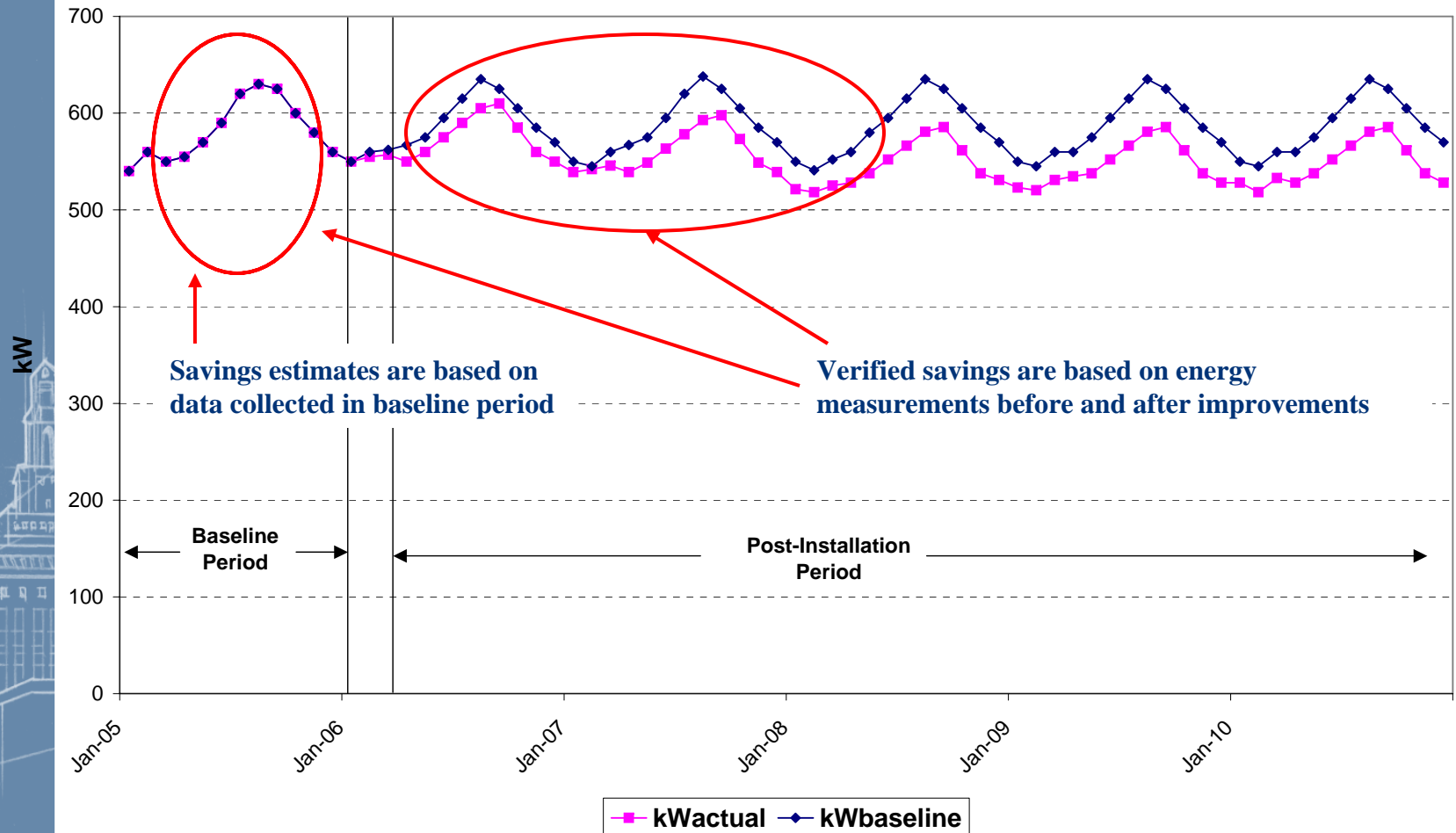
What is Measurement and Verification?

IPMVP Chapter 3 says:

Energy Savings = Baseyear Energy Use – Post-Retrofit Energy Use ± Adjustments

- **Baseline or post-installation energy use must be modeled**
- **Energy use model must be able to generate energy use data that can be compared with measured data, in order assure its accuracy**

Quantifying Savings



M&V Plan Requirements

- **Based on IPMVP Guidelines (partial list):**
 - **Select M&V Option**
 - **Identify systems to be monitored**
 - **Define baseline period and collect baseline data**
 - **Develop baseline energy model**
 - **Install measures**
 - **Collect post-installation data**
 - **Determine savings**

Overlap of Data Requirements

IPMVP M&V Plan Requirements	RCx Plan
Description of ECM and intended result	X
Description of ECM boundaries	X
Description of baseyear conditions and energy data	X
energy and demand profiles	X
occupancy type, density, and periods	X
space conditions for each operating period	X
equipment inventory	X
equipment operating practices	X
significant equipment problems	X
Description of planned changes to baseyear conditions	X
Identification of the post-retrofit period	
Establishment of conditions to which all energy measurements will be adjusted	
Documentation of the procedures used to verify proper installation of the ECM	X
Specification of IPMVP Option	
Specification of data analysis procedures	
Specification of metering points and meter characteristics	
Option specific information (e.g. simulation software used under Option D)	
Specification of quality assurance procedures	
Quantification of expected accuracy associated with the measurement and analysis	
Specification of how results will be reported and documented	X
Specification of data available for savings verification by a third party	
Descriptions of how non-routine baseline adjustments will be made	
Definition of budget and resource requirements for the M&V effort	X

IPMVP M&V Options

Retrofit Isolation Options:

- **Option A: Allows stipulation of some parameters**
- **Option B: Retrofit isolation – continuous monitoring of parameters**
- **Focus is on systems and equipment – similar to RCx.**

Whole Building Options:

- **Option C: Utility bill analysis**
- **Option D: Calibrated computer simulation**
 - **Sometimes used with isolated systems, as applicable**
- **Used when savings distinguishable from variation in use (typ. >15%)**
- **For UC Berkeley, Option B was selected**
 - **Magnifies savings as a proportion of use**
 - **+ addresses MBCx project goals: i.e. persistence, tools, etc.**



UC Berkeley – MBCx Program

- **Project funded under the UC/CSU/IOU Partnership’s Monitoring-Based Commissioning (MBCx) Program**
 - **RCx process enhanced by addition of permanent monitoring capability to understand system performance**
 - **Diagnostics**
 - **M&V**
 - **Soda Hall:**
 - **Steam meters added**
 - **Tan Hall:**
 - **Electric and steam meters upgraded**
 - **Both: electric and steam meters connected to Web-based tool**
- **MBCx project:**
 - **BAS capabilities in each building expanded with addition of points and programming to enable on-going M&V and diagnostics**



UC Berkeley MBCx Project

- **UC Berkeley has significant monitoring resources to devote to this project**
 - **Web-based utility information system**
 - Whole building kW and steam meters
 - Electric and steam trended at 15 minute intervals
 - Data stored indefinitely
 - **Web-based points mapped from BAS**
 - Chiller kW
 - BAS points trended at 1 minute intervals
 - Data stored for 6 months

Soda Hall

- UC Berkeley's Computer Science Department (24/7 operation)
- 109,000 ft²
- Energy Use Intensity: 174 kBtu/ft²-yr
- 2 - 215 ton chillers (lead/lag)
- Constant Speed Primary/Variable Speed Secondary Chilled Water System
- Two 2-speed, forced draft, open loop cooling towers
- 3 Main VAV AHUs,
 - AHU1 serves building core,
 - AHUs 3 and 4 serve the perimeter, with hot water reheat
- 11 computer room DX units, water cooled with variable speed pumps
- Steam to hot water heat exchanger, 2 variable speed HW pumps

Soda Hall Findings

- **Minimum VAV Box Damper Positions at 50%**
 - **Causes excessive reheat in perimeter zones**
 - **Little modulation of fan VFD**
- **Several AHU VFDs broken or not modulating**
 - **Return to designed VAV operation**
 - **Return to scheduled operation**
- **Re-establish supply air temperature set point reset control in AHU1**
- **Other measures**
- **Approximately 483,000 kWh (10%), 2.7M lbs/yr steam (51%)**
 - **Estimated using DOE2 analysis**
- **Cost reduction \$84,000 (14%), Payback 0.7 years**

Soda Hall Measures

Measure No.	Description	Implementation Date	Estimated Savings			Estimated Measure Cost, \$	Payback, yr
			Energy, kWh/yr	Energy, lbs/yr	Dollars, \$/yr		
AHU1-2	Resume supply air temperature reset control and return economizer to normal operation	10/25/2006	129,800	266,250	\$19,004	\$1,550	0.1
AHU1-3	Repair/replace VFDs in return fans	10/25/2006	34,308		\$4,460	\$7,000	1.6
AHU1-4	Reduce high minimum VAV box damper position	3/9/2006	46,300	119,300	\$6,973	\$15,250	2.2
AHU3-2 & AHU4-2	Option 2: Reduce high minimum VAV box damper position	3/9/2006	30,600	2,328,100	\$22,603	\$17,250	0.8
AHU3-3 & AHU4-3	Re-establish scheduled fan operation and VAV AHU-3 (includes repair/replace VFD on return fan EF-17), AHU-4 (includes repair/replace VFDs on supply SF-18 and return EF-19 fans, and elimination of low VFD speed setting during the day)	10/25/2006	242,000		\$31,460	\$14,000	0.4
Total			483,008	2,713,650	\$84,500	\$55,050	0.7
Percentage Savings			10%	51%	14%		
Utility Data			Steam	5,325,717	lbs		
			Electricity	4,871,678	kWhr		
			Cost	\$621,575			

Soda Hall Affected Systems

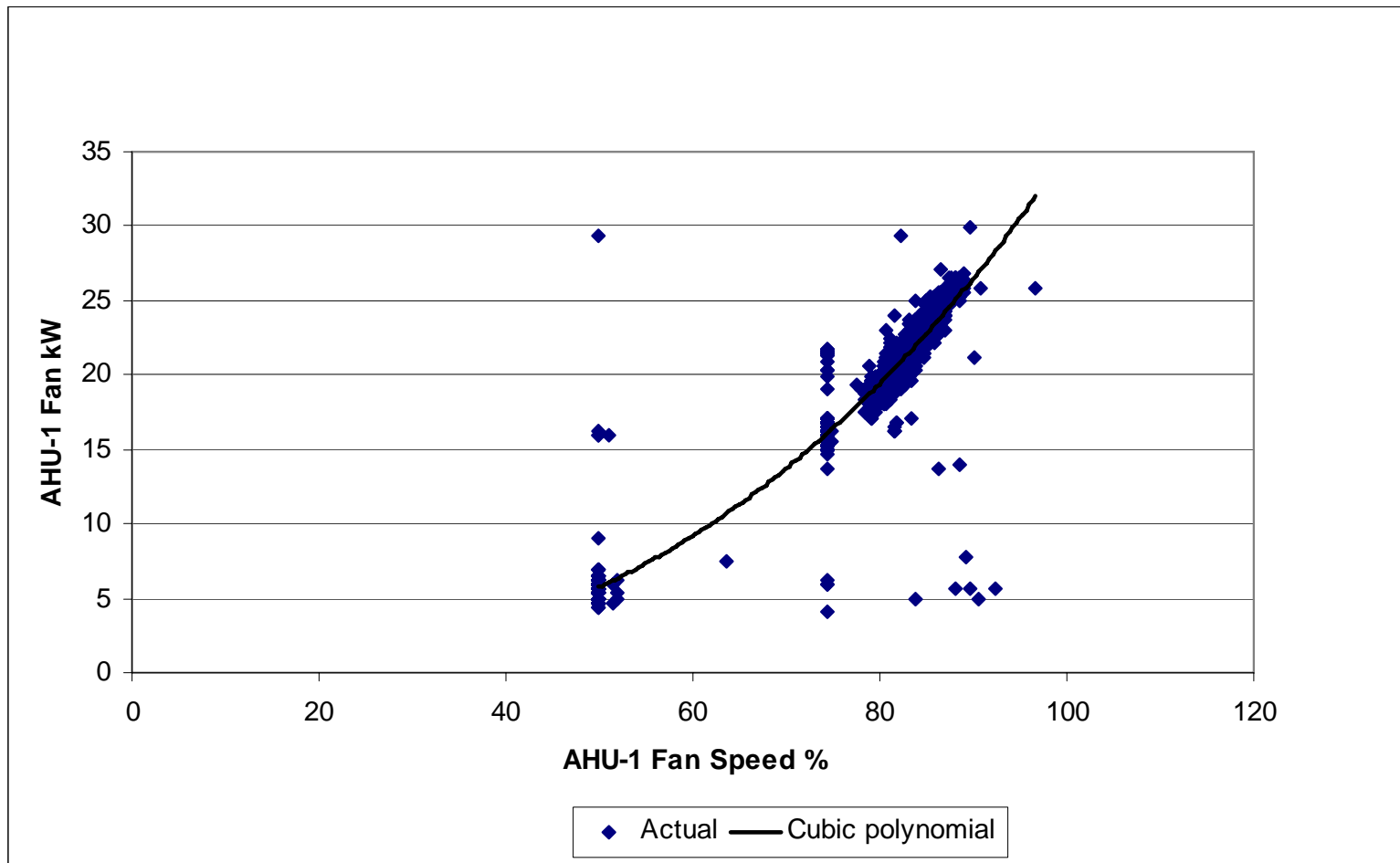
System	Equipment	Affected by ECM?	Available Points
<u>Whole Building</u>		X	
	Main Electric Meters (2)		kW
	Main Steam Meters (2)		lb
<u>Chilled Water System</u>		X	
	Chillers 1 and 2		kW
	Primary Chilled Water Pumps P-5, P-6		Status
	Secondary Chilled Water Pumps, P-3, P-4		VFD speed
<u>Condenser Water System</u>		X	
	Cooling Towers		High/Low Status
	Condenser Water Pumps P-7, P-8		Status
<u>Air Distribution System</u>		X	
	AHU-1, SF-11, EF-12, EF-13		VFD speed
	AHU-2, SF-14, EF-15		Status
	AHU-3, SF-16, SF-17		VFD speed
	AHU-4, SF-18, SF-19		VFD speed
	AHU-5, SF-20		Status
<u>Chiller Room Fans</u>			
	Chiller Room 181, SF-2, EF-2		Status
	Chiller Room 179, SF-3A, SF-3B, EF-1A, EF-1B		Status
<u>AC Units</u>			
	Condenser Water Pumps P-9, P-10		VFD speed
	AC-31 through AC-41		Status
<u>Hot Water System</u>		X	
	Hot Water Pumps P-1, P-2		VFD Speed



Define the Baseline Period & Collect Data

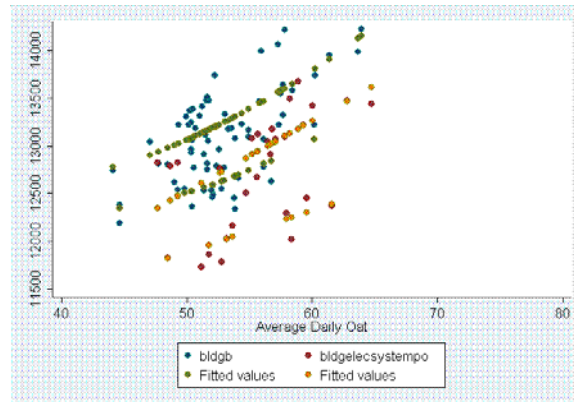
- 8 months of trended data collected
- Baseline period selected to cover widest range of operating conditions ~ 3 months.
- Energy use for each system to be totaled each day
 - Basis for analysis and reporting
- “Spot” measurements of kW for constant load equipment
- Short term logging of variable load equipment kW
 - Corresponding speed data from EMS
 - Relationship between kW and speed developed

"Proxy" Variable: VFD speed for kW

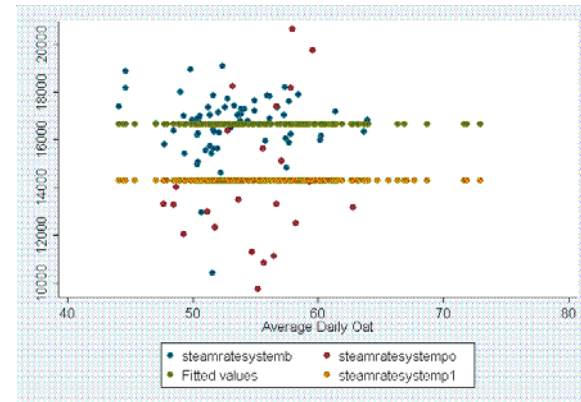


Baseline Model: Soda Hall

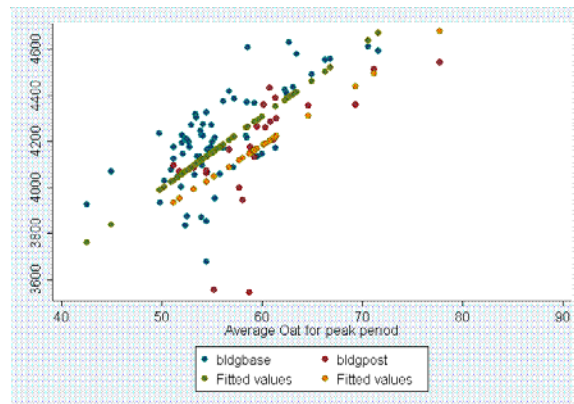
- **Total Building Electric**



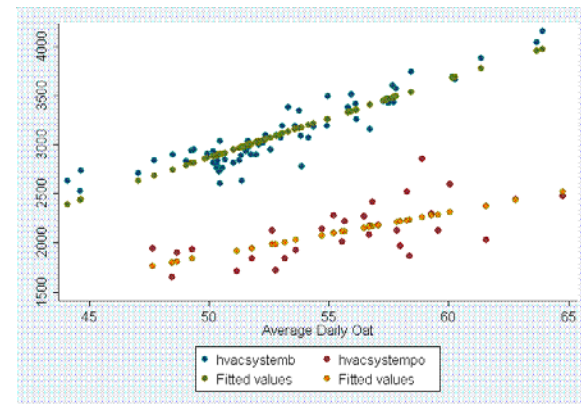
Building Steam



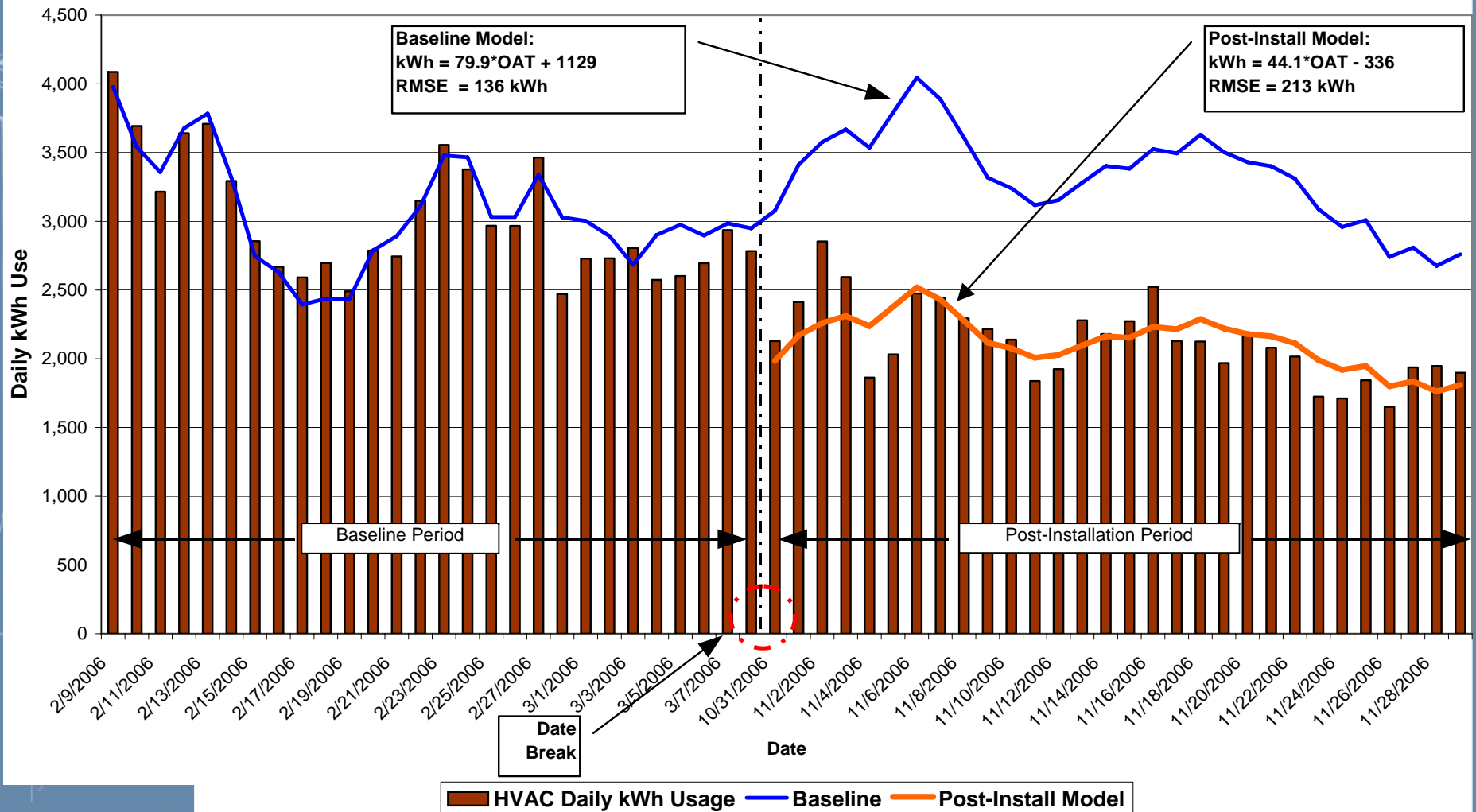
- **Peak Period Electric**



HVAC System Electric



Soda Hall M&V: HVAC Systems



Soda Hall: Estimated vs. Verified Savings

Source	Estimated Savings*	Verified Savings**	
		Whole Building	HVAC System
kWh	483,008	216,716	462,472
kW	-	22	50
Lbs. Steam	2,713,650	854,407	

* based on eQUEST model

** based on baseline and post-installation measurements and TMY OAT data



Tan Hall

- **UC Berkeley's Chemistry and Chemical Engineering Departments**
- **7 above-grade, 2 below-grade levels**
- **106,000 ft²**
- **100% outside air through 4 VFD-controlled 100 HP supply fans**
- **Steam heating and CHW cooling coils in AHU**
- **Separate exhaust system on roof: 4 VFD-controlled 60 HP exhaust fans**
- **1 475-ton chiller, constant speed primary loop**
- **Constant speed CW loop – Tower shared among buildings**
- **Steam-to HW HX system, circulated to perimeter zone boxes**

Tan Hall Findings

- **Chilled water and condenser water pumps operating in parallel instead of lead/lag**
 - **Balancing vales on each were closed down**
 - **Shut off one pump, rebalance flow and operate in lead/lag mode as intended**
- **Chiller outside air lockout temperature sequence not functioning**
 - **OAT set point also too high**
 - **Correct operation and lower set point 2 °F**
- **Leaky steam valve in AHU – caused simultaneous heating and cooling**
- **Savings: 654,000 kWh (14%), 90 kW, 10.5 M lbs steam (62%)**
 - **Estimated using bin analysis**
- **Cost reduction \$154,000 (19%), Payback 0.02 years**

Tan Hall Measures

Measure No.	Description	Implementation Date	Estimated Savings				Estimated Measure Cost, \$	Payback, yr
			Energy, kWh/yr	Energy, lbs/yr	Peak Demand, kW	Dollars, \$/yr		
CHW-1 & CW-1	Eliminate simultaneous chilled water pump and condenser water pump operation	5/24/2006	68,849	-	33.3	\$9,639	\$2,900	0.3
CH-5	Chiller outside air lockout temperature set point not operating	12/22/2005	361,184	-	0.5	\$29,046	\$0	-
CH-6	Chiller outside air lockout temperature and Sat set point change	6/26/2006	119,767	-	8.3	\$16,767	\$0	-
AHU3-4	Eliminate simultaneous heating and cooling	5/24/2006	103,775	10,543,991	48.8	\$98,880		
Total			653,575	10,543,991	90.8	\$154,332	\$2,900	0.02

Percentage Savings

14%

62%

19%

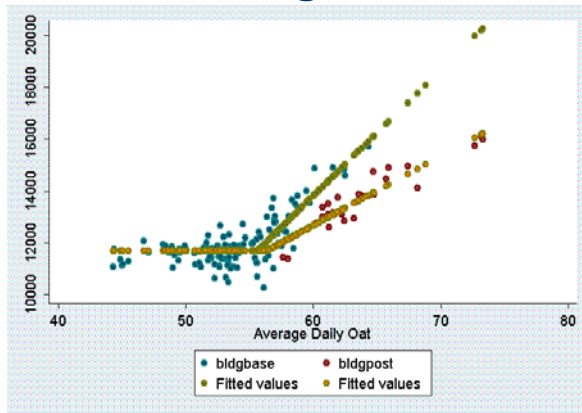
Utility Data		
Steam	17,139,542	lbs
Electricity	4,720,647	kWhr
Cost	\$798,007	

Tan Hall Affected Systems

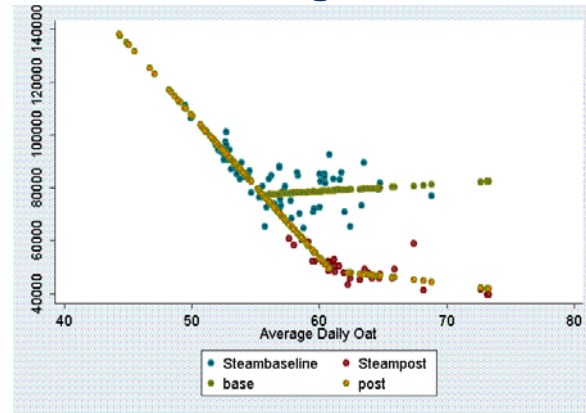
System	Equipment	Affected by ECM?	Available Points
<u>Whole Building</u>		X	
	Main 480/277 Electric Meter		kW
	Main 220/110 Electric Meter		kW
	Main Steam Meter		lbs/hr
<u>Chilled Water System</u>		X	
	Chiller (VS)		kW
	Primary Chilled Water Pumps CHWP-1, CHWP-2 (CS)		Status
<u>Condenser Water System</u>		X	
	Condenser Water Pumps CDWP-1, CDWP-2 (CS)		Status
	Cooling Tower (CS, 2-speed)		Not Avail.
<u>AHU-3</u>		X	
	AHU-3 Supply Fans SF-1, SF-2, SF-3, SF-4 (CS)		S/S & Speed
	AHU-3 Exhaust Fans EF-1, EF-2, EF-3, EF-4 (CS)		S/S & Speed
	Terminal Boxes and Fume Hoods associated with AHU-3		NA
<u>AHU-1</u>			
	AHU-1 Chemical Storage AH-1, SE-1		Status
<u>AHU-2</u>			
	AHU-2 Chemical Storage AH-2, SE-2		Status
<u>Heating Water System</u>		X	
	Heat Exchanger HWC-1		
	Hot Water Pumps HHWP-1, HHWP-2		Status
<u>Lighting System</u>			
	Lighting Circuits		NA
<u>Plug Loads</u>			
	Plug Load Circuits		NA
<u>Domestic Water</u>			
	Domestic Water Pumps		NA

M&V Models: Tan Hall

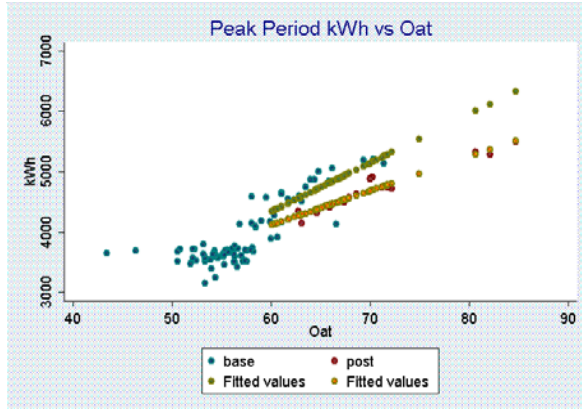
Whole Building Electric



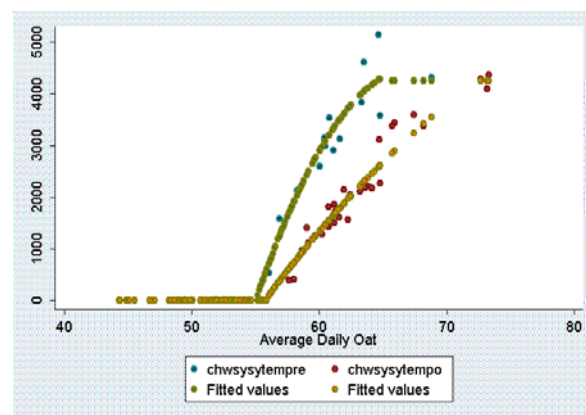
Whole Building Steam



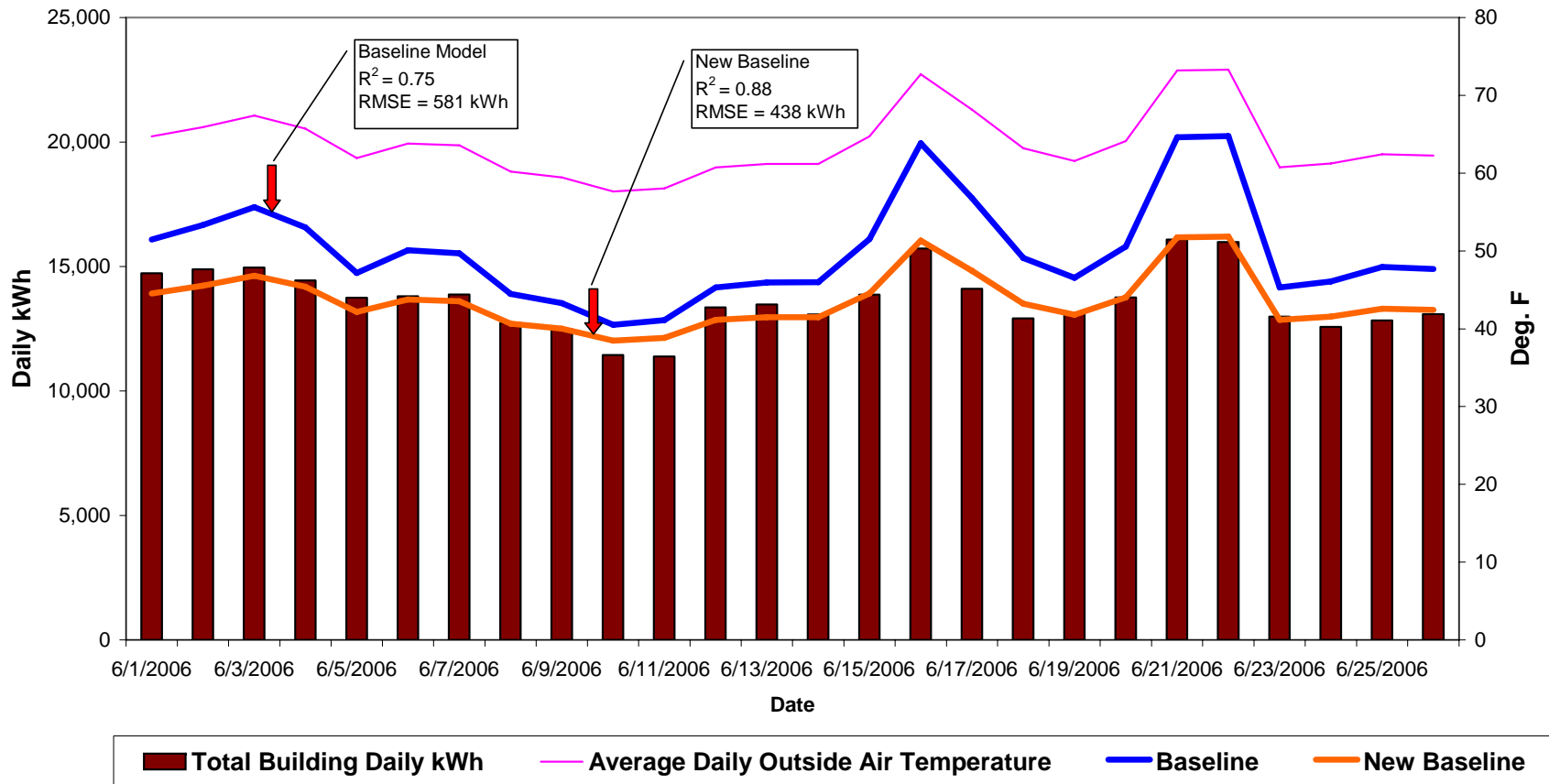
Peak Period Electric



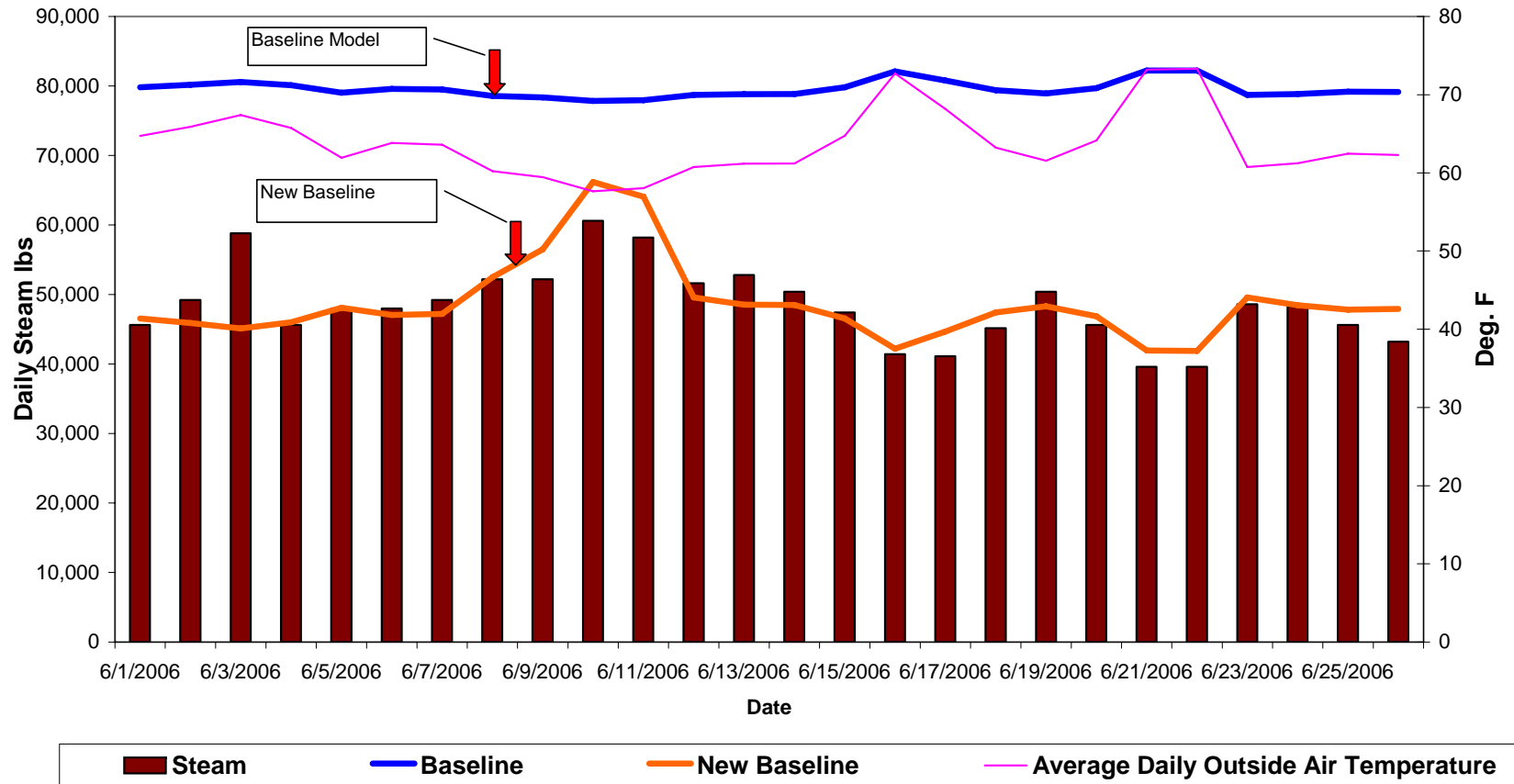
Chilled Water System Electric



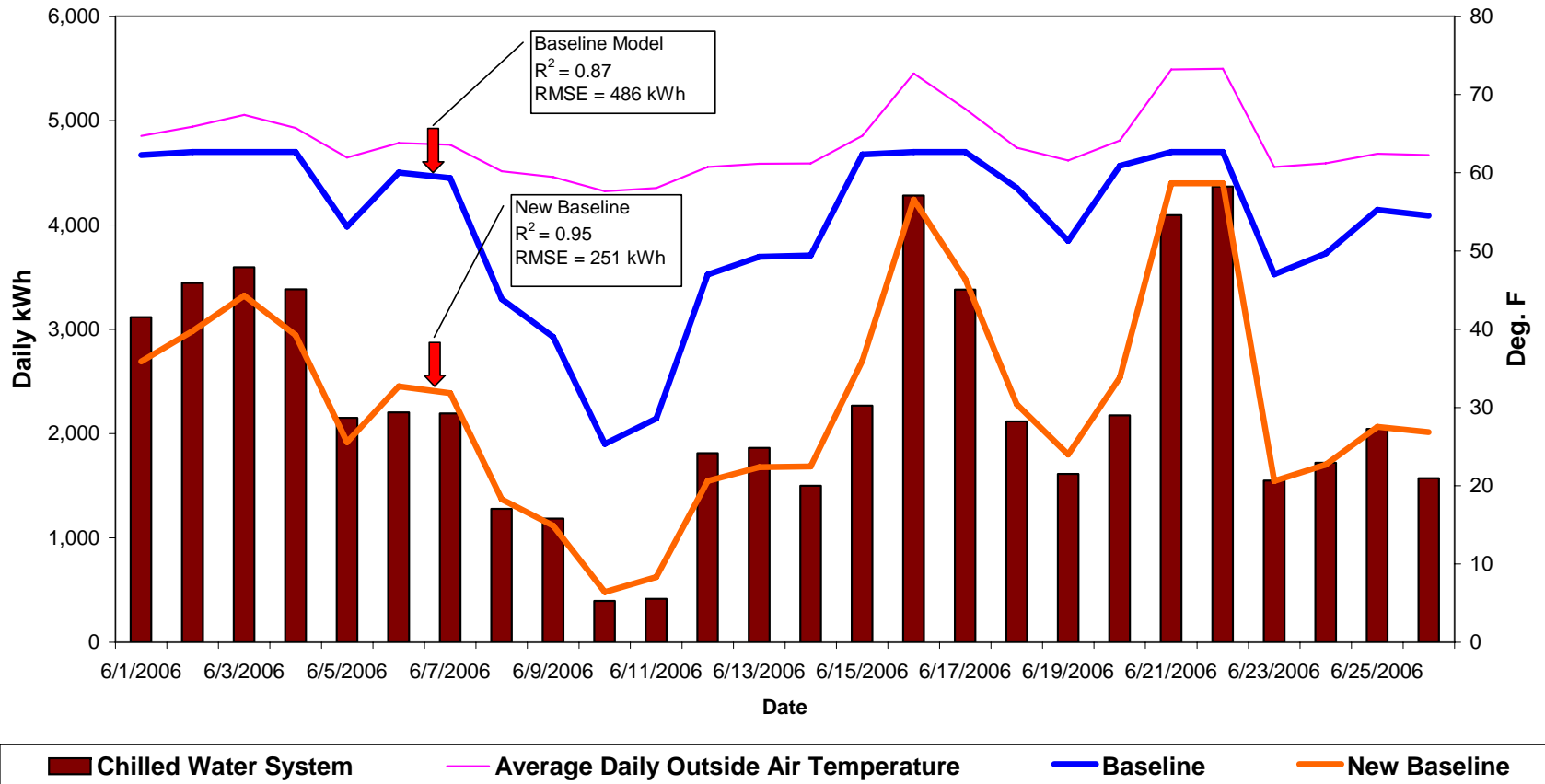
Tan Hall M&V: Whole-Building Electric



Tan Hall M&V: Whole-Building Steam



Tan Hall M&V: Chilled Water System



Tan Hall: Estimated vs. Verified Savings

Source	Estimated Savings*	Verified Savings**	
		Whole Building	CHW System
kWh	653,575	663,184	686,519
kW	91	69	
Lbs. Steam	10,543,991	5,995,232	

* based on engineering calculations

** based on baseline and post-installation measurements and TMY OAT data

Costs

Building	Metering Costs	MBCx Agent Costs	In-House Costs	Total
Soda Hall	\$ 4,442	\$ 62,160	\$ 51,087	\$ 117,689
Tan Hall	\$ 22,573	\$ 53,000	\$ 15,300	\$ 90,873

- **Including all costs, project remains cost-effective:**
 - **Soda Hall: 1.7 year payback**
 - **Tan Hall: 0.7 year payback**
- **Added costs of metering hardware and software did not overburden project's costs**
- **In private sector – metering costs lower**
 - **Existing electric meters**
 - **Sophisticated BAS systems**
 - **MBCx approach should be viable**

Discussion

- **Consider new approach:**
 - **Focus project resources on verified savings instead of estimated savings approach**
 - **More rigorous savings analysis, more reliable results**
 - **Install all low-cost measures**
 - **Estimate savings for only higher cost measures**
 - **Leave in place capability to track & tally savings**
 - **Diagnostic benefits of approach**
 - **Addresses savings persistence**

Discussion, cont.

Integrating M&V into RCx:

- **Smooths hand-off with program evaluation teams**
 - **RCx providers define M&V plans, collect baseline data, develop baseline models**
 - **Evaluators review M&V plans, data, calculations**
 - **Collect post-installation data, complete analysis**
 - **Maintains independence between implementers and evaluators**
 - **Owners receive benefits**
- **Barrier**
 - **Lack of understanding of M&V**
 - **RCx programs need to require/provide training**

Conclusion

- Soda & Tan Hall projects showed technique to integrate M&V into RCx
- Integrated M&V procedures may become tools for operators and owners:
 - For operators: diagnostic capability, track energy use
 - For owners: verification of savings
- Program benefits:
 - Persistence of RCx savings
 - Less uncertainty on savings
 - Potential for smoother transition with evaluators
- Other benefits
 - Establish new baselines for next project

Related Work

M&V Guidelines:

- Energy Valuation Organization's International Performance Measurement and Verification Protocol (IPMVP)
 - New release available in December at: www.evo.org
- ASHRAE Guideline 14: www.ashrae.org
- California Commissioning Collaborative: Verification of Savings Project
 - Review current M&V methods within RCx projects
 - Recommend best practices for M&V in RCx
 - Disseminate results