

After the (RCx) Party is Over – Unrequited or Life Long Savings?

**David Jump, Ph.D., P.E., Matthew Denny, P.E.,
Jeff Gallishaw, Doug Wiedwald, P.E.**
Quantum Energy Services & Technologies, Inc. (QuEST)

Synopsis

The benefits of integrating M&V into RCx projects, particularly those sponsored under utility programs, are many. Primary among them is the establishment of an internal energy tracking system facility operators can use to maintain savings persistence. Other benefits include: establishment of a robust, transparent, and repeatable savings verification strategy, the method's diagnostic capabilities, and creation of updated energy baselines from which additional savings may be quantified. These are key elements that should be included in any RCx project that has energy savings as an objective.

Direct measurement of energy (electric, natural gas, steam, chilled and hot water) and its influencing variables (ambient temperature, operation schedules, etc.) have been applied in these projects under International Performance Measurement and Verification Protocol (IPMVP) Options B and C. This paper discusses progress and results from multiple sites, including office buildings, high-technology office buildings with data centers, and laboratories where this method has been integrated into RCx projects. It outlines the M&V Option selection criteria and method development, and examines techniques used to collect the required data. The paper also discusses factors determining the time period for baseline and post-installation data collection, energy modeling techniques, and other important factors.

About the Authors

David Jump, Ph.D., P.E. is Director of Engineering at Quantum Energy Services & Technologies' (QuEST), a firm that provides commissioning, energy engineering, and construction services throughout California. He has developed and implemented California utility retrocommissioning energy efficiency programs since 2002. He is an ASHRAE member and is active in the building commissioning industry. He currently serves on the California Commissioning Collaborative Advisory Board, is acting president of the Building Commissioning Association's Southwest Chapter, and is current chair of the Efficiency Valuation Organization's IPMVP Committee. David received a Ph.D. in Mechanical Engineering from the University of California, Santa Barbara and has over 18 years of experience in the energy-engineering field.

Matt Denny, P.E. is an Engineer at QuEST. He holds a B.S. in Mechanical Engineering from San Francisco State University. Mr. Denny is lead engineer on QuEST's monitoring-based commissioning projects with the University of California. Mr. Denny has recently completed retrocommissioning projects for UC Berkeley, UC Davis, and Lockheed-Martin.

Jeff Gallishaw is an Engineer at QuEST. He holds a B.S. in Mechanical Engineering from San Francisco State University. Mr. Gallishaw leads and provides support on QuEST's monitoring-based commissioning projects at UC Davis, and in Silicon Valley.

Doug Wiedwald, P.E., is an Engineer at QuEST. He holds a B.S. in Mechanical Engineering from UC Davis. Mr. Wiedwald supports QuEST's monitoring-based commissioning projects at UC Davis, and in Silicon Valley.

Introduction

The benefits of integrating measurement and verification (M&V) in existing building commissioning (EBCx) projects focused on energy savings, particularly those sponsored under utility programs, are many. Primary among them is the establishment of an internal energy tracking system facility operators can use to maintain savings persistence. Other benefits include: establishment of a robust, transparent, and repeatable savings verification strategy that is in line with energy efficiency program evaluation protocols, as well as the diagnostic capabilities of the method, and creation of updated energy baselines from which additional savings may be quantified. These are key elements that should be included in any RCx project that has energy savings as an objective. Previous papers presented at the National Conference on Building Commissioning^{1,2} have discussed these benefits.

In this paper, we present ongoing and recently completed work applying whole-building M&V methods in EBCx projects. We discuss its general application, factors influencing method selection and analysis, and other issues that influence the method and process. Several examples are provided.

Overview of M&V

Two documents formally define M&V^{3,4}. The projects presented in this paper were based on IPMVP. The concept of M&V is demonstrated in Figure 1. For any equipment, system, or building where an energy use improvement will be implemented, a baseline of its energy use is established and used to predict what it would have been after improvements have been implemented. The energy savings is the difference between the predicted baseline energy use and the measured energy use in the post-implementation period. The baseline energy use is a model that represents how the energy use varies with influencing parameters. These parameters must be identified and may include ambient temperature, equipment load, and operating schedule. The baseline energy use model may be *predictive*, such as a set of equations developed from engineering principles that describe energy use in equipment and systems (or as found in whole-building energy simulation software), or the model may be *empirical* as when relationships based upon data collected on the system's energy use and operating characteristics are developed.

Both IPMVP and ASHRAE 14 require measurements of energy and independent variables before and after measure implementation in order to apply these methods. Creating models of baseline energy use allows it and the post-installation use to be compared under the same set of conditions. It also is the only way an estimate of the savings uncertainty can be made.

¹ "Tracking the Benefits of Retro-Commissioning: M&V Results from Two Buildings," Jump, D., M. Denny, and R. Abesamis, proceedings NCBC, 2007.

² "Tracking the Benefits of Retro-Commissioning: an Integrated Measurement and Verification Approach," Jump, D., K. Kinney, M. Denny, and R. Abesamis, proceedings NCBC 2006.

³ "International Performance Measurement and Verification Protocol," (IPMVP), available at www.evo-world.org

⁴ "Guideline 14, Measurement of Energy and Demand Savings," available at www.ashrae.org.

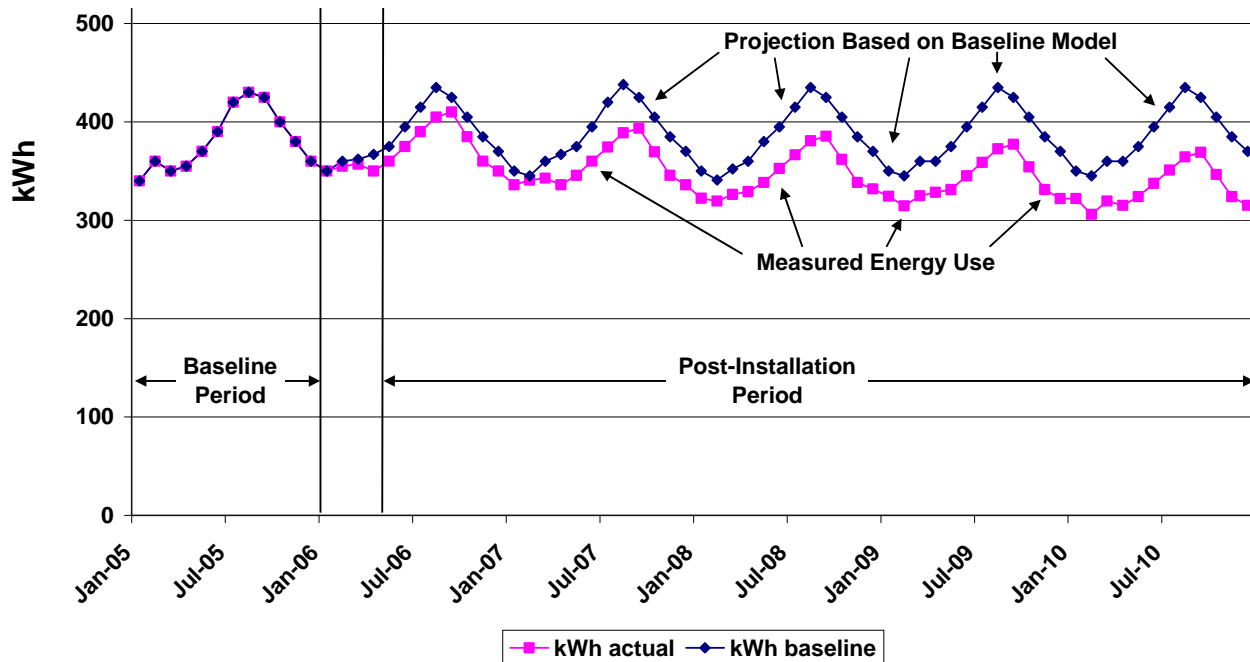


Figure 1: Graphical Illustration of M&V

Approach

We used empirical models in the examples presented here. The modeling approach was the same regardless of whether an IPMVP-Option C Whole Building or IPMVP Option B-Retrofit Isolation approach was used. We used various methods to develop the empirical models: linear regressions, multivariable regressions, change-point modeling⁵, and multivariable change-point modeling. When these methods did not yield a satisfactory relationship between the energy and independent variable, we used simple averages of the energy variable.

The most recurrent independent variable used was ambient temperature, as all of the buildings were located in California, where humidity effects are relatively low. Other independent variables used included day of week, hour of day, and occupied/unoccupied periods of building operation. Note that data for these time or schedule variables can be derived from the date and time stamp in the energy monitoring logs. In order to keep it simple, and therefore useful for building operators, we restricted the list of independent variables to information that can be obtained from the energy management system (EMS), or similar source.

Retrofit isolation M&V techniques require all energy use in a defined system be measured. We define systems according to their function, and include all equipment associated with that system to be monitored. For example a “chilled water system” is defined as all the equipment that provides chilled water, including the chillers and associated primary and secondary pumps. The energy use of the entire system is monitored. To facilitate monitoring and cut the expense of adding energy metering points, we use proxy variables based on equipment feedback status signals for constantly loaded motors, and speed feedback signals for motors with variable

⁵ We use the same meaning for change point modeling as defined in ASHRAE Research Project 1050.

frequency drives. Here an area of overlap with EBCx processes exists, as monitoring and analysis of feedback signals is a common component of functional testing and trend analysis. Converting these feedback signals into proxies for energy use requires independently installed loggers and has been discussed in the author's previous NCBC papers.

The whole-building M&V techniques used here require that the energy use be metered on a short-interval basis, such as the 15 minute interval used by most utilities for accounts with significantly high electric loads (e.g. over 500 kW). Although more rare, some buildings have whole-premise short interval data for natural gas, chilled water, hot water, and steam. Some buildings have multiple meters. This is often fortunate as the systems where the improvements are made can be isolated onto one meter, and their overall impact can be clearly demonstrated above the measurement and model uncertainty.

We use the daily total energy use of the building or systems, and in some cases the hourly total energy use, as the basis for the empirical model development. The selection of which to use is based in the amount of data available, the range of conditions which the building or systems experience during monitoring, and whether daily operation schedules are important influencing variables. Analysis of daily or hourly total energy use also reveals important diagnostic information, such as the presence of simultaneous heating and cooling, unusually high base loads, and other unexpected equipment operation.

Results

Examples 1 and 2 in the Appendix provide the energy baselines set up for two in-progress projects. Examples 3 and 4 provide the energy baselines and post-installation follow-up for two completed projects. The M&V approach used is primarily Option C - Whole-Building, using interval meter data in one or multiple meters. Option B – Retrofit Isolation examples were provided in our 2007 NCBC paper. Each of the examples provided here includes a basic description of the building, the number of interval meters available, the type and quality of the baseline model developed, and the system improvements recommended. The two in-progress projects include an ex-ante estimate of savings. The two completed projects provide the results based on the M&V process.

Following is a discussion of the M&V technique applied in each example. Through this discussion, we wish to convey how we assessed the available data and developed the method to meet the project's needs.

Example #1 (Baseline Only)

This was an EBCx project in an office and information technology learning center. The facility consisted of four four-story buildings in California's Climate Zone 12. It is cooled with several roof-top packaged HVAC units and heated with a boiler/hot water distribution system to reheat coils in the VAV boxes. It had only one electric interval meter for the entire campus, and two gas meters providing only monthly data, however several years of data were available. The EMS had limited trending capability. The savings are estimated to be about 5% of the annual energy use, and to be obtained from measures affecting the roof-top units (economizer repair and reduction of simultaneous heating and cooling), reduced HW pump operation, and lighting controls. The

baseline model that we developed was based on daily total energy use and has a CV-RMSE of 6%, and R^2 of 0.93, indicating that the independent variables “explain” the energy use in this facility very well. The scatter and time-series plots demonstrate how well the model fits the data. The fraction of savings is slightly less than the model error, so if the savings estimate is not conservative, it will be difficult to distinguish it from “noise” in the data. However, only a little more savings is needed for this approach to distinguish savings, as opposed to the 15% or 20% rule of thumb usually recommended for Option C methods using monthly bills.

Example #2 (Baseline Only)

An EBCX project was initiated in this 180,000 ft² 100% outside air ventilated biological sciences building in California’s Climate Zone 3. The building has six levels, with five above-grade levels of laboratory space. Space conditions are maintained by constant-volume air handlers with pre-heat and cooling coils, a chilled and hot water system, and reheat coils in the terminal units. Exhaust from the laboratories is entirely through fume hoods. The building had four electric meters, with all of the major equipment on the two 480V meters, and a steam meter. Approximately 6 months of data was available. The electric savings is estimated to be about 15% of the annual electricity use, and to be obtained from measures primarily affecting the chiller: install a chilled water lockout and heat recovery system, reset the chilled water supply temperature and the supply air temperature, and reset the hot water supply temperature. A baseline model for each of the two 480V electric meters and the steam meter was developed, each with CV-RMSE of 12% or lower. The R^2 values for the electric meters were low (<0.50), while the value for the steam baseline was reasonable (0.78). This implies that while the electricity models are fairly accurate representations of the baseline data, the independent variables do not fully explain the variation in the daily energy data. The time-series plot for the 480R meter demonstrates how well the model fits the data. Because most of the savings are expected to come from reduced chiller operation, we installed a wattmeter on the chiller and are trending it in the building’s EMS. A scatter plot and model of that data, which is based on hourly data, is shown in the example. Its CV-RMSE (7%) and R^2 (0.95) are much improved. This model will be used to verify the savings at the chiller, and compared to analyses on the 480V meters to gain insights on how to use the much more accessible 480V meter data.

Example #3 (Completed)

In this 400,710 ft² university library in California Climate Zone 12, there were five electric meters, two chilled water meters, and 3 hot water meters. The chilled and hot water meters were installed as part of this project, which limited the amount of baseline data to 8 weeks. A year of electric interval data was available. The library has four above-grade floors and one below-grade floor. It is served by the campus’ central chilled water and steam loop. Hot water is generated from the steam through three heat exchangers. Three variable volume and eight constant volume air handling units provide space conditioning throughout the floors. Several operational deficiencies were found that when corrected would yield significant electric, chilled, and hot water savings (please see Appendix). Ex-ante savings estimates were not developed for these measures. The electric savings were from two VAV AHU systems that were connected to one electric meter. Similarly, the chilled water savings came primarily from the loop associated with one chilled water meter. Of the three hot water meters, one was defective, and another one was not installed in time for analysis. The hot water savings were estimated from the third meter. In

order to make an annual savings estimate based on the data, a model from the post-installation data was also made. Ambient temperatures from a local TMY weather file were used with the baseline and post-installation models to determine savings. The empirical models were good for the electric meter baseline and post-installation models. The R^2 were good for the chilled water model, but the CV-RMSE were poor. This model was based on hourly data, as there was not enough variation in the baseline and post-installation daily data to develop a good daily model. Because of the project timeline, savings based on these estimates were reported to program owners and managers; however, to be more accurate, more data should be collected and included in the analysis, and an assessment of the savings uncertainty made. Finally, the hot water usage, while very poorly modeled in the post-install case due to scatter in the hourly data, clearly shows savings.

Example #4 (Completed)

In this 135,881 ft² high technology office building in California's Climate Zone 3, a controls system upgrade and air and water system rebalancing project was undertaken. These projects were completed approximately one month apart. Savings were estimated based on models developed from baseline data, from data in the interim period between projects, and from after both projects were completed. Independent variables chosen were ambient temperature and occupied/unoccupied hours of operation. Instead of using a multi-variable regression, the data were separated for occupied and unoccupied hours and independent linear regressions with ambient temperature were developed. In all cases, the CV-RMSE were 11% or lower, however all R^2 values were very low, except for one (see Appendix). Based on this procedure, the controls project's savings were predicted to be 4.3% of the annual whole-building use total, and the rebalancing project saved 7.7% of the total.

Discussion

Each of the models developed are simple equations based on readily available data. Whole-building electric data are generally available for large facilities from the local utility. As demonstrated in some of these projects, additional points to monitor chilled water, hot water or steam can be added may be added to the building's EMS or independent monitoring system.

Many buildings have multiple meters, and the systems and equipment connected to these meters should be identified. The impact of the EBCx measures installed on these systems can then more readily be demonstrated above the model uncertainty.

In developing a model, it is always better to have more data for analysis. In the event that there is limited data, we recommend that shorter time intervals be used in order to determine the relationship between the energy and independent variables (e.g. ambient temperature).

The baseline (and post-installation) models are simple equations that can be programmed into many energy management systems. This will allow the building's energy performance to be more closely tracked, and account for savings from prior projects.

Appendix

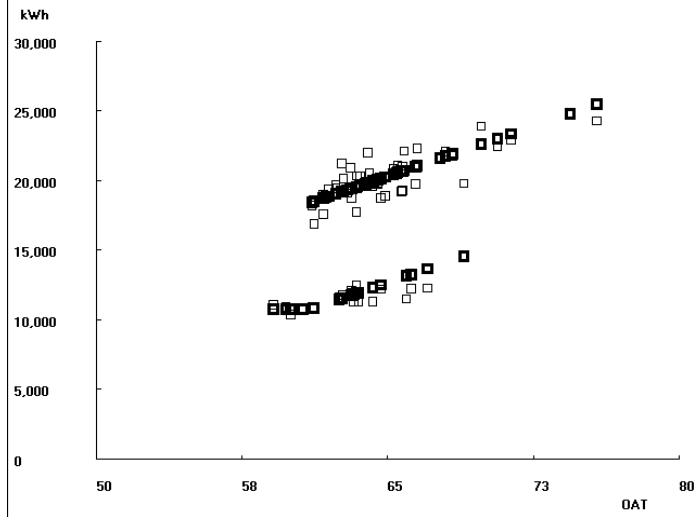
Example #1: Office/IT Center

Description

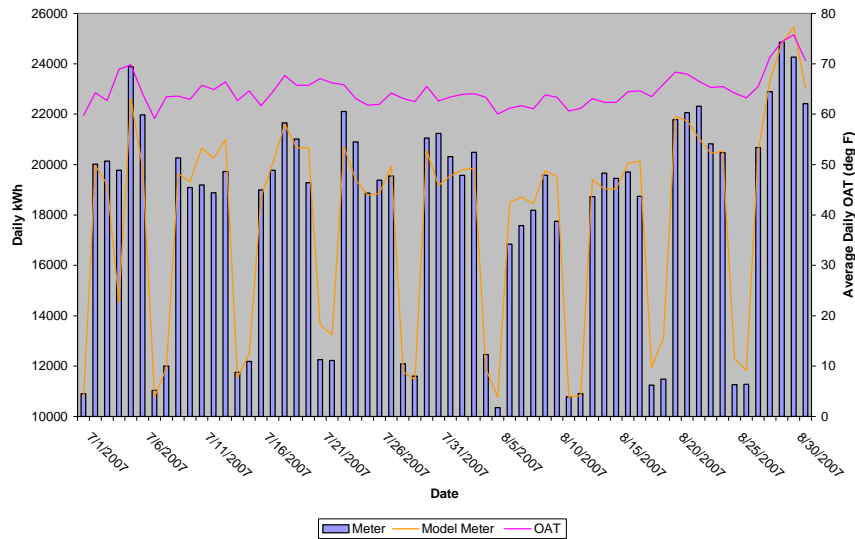
- 4 Buildings, 364,000 ft²
- 1 Electric Meter (interval)
 - Several years available
- 2 Gas Meters (monthly)
 - Several years available

Baseline Electric Model:

- 3p Multivariable
 - Time unit: Daily
 - Independent Variables
 - OAT
 - Day of week
- CV-RMSE: 6.3%
- R²: 0.93



Electricity



Measures:

- Economizer repair
- Overridden boiler lockout – simultaneous heating and cooling
- HW pumps continuous operation
- Lighting controls

Estimated Savings:

Office / IT Center				
	Usage	Estimated Savings	% Savings	Cost Savings
Average Annual Electricity Use (kWh/yr)	5,775,685	305,175	5.3%	\$39,673
Annual Natural Gas Use (therms)	155,237	20,287	13.1%	\$16,230
Total				\$55,902

Example #2: University Biosciences Laboratory Building

Description

- 180,000 ft²
- 100% OA
- 4 Electric Meters (int.)
 - 2 480V
 - 2 120V
- 1 Steam (int.)
 - 6 mos. available

Baseline Models:

480V R

- 4p Multivariable
 - Time unit: Daily
 - Independent Variables
 - OAT
 - Day of week
- CV-RMSE: 6.4%
- R²: 0.39

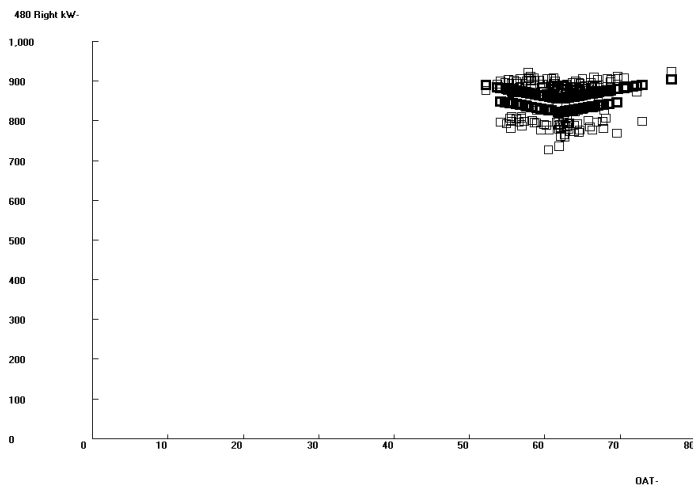
480V L

- 4p Multivariable
 - Time unit: Daily
 - Independent Variables
 - OAT
 - Day of week
- CV-RMSE: 7.9%
- R²: 0.49

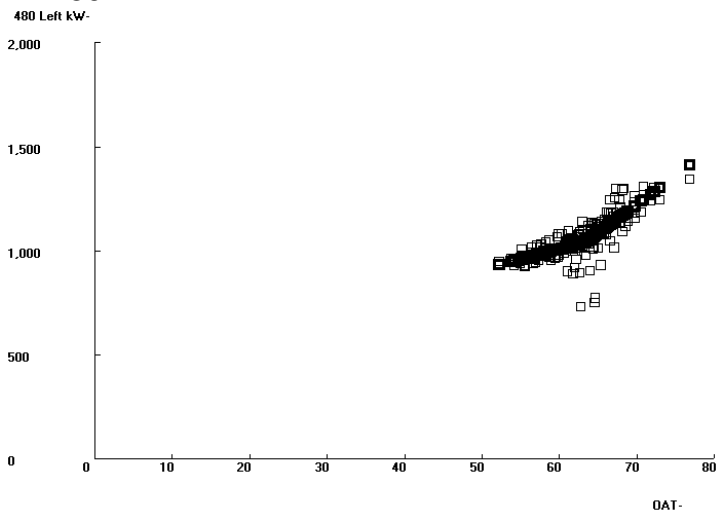
Steam:

- 4p Multivariable
 - Time unit: Daily
 - Independent Variables
 - OAT
 - Day of week
- CV-RMSE: 11.6%
- R²: 0.78

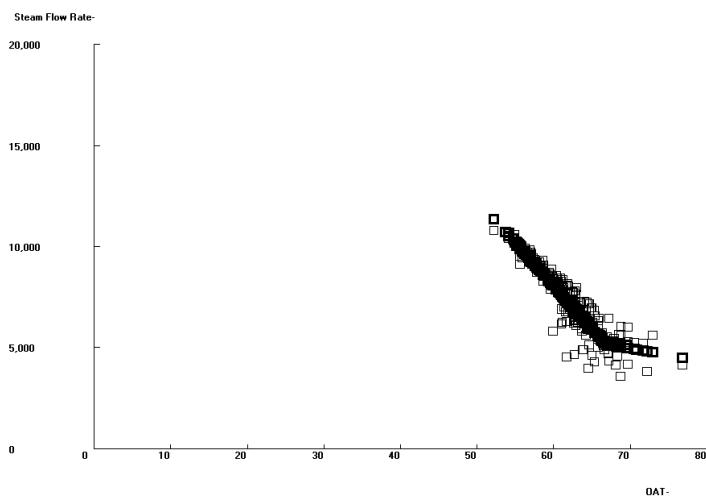
480V R



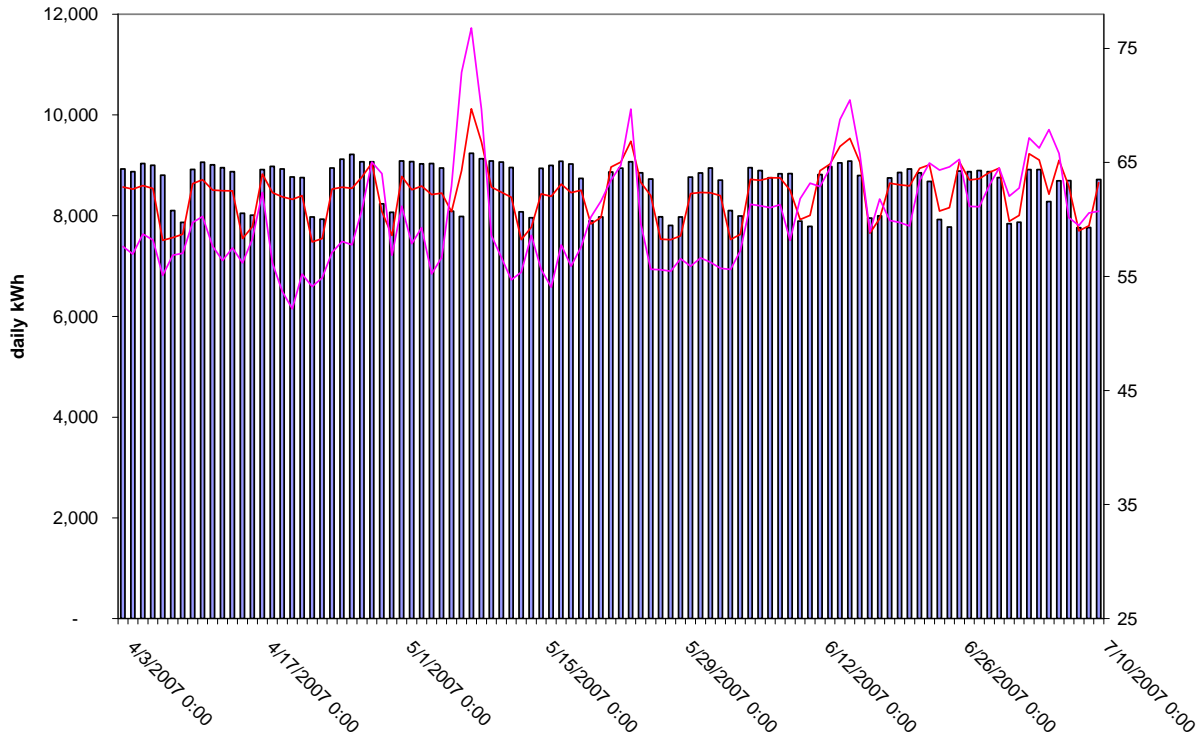
480V L



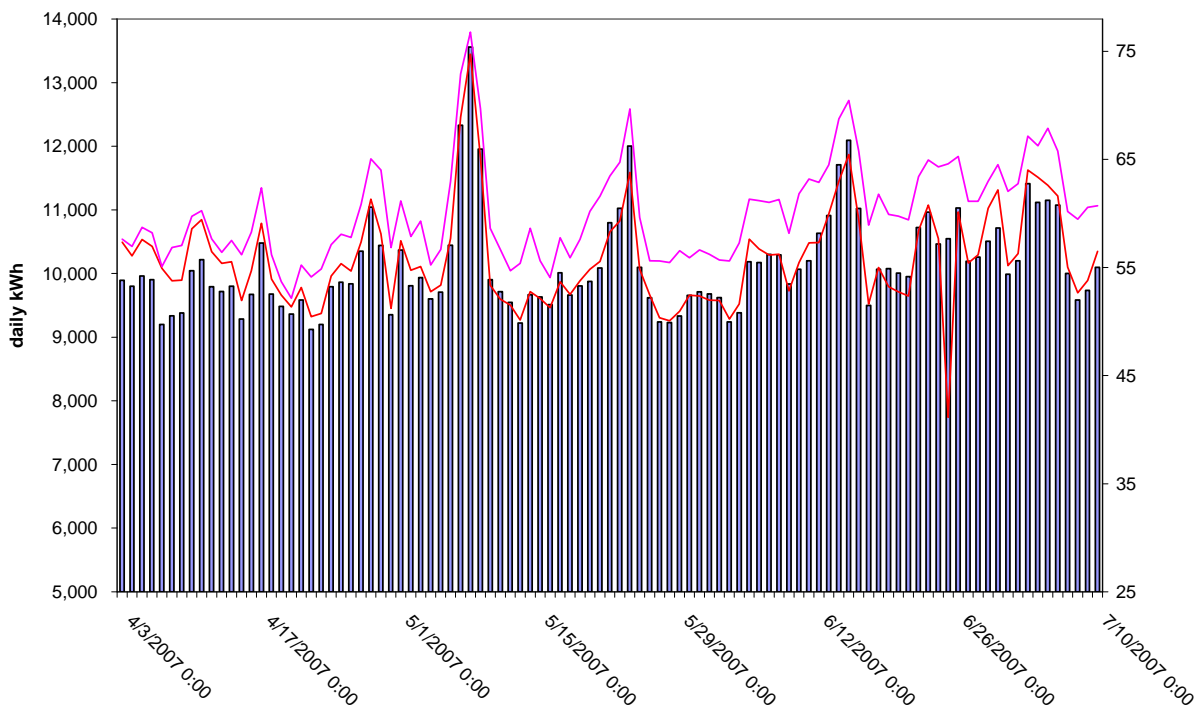
Steam



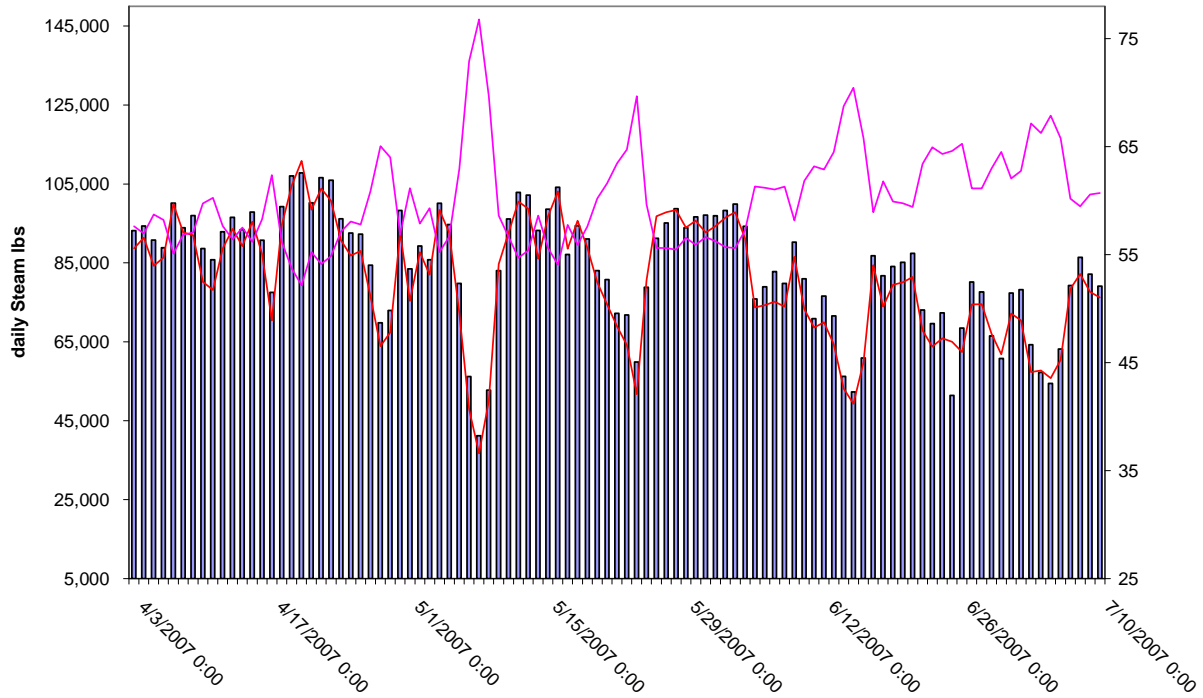
480V R Meter



480V L Meter



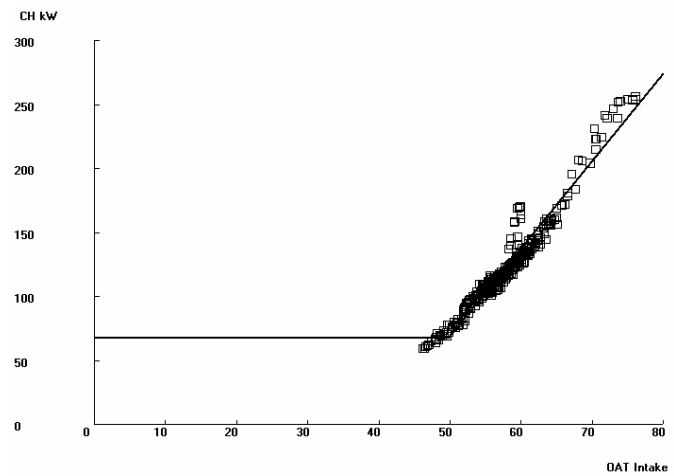
Steam Meter



Measures:

- Chilled water lockout and heat recovery
- Supply air temperature reset
- Chilled water supply temperature reset
- Heating hot water reset

Chiller Model



Estimated Savings:

University Biosciences Laboratory				
	Usage	Estimated Savings	% Savings	Cost Savings
Average Annual Electricity Use (kWh/yr)	9,932,225	1,454,105	14.6%	\$159,952
Annual Steam Use (lbs)	28,335,347	TBD		
Total				\$159,952

Example #3: University Library

Description

- 400,710 ft²
- 5 Electric Meters (int.)
 - > 1 year available
 - > 90% impact on 1 meter

- 2 CHW Meters (int.)
 - ~ 8 weeks pre
 - ~ 3 weeks post
 - > 90% impact on 1 meter
- 3 HW Meters (int.)
 - ~ 8 weeks pre
 - ~ 3 weeks post
 - 1 meter unusable

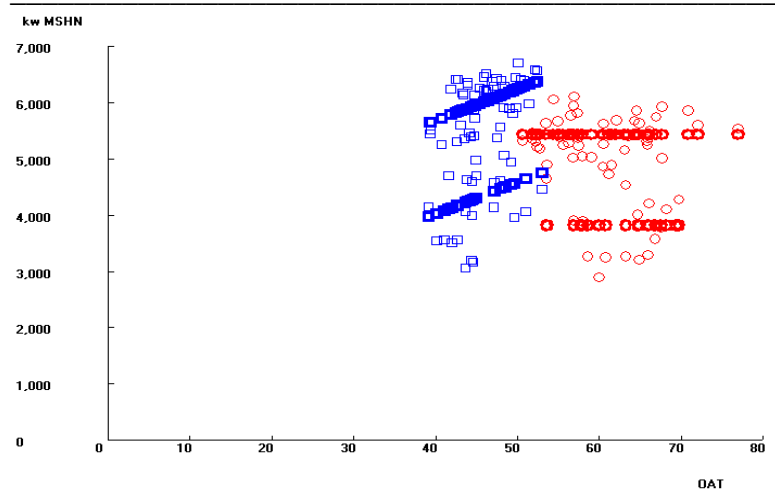
Electric Models:

Baseline

- 2p Multivariable
 - Time unit: Daily
 - Independent Variables
 - OAT
 - Day of week
- CV-RMSE: 10.5%
- R²: 0.70

Post-Install

- CV-RMSE: 8.3%
- R²: 0.77



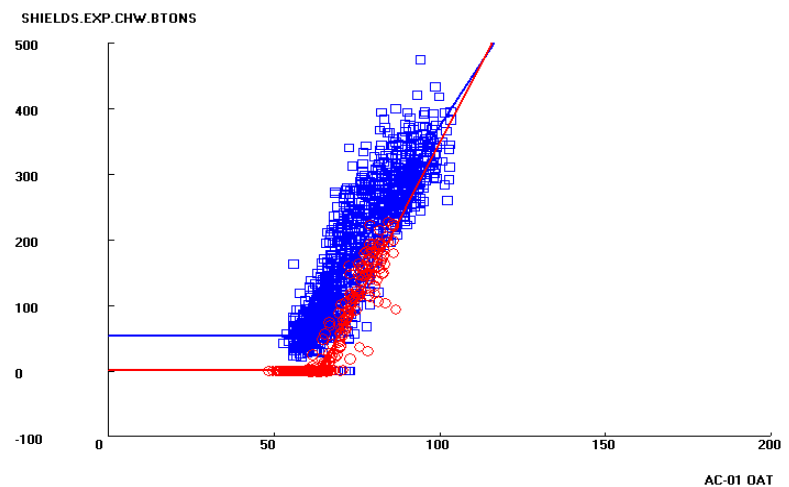
CHW Model

Baseline

- 2p
 - Time unit: Hourly
 - Independent Variable
 - OAT
- CV-RMSE: 28%
- R²: 0.80

Post-Install

- CV-RMSE: 46%
- R²: 0.90



HW Model

Baseline

- 4p Multivariable
 - Time unit: Hourly
 - Independent Variable
 - OAT
 - Day of week

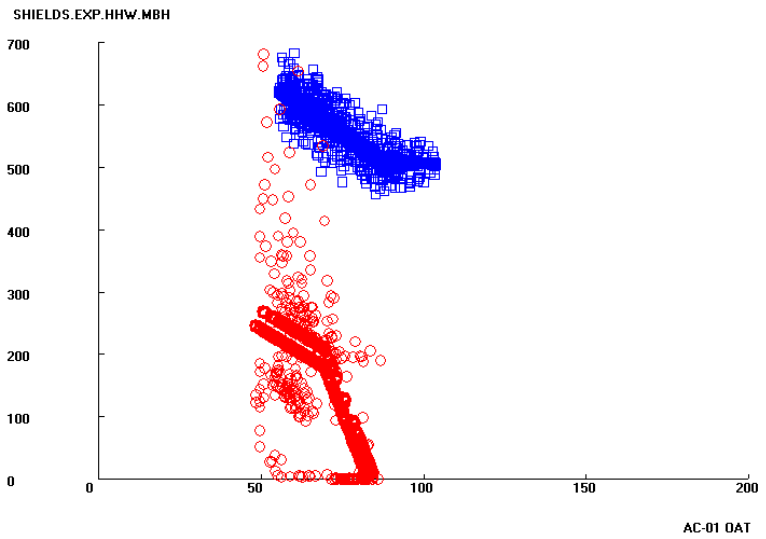
• CV-RMSE: 4.8%

• R^2 : 0.69

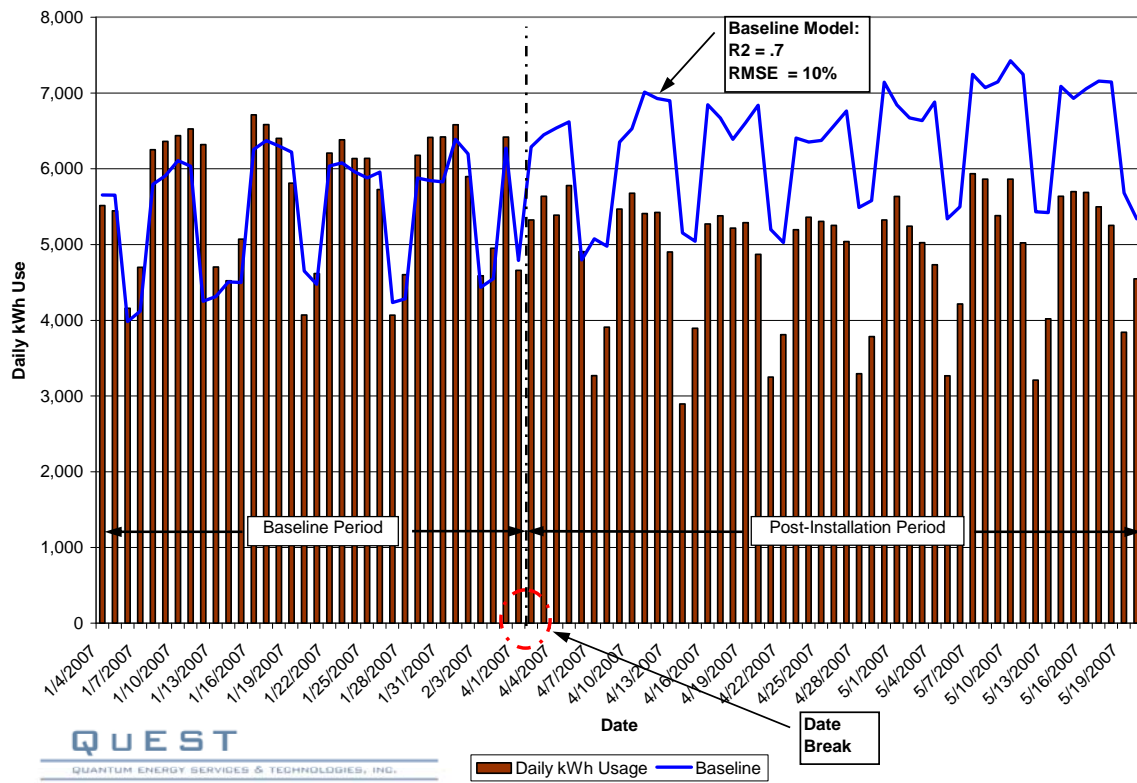
Post-Install

• CV-RMSE: 64%

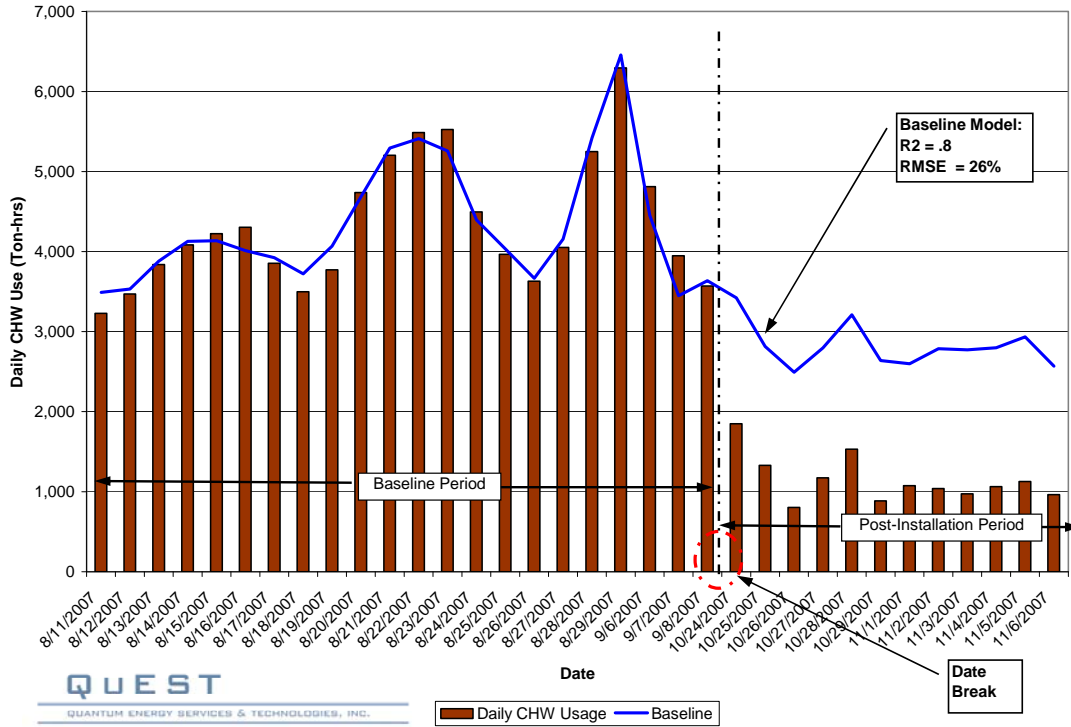
• R^2 : 0.30



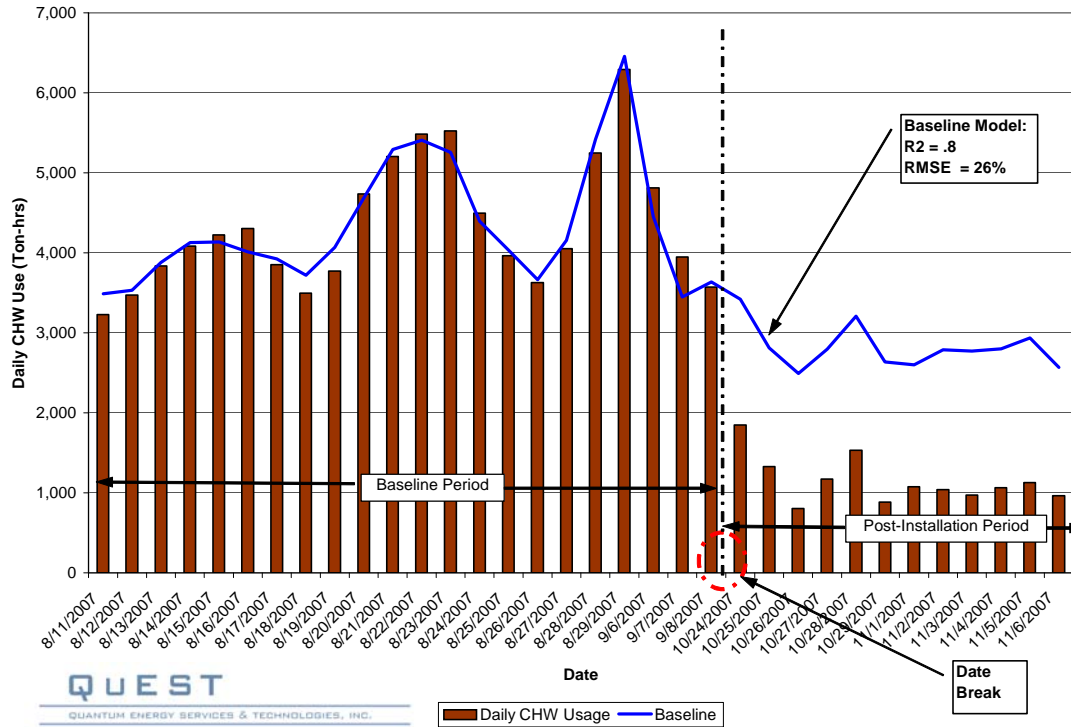
Electricity



Chilled Water



Hot Water



Measures:

System	Description of Deficiencies/Findings
AC01 & AC02	<ul style="list-style-type: none"> Excessive fan speed due to failure to meet static pressure set point Economizer malfunction Simultaneous heating and cooling in air stream
AC21, AC25, AC25, AC51, AC53, AC54, AH1, AH2, AH3	<ul style="list-style-type: none"> Economizer Repair Economizer Control Optimization Supply Air Temperature Reset with Occupancy Schedule
CHW & HW Pumps	<ul style="list-style-type: none"> Chilled water supply temp set point reset Chilled water pump lockout Reset CHW EOL pressure set point

Savings:

Energy	Energy Savings at Building	Convert to MBTU	Savings at Campus Meter (COP=0.8, Boiler eff.=0.8)	Cost Savings (\$1/Therm, \$0.116/kWh)
Electrical	484,560 kWh	-	484,560 kWh	\$56,209
Chilled Water	566,560 Ton-hrs	6,798,720	84,984 Therms	\$84,984
Hot Water	3,632,438 Mbtu	3,632,438	45,405 Therms	\$45,405
Total				\$186,598

Note: Electric savings is approximately 11%.

Example #4: High Technology Office

Description

- 135,881 ft²
- 1 Electric Meter (interval)
 - Several years available
- 1 Gas Meters (monthly)
 - Several years available

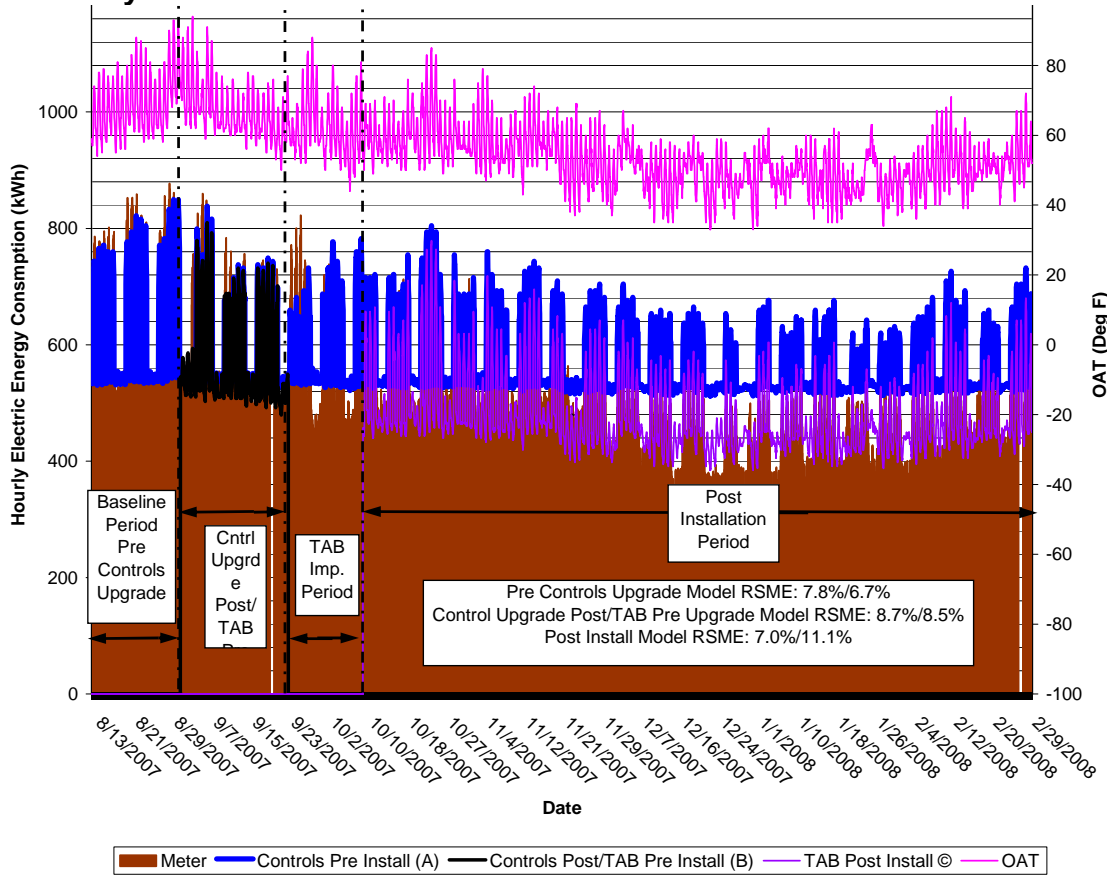
Baseline Electric Models:

- Simple Linear Regression
 - Time unit: Hourly
 - Independent Variables
 - OAT
 - Separate models
 - Occupied
 - Unoccupied

Model Statistics

	Pre Controls Upgrade		Post Controls/Pre TAB		Post Install	
	Occ	Unocc	Occ	Unocc	Occ	Unocc
R2	0.3	0.02	0.25	0.18	0.7	0.2
CV RSME	7.8%	6.7%	8.7%	8.5%	7.0%	11.1%

Electricity



Measures:

- Controls Upgrade:
 - Chilled water reset
 - Chiller scheduling
 - Supply air temperature reset
 - VFD on CW pump
 - Hot water reset
- Re-balance air and water systems

Savings:

High Technology Office				
	Annual Pre Install Use (kWh)	Annual Post Install Use (kWh)	Annual Savings (kWh)	% Decrease (Increase)
Controls Upgrade	5,109,807	4,892,552	217,255	4.3%
Effect of TAB	4,892,552	4,518,154	374,398	7.7%