Do Completed Projects Result In Energy Savings?

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ABSTRACT

Since 1978, the California Energy Commission has assisted and funded approximately $120 million in energy efficiency projects in schools, colleges, hospitals and other public facilities through federal and state grant and loan programs. In all cases, energy savings identified in the energy audit were assumed to be achieved if the participant installed the project and had no problems after installation. Except for an occasional comparison of pre- and post-retrofit utility bills, no post-project monitoring was done to verify savings in the energy audits.

Between 1994 and 1997, the State monitored the energy savings associated with installing energy efficient lighting, high efficiency motors, energy management systems (EMS) and/or variable frequency drives at seven facilities. The results indicate that lighting and motor replacement projects generally were within 20 percent of the estimated savings in the energy audit if the baseline conditions were correct. The measured savings from EMS's, chiller replacements and variable frequency drives showed substantially less savings than predicted. This was primarily due to post-retrofit changes in equipment scheduling, facility operations and installation of equipment that increased cooling loads. The savings reductions were not due to the technology but to operation changes. The findings indicate a need to include commissioning, equipment monitoring and verification, and/or training into program design to ensure project savings are achieved, especially when heating, ventilating, air conditioning projects are installed. Lighting and motor replacement projects require less stringent monitoring.

Introduction

Background

The California Energy Commission has administered the United States Department of Energy's (DOE) Institutional Conservation Program since 1978. This program has helped mainly schools, colleges and hospitals reduce energy use and cost by providing partial funding for energy audits and energy efficiency projects. Between 1978 and 1994, the program awarded over $60 million in grants to over 700 facilities in California. Awards were made to projects with the lowest simple payback, project cost divided by estimated annual energy cost savings. A contractor for DOE, the Energy Technology Engineering Center, and Energy Commission staff technically reviewed each energy audit before grants were awarded, but there was no equipment verification nor follow-up after the projects were completed. It was assumed that if the grant recipient installed the projects and did not inform us of problems, the project was successful and achieving the savings in the energy audit.

To improve the quality of the energy audit and ensure a minimum level of information, the Commission developed guidelines for preparation of the energy audit in 1992. This resulted in better audits and increased the likelihood of successful installations and realization of associated energy savings (Lew 1994).

Between 1994 and 1997 we hired consultants to monitor some of the commonly-funded lighting and heating, ventilating and air conditioning (HVAC) projects. The objective was to determine if the predicted energy savings were realized, to identify causes for deviations from predictions and to identify potential program improvements that would increase energy savings. As pre- and post-monitoring is expensive, we also wanted to identify which measures would benefit from monitoring.

Projects Monitored

The monitoring program evaluated savings from the installation of T8 lamps and electronic ballasts, compact fluorescents, high pressure sodium lamps, high efficiency motors, energy management systems (EMS), chiller replacement and variable frequency drives. The monitoring budget dictated the program size.

Facilities were selected based on their ability to complete their project installation within the term of our monitoring contract (1994-1997). A secondary criteria looked at the complexity and cost of the metering. The desire was to meter multiple facilities, rather than spend all monitoring funds on a few. The selected facilities and the projects monitored are listed in Tables 1 and 2.

Table 1. Monitored Facilities with Lighting/Motor Replacement Projects

Facilities Monitored	Area (Square Footage)	Projects Monitored
Clovis West High School, Clovis	203,165	• T8 lamps and electronic ballasts • High pressure sodium lamp • High efficiency motor replacement
Foothill Presbyterian Hospital, Glendora	98,985	• T8 lamps and electronic ballasts • Compact fluorescent lamp
Marymount College, Rancho Palos Verdes	61,423	• T8 lamps and electronic ballasts • High pressure sodium lamp
Santa Clara Valley Medical Center, San Jose	355,616	• T8 lamps and electronic ballasts

Table 2. Facilities with Heating, Ventilating and Air Conditioning/Controls Projects

Facilities Monitored	Area (Square Footage)	Projects Monitored
Bird Street Elementary School, Oroville	9,848	• EMS (HVAC and domestic hot water systems)
Foothill Presbyterian Hospital, Glendora	98,985	• Variable frequency drive on air handler motor
Inter-Community Hospital, West Covina	253,570	• Water cooled, reciprocating chiller • Variable frequency drive-chill water pumps
San Bernardino Valley College, San Bernardino	148,000*	• EMS

* Administrative, Chemistry and Library Buildings

Methodology

When we started this project, there was no standard protocol for the measurement and verification of the energy savings associated with energy efficiency project installations, similar to the *North American Energy Measurement and Verification Protocol* published in 1996 by DOE. We contracted with two firms, Aloha Systems, Incorporated, and Pacific Sciences, Incorporated, to develop a monitoring plan that would determine whether the installed energy projects resulted in estimated energy savings. Both firms had experience monitoring and verifying the energy savings from energy conservation projects and utility demand side management programs (Shirilau 1994 and Swanson, 1995). Aloha Systems was contracted to do the lighting and Pacific Sciences the HVAC monitoring.

Lighting

To maximize the percentage of lamps monitored, circuits were selected based on: 1) number of lights controlled together, 2) type of existing and replacement lamp and fixture, and 3) room type and assumed hours of operation (Shirilau 1994, 1996). The operating and non-operating times of equipment was recorded using lighting loggers manufactured by Pacific Science and Technology. These loggers contain a photosensor and computer chip and record on and off times of the light fixture. Data is downloaded to a personal computer and analyzed with the manufacturer's software and a standard spreadsheet program. For facilities on time-of-use electric rate schedules, loggers that recorded the exact on and off times were used. The software calculates the load profiles for the period of data collection. From these profiles, annual energy use by utility time-of-use periods can be extrapolated. Cumulative loggers were used for facilities not on time-of-use schedules. These loggers recorded the total number of on-time hours during the metering period.

Electric load data was measured on each lighting circuit with a wattmeter. Our consultant surveyed the existing and new fixtures to compare data on fixture type and numbers with the original audit report.

Each pre- and post-retrofit metering period occurred over a two to three month period and included weekday, weekend and holiday schedules and vacation scheduling for the schools. For facilities with uniform year-round operations, such as hospitals, extrapolation from the metering period to an annual basis assumed that the average week of the monitoring period was the same as the average week of the year (Shirilau 1996). For facilities with non-uniform year-round operations, such as schools, the load profiles were developed by taking weighted averages of the fall and winter in-session periods and collecting monitored data over one of the vacation periods (Shirilau 1996). It was assumed that the entire year could be modeled using the in-session and vacation load profiles. Table 3 identifies the number of load profiles developed for each facility.

Table 3. Projects Monitored and Number of Load Profiles Developed for Each Facility

Facility Name	Project Monitored	Number of Load Profiles
Clovis West High School	• T8/electronic ballast • High pressure sodium	10
Foothill Presbyterian Hospital	• T8/electronic ballast • compact fluorescent	19
Marymount College	• T8/electronic ballast • High pressure sodium	3
Santa Clara Valley Medical Center	• T8/electronic ballast	19

Motor

The existing and new motors were monitored at Clovis West High School using magnetic load recorders to determine their on- and off-times. These recorders operate similarly to the lighting data loggers, except they detect magnetic fields which indicate that the motors are operating. Power demands of each motor were measured at the motor control center using a Dranetz power and demand analyzer. The monitoring period for the motors was similar to the lights.

Heating, Ventilating and Air Conditioning/Control

The HVAC energy use data was gathered once for the pre-retrofit monitoring period and again for the post-retrofit monitoring period. Each monitoring period was for two to three months. Equipment with constant loads, such as pumps and fans, were monitored with Pacific Science and Technology's TOU-M or TOU-CT SmartLoggers. Operating schedules obtained from the SmartLoggers were combined with one-time power measurements to provide energy use information (Swanson 1996, 1997). The cooling systems are variable load equipment and were monitored using real power recording data loggers. The data loggers were configured to record average power (kW) readings in 15 minute intervals. The gas appliance run-times were monitored with TOU-CT SmartLoggers to record the operation schedule of the electronic ignition device of the water heater. The gas consumption rate was based on the nameplate ratings for each piece of equipment. Gas cost and use was obtained from the local utility.

Motor power draw was monitored with an energy logger. This logger was configured to obtain instantaneous power values several times per second and record an average power value every 15 minutes. Split-core current transformers and a voltage tap were used to obtain true power measurements.

Outdoor air temperature (OAT) and indoor air temperature (IAT) were monitored and 30 minute average temperature data were recorded. The OAT sensor was usually installed on the north side of the building in a shaded area or in the outside air supply intake. The IAT sensor was in the return air duct of one of the HVAC units.

Assumptions for annual energy use were based on the monitored data and correlation with local weather data for a typical meteorological year (Swanson 1996, 1997). Linear regression analysis models correlated OAT with annual energy consumption of the pre- and post-retrofit HVAC systems (Swanson 1996, 1997). The following is a description of each facility:

Bird Street School. The system evaluated was the EMS. Energy monitoring equipment was installed to determine the pre- and post-retrofit energy use of the equipment to be controlled by the EMS. Data was collected on the HVAC equipment, pump, fan, equipment operation schedule and daily IAT and OAT.

Linear regression analysis models correlated OAT with total energy for air conditioning and the compressor. The coefficient of determination (R^2) was calculated to verify correlation between OAT and the energy used for air conditioning and for the compressor. Table 5 lists the equipment monitored and the R^2.

Foothill Presbyterian Hospital. The variable speed drive on the existing 60 horsepower main supply fan was investigated. Energy monitoring equipment was installed to determine the energy use of the existing supply fan motor and the energy use after installation of the variable speed drive. The IAT was monitored to determine if the VSD altered the conditioned space temperature and to refine the energy consumption models (Swanson 1997).

For each of the pre- and post-retrofit periods, the HVAC system energy use was correlated to the difference between outdoor and indoor air temperatures to develop a model to determine annual energy consumption (Swanson 1996, 1997).

Inter-Community Medical Center. The system evaluated was the high efficiency electric chillers and variable speed drive chilled water pumps. Energy loggers were installed on equipment affected by the new chillers to determine the pre- and post-retrofit energy use. The equipment monitored included the existing and new chillers, existing chilled water pumps, new variable speed drive chilled water pumps, and operation of the existing absorption chiller and boilers during the post-retrofit period.

The chillers and the variable speed drive pumps were monitored with data loggers, split-core current transformers and voltage taps to obtain the true power measurements (Swanson 1996, 1997). The boilers were monitored with TOU-CT loggers to sense current in the electronic modules that control the gas valves to the burners (Swanson 1996).

The OAT recorder was placed in the fresh air supply air handler before the filter bank. The IAT recorder was located in a main return air duct. The HVAC equipment energy use was correlated to the difference between OAT and IAT and OAT alone (Swanson 1996, 1997). This determined energy consumption during the pre- and post-retrofit periods.

Linear regression analysis models correlated OAT with total equipment power demand. Formulas were developed to estimate chiller and pump electric energy consumption. There was poor correlation between OAT and motor consumption after installation of the variable speed drive, possibly due to limited monitored data and minimal variation during the monitoring period (Swanson 1996, 1997). Table 5 lists the equipment monitored and the R^2.

San Bernardino Valley College. The system evaluated was the EMS installed in the Administration, Chemistry and Library Buildings. Energy monitoring equipment was installed to determine the pre- and post-retrofit energy use of equipment controlled by the EMS. The equipment monitored including chillers, boilers, motors, chilled and condenser water pumps, cooling tower (CT) fan, supply fans and air handlers. Due to the timing of the EMS installation, no post retrofit data for the heating season was available. The local utility provided the OAT data.

Linear regression analysis models correlated OAT with chiller energy use for the buildings and the CT fans. These models help calculate annual energy consumption of the pre- and post-retrofit HVAC systems. Table 5 lists the equipment monitored and the R^2.

Table 5. Equipment Monitored and the Coefficient of Determination (R^2) (Swanson 1996, 1997)

Facility	Equipment Monitored	R^2
Bird Street	• Supply and return fan • Condenser and Compressor • Gas heater • DHW gas water heater • DHW circulating pump	• 0.88 (supply + return fans vs OAT) • 0.86 (compressor vs OAT)
Inter-Community Medical Center	• Chillers (existing + new) • Absorption chiller • Chilled water pumps (existing + new) • Secondary chilled water pumps (VSD) • Heating hot water pumps • Boilers	• 0.50-0.55 (total chiller draw vs OAT) • 0.24 (VSD pump draw vs OAT)
San Bernardino Valley College (Chemistry, Library, Administration Buildings)	• Chillers • Chilled water pump • Condenser water pump • Cooling tower fan • Air handling units • Boilers • Supply fans	• 0.78 (Admin-chiller vs OAT) • 0.71 (Chem-chiller vs OAT) • 0.64 (Library-chiller vs OAT) • 0.72 (CT fans vs OAT)

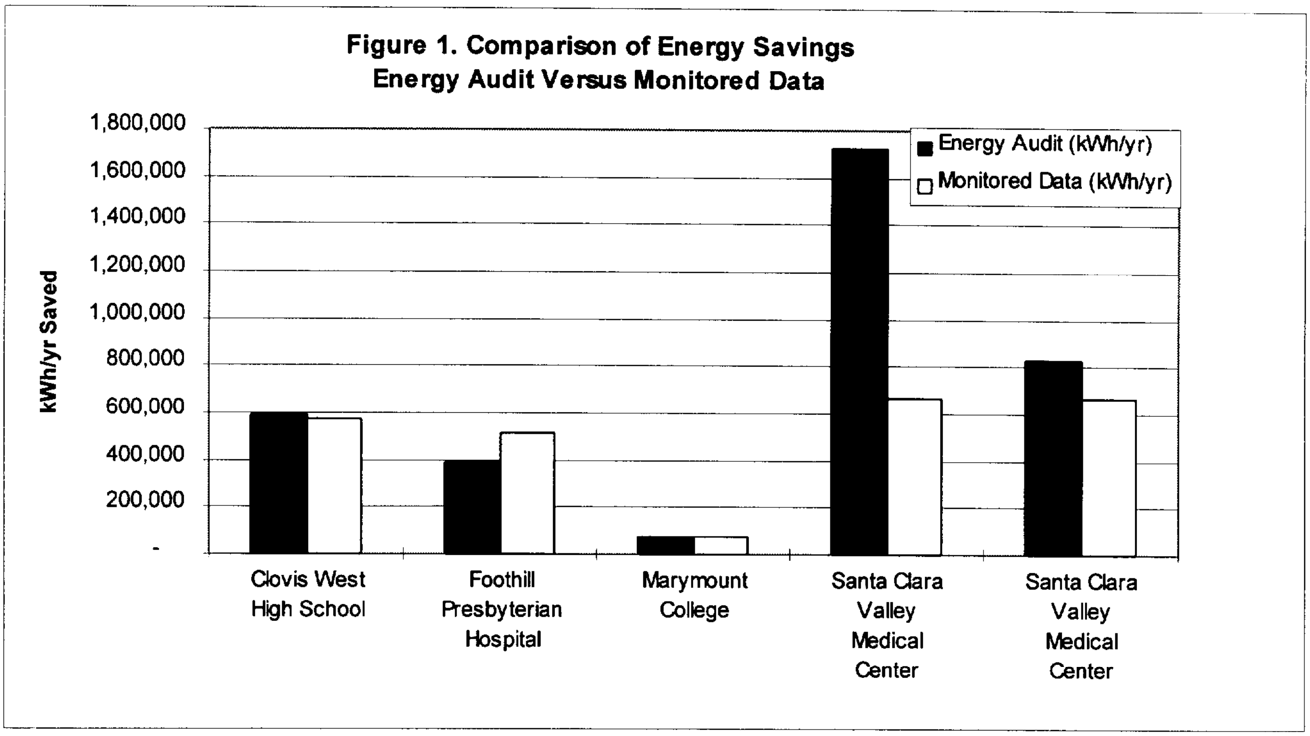
Results

Lighting

Three of the four metered facilities had equal or higher savings than indicated in the energy audit and one had lower savings. The following are the main findings:

- In most cases the pre- and post-retrofit light counts were within 15 percent of the number in the energy audit (Shirilau 1996, 1997).
- Measured wattages for the existing and retrofitted light fixtures were similar to those in the energy audit (Shirilau 1996, 1997).
- Operating hours differed from the energy audit (Shirilau 1996, 1997). Both over- and under-estimation occurred within the same facility.
- Mis-identification of pre-retrofit fixture wattages was the main reason why one facility, Santa Clara Valley Medical Center, had 60 percent less savings than estimated in the energy audit (Shirilau 1996, 1997). The audit had assumed that the light fixtures used 40 watt rather than 34 watt lamps. If the audit correctly identified the fixture wattages, the monitored energy savings would have been within 20 percent of the estimate in the audit.

Figure 1 compares the savings estimated in the energy audit with the monitored data. For Santa Clara Valley Medical Center, the results from the monitored data and the estimated savings with the corrected light fixtures in the energy audit are provided.

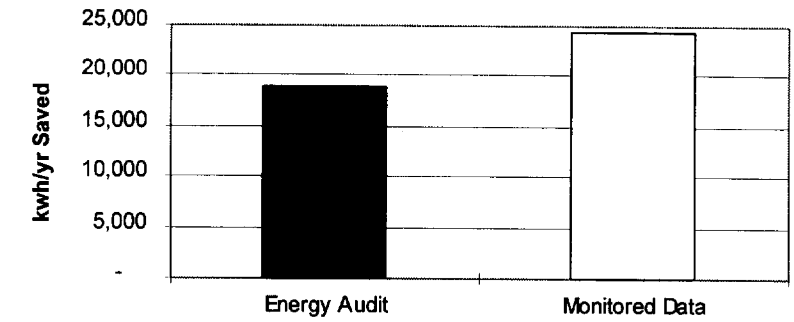


All monitored facilities use less energy now than before the retrofit. Many cited other benefits that were equally important, including, standardization of lamps and ballasts, elimination of polychlorinated biphenyls (PCB) ballasts, improved lighting (more light and color), reduction of maintenance and renovation of fixtures to eliminate electrical hazards (Adams 1998, Goebel 1998, Sayner 1998).

Motor Replacement

Monitored savings for the motor replacement project are higher than predicted in the energy audit due to the motors actually running near 100 percent load instead of at the 75 percent estimated in the energy audit (Shirilau 1996, 1997). These motors were the swimming pool pumps that operated 24 hours per day, year round at nearly constant load. Figure 2 compares the energy savings in the energy audit with the monitored savings.

Figure 2. Comparison of Motor Energy Savings: Energy Audit Versus Monitored Data



Heating, Ventilating and Air Conditioning

All monitored results differed substantially from energy audit estimates of savings. The following is a discussion of the differences by facility:

Bird Street School. Changes in operating schedule reduced the energy savings substantially. This was not due to the EMS but the school's decision to alter equipment operations. The following summarizes the changes:

- The school's HVAC operating schedule changed. The audit indicated that the HVAC equipment operated 12 hours/day. During the pre-retrofit metering period, the HVAC equipment operated 8.5 hours/day due to custodial schedule changes (Swanson 1996, Galloway 1998).
- Though there were no classes in July, the school could not shut down the HVAC equipment because administrative and custodial staff continued to work in the school during this period (Swanson 1996, Galloway 1998).

Foothill Presbyterian Hospital. The audit assumed that the current 60 horsepower air handler was more than needed to meet the hospital's minimum air requirements. Installation of a variable frequency drive would save energy when reduced air flow would be adequate to meet the hospital's requirements. The 60 horsepower air handler provides a maximum of 50,000 cubic feet per minute (CFM) (Goebel 1998). After the energy audit was completed, the hospital added 24 exhaust fans to comply with State ventilation requirements (Goebel 1998). The exhaust fans eliminated any excess air handler capacity and the fan motor had to run at full speed to meet minimum air requirements. This has resulted in no energy savings for the project.

Inter-Community Medical Center. After installation of the new electric chiller, the medical center decided to operate a less efficient absorption chiller as their main chiller believing that this would reduce operating costs (Swanson 1996). This change substantially reduced energy savings. The following summarizes the changes that affected savings:

- The regular operation of the less efficient absorption chiller resulted in a substantial savings penalty, at least $30,000 annually (Abramson 1996, Swanson 1996).
- The energy savings from the chiller and pump replacement projects are less but the metered results may underestimate true savings due to the limited monitoring (Swanson 1997).

San Bernardino Valley College. Changes in site conditions and equipment operations have substantially reduced savings. These changes are not attributed to the EMS. The following summarizes the changes that have affected the energy savings (Swanson 1996, 1997):

- Operating hours of many buildings monitored have increased.
- In one building, newly-installed exhaust fans and evaporative coolers added to the cooling load.
- Regular maintenance on chillers was postponed, pending the purchase of new chillers.
- Lighting retrofits installed during the monitoring period further reduced the monitored energy savings. Reductions in lighting load reduced the cooling load which decreased the savings attributable to the EMS.

Table 6 compares the changes at each monitored facility and their effect on savings. Table 7 compares the energy savings differences between the energy audit and the monitored results.

Table 6. Comparison of Changes that Affected Energy Savings

Changes	Bird Street School	Foothill Presbyterian Hospital	Inter-Community Medical Center	San Bernardino Valley College
Facility Schedule	yes	no	no	yes
Site Conditions	no	no	no	no
Equipment Operations	no	yes	yes	yes
Installation of New Equipment	no	yes	no	yes

Table 7. Comparison of HVAC Energy Savings: Energy Audit versus Monitored Data

Facility	Estimated Energy Savings (Swanson 1996,1997)	
	Energy Audit (kWh/yr)	Monitored Data (kWh/yr)
Bird Street School	34,358	9,489
Foothill Presbyterian Hospital	118,514	-
Inter-Community Medical Center	1,628,000	1,091,000
San Bernardino Valley College	214,612	-

(-) signifies no energy savings.

Due to the baseline condition changes, only one facility, Inter-Community Medical Center is using less energy now than before the retrofit. The other facilities which had controls related projects, had little or no energy savings. If the current operating schedule and equipment changes were considered, the EMS and VFD projects could not have been justified on energy savings. However, these facilities have cited other important benefits that justify the projects, including assistance with maintenance scheduling and HVAC equipment troubleshooting (EMS), minimizing customer complaint calls through improved temperature control (EMS) and improving the power factor on motors (VFD) (Galloway 1998, Goebel 1998, King and Tafolla 1998). These non-energy benefits have helped them improve the operations of their facility.

Monitoring Costs

Monitoring costs can be a substantial part of total project costs. The following table compares monitoring costs to total project costs and the monitored cost savings:

Table 8. Comparison of Monitoring Costs to Project Costs

Project Type	Total Monitoring Costs	Total Project Installation Costs	Total Monitoring + Project Costs	Monitoring/ Total Costs
Lighting + Motor Replacement	$68,170	$943,210	$1,011,380	7%
HVAC	$69,330	$565,410	$634,740	11%
Total	$137,500	$1,508,620	$1,646,120	8%

Conclusions

The results of the metering and evaluation show that projects which are less effected by operating schedule changes, such as lighting and motor replacement projects, will yield energy savings for the facilities. In fact the energy savings may be similar to the energy audit if the engineer's assumptions and baseline characterization of equipment and operating schedule are correct. For projects whose savings are totally dependent on the facility reducing its operating schedule, such as EMS, our evaluation shows that energy savings may not occur.

When operations change, a recalculation of the baseline could be done to determine the "actual" savings. In our evaluation, this was not done due to our limited project budget. Had we readjusted the baseline, the HVAC savings could have been greater. The following are our main conclusions:

- Lighting and motor replacement projects resulted in similar energy savings to the energy audit.
- The EMS and HVAC projects did not realize the predicted energy savings due to operating and facility changes. However, even when facilities did not save energy with their EMS installations, many cited equally important maintenance and scheduling benefits (Galloway 1998, Goebel 1998, King and Tafolla 1998).
- A good energy audit with correct baseline assumptions for equipment and operations ensures that the energy savings will likely be achieved if site conditions and operations do not change. At Santa Clara Valley Medical Center, the auditor incorrectly identified 34 watt lamps as 40 watts. This resulted in a 60 percent reduction in savings (Shirlau 1997).

- To optimize equipment operations, follow-up monitoring and evaluation on HVAC energy efficiency projects has real value even if the facility has no complaints about the installation. At Inter-Community Medical Center, the facility manager thought that operating the existing absorption chiller in lieu of the high efficiency electric chiller would save money. When this change was discovered during metering, the facility manager changed his operating strategy (Gifford and King 1997). Had we not metered the facility, the medical center would have paid $30,000 more for cooling costs annually (Abramson 1997, Swanson 1997).
- With the potential of decreased electric rates in the future, it may be prudent for auditors to assume lower future rates. Of the eight facilities monitored, five have already or will be purchasing electricity at rates lower than was indicated in the energy audit. As the rate affects the dollar savings and project economics, it is important for auditors to be sensitive to potential rate changes.
- As the expense of metering and evaluating projects is high, it appears to be most justified on projects with many operating assumptions and uncertainties, such as HVAC equipment and EMS, and less on lighting and motor replacement projects.
- The lighting and HVAC technology did not affect energy savings. Changes in equipment and facility operations, or adding energy loads all negatively affected the energy savings.
- Auditors cannot be responsible for unmet energy savings when facility operation changes or does not follow project recommendations. Facilities need to be informed of the consequences of changing equipment operations and its affect on savings. This will be important as future utility incentive programs for energy efficiency focus on measured energy savings.

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