Commissioning the ACT² Project Pilot Demonstration

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A major California utility has initiated a demonstration project to test the hypothesis that substantial energy efficiency improvements can be achieved in customer facilities at costs competitive with supply. This paper describes the commissioning process for the pilot demonstration site in San Ramon, California and how energy and system monitoring was used to re-commission the various energy efficiency measures installed.

The specific objective of the Advanced Customer Technology Test (ACT²) for Maximum Energy Efficiency project is to provide scientific field test information, for use by the utility and its customers, on the maximum energy savings possible, at or below projected competitive costs, by using modern high-efficiency end-use technologies in integrated packages acceptable to the customer.

The utility chose a "Learn by Doing" approach in the development of the project design, technology design methods, and measurement and monitoring techniques. The project planning was done in parallel to a "pilot demonstration", with the hope that our planning would be responsive to lessons learned in pilot demonstration.

A design to maximize energy efficiency at the pilot demonstration site was installed during the summer of 1992, and commissioned in early fall 1992. A detailed commissioning plan was written by the system designers prior to the start of construction and was provided to installation contractors as part of the bid specifications.

The paper describes the initial commissioning process, the first year's energy consumption results, and how the end use monitoring system enhanced the project's ability to re-commission the energy efficiency measures.

Introduction

The ACT² project is a field test of the hypothesis that high energy savings can be achieved in homes and businesses at costs lower than new energy supply. The strategy of ACT² is to design, install, monitor and evaluate optimized, integrated packages of modern energy-saving technologies in a cross-section of residential and commercial buildings and industrial and agricultural sites, in PG&E's service territory (SBW 1992).

This research and development project consists of demand-side demonstrations to measure actual economic and technical performance of the packages, and to determine adverse or beneficial effects on the user. In addition, the project also measured site environmental quality parameters before and after the energy efficiency improvements.

When evaluating the economics of the Energy Efficiency Measures (EEMs), the costs of the EEMs in a customer's home or business are analyzed equivalently to power plant construction costs, using utility discount rates and life-cycle costing. This allows a fair comparison of demand-side and supply-side project investments. Since some of the candidate EEMs are emerging technologies, estimated mature market costs (rather than current market costs) are used in the economic evaluation. This approach is quite different from that used in the utility's traditional energy efficiency programs.

ACT² is a "proof-of-concept" research and development project to determine the cost-competitive potential for maximum energy efficiency. Further, ACT² will demonstrate how high levels of energy efficiency can be achieved, measured and evaluated. The ACT² project is not designed to determine market potential nor penetration of specific technologies. Because maximum energy efficiency relies on all components working properly and many of the ACT² advanced technologies are being combined in new and creative ways, commissioning becomes of utmost importance.

Implementation

Because of the unique nature of this project, there was little design and monitoring precedent to guide project planning and development. The utility chose to develop the project plan in conjunction with a pilot demonstration. This "learn by doing" approach allowed the ACT^2 staff to use the Pilot Project experience to identify the details and complications involved in the planning and budgeting of field demonstrations at customer facilities. This demonstration also tested the commissioning plan procedures under close supervision of the appropriate designers to evaluate their effectiveness. The lessons learned from the Pilot Project have been incorporated into the commissioning plans for the remaining ACT^2 sites.

The Pilot Building Description

The pilot demonstration is a 22,000-ft^2 (2,050-m^2) portion of the 140,000-ft^2 (13,050-m^2) Sunset Building in San Ramon, California. It is occupied by the utility's R&D department (Figure 1). The site was chosen because it is typical of many low-rise office buildings in California. Additionally, the ACT^2 project team occupied offices in the test area which allowed the team to experience first-hand the daily problems and successes of installing the new technologies. This section of the building was selected because it was relatively isolated, thermally and electrically, from the rest of the building. The original building audit indicated that it is served by its own electrical subpanels and HVAC systems. Choosing only part of the building as the pilot site reduced the project costs, but presented unique building energy simulation modeling and design challenges. These challenges included adjusting the simulation model for the thermal interactions between common walls and ceilings and the elimination of roof/ceiling daylighting opportunities. Since the purpose of the pilot site was to learn how to do an ACT^2 demonstration, these shortcomings were considered acceptable.

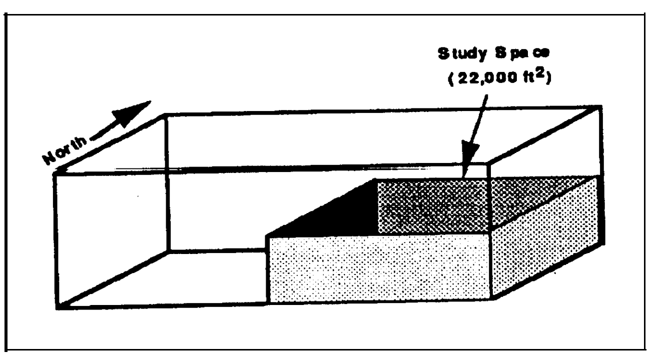

Figure 1. Pilot Demonstration Site

Pre-Retrofit Monitoring

In order to achieve the project's mission, three different categories of information, or data, needed to be collected. These three categories are energy use, customer satisfaction, and cost. The effect of commissioning on building performance can be measured by the first two categories, energy use and customer satisfaction. Cost data is used to determine the economic viability of commissioning.

Collecting energy use data is relatively simple yet costly. Electrical and gas data (consumption and demand) was collected at the circuit breaker or device level for one full year prior to the retrofit in order to develop an energy usage baseline. Two years of post-retrofit data is being collected for analysis purposes. Customer satisfaction data included measurable variables such as power quality, indoor air quality, radon, as well as subjective variables such as occupant opinion. Cost data is documented as the actual cost charged by the contractor(s) performing the commissioning.

Determining the energy savings and the environmental impacts attributable to each Energy Efficiency Measure (EEM), when multiple measures were installed simultaneously, required a comprehensive monitoring system. Energy use and site environmental conditions had to be measured at a higher level of detail and accuracy than most studies performed in the past. Measurements taken at the Sunset building are shown in Table 1.

These measurements were used by the designers to prepare the basecase simulation model and the retrofit designs. They also will be used by the impact evaluation team to analyze the results of the retrofit. All measurements met current industry standards (see bibliography for the standards used), and no pre-retrofit site environmental conditions problems were identified (Brohard 1992).

Energy use profiles were as expected, with a typical summer air-conditioning dominated energy use pattern. On an annual basis, the electrical energy use was 51% HVAC, 28% lighting and 21% plug loads/miscellaneous. Gas usage was predominately space heating with a small fraction for domestic water heating.

The Pilot Building Design

The final design for the pilot demonstration site retrofitted only three areas: building envelope, lighting and HVAC. A fourth area, office equipment, was addressed and was determined to be cost-effective, but the large number of computers at the site made the cost of replacing them

Table 1. Pre-Retrofit Measurements for the Pilot Demonstration Site

Type	Frequency	Duration
Electrical use/demand, circuit breaker level	Half-hourly	One year
Gas use, appliance level	Half-hourly	One year
Weather/solar	Once per second	Continuously
Electrical use, device level	Five minutes	One week
Indoor air temperature, 11 locations	Half-hourly avg.	One year
Indoor/outdoor RH	Half-hourly avg.	Continuously
Light levels, flicker, glare	One-time	
Power quality	8 hours	One-time
Acoustic noise	8 hours	One-time
Indoor air quality	8 hours	One-time
Radon	Continuously	Six months
HVAC efficiency	One minute	Four months
Ventilation efficiency & infiltration	One-time	Two weeks
Occupant thermal comfort	Daily	Two weeks

prohibitive. Inclusion of the estimated energy savings due to this EEM, projects a total reduction in energy usage in excess of 60% of the base case energy usage.

Building Envelope

Glazing system retrofits are particularly expensive with building owner's appearance constraints limiting the designer's options. Reduction in the building's energy use, due to lighting and HVAC EEMs, also reduces the savings potential for efficient glazing systems. In San Ramon's mild climate, wholesale retrofit of the glazing with a lower U-value glazing can actually increase energy consumption. Improving the glazing reduces the amount of internally generated heat lost through the glazing at night, in early morning and on mild days, resulting in increased A/C use to reject the heat. The final design only called for replacement of the glazing (retaining existing frames) on the south side of the building. Although the energy savings due to the improved thermal performance alone would not have justified the EEM, the coincident downsizing of the A/C compressors provided the additional economic justification necessary for approval. The new glazing is dual-pane, argon-filled, spectrally selective, low-emissivity glass. The glass is blue-green in color. The windows had occupant controlled mini-blinds which remained in place.

Lighting

The building owner required that the ceiling lighting system be capable of maintaining a uniform level of 30 foot-candles throughout the space (leasing considerations). This constraint reduced the ceiling mounted/furniture mounted lighting fixture options.

The final design included energy efficient overhead lighting, task lighting, and controls. The existing two-ballast, 4 - lamp, T-12 overhead lighting fixtures were retrofitted with 2 T-8 fluorescent lamps, one dimmable electronic ballast, and a specular silver reflector. Occupancy sensors were installed throughout the space (open areas as well as private offices). Perimeter lighting circuits are also dimmed with photocells to utilize natural daylight. Additionally, lumen maintenance (manually tuned by dimmers) is incorporated in both the private offices and open areas.

The existing task lights were standard, single lamp four-foot fluorescent fixtures mounted under the shelf above each work surface. These fixtures were replaced with two 13-Watt compact fluorescent fixtures with asymmetric reflectors. These task lights are manually controlled by the occupant.

HVAC System

The most dramatic energy savings came from retrofitting the air-conditioning system. The existing system consisted of three, constant volume, packaged DX air-conditioning units, supplying cool air to multiple VAV boxes with a ceiling plenum return. Static pressure control was accomplished by bypassing supply air to the return duct at the unit. The space was heated with three forced air furnaces ducted to the perimeter of the building.

These three units were replaced with two indirect evaporative low air-velocity, high coolant velocity, variable speed air handlers and a central variable speed chiller system. The new air handling units incorporate three integrated stages of cooling. The first stage is economizer, the second stage is variable speed, double-indirect evaporative cooling, and the third stage is chilled water boost provided by the central chiller. Each cooling coil is 4-row with extra wide fin spacing designed for low air velocity. All motors are high-efficiency units with variable speed controls. The chiller system consists of two, 17 ton, variable speed, reciprocating compressors, a variable speed chilled water pump, an oversized barrel, and an evaporative variable speed condenser. All existing pneumatic variable-air-volume (VAV) boxes were retro-fitted to direct digital control (DDC).

The existing forced air furnaces were not retrofitted but were connected to the DDC system for control operation.

Projected Energy Savings

The projected energy savings shown in Table 2 are for the envelope, lighting and HVAC systems EEMs. If the estimated energy savings for the office equipment EEMs were included, the analysis projected an additional 18% reduction in electrical usage. Energy saving estimates were performed using the DOE-2 building energy simulation model.

It should be noted that the ASHRAE guidelines for building comfort conditions were not consistently maintained during the pre-retrofit period. Normalizing the building simulation model to reflect ASHRAE conditions would have increased the base case energy consumption and resulted in additional energy savings. Using the ASHRAE conditions normalized base case model projected total reductions of 69% electric consumption, 63% demand and 79% gas reduction not including the potential savings from improved office equipment.

Commissioning the Building Systems

Since the ACT^2 commissioning guidelines had not been completed, the pilot project design firm was requested to develop a commissioning plan for the integrated package of systems and components to be installed in the building. The three parts of their commissioning plan were; sensor calibrations, static installation observations and tests, and functional performance tests.

Proper commissioning of the DDC system is critical since its main function is to integrate the various mechanical system components. Commissioning the DDC system first would simplify the startup and testing of the individual components. However, the effort and skill required for the commissioning of the DDC system was severely underestimated by the design firm and was still not complete after the first full year of system operation. Therefore, the actual energy consumption did not meet the projected energy consumption targets. The system is currently being recommissioned by the HVAC contractor.

System Commissioning Procedures

As part of the commissioning process, various hand held instruments were tested and calibrated prior to the actual field work. This would insure that at least one potential source of error was minimized. The key commissioning procedures are summarized below.

Table 2. Projected Energy Savings for the Pilot Demonstration

	Base Case Model	Final Design	Approximate Savings (%)
Annual electric use:	338,400 kWh	119,600 kWh	65
Peak electric demand:	135 kW	53 kW	61
Annual gas use:	289 MBtu	241 MBtu	17
BTU per sq. foot:	74,500	33,500	-

Air Distribution System Commissioning.

1. Test, adjust, and record each fan's speed to achieve design cubic-feet-per-minute (CFM) airflow requirements.
2. Measure and record motor current and voltage for each fan at maximum and minimum speeds.
3. Perform a pitot-tube traverse of the main supply and return ducts to obtain total CFM.
4. Measure and record evaporative cooling fan CFM.
5. Test and adjust system minimum outside air by pitot-tube traverse.
6. Test and record system static pressures, including suction and discharge static pressure of each fan.
7. Take wet and dry bulb air temperatures on the entering and exiting side of each cooling coil and evaporative-cooling section.
8. Test and record water-flow rate through each direct and indirect evaporative-cooling section.
9. Measure and record total-flow rate of each evaporative-cooling pump.
10. Measure and record the amps and volts of each evaporative-cooling pump.
11. Adjust main ducts, zone ducts, and branch ducts to within CFM design requirements. Traverse main ducts for total CFM requirements.
12. Test and balance each diffuser, grille, and register to within 10% of design requirements.
13. Identify the location of each grille, diffuser, register, and terminal box. This information shall be recorded on air-outlet data sheets.
14. Set volume regulators on all terminal boxes to meet the design maximum and minimum CFM requirements. All outlets connected to the terminal box shall be read out in the maximum and minimum CFM modes and their readings recorded on the air-outlet data sheets.
15. Perform duct-leakage tests in accordance with the mechanical specifications.

Chilled Water System Commissioning.

1. Adjust chilled water pump to meet design water flow rate through the chiller.
2. Measure and record motor current and voltage.
3. Adjust circuit setters on each chilled water coil to within 10% of design flow rate.
4. Adjust and record position of chilled water bypass valve to maintain required minimum flow rate through the chiller when the chilled water coils are shut down.
5. Measure and record flow rate through the chiller at maximum and minimum flows.

Chiller Commissioning.

1. Measure and record chiller capacity at maximum and minimum speeds.
2. Measure and record chiller amps and voltage at maximum and minimum speeds.
3. Measure and record the chiller suction and discharge pressure at design and minimum chilled water flow rates.
4. Complete compressor test report at full load with design chilled water flow, and minimum load with minimum chilled water flow.

Evaporative Condenser Commissioning.

1. Test and adjust chemical-control system and bleedoff flow rate to maintain total dissolved solids, and chemical concentrations at manufacturer's recommended levels.
2. Measure and record fan CFM, amps, and volts at maximum and minimum fan speeds.
3. Measure and record pump motor amps and volts.

Direct Digital Control System Commissioning.

1. Initialize all output points (valves, dampers, speed controls, etc.). This will ensure that the balancing personnel can manually set each controlled device for commissioning purposes.
2. Calibrate all DDC points to ensure that the value of each equals the actual measured value.
3. Calibrate temperature sensors according to Mechanical Specification Section.
4. Install software and source code and calibrate to control all points as described in the Mechanical Specification Section.

Lighting System Commissioning.

1. Operate all T-8 lamps at 100% output for 100 hours before dimming.
2. Replace any ballasts that have failed or become noisy in the first 30 days of operation.
3. Calibrate each ambient light sensor for 30 foot-candles (fc) at night following manufacturer's directions.
4. Measure light levels at all primary task surfaces. If the average light level at any primary task surface is below 30 fc, adjust the control until the average light level is at 30 fc. This procedure must be performed at night so that ambient light does not affect the measurement.

Occupancy Sensor Commissioning.

1. Set the time delay to the minimum setting.
2. Set the sensitivity at the maximum.
3. Create motion outside the room.
4. If the lights go on, lower the sensitivity setting and repeat until the lights stay off.
5. Create small motions in the room and check that the LED indicator light on the sensor comes on.
6. If occupants will often have their backs to the sensor while working, set the time delay for 12 minutes. In other cases, set the delay for 7 minutes.
7. If it is not possible to find a setting that will prevent both false ons and offs, it will be necessary to relocate the sensor, add a sensor or replace the sensor with another type (such as replacing an ultrasonic sensor with a dual-technology sensor).
8. Revisit the room after one week of normal use and interview occupants to identify problems. Readjust as necessary.
9. Complete the "Occupancy Sensor Report" for each sensor.
10. In open areas, set the sensitivity to the maximum and set the time delay to 12 minutes.

Photometric Survey. After daylighting and tuning controls have been adjusted, take light level readings at night at all workstations and complete the "Photometric Survey Report".

Final Acceptance. At the time of final inspection, the balancing agency shall recheck, in the presence of the design firm's personnel, specific and random selections of data recorded in the test and balance report, using the same measurements and procedures used during the original test and balance. If random tests demonstrate a measured deviation of 10% or more from that recorded in the test and balance report, the report shall be automatically rejected. In the event the report is rejected, all systems shall be readjusted and tested, new data recorded, a new test and balance report submitted, and an new inspection test made, all at the contractor's expense.

System Commissioning Results

This building was extremely successful as a 'pilot' test site. This includes incorporating the commissioning lessons learned into the ACT^2 Project Plan Commissioning Guidelines (discussed later in this paper). But, it is not always easy to determine where 'commissioning' ends and system 'tuning' begins. This is particularly true for HVAC systems which, by necessity, can only be commissioned during the heating or cooling seasons. Adjustments made later could either be termed 'recommissioning' or simply 'tuning'.

How Long Did It Take. The designer's commissioning plan estimated four weeks to fully commission the site. It also planned for some minor 'tuning' during the first year.

Many of the functional tests were completed within the estimated four weeks. However, large numbers of the occupancy sensors had to be relocated because they were installed too close to supply air diffusers, causing false 'on' signals. Lamp and ballast failures occurred regularly. HVAC system control problems could not be eliminated. The HVAC system off-hours override did not operate reliably.

When the scheduled commissioning period had ended, the contractors wished to be paid. To that end, any unresolved problems were called 'first year tuning' issues so that the commissioning period could be terminated. Unfortunately, most of the DDC software problems were not tuning issues and are still not corrected. The ACT^2 project staff has initiated a recommissioning program to resolve the persistent lighting and HVAC system problems. It is anticipated that after the building is properly commissioned, the actual energy consumption will match the predicted values.

Who Did What. The commissioning plan was prepared by the design firm to ensure that HVAC and lighting system's operation satisfied their design specifications. The design firm then acted as the 'prime' contractor, hiring the general contractor to install the equipment and commission it. In this regard, the design firm also acted as the owner's representative. The general contractor installed the equipment and performed the static installation checks under the observation of the prime contractor. Subcontractors performed the start-up and fictional tests of the equipment and systems. Spot verification checks were performed with the owner participating in the observations to accelerate the approval of invoices for the installation and tuning tasks.

Lighting System Findings. During the commissioning process, about one-third of the occupancy sensors were adjusted for sensitivity and all the ballasts were adjusted to the specified light levels (dimmed). The daylighting function (automatic dimming of perimeter light fixtures) was extremely difficult to adjust. Although it was obvious the lights were dimming automatically, the designer could not verify that the system was operating correctly (maintaining light level setpoint). An unusually high lamp and ballast failure rate was noted without a plausible explanation for the failures. Many of the occupancy sensors were relocated away from the supply air diffusers causing false 'on' signals. After a year of trying to adjust two occupancy sensors, a service technician found that the sensors were not connected to the light fixture. It was never determined if the sensors had been disconnected or were never connected.

Due to the many problems associated with the lighting system controls, the projected energy reductions have not been achieved. It has been estimated that reconfiguring the occupancy sensor control system could save an additional 21,000 kWh/year savings (approximately 6% of the total site energy use).

In an effort to confirm these estimated savings, the open work area in one-half of the test space was reconfigured to optimize the use of occupancy sensors in mid November 1993. Since the monitoring system collects energy use data for each half of the building, the before and after energy profiles could be compared. Figure 2 illustrates the reduction in lighting energy use after the recommissioning of the occupancy sensors. This information, combined with modeling estimates were used to generate the estimate of additional savings stated above.

Findings: HVAC. During the commissioning process, various start-up, test, and balance tasks were monitored. These task included, but were not limited to, VAV box airflow adjustments, chilled water maximum flow rate adjustment, cooling supply fan maximum speed adjustment, plumbing leak repairs and non-functional equipment replacement. HVAC equipment check-out and start-up proceeded as expected, with the normal number of problems associated with new equipment installation.

However, the DDC system evolved into the Achilles heel of the project. The design team did not fully understand the relationship between control system complexity and the programming/de-bugging effort requirement. Not enough time was allocated to de-bug the software or formulate a procedure to exercise the system. Therefore as the numerous bugs surfaced, both with firmware and control algorithms, the time required to track down and correct the problems became enormous. This is a very common phenomenon for control systems that are not

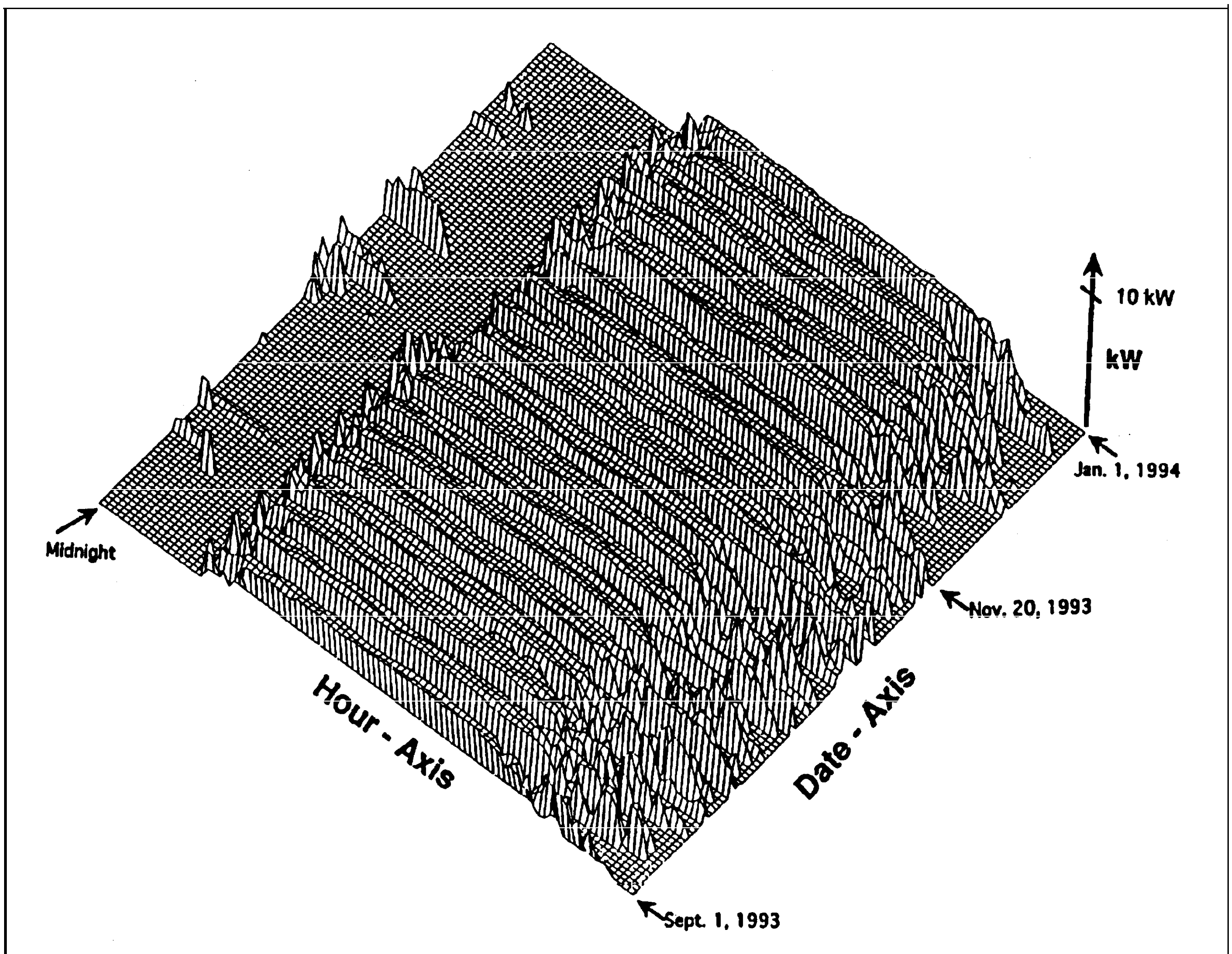

Figure 2. Occupancy Sensor Recommissioning Results

properly de-bugged, or commissioned, before being placed in full operation. Trying to tune or adjust a mechanical system with an unstable control system makes troubleshooting problems nearly impossible. In many instances, symptoms were corrected without repairing the root cause, allowing the symptom (or a similar one) to resurface later. An example is the off-hours override system. The user interface screen would indicate an override and remain ‘locked’ in that mode. The controls firm would reset the system, only for the symptom to reappear again and again.

After the initial 4-week commissioning period, a number of hardware problems were experienced, such as motor bum outs and VAV box controller failures. The motor bum outs were confined to the evaporative cooling fans which are powered by a VSD. The motor failures were caused by a combination of manufacturing defects (missing the arc shields) and improper wiring techniques (excessively long wire length between the VSD and motor). Replacement of the motors and installation of load line reactors resolved the problems satisfactorily. A good commissioning plan would have caught the line length problem, but short of disassembling the motors, no inspection would have caught the motor shortcoming.

The DDC system bugs prevented full optimizing and implementation of a majority of the energy related algorithms (i.e. the evaporative variable-speed fans only operated at 100% speed, the optimum start feature is disabled). These problems resulted in building comfort issues and prevented realization of the projected energy reductions. The DDC system recommissioning effort is currently underway and it is estimated that the recommissioning could result at least in an additional 20,000 kWh/year savings (6% of total site energy use). This estimate is based on the known system problems, the energy savings projected by the designers, and the performance of the system to date.

Findings: General. The pilot site demonstration highlighted four areas of concern when implementing a commissioning process. These four areas are 1) equipment intentionally not installed according to specifications, 2) equipment unintentionally not installed according to the specifications, 3) equipment failures, and 4) unanticipated problems.

For this site, the prime and general contractor did an excellent job in insuring that there was no intentional installation errors. An example of an intentional installation error would be sheetmetal workers fabricating ductwork on the site as they think it should be fabricated, rather than as shown on the plans. If questioned about the error, the worker would typically answer ‘ I’ve never done it that way before, so the plans must be wrong’.

There were, however, several instances of unintentional installation errors. An example this type of error would be the location of the occupancy sensors next to the supply air diffusers. The occupancy sensor plans did not show the diffuser locations. The electrical contractor, not fully understanding how the ultrasonic occupancy sensors functioned, installed them precisely as shown on the plans, regardless of diffuser locations.

Equipment failures can not be prevented, but should be anticipated and addressed in the commissioning plan. Unanticipated effects are just as they are named, unanticipated. An unanticipated effect can be anything at all, such as sudden changes in building occupancy or hours part way through the retrofit. Although there is no method for addressing unanticipated effects prior to the fact, the commissioning ‘agent’ should be cognizant of their possibility.

An important general finding is that even if the as-designed equipment is correctly installed and commissioned, the actual energy use may not match the predicted value. This will occur when the building system component(s) is not capable of performing as designed. An example of this finding is the occupancy sensor design for the pilot project. The occupancy sensor system, installed in the open work areas of the building, was not capable of controlling the lighting systems as intended by the designer. It is important to understand that commissioning in and of itself can not insure design intent satisfaction. Proper commissioning can only insure that building systems operate as designed.

Using Monitored Energy Data to Improve Commissioning

A major obstacle encountered while trying to fully commission the HVAC EEMs was the DDC system not being completed or de-bugged at the start of the EEM commissioning task. Unfortunately, since the building was occupied, the HVAC system had to be in operation while the DDC system was completed. This virtually eliminated the use of the DDC system for commissioning tasks. Although there was an end-use metering system in place when the EEMs were installed, most of the monitoring points were aggregated up to system level measurements. Circuit and component level energy monitoring would have enhanced and accelerated the commissioning process.

The energy monitoring plan called for new sensors to be installed during the installation of the EEMs with data collection occurring during the commissioning process. For several reasons, this did not occur. The data collection contractor did not have staff available to install the sensors during when the EEMs were being installed. As a monitoring data available for the commissioning task.

If circuit breaker level energy data had been available, profiles of actual energy use could have been compared to the expected profiles of the HVAC energy use. Any differences could have focused the commissioning effort by quickly identifying problem areas. Comparing analog data from the monitoring system to the DDC system could have located malfunctioning sensors, VAV controllers, and unstable control sequences. The lighting control system commissioning process would have also benefited from the end use metering, by quickly highlighting unexpected load shapes. It would have been obvious that the lights were staying on longer than predicted. Data visualization is invaluable when checking the operation of a building or a data collection system.

For example, when the monitoring system was fully operational again, the data showed a large spike of electrical energy use for the cooling system supply fans every morning from approximately seven to nine A.M. Upon questioning the responsible contractor, they reported that they had altered the DDC program to run the fans at full speed in the morning due to complaints of low space temperature. They thought that the perimeter heat could be distributed throughout the space in this new 'warm-up' mode. However, since the furnaces were not retrofitted, and they were not capable of operating in this fashion (size considerations), the problem was compounded. Rather than improving the space conditions, they were further compromised, but with increased energy consumption. The solution accidentally surfaced when a power failure disrupted the DDC system's clock and the cooling supply fans started later in the day with a resulting space temperature improvement. The monitoring system allowed the designers to assist in the solution of the problem.

From the lessons learned at the pilot site, the ACT² Project Commissioning Guidelines were modified to insure that the follow-on demonstration sites would not be subjected to many of the same problems.

ACT² Commissioning Guidelines

Using the lessons learned from the pilot site and incorporating information from other published commissioning guidelines, the project team developed the ACT²'s Installation Commissioning Plan Guideline. The guideline requires the commissioning plan to describe the 'design intent' for each Energy Efficiency Measure (EEM) and to identify the measurements necessary to quantify the EEM performance. The commissioning plan enumerates the tests that must be performed to determine whether the EEMs are properly installed and operating correctly. Even this plan, however, does not address whether the design was proper. ACT² believes that a separate design review process should address the 'design intent' issue, and that the commissioning plan and process should not include this task.

The four parts of the ACT² commissioning guideline are:

1. Static Installation Test Plan. The inspections and tests that must be performed to ensure that each EEM is implemented in accordance with the final design construction drawings and specifications.
2. Functional Performance Test Plan. The dynamic tests of EEMs, under various operating conditions, which are to be performed at the site. These tests will be performed for components, subsystems, systems and groups of interrelated systems in that order. The tests are intended to ensure optimal performance of each individual EEM and the package of EEMs implemented at a site.
3. Site Environmental Quality Test Plan. The inspections and tests that will be performed by the Site Environmental Quality team to determine if the EEMs conform to the environmental design criteria established during preliminary design.
4. Recommissioning Test Plan. The dynamic tests that will be performed periodically throughout the ACT² operation period to ensure that the EEMs continue to operate properly.

The static installation test plan guidelines address the issue of whether the equipment as installed meets design specifications. It consists of procedures and customized forms for each EEM, designed to answer the following questions:

1. What equipment is required by the design?
2. Is the required equipment in place?
3. How must the equipment be installed for it to work properly?
4. Is the equipment installed properly?

The forms include a summary of the results, general comments, name of the person completing the form, and the date of completion.

The functional performance test plan is used to determine if the equipment required by the design is operating properly. This plan addresses the following areas:

1. Design - Does the system satisfy the design requirement?
2. Hardware - Is the correct hardware installed and is it installed properly?
3. Calibration - Are the control sensors, controllers, etc. properly calibrated?

4. Setpoints - Can the system achieve the designed setpoints?
5. Control Sequence - Do the correct control actions occur in response to the correct stimuli?

This plan recommends a hierarchical testing approach, checking each component of a system before commissioning the system. This should reduce the time required to fully commission a building, since by the time you reach the system level test, all of the individual problems should be resolved. The recommended hierarchy is:

1. System Components (e.g. damper motors, sensors, etc.)
2. System Equipment (e.g. rooftop units, chillers, etc.)
3. Complete Systems (e.g. chilled water system)
4. System Interaction (e.g. chilled water system and waterside economizers, lighting sweep and daylighting control, etc.)

The plan should include the following items:

1. Instructions for test instrumentation
2. General instructions regarding test units, test personnel, tenants to be notified, test schedule, etc.
3. Date, time and person performing each test
4. Outdoor dry bulb temperature during the test
5. Description of the component to be tested and the relevant sequence of operation
6. Cautions to the tester
7. Test plan
8. Instructions regarding final setpoint and schedule settings
9. Space for description of field-required changes and results

The site environmental quality test plan is specific to the ACT^2 project. These are tests designed to ensure that the ACT^2 process does not degrade the site environmental quality at the site (or create a condition where any environmental parameters exceed the accepted standards). However, measurements such as carbon dioxide concentrations could be used to verify proper air distribution and dust concentrations as a check for air filter effectiveness.

The recommissioning test plan is required because commissioning is not a one-time activity. Even comprehensive operations and maintenance attention will not guarantee continuous proper functional performance. This is particularly true if the original commissioning was a one-time activity after construction. As pointed out in the Sunset building, it is necessary to observe the system operation under different weather conditions and times to truly commission it. The recommissioning test plan should address all the points listed above under commissioning plan.

Conclusions

The Advanced Customer Technology Test (ACT^2) for Maximum Energy Efficiency project has pointed out the value of building commissioning. It has also shown there is a need for further research as well as practical experience with building commissioning. The major area requiring more work is in functional testing; how, who, and cost. The project has highlighted the fact that the current industry commissioning practices are woefully inadequate at best and in most cases does not occur.

The project has also shown there needs to be a very strong emphasis on commissioning, or design review, during the design phase of any project. Commissioning in and of itself can not fix a poor design. Commissioning is not a one-time task, it should start during the design phase and continue through the first year of operation at a minimum.

The pilot project highlighted the need for equipment performance measurements to provide feedback during the commissioning process. This feedback must not only consist of energy consumption measurements, but should include analog data (temperature, flow, pressure, etc...) so that relational checks (COP vs. outside air temperature, Compressor kW vs. outside air temperature, etc...) can be assessed.

Lastly, designs must incorporate the ability to commission. In most instances, the installed equipment does not provide for process measurements, such as thermal wells, Pete's plugs, or straight sections in the supply/return ducts to accurately measure air flow. There must be consideration given during the design phase to the commissioning process.

The ACT^2 project has provided a valuable demonstration of the necessity, and shortcomings, of building commissioning.

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