ACT^2 Pilot Project: Results to Date from the Pilot Demonstration Building

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A major California utility company is conducting an Advanced Customer Technology Test for Maximum Energy Efficiency (ACT^2 for Maximum Energy Efficiency) project to test the hypothesis that substantial energy savings (perhaps as high as 75% over current practice) can be achieved in buildings, and industrial and agricultural processes, at costs competitive with supply through the use of modern energy-efficient end-use technologies and systems.

The first ACT^2 demonstration project used a "learn-by-doing" approach in an existing office building. Construction was scheduled to be completed in August, 1992. The lessons learned from this pilot site were used to assist in preparing the project plan for follow-on demonstrations. This paper presents the design approach taken by the design firm, the energy efficiency measures (EEMs) selected, the estimated energy savings achieved, and the lessons learned from this pilot demonstration site which are applicable to follow-on demonstration sites.

Introduction

Project Description

The ACT^2 project is a field test of the hypothesis, proposed by many energy-efficiency advocates, that high energy savings can be achieved in homes and businesses at costs lower than new energy supply. The strategy is to design, install, monitor and evaluate optimized, integrated packages of modern energy-saving technologies in a cross section of residential and commercial buildings, as well as in industrial and agricultural sites, in the utility's service territory (PG&E 1990).

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, impacts on the site environmental quality are monitored. Major tasks for each demonstration include (SBW 1991):

Site investigation, prioritization and selection;
Contracting with participants;
Pre-monitoring and baseline modeling;
Design, purchase, installation and commissioning of a maximum energy efficiency package;
Operation by the utility and then the owner/tenant;
Post-monitoring, analysis, reporting, and
Possibly decommissioning.

To determine economic competitiveness, the investment in energy efficiency measures in a customer's home or business will be treated as if it were a power plant, i.e., utility discount rates and life-cycle costing will be used. By this treatment, the decision to make an investment in demand-side measures is made on the same basis as for a supply-side investment, and the unit costs of both options then can be compared fairly. Since many of the candidate energy efficiency measures are just emerging, estimated mature market costs, rather than current market costs will be used to more realistically reflect each EEMs' competitiveness. This approach is quite different from that used in the utility's traditional energy efficiency programs.

Rationale

Currently, to achieve its objectives of meeting significant amounts of future load growth with customer energy efficiency (CEE), the utility relies primarily on single component energy efficiency measures (EEMs). Sometime after the mid- 1990s, a more complex approach will be needed to continue effective CEE contributions. Utility-funded integrated packages of energy saving end-use technologies at customer sites may be the preferred approach to achieve additional customer energy efficiency.

Energy and environmental experts predict that technologies like high-efficiency lighting, adjustable-speed-drive motors, and selective coatings on window glazing, can produce substantial (perhaps as high as 75%) energy savings at costs less than supply. This requires that all cost-effective opportunities for savings be included no matter how small, and to take advantage of synergistic effects among technologies in an integrated package. Projections of energy savings of this magnitude have been verified only in part, usually based on individual EEM performance. Scientifically valid field tests of energy efficiency packages, integrated for maximum energy efficiency, have not yet been conducted. ACT^2 is a "proof-of-concept" research and development project to determine the cost-competitive potential for maximum energy efficiency. Further, ACT^2 will demonstrate how it can be achieved, measured and evaluated. The ACT^2 project is not designed to determine market potential nor penetration of specific technologies.

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 conducting a pilot demonstration. This "learn by doing" approach for ACT^2 avoids trying to foresee all the details before launching a number of demonstrations in customer facilities. Given the uncertainty this project faces in design and monitoring, there is considerable risk of spending money unwisely. A pilot demonstration, in addition to minimizing that risk, allows some hardware to be put into the field early under tightly-controlled circumstances, and improves the chances that the follow-on demonstrations will have some experience to draw on.

Selecting the Pilot Site Design/Build Firm

Many firms can effectively design buildings. No firms, however, were identified which had already designed a 'maximum energy efficiency' type building. A 'design challenge' was held to screen potential design firms for the pilot demonstration site. Five firms were paid to prepare conceptual designs for the pilot site and present them to the utility, an expert review panel, and each other. The conceptual designs were all impressive, achieving an estimated 67% to 85% energy savings at the site. The focus of the design challenge was on identifying a design process as well as achieving high energy savings. Hence, the previous estimates may overstate what can actually be achieved. One of the firms was chosen by the review panel to produce the detailed design based on its proposal and elements from each of the other designs and supervise the installation.

The Pilot Building Description

The pilot demonstration is a 22,000-ft^2 (2,050-m^2) portion of the Sunset Building. 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 and because the ACT^2 project team is housed in the building. This proximity allows the team to experience firsthand the daily problems and successes of installing the new technologies. The particular section 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. The choice of using only part of an existing building as the pilot site allowed the project to spend less money than an entire building would have required, but presented unique challenges which had to be addressed. These challenges included adjusting the simulation model for common wall and ceiling, eliminating the opportunities for daylighting through the roof, and the need to account for system interactions between the test space and the conditioned space adjacent. Since the purpose of the pilot site was to learn how to do an ACT^2 demonstration, these shortcomings were considered acceptable.

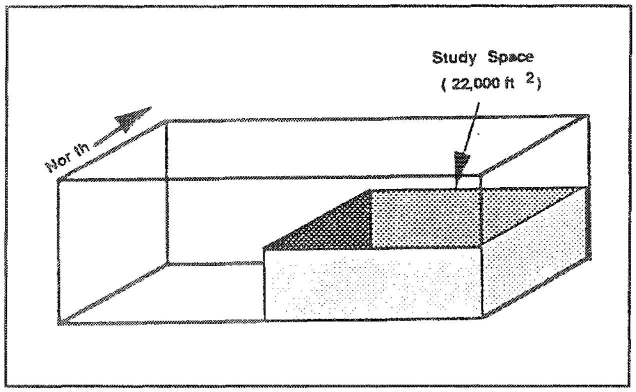

Figure 1. The Sunset Building

Results from the Pre-monitoring Phase

The need to determine the energy savings attributable to each energy-efficiency measure installed and the resulting effect on site environmental conditions makes the task of monitoring quite formidable. Energy use had to be measured at a more detailed level than most studies have done in the past, and comprehensive measurements of site environmental conditions had to be performed. Measurements taken at the Sunset building are shown in Table 1.

The results of these measurements have been used by the designers in preparing the basecase simulation model and the retrofit designs. They also will be used by the impact evaluation team to assist in analyzing the results of the retrofit. A brief summary of the findings from each of these tests follows.

Energy Use

The existing space was modeled by a national laboratory using the DOE-2.1D simulation (LBL 1989) with weather data from the nearest California Energy Commission (CEC) weather station in Sunnyvale. This run estimated the annual energy use at 354,000 kWh. The design firm modified the model inputs to reflect some short-term measured data, field conditions observed at the site (such as economizers stuck open and computers left on overnight), and average local weather data. The design firm's modified model estimated the energy use to be 477,000 kWh/year.

The pilot site's actual monitored energy use for the 12 month period from July 1, 1990 to June 30, 1991 was 328,000 kWh/year. As part of the building analysis, the actual weather for this period will be run in the model and compared to the predicted energy use to check for correlation.

Natural gas use for the space was estimated by the design firm at 12,000 therms/year. The actual usage was considerably less, but a milder winter and poor maintenance of the furnaces (occasional periods of non-operation) may account for part of the difference.

During the baseline test period, the HVAC system consumed 49% of the total electrical use, the overhead lighting 29%, and plug loads 20%. The main copier used 1% of the energy and the remaining 1% was miscellaneous. The main variation between actual and predicted values is in HVAC use. This supports the idea that most of the variation is due to weather conditions during the test period. In addition, maintenance of the existing HVAC units and their controls was sporadic at best. The units failed to provide adequate heating and/or cooling numerous times during the monitoring period. This will also contribute to the difference.

Electrical Use, Device Level

Task lights, for the most part, are turned off at night by individual occupants. Very few are ever left on overnight. It is interesting that during the short term tests, of the 105 task lights, less than fifty percent were ever on at one time. This appears to be due to the nature of the R&D organization in the test space. Occupants are routinely away from their desks or out of the building.

Computers and printers are in use at about the same rate as the task lights. During the short-term tests, less than half of the computers and printers were ever on at one time. Once again, computers are usually turned off at night with a few remaining on 24 hours per day. There are 118 desktop computers in the test space and 77 printers. Ten of the printers are currently networked, the remainder are dedicated to a single user.

There are four copiers in the space, three small-volume (4,000 copies per month) copiers and one large-volume (110,000 copies per month) machine. The large machine consumes slightly over one percent of the entire building load. The load profiles of all the machines are consistent and match building occupancy. Copying energy use begins between 6:00 and 7:00 a.m., remains roughly level until 6:00 p.m., then tapers off until about 11:00 p.m.

The remainder of the plug load equipment is miscellaneous: typewriters, fax machines, modems, scanners, disk drives, video equipment, vending/coffee machines, fans and heaters.

Indoor Air Temperature

Air temperatures were monitored continuously for the pre-monitoring period. Except for occasional periods when the HVAC system was inoperative, the indoor temperatures ranged from 69 to 75 degrees F, averaged over the six summer months, and 63 to 74 degrees F averaged over the six winter months. Indoor relative humidity (RH) remained fairly constant in the 30 to 50% range with occasional dips. Outdoor RH ranged from less than 15% to 100%, with large daily swings typical of the particular climate. Morning fog, causing high RH readings, quickly burns off in the summer, dropping the RH values.

Lighting

Illuminance levels were recorded at every workstation to determine the pre-retrofit conditions. In addition,

Table 1. Scope of Measurement

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	Continuously	Three-times, 8 hours
Acoustic noise	Continuously	One-time, 8 hours
Indoor air quality	Continuously	One-time, 8 hours
Radon	Continuously	Six months
HVAC efficiency	One minute	Four months
Ventilation efficiency & infiltration	--	Two weeks
Occupant thermal comfort	Daily	Two weeks

photographs of the CRT screens were taken to capture reflections of glare from the existing lights. Flicker measurements and color corrected photographs were also taken to complete the pre-retrofit conditions package. The illuminance levels without task lights ranged from a low of 10 foot-candles to a high of 130 foot-candles. Eighty percent of all measurements were above the Illuminating Engineering Society of North America (IES) recommended level of 30 foot-candles (IES 1984). Task lights increased these levels between 10 to 20 additional foot-candles at the work surface. The Color Rendition Index (CRI) of the overhead lights is 52 and 62 for the task lights. The percent flicker in the space was measured between 29 and 32%. These measurements are within IES guidelines.

Power Quality

Power quality measurements were taken over a two month period at the electrical panel, the large copy machine, one small copy machine, and in several offices. Total Harmonic Distortion ranged between 1% and 2.5%, within the Institute of Electrical and Electronics Engineers (IEEE) 519 guideline of 5% (IEEE 1981). The load current on the three phases in the building is extremely unbalanced. The neutral current exceeds the phase current on two legs. Although the current is within acceptable limits, the legs will be balanced during the retrofit. Displacement power factor was between .97 and .99 while true power factor ranged between .66 and .71. The current distortion ranged between 80% and 105% where measured in the private offices. These results are typical of other office buildings tested in the area.

Noise

Ten pre-selected locations in the building were recorded with Type 1 precision sound level meter/recorders. The data was analyzed in terms of octave-band sound pressure levels and A-weighted sound levels. The data was compared against the ASHRAE recommended ranges in terms of dBA and Noise Criterion (NC) rating (ASHRAE 1989a). The results show that noise levels in the conference rooms are generally at the lower range of recommended background noise, but the noise level in one conference room exceeds the upper range due to a noisy supply register. Noise levels in the private offices are generally below or at the lower range of recommended background noise, but the noise in one office was at the upper range due again to a noisy supply register. Noise levels measured in all the open office areas are either below or within the range of recommended background noise.

Indoor Air Quality

Eight parameters of air quality along with temperature and relative humidity were measured in the test space. The air quality parameters measured were:

Particulate matter
Carbon Dioxide
Nitrogen Dioxide
Radon
Formaldehyde
Ozone
Carbon Monoxide
Total volatile hydrocarbons

In order to develop a reference data base of air quality, the same 8 parameters were measured outdoors on the roof of the building near the ventilation system inlet. Ozone was measured continuously for 8 hours in the main copy room. Radon was measured continuously for six months throughout the space and in other areas for control.

The results of all gaseous parameter tests were at the sensitivity threshold of the analytic procedure used. They were all well below any guidelines or standards that currently exist. The particulate measurements varied the greatest (.053 mg/m^3) due to the foot traffic during the test, but were still far below recommended levels of .365 mg/m^3 (EPA 1986, CARB 1989). The temperature and humidity levels were all within the ASHRAE comfort ranges during the test (ASHRAE 1981). Ozone in the copy room averaged 14 ppb during the test and ranged from 10 to 27 ppb. The high value was observed during a period of extended use of the copy machine. There was no measurable amount of radon over ambient conditions during the test.

HVAC Efficiency

One of the major challenges the ACT^2 project faces is how to determine the energy savings contribution by each measure or technology installed, when multiple, integrated measures are going in all at once. For example, how can energy savings be measured for a new, high-efficiency air conditioning system when the internal heat gains are being reduced at the same time? The approach ACT^2 is attempting to use is to measure the efficiency of the old and new HVAC units to eliminate one of the variables in the analysis. If the efficiency of the HVAC unit as well as the energy use is known, the amount of cooling the unit is providing can be calculated. To further complicate the matter, the supply and return ducts are not easily accessible in the Sunset building. Therefore the rejected heat from the units was measured and an energy balance was performed to determine the amount of cooling provided and to prepare efficiency curves for each unit. The three rooftop units were equipped with fluid flow, pressure and temperature sensors on the refrigerant lines along with the electrical meters. A temporary weather station recorded weather conditions for the period of the test. On one of the units a section of ductwork was installed before the condensor coils to measure air flow and temperature across the coils as a check of the accuracy of the flow sensors for determining rejected heat. The forced air perimeter furnaces were tested by measuring the energy input (natural gas) and the stack heat loss of the system. The summary results of the tests are listed in Tables 2 and 3.

Ventilation Efficiency/Infiltration

In order to fully characterize the existing ventilation conditions and determine infiltration, a national laboratory performed a ventilation efficiency test and an air tightness test on the pilot site. The ventilation rate of the entire building was measured to be about 2 air changes per hour of outdoor air which exceeds ASHRAE standard 62-1989 by a factor of two (ASHRAE 1989.b). Ventilation in all areas was found to be adequate except for conference rooms, which were significantly under ventilated. Ventilation efficiency was found to be quite good, very close to 100% in all areas. Ventilation efficiency is a measure of how well the system mixes fresh air with the air already in the space. The leakage area of the exposed building envelope was measured at an equivalent of 5.4 ft^2 (0.5 m^2) to the outside plus 1.1 ft^2 (0.1 m^2) of leakage area to other

Table 2. Cooling System Ratings

Cooling System	HVAC #1 Actual/Rated	HVAC #2 Actual/Rated	HVAC #3 Actual/Rated
Compressor 1 on time (%):	24.1	0.0	41.7
Compressor 2 on time (%):	0.3	25.7	n/a
Blower on time (%):	99.8	99.5	99.9
Compressor COP - actual/rated:	3.04/3.01	3.16/3.01	2.55/2.57
Compressor KW/ton - actual/rated:	1.16/1.17	1.11/1.17	1.38/1.11
Total system COP, compressor on:	1.99/2.38	2.22/2.38	1.79/2.57
	1.77/1.48	1.58/1.48	1.96/1.37
Overall total system COP:	0.96	1.22	1.29
Overall total system KW/ton:	3.68	2.87	2.73

Table 3. Heating System Ratings

Heating System	South Unit	North Unit
Input/Output rating (Btu/hr):	75,000/56,250	126,500/102,000
Efficiency (5) - actual/rated:	76.3/75.0	80.5/80.8

parts of the building. With no mechanical systems operating in the test section, this leakage induced an air infiltration of 0.6 air changes per hour.

The most significant finding of this test is that the test section is much more closely coupled to the other zones in the building than originally thought. As the entire building is significantly overpressurized (i.e. about 7.4 inches of Hg. (25 kPa)), any changes to the test section's air handlers may have significant impact on the air and energy balance of the test section. The analysis team will need to measure and account for these interactions when analyzing the energy savings of the retrofit.

Occupant Thermal Comfort

In order to determine if the retrofit package has an effect on the thermal comfort of the occupants, a California university performed an occupant thermal comfort study of the existing conditions. The parameters measured were designed to satisfy the requirements of ASHRAE and the International Standards Organization (ISO). The study includes a subjective survey of background information on occupant's demographics, job satisfaction, work area satisfaction, health, and characteristic emotions, and current information on the occupant's thermal sensations, clothing, and emotions. The physical measurements taken are of air temperature, relative humidity, air velocity, globe temperature, and radiant asymmetry to satisfy the requirements of ASHRAE 55-1981 and ISO 7726 & 7730 (ASHRAE 1981, ISO 1984, ISO 1985).

The study revealed, from a thermal comfort perspective, that the pilot test site is fairly representative of other tested office buildings in the surrounding area. The site meets ASHRAE and ISO comfort zone specifications with the partial exception of humidity. On a few occasions the building was found to be slightly drier than the ASHRAE standard. Though slightly out of bounds, the values are not a cause for alarm. The subjective portion of the study found that the responses of the Sunset building occupants are fairly representative of other offices in the area. During this test, a three day occupancy study was also run. On three random days, a researcher was hired to perform half-hourly counts of occupants, their location, task lights on, and computers on. The three days were estimated to be fairly typical work days. It was found that on any particular day, no more than roughly one-third of the workforce was in the test space. It is felt that this is due to the nature of the R&D organization occupying the space.

The Pilot Site Design Approach

The design/build firm chosen for the project was faced with the difficult task of developing a brand-new method for designing for maximum energy efficiency within the project constraints. An imposed requirement to document every step taken and to make the process repeatable for scientific purposes increased the difficulty of the task. The usual building design approach is one of matching the designer's time to a fee set by the owner, which typically allows little time or resources for investigation of new technologies or novel applications of existing technologies. A typical design firm therefore uses rules of thumb, employs large safety factors, specifies low-first cost equipment, and uses a sequential design process. This approach is unlikely to achieve maximum energy efficiency.

The ACT^2 project allows the designer to spend as much on the design as can be justified by the economic model. Instead of being able to allocate a set time for the design task, designers time is justified by the energy savings they can obtain. In addition, the designer must use an iterative approach, where the design of the building systems feed back on each other throughout the process.

The design firm came up with the following approach for the pilot demonstration design:

1. Obtain economic criteria.
2. Develop design criteria with utility and the building owner.
3. Define baseline conditions and energy consumption.
4. Develop energy efficiency measures for lighting and office equipment that minimize energy consumption within the economic criteria.
5. Develop envelope and HVAC measures that consider the new, reduced internal heat gains from step 4.
6. Optimize the envelope to take advantage of the internal loads and HVAC design efficiencies.
7. Optimize HVAC design and sizing for new loads.
8. Repeat the process until each system is as efficient as economics allows.
9. Submit the preliminary design for review to utility.
10. Repeat process for any changes proposed, finalize the design.
11. Submit the design for final review.

Most design firms specializing in energy efficiency have sources of information for steps 4 and 5, and in the case of this project, the utility augmented the list of technologies which the design firm considered. Steps 6, 7 and 8, optimization, were found to be the most difficult part of the design process.

The problem with analyzing an integrated energy efficiency design is that the order in which the technologies are considered affects the savings associated with the technology. For instance, a lighting measure results in greater savings if it is implemented before, rather than after, a space cooling measure. To further complicate the issue, the cost of a measure can be affected by the order it is considered. An example is a daylighting dimming system. The cost of a stand-alone daylighting system would require including the cost of installing new (dimmable) ballasts. If the daylighting system is considered after new lamps and ballasts, the incremental cost of installing the daylighting control is reduced by the cost of the ballast installation. One solution to the problem is to model each possible combination of technologies imaginable and pick the combination which yields the most energy savings without allowing any one measure to exceed the economic criteria. This approach would be incredibly time consuming. Therefore the designer needs a way to analyze the bounds of each measure and make more logical selections.

The pilot demonstration site design firm developed a method where it bounded each measure to be considered with the best and worst conditions. The designers first calculated the cost-to-benefit ratio of each measure when it is the first measure installed (highest cost, most energy savings), then they repeated the procedure figuring in all cost savings due to integration and the energy savings reduction due to other measures (see Figure 2). This process produced a range of cost-to-benefit ratios which allowed the designer to quickly assess which measures are always cost effective, regardless of implementation order, and those measures which will require further analysis. Since this process reduced the number of measures requiring further analysis, the designers could use a standard parametric analysis of the measures using the DOE-2 model. Assuming the design firm has looked at all reasonable energy saving measures for the site, this approach produces a package wherein each technology meets the cost effectiveness criteria and the entire package maximizes energy efficiency. The ACT^2 project is not requiring the follow-on designs to necessarily follow this approach and the economic criteria used by the pilot site design firm are not the same as will be used in the follow-on demonstrations.

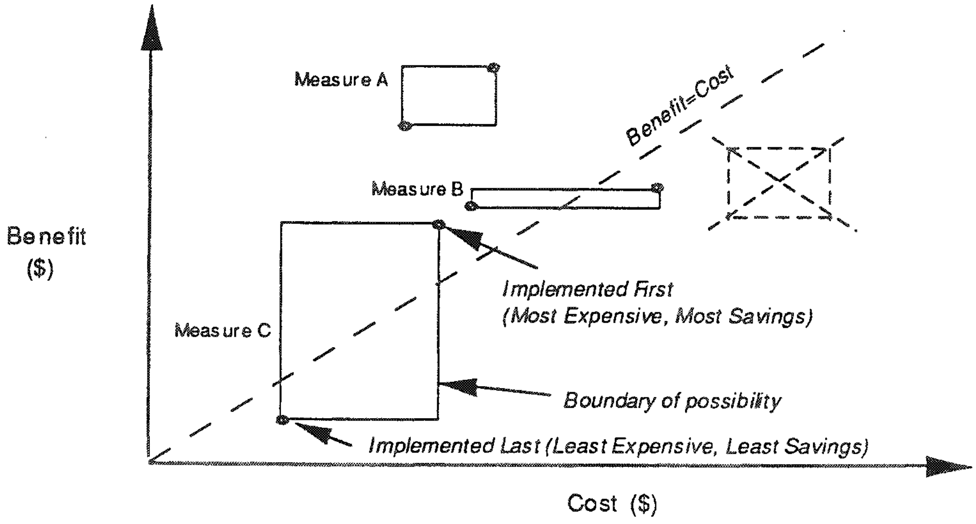

Figure 2. The Design Firm's Method

The Pilot Building Design

The final design for the pilot demonstration site modifies three areas: building envelope, lighting and HVAC. A fourth area, office equipment, was examined and found to be cost-effective to change, but due to the high number of computers, it was too expensive for the project to replace at this site. The additional savings due to replacing office equipment would have pushed the total estimated savings to over 80% of the current use.

Building Envelope

Glazing system retrofits are particularly expensive to accomplish and the owner's constraints as to the appearance of the glass can limit designer options. After the inclusion of energy-efficient lighting and HVAC equipment, little savings were left to be captured with more efficient glazing systems. The final design calls for retrofitting only the glazing itself (no framing) on the south elevation. The new glazing will be dual-pane with reflective film on the interior surface of the exterior pane. The color of the glass is bronze, to match the remaining glass surfaces in the building. The windows currently have miniblinds controlled by the occupants which will remain in place after the retrofit.

Lighting

The owner required that the new ambient lighting system be capable of maintaining a uniform level of 30 foot-candles throughout the space even if the current tenant moved out. This criteria limited the options to non-furniture mounted fixtures and overhead lighting capable of supplying the requested illumination.

The final design addressed ambient lighting, task lighting, and controls. The overhead lighting fixtures will be retrofitted with specular silver reflectors, T-8 fluorescent lamps and dimmable electronic ballasts. Large open areas and each private office will be controlled with occupancy sensors. In addition, perimeter lighting circuits will be controlled with daylight sensors to utilize daylighting. To meet the owner's light level requirements, yet take advantage of savings possible by tuning down lighting in certain areas, the ballasts will be dimmed from two central locations in the test area.

The current task lights are standard, single lamp four-foot fluorescent fixtures mounted under the shelf above each work surface. These fixtures will be replaced with 13-Watt compact fluorescent fixtures mounted in their place. These lights will remain manually controlled by each occupant.

HVAC

The most dramatic savings will come from retrofitting the existing air-conditioning system. The existing system consists of three, constant volume, packaged DX air-conditioning systems supplying cool air to multiple, ceiling bypass, VAV boxes in the space. The ceiling plenum provides the return air route to the units. Three perimeter forced air furnaces provide heating and share the common ceiling plenum for return air.

The new air conditioning system will replace the existing rooftop units with a two-zone, low air-velocity, high coolant velocity, central plant system. The existing supply and return ducts will be utilized by two, low air velocity, variable speed air handling units. Each unit will incorporate economizers and indirect evaporative cooling. The indirect evaporative cooling will supply most of the building's cooling needs. All motors will be high-efficiency units with variable speed controls. Peak cooling requirements will be supplied by two, staged, 15 ton, variable speed, reciprocating chillers. The chillers will be constructed with an oversized chiller barrel to improve heat transfer. A new cooling tower with a variable speed fan will be installed. The cooling coils will be 4-row, extra wide fin spacing models designed for low air velocity. Wiring and piping will be optimized for energy efficiency. All large pumps will also be variable speed. The existing ceiling by-pass variable-air-volume (VAV) boxes will be retrofitted to full VAV operation and connected to the direct digital control (DDC) system. Nine new diffusers will be installed in those areas where the air velocity will be low enough to require them. Any new ductwork installed shall be designed for low-friction losses.

It was not cost-effective to replace the existing forced air furnaces with energy efficient units, therefore they will remain in place. However the units will now be tied into the DDC system for control operation.

Projected Energy Savings

As discussed earlier, the actual usage has been running less than the base case model predicted. The figures above are based on average weather data and building conditions kept within acceptable design conditions. Actual weather data is currently being collected for use in the model and compared to the actual energy usage. In addition, the building is occasionally outside of design conditions for thermal comfort and this will be considered in the analysis.

Table 4. Projected Energy Savings

	Base Case Model	Final Design	Approximate Savings
Annual electric use:	477,000 kWh	116,000 kWh	76
Peak electric demand:	126	39kW	69
Annual gas use:	12,000	1,200	90
Overall annual cost:	$81,500	$19,000	76
BTU per sq. foot:	152,600	25,500	-

Lessons Learned

As described earlier, the pilot demonstration site of the ACT^2 project was designed as a 'learn-by-doing' demonstration. It was anticipated that mistakes might be made at the site. We are learning from them so the remainder of the demonstration sites are not suffering from the same mistakes and are benefiting from the knowledge gained with the pilot site. Lessons learned can be separated into three main categories: communication, contracting and technical issues.

Good communications was a common thread running through all the lessons. With 20-20 hindsight, we can see that mistakes and time delays could have been avoided with more communication. Utilities and design firms do not speak the same language and can have different understandings of the meaning of the same term. Just because no questions are asked does not mean that the other party understood the information. This 'communication gap' is magnified on a project of the size and complexity of the ACT^2 project. The pilot site design was hampered by this miscommunication mainly in the area of the economic criteria. The economic criteria were not in place when the design firm began work on the pilot site. The original criteria were later modified, but the changes were not communicated clearly enough to the firm and the design was nearly completed with criteria beyond what the utility desired. Due to the high cost of a complete redesign, the design firm was requested to scale back the design to a reasonable 'mature market' installation cost. This type of problem can be avoided with thorough and complete communications, including having the receiving party 'feed back' the instructions/information to insure understanding.

Including frequent review periods can assist in avoiding the same sort of communication problems. Although expensive, frequent review also allows errors to be caught early and corrected before the design is too far down the path to easily (and cheaply) change. When working on an R&D project like this one, which pushes the envelope, design firms can have trouble differentiating between performing research on individual competing technologies versus designing and demonstrating the whole package. Careful oversight is needed during the reviews to prevent time and effort being spent by designers on pure research instead of design.

Technical lessons included both energy-efficient design as well as monitoring. We learned that for monitoring and analysis at a level as intense as this project requires, the cost can easily equal or exceed the EEM design and installation cost. This is particularly true for the residential sites.

We have now learned to avoid any measures which will require the tenant to relocate during the construction phase at retrofit sites. Occupant relocation is extremely expensive and can destroy the economics of the package, eliminating the proposed energy-efficiency measure.

Leave enough time to perform validation of the basecase model. Use of an erroneous basecase model may mis-calculate energy consumption and therefore energy savings, invalidating the economics of the package.

Using only a portion of a building causes problems and is discouraged. Due to unforeseen interactions between building systems, we found it impossible to completely isolate the building section physically, electrically and mechanically from the rest of the building. This condition magnifies the task of analysis. However it must be noted that this condition will apply when dealing with a highrise, where one floor at a time is usually addressed. Therefore the pilot site is typical of the type of problems to be faced with highrises.

The designers must not rely on visual inspection of the existing conditions only. Every person who noticed that the economizer dampers were stuck open assumed large amounts of outside air were being drawn in. In reality, very little outside air was entering the building because the return air dampers were also stuck open.

The last area of lessons were in contracting. As much time as possible must be built into the schedule for contract negotiations. Large utilities have numerous standard conditions to cover their liability. Negotiating terms with the customer and contractors proved to be a time consuming stumbling block. What may seem like a simple contractual arrangement can become mired in negotiations about insurance and liability issues. Leave much more time than you think is necessary for contracting.

These lessons, plus numerous more-detailed, project specific lessons have been incorporated into the project plan for the follow-on demonstration sites. As a learn-by-doing exercise, the pilot demonstration site has been and will continue to be a success.

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