Revisiting the ACT^2 Commercial Pilot, Five Years Later

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ABSTRACT

The 1992 ACT^2 Commercial Pilot was the first in a series of research projects designed to assess the real world limits of energy efficiency technologies. The authors were the design team project director and the utility project director. The design projected building energy savings in excess of 60% of the pre-retrofit energy consumption. The building retrofit, completed in 1993, included a dramatic reduction in the installed capacity of mechanical cooling equipment through the use of double indirect evaporative cooling, combined with reductions in lighting and thermal loads. The facility was extensively monitored by the utility for two years after the retrofit, basically substantiating the projected energy savings under controlled conditions. The facility has now been under private control for the past three years. The paper summarizes the original design objectives and reviews the design as installed. It then presents a summary of the performance as observed during the period that the facility was monitored by the utility. The authors discuss the actual market forces that have effected building operation, maintenance, and energy use; and summarize the estimated current state of building energy efficiency. This reconstruction is based on interviews with the building owner, the building occupants, and an inspection of the facility. The paper presents an interesting retrospective on what happens when an advanced building energy efficiency design is subjected to real world operating conditions. The authors draw conclusions from the design and monitoring experience and make recommendations concerning energy savings sustainability for future advanced design projects.

Introduction

In 1991 Pacific Gas & Electric Company (PG&E) Research and Development (R&D) commenced an ambitious research program to assess how much energy and demand could be reduced when energy conservation technologies were applied systematically during the building design process. PG&E's pilot project for the Advanced Customer Technology Test (ACT^2) program was it's own R&D facility which occupied a 20,400-square-foot area of the Sunset Building in San Ramon, California. After a design competition, PG&E hired Brown, Vence & Associates (BVA) of San Francisco to design and install a package of retrofits that would minimize energy consumption while utilizing a 30-year life cycle cost for Energy Efficiency Measures (EEMs). BVA teamed with general contractor, Swinerton & Walberg to complete the installation and commission the facility. Following commissioning, PG&E monitored the performance of the EEMs for two years, documenting the overall energy consumption of the redesigned space. In 1995, after the completion of the monitoring, PG&E moved to another facility and the space was occupied by Pacific Telesis.

To write this paper, the authors (who are the design team project director and the utility project director) revisited the facility in March of 1998 to observe retention rates and the state of operation of the installed EEMs. Reasons for changes in equipment and operation were discussed with the building occupant, the building owner, and the building maintenance staff, including the HVAC maintenance contractor. This information was combined with existing design and monitoring information to estimate current energy use and to comment on real world retention issues.

Original Design

Base Case

The existing study space was served by three package rooftop direct expansion air conditioning units and three rooftop forced-air furnaces. Lighting was supplied by standard four-tube (34W, T-12), 4-foot fluorescent fixtures with magnetic ballasts, manually switched. Each work station in the open offices had fluorescent undershelf task lights. Water heating was supplied by a central gas-fired storage type heater. There were three small copiers and one large volume copier in the space. The remainder of the electric load was office equipment, approximately 100 personal computers, 60 printers, and some miscellaneous items such as fans and scanners.

Baseline energy consumption for the study space was estimated using DOE-2.lE (version 386PC/2. IB-B09). The model was calibrated using four days of electric load measurements of lighting, HVAC, and receptacles in the study area. The base case annual energy consumption was 448,866 kWh and 11,075 therms. The peak demand was estimated at 126 kW.

Sunset Building Retrofit Design

The economic criteria used for the final design were based on the premise that a project that achieves 75 percent energy savings would result in an $800,000 mature market capital cost (1992 dollars). While each measure was to have a benefit-to-cost ratio greater than one, the interactions and the quantification of savings resulted in some measures having a ratio less than one. Based on these project economic criteria and the limitations set out by the building owner, a design was developed that incorporated sophisticated energy efficiency measures (EEMs) using integrated advanced design techniques. This design was unique in that it combined, in a synergistic fashion, high efficiency heating, ventilation, and air conditioning (HVAC) system components and lighting with a flexible and integrated control system. Although not broken out as a separate EEM, DDC control system will help maximize the energy savings by both anticipating the changes in load and optimizing the individual systems.

The final design components are listed below, grouped by end-use category. The EEM numbers in parentheses were assigned during the optimization process and reflect the order of implementation.

Envelope:

- Replace existing glazing on the south side of the building with an optically tuned multi-pane glazing system. (EEM 4)

Lighting:

- Retrofit existing lighting fixtures with new reflectors, T-8 lamps, and dimmable electronic ballasts. Supply high-efficiency task lights. (EEM 3)
- Install daylighting controls for the perimeter lighting fixtures. (EEM 6)
- Install occupancy sensors for both open areas and enclosed offices. (EEM 5)

HVAC:

- Using the existing ductwork, modify the ceiling bypass variable-air-volume (VAV) air distribution boxes to full VAV operation. Install two high-efficiency air handling units. Seal all major leaks in the existing duct system. (EEM 7)
- Install high-efficiency two-stage indirect evaporative cooling to supplement mechanical cooling coils. (EEM 2)
- Install an exceptionally high-efficiency chiller system that is capable of operating at high efficiency over a broad range of loads. (EEM 1)

Design Operation

The individual EEMs were designed to take advantage of synergism between the EEMs to maximize energy efficiency for the whole system. The following is a description of the operation, interactions, and synergism of each type of system.

Envelope. The installation of the multi-pane optically optimized glazing on the southern exposure of the study space was the best compromise between minimizing heat transfer and maximizing light transfer on the southern exposure. The new glazing (Cardinal TI-230) had a shading coefficient of 0.19, a visible transmittance of 0.22, and an insulation value of 0.31. This choice of glazing allowed maximum benefit from perimeter daylighting while minimizing the thermal load on the HVAC system in general. The glazing was also designed to minimize the range of loads to which the southern perimeter HVAC zone will need to respond, passively improving comfort in the southern perimeter zone. Due to the high efficiency of the final HVAC and lighting systems and the mild climate in San Ramon, the benefit-to-cost ratio of the glazing retrofit as a stand-alone measure was less than one.

HVAC. The HVAC modifications were (1) install a two-stage indirect evaporative cooling, developed in conjunction with Aztech Sensible Cooling Systems, as the primary source of cooling; (2) install variable speed fans on all sections of the air handler and the evaporative cooling system to minimize energy losses at partial loads; (3) install a smaller capacity high-efficiency chiller system that can operate at low loads and can operate efficiently over its full operational range; and (4) modify the ceiling bypass VAV system to a full VAV system. These components operate and complement each other in the following manner.

The two-stage indirect evaporative cooling system was designed to supply the majority of the cooling needs of the study area without increasing the moisture content of the air supplied. This was done by using evaporative cooling to cool an intermediate fluid, then passing this fluid through a heat exchanger to cool a second air stream. If this process is done twice in succession, it is possible to cool the final air stream to the wet-bulb temperature of the air with out increasing its water content. Due to the generally low relative humidity in the San Ramon area (and throughout much of the PG&E service area), two-stage indirect evaporative cooling can supply a large part of the cooling load of the study area. The evaporative cooling section used four low-air-velocity coils and an economizer and damper system to maximize efficiency. Variable speed drives are used throughout.

Given the use of the evaporative cooling system, the chiller system was projected to operate at partial load much of the time. Thus it was essential that the chiller system be highly efficient over a broad range of loads. The chosen system was designed to operate efficiently from 100 percent down to 16 percent load. It is composed of two variable speed drives, 15 ton CHARG reciprocating compressors in combination with an oversize chiller barrel, and an oversize cooling tower to improve system efficiency.

Once an efficient method of supplying cool air has been developed, supplying only the necessary amount of cool air and minimizing cooling and re-heating of supplied air is the next step in minimizing energy consumption. To achieve this, the ceiling bypass VAV system was replaced with a full VAV system. Thermafuser diffusers were installed to provide good air distribution at the lower air velocities supplied by the VAV distribution system.

Other HVAC features included variable speed drives to minimize the power consumed by the all fans, a direct digital control (DDC) system to optimize all space conditioning needs including the existing forced-air.

Lighting. The lighting design achieved energy efficiency by (1) using the natural light available on the perimeter, (2) reducing ambient light levels while improving task lighting, (3) installing high-efficiency lights and ballasts, and (4) using occupancy sensors to turn off lights when they are not needed.

Lighting level sensors were used, in conjunction with state-of-the-art continuously dimming electronic ballasts in perimeter zones. The fluorescent lights within 15 feet of the window were designed to automatically adjust to maintain constant light levels as natural daylight fluctuates.

Existing fluorescent fixtures were retrofitted with the electronic ballasts, 32-watt T-8 lamps, and specular reflectors. At the same time the existing four-tube configuration was replaced by a two-tube configuration, resulting in a 30-footcandle (fc) ambient light level. This met the Illuminating Engineers Society (IES) recommendations for work spaces with high VDT use.

Workstations were supplied with SPI STD-30 undershelf task lights that could be adjusted to two different light levels, to meet individual needs. Private offices, where ambient levels of light projected to be higher, were supplied with CLS Table Model task lights on request.

Existing incandescent downlights were retrofitted with screw-in compact fluorescent downlights.

The net result was lower average ambient light level that reduced glare on computer screens coupled with improved task lights that provided light levels above 50 foot-candles and reduced glare on paper tasks.

Occupancy sensors were installed to control the overhead lights both in open areas and private offices. Open area lights were grouped into 12 to 18 fixture groups to avoid undue off-on switching during the work day. Task lights were manually controlled in all areas.

Energy Savings Projections

The design team estimated that the retrofits would reduce energy consumption by 73 percent relative to the baseline energy use established by PG&E:

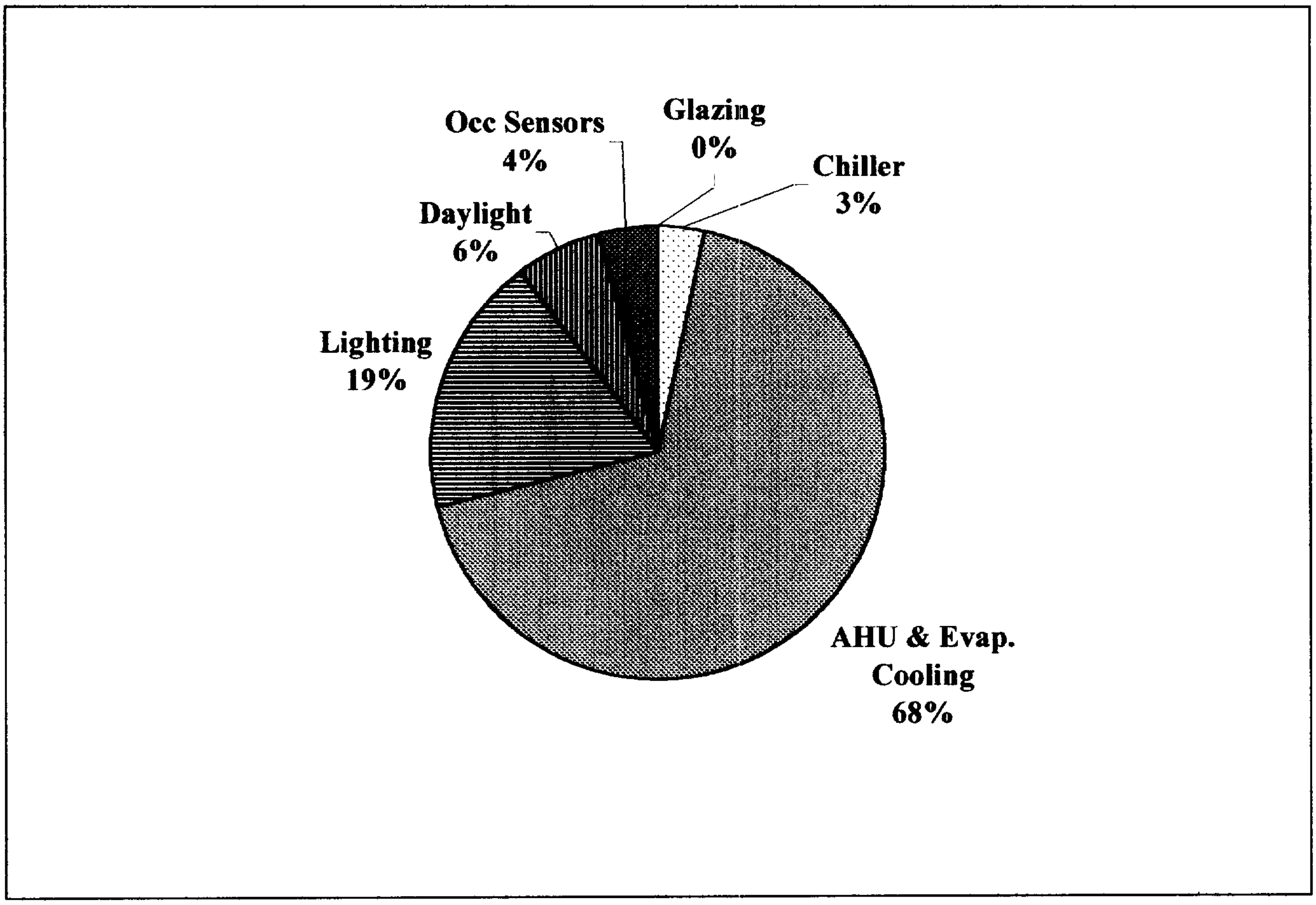
Exhibit 1. Design Estimates of EEM Savings (kWh)

	Calibrated Base Case	Daylight Controls	AHU & EvapCool	Occupant Sensors	Lighting Fixtures	Chiller	South Glazing	Total Savings
Electricity Use	372,547	357,449	189,252	179,106	133,253	124,996	124,784	-
Energy Savings	-	15,098	168,197	10,146	45,853	8,257	212	247,763

The design resulted in an energy density of 35,100 Btu per square foot. These large reductions in energy consumption were achievable because of the economic criteria utilized in the design. The ACT^2 program applied a cost-effectiveness test that compared the life cycle cost of EEMs to the cost of new electric and gas supply resources. By utilizing a 30-year life cycle cost for EEMs, PG&E departed from the usual limits of payback for energy efficiency projects, thus allowing experimentation with new technologies with higher first costs.

Savings were accomplished through a design process that emphasized the application of advanced, commercially available, high energy-efficiency technologies to solve design challenges. Most of the technology used in the design had been field-proven. Some advanced equipment with limited field experience also were used because the technologies were expected become important in future energy-efficient design.

Exhibit 2. Distribution of Mbtu Savings by EEM



Monitored Data Use

The ACT2 Project collected extensive data on energy use and other building and environmental conditions throughout the pre- and post-construction study period (Exhibit 3). This data was used to calibrate the building energy simulation models to closely match how the building actually performed. With a highly accurate energy simulation model, typical annual meteorological data could be inserted to determine how the building would operate over time. The project could then compare the typical base case, or pre-retrofit energy use, with the typical post-retrofit energy use independent of the specific weather conditions present during the test. Energy efficiency measure impact evaluations were then performed, using the calibrated models, to determine how well each technology performed and how well the building as a whole performed.

Exhibit 3. Monitored points

Electric Power Demand & Use	Natural Gas Use	Indoor Conditions	Outdoor Conditions
Equipment	Furnace 1	All zone temps	RH
Copier room equip	Furnace 2	AHU supply flow rates	solar insolation
Lighting-North & South*	Furnace 3		temperature
Lighting-South areas			wind speed
All relief fans*			wind direction
All secondary fans*			
All AHU ctrl pumps*			
Condenser fan & pump*			
Compressor no.1 & 2*			
Chilled water pump			
All furnace fans*			
Mixed HVAC			
Chiller control			
Roof plugs			
Duct detectors			

* All points monitored individually.

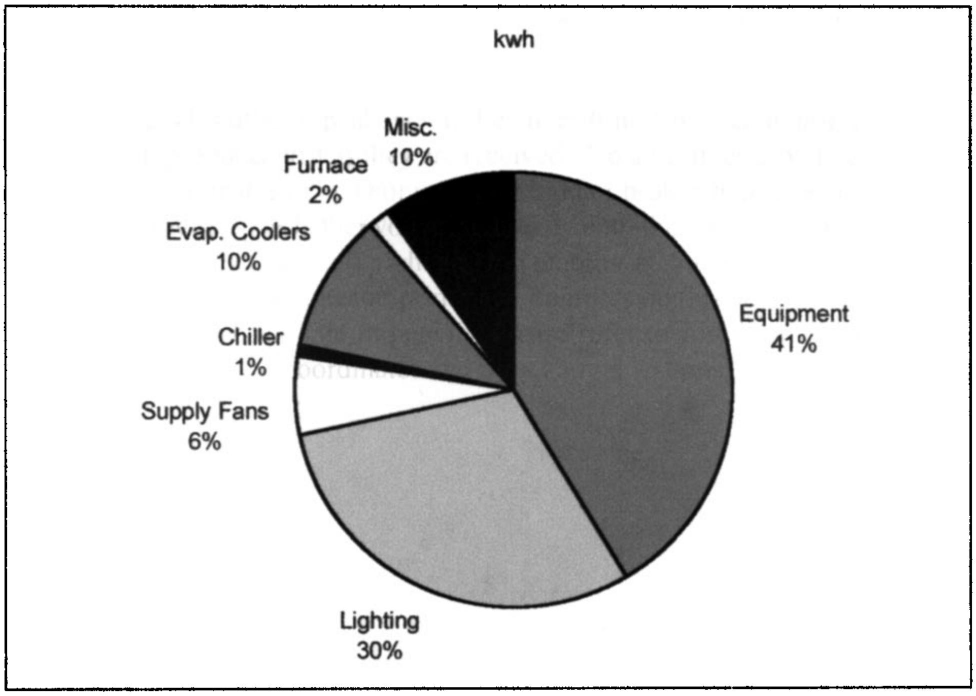
By calibrating the original base case model using monitored data, energy saving predictions were found to be lower than first estimated by about 21%. This more accurate base case energy use model therefore recalculated the actual, or achieved total energy savings to 53%. The reader should keep in mind that the retrofit project did not attempt to replace any office equipment (plug loads) at this site due to the cost involved and the fact that in today's office environment computer hardware turns over extremely rapidly on it's own. This lowered the total possible energy savings not only by the amount of extra energy consumed by the older, less efficient office equipment, but added additional heat load to the air conditioning system.

Exhibit 4. Base case Energy Consumption (kWh)

End-Use Category	Interior Equipment	Interior Lighting	Supply fans	Cooling	Evap. Cooler	Furnace Fans	Misc.
Fans	74,372	89,825	85,235	119,961	0	3,154	0
Total Elec. (kWh)	-	-	-	-	-	-	**372,547**

The ACT^2 Project monitored pre and post energy consumption in the following categories: Interior equipment, interior lighting, supply fans, chiller, condenser and chilled water pump, evaporative cooler and relief fans, furnace fans and gas use, and miscellaneous. All of these uses are covered in Exhibit 3 with the exception of the gas use. After the retrofit was completed, the total electric energy consumption of 175,906 kWh was achieved. This electric energy consumption is shown by category in Exhibit 5. The equipment in Exhibit 5 is office equipment (i.e., computers and copiers) while the miscellaneous is variable speed controllers and the crankcase heater for the chiller.

Exhibit 5. Energy Consumption by Category



This level of monitoring allowed the project to determine the energy savings for each of the installed technologies. The actual monitored data was used to calibrate the DOE-2 energy simulation model, which was then run using Typical Meteorological Year (TMY) weather data to get an accurate picture of the average annual energy use.

It must be noted that simply listing the energy saved by each technology can be very misleading. When applying the ACT^2 approach, installing a package of multiple, synergistic energy efficiency measures, the energy savings associated with any one technology are inextricably tied to the energy savings for other measures. Remove any one technology and the energy savings and cost effectiveness of the other measures are affected. In addition, many technologies address the same end-use, such as daylighting controls, occupancy sensors, and lighting fixtures, making direct measurements accurate only for the combined total energy savings in that category. A summary of the annual energy savings by measure is listed in Exhibit 6. This table shows the energy savings associated with each measure in the order they were added to the whole package in accordance with the supply curve approach.

Exhibit 6. Summary of Annual Energy Efficiency Measure Energy Savings (kWh) As Mearured in Post Installation Monitoring

	Calibrated Base Case	Daylight Controls	AHU & EvapCool	Occupant Sensors	Lighting Fixtures	Chiller	South Glazing	Total Savings
Electricity Use	372,547	362,038	211,512	201,265	171,563	175,783	175,906	
Energy Savings	-	10,509	150,526	10,247	29,702	-4,220	-123	196,641

The total savings are roughly 21% lower than the originally calculated savings estimate (shown in Exhibit 1). A brief discussion of the savings for each measure follows:

Monitored Estimates of Savings by Measure Type

Lighting, General. The lighting measures were essentially fully installed and operational at the site. However a modeling error erroneously calculated savings at 46,000 kWh per year, while the correct amount is approximately 30,000 kWh per year. The measure did save an estimated 29,702 kWh per year.

Daylighting Controls. The energy savings for the daylight dimming controls was slightly lower than originally calculated. The cause of the discrepancy was in the lighting schedule assumed. The actually monitored lighting schedule determined the lights operated for longer hours than modeled. The total lighting energy use was therefore higher than originally thought while no proportional savings were achievable since no daylighting is available in the extended evening hours.

AHU & Evaporative Cooling. The monitored data determined that the calculated energy consumption of the air handling units was very close to the actual consumption. The actual use was about 10% higher than originally calculated due mainly to higher than predicted fan and pump energy use. The fans used about 6% more energy than anticipated due to control errors causing the evaporative fans to run at full speed rather than modulating as intended.

Occupancy Sensors. The actual energy savings matched the predicted energy savings for this measure. Since no occupancy sensor data was collected, the same assumptions were used in the calibrated model as in the base case model.

Lighting Fixtures. The monitored energy use for task lighting closely matched the original energy saving calculations. However the monitored energy use for the overhead lighting measure was significantly less than originally calculated. This discrepancy was due to an error in the lighting density in the space as well as a modeling error discovered by using monitored data. (See "Lighting, general" above.) The original model used for design was calibrated using pre-retrofit monitored data. The model did not match the actual use and a 'calibration factor' was applied uniformly across the data. The post-retrofit monitored data showed that the actual energy use discrepancy was caused by increased after hours lighting use and the daytime energy use matched the model well. Therefore the 'calibration factor' of 1.32 which was applied to the original lighting model, overstated energy savings by 32%.

Chiller. Although the installed chiller was extremely energy efficient, the measure actually consumed more energy than the less efficient system it replaced. This fact was due entirely to the energy consumed by parasitic loads, the crankcase heater and controller energy. Since the evaporative coolers supply nearly the entire building load, the operation hours of the chiller were surprisingly low. Therefore the parasitic loads dominated the energy consumption of the measure.

South Glazing. Once again, this measure actually consumed more energy than the system it replaced. The building was dominated by internal heat gain and must reject heat throughout the year. Since the new HVAC system was so efficient, cooling savings for the window system are very low in the summer months. In the winter months, the old windows allowed a large amount of heat to escape to the cool outdoors. The new, higher R-value windows did not allow the heat to escape, causing the cooling system to make up the difference.

Five Years After Retrofit

In order to assess the longevity of the savings achieved by the installed EEMs, the authors contacted the building owner and the current tenant and set up a site inspection and interview approximately five years after installation. The retrospective process included interviews with the building owner, the tenant's facilities manager, the facility maintenance personnel, and the contractor responsible for the maintaining and servicing the HVAC system. The following discussion presents the findings of the inspection by EEM including comments on reasons for changes. This is followed by an estimation of the current level of retained energy savings.

Operational Status of EEMs

Lighting General, and Daylighting Controls. Discussions with the facilities manager and the facility maintenance personnel established that virtually all of the lighting control features at the site had been deactivated. This meant that the dimming fluorescent ballasts had been set to the 100% condition, the perimeter daylighting control had been deactivated so that the lights were on full whenever they were on, night-time shut down controls had been deactivated, and the occupancy sensors had been either deactivated or removed. The reason given was that the occupants didn't like the low ambient light levels (ambient lighting levels were 30 foot-candles post-retrofit, currently estimated at 60 foot-candles) and did not like the lights going off automatically. The comment about low light levels was interesting since a walk through of an adjacent space occupied by the same tenant had considerably lower light levels (estimated at 40 to 45 foot-candles) but was considered acceptable. The perceived reason was that the space was recently remodeled, had higher ceilings and a much more open feel when compared to the standard acoustic tile ceiling in the test space.

AHU & Evaporative Cooling. The air handling unit and evaporative coolers appeared to be functioning as designed. The contractor maintaining them appeared to understand how they were intended to operate. The water in the sumps of the evaporative coolers was clean and the media was wet when inspected. One of the supply fans was cycling significantly, which was later determined to be due to a malfunctioning fan control unit that was sending it a periodic signal to cycle. This was pointed out to the maintenance personnel.

The HVAC night time shutdown had been reprogrammed so that the HVAC operated all night, again for occupant comfort.

The Thermafuser diffusers were still in place and operating. One office user had propped the diffuser open with paper clips because he was cold all the time. When queried, the facilities manager and maintenance personnel indicated that the study area had approximately the same frequency of complaints for temperature maladjustment as the adjacent non-retrofitted spaces. The occupants indicated that the Thermafusers, which were installed to properly diffuse the air from the HVAC when volumes were low, seemed to accomplish the task.

Occupancy Sensors. As mentioned above, lighting controls had been programmed so that the occupancy sensors did not control the lights. The occupancy sensors were still installed in the ceilings of the open spaces and were hooked up, as evidenced by the indicator light. The private office occupancy sensors had been removed and replaced with standard switches. The Sentry switches designed for night time use to avoid setting off the occupancy sensors were in place but programmed as standard switches.

Lighting Fixtures. The majority of the ceiling mounted T-8 lighting fixtures installed during the retrofit were still in place. As stated above, the controls had been set to maximum so no dimming was being used. The compact fluorescent down lights installed in the central hall had been replaced with center mounted single tube indirect T-8 fixtures, increasing the light level in the hallway from 30 foot candles to approximately 60 foot-candles. All two level desk lighting had been removed when PG&E vacated the space. The cubical desk lights that are now in place are single tube 2 foot T-8 fluorescent lights.

Chiller. The chiller system was still in place and operating as originally designed. The contractor responsible for HVAC maintenance indicated that the chiller only comes on when the ambient temperature exceeded about 80 degrees Fahrenheit. Up to that point all cooling needs are handled by the indirect evaporative coolers.

The chillers system experience a catastrophic failure in the summer of 1997, when for unknown reasons the chiller barrel frosted up and both compressors seized. The building was without the supplemental chilling source for approximately three weeks during the hottest part of the summer. The event produced several interesting pieces of anecdotal information. First, the chiller system took three weeks to repair because the chiller barrel was a special order item. A standard unit would have been repaired in a day or two at most. Second, the HVAC contractor responsible for maintaining the system said that the double indirect evaporative cooling system worked like a champ during the whole event and did a pretty good job of cooling the building despite the loss of the chiller. Third, the building occupant blamed the system and wanted the building owner to replace it because he had three weeks of complaints due to internal temperatures of 80 degrees Fahrenheit. What the occupant did not know was that the situation would have been a lot worse (even if period of disruption would have been shorter) without the double indirect evaporative cooling system.

South Glazing. The glazing was still in place and functioning as designed. When asked, the maintenance personnel and building managers said that they had no complaints of temperature fluctuation in the areas near the windows in the retrofitted space, however they did have temperature fluctuation complaints in the space directly above with the same exposure and the old glazing. Thus despite the finding that the glazing is not saving energy, it is reducing temperature fluctuation and loading on the cooling system.

Estimated Effect of Changes on Energy Savings

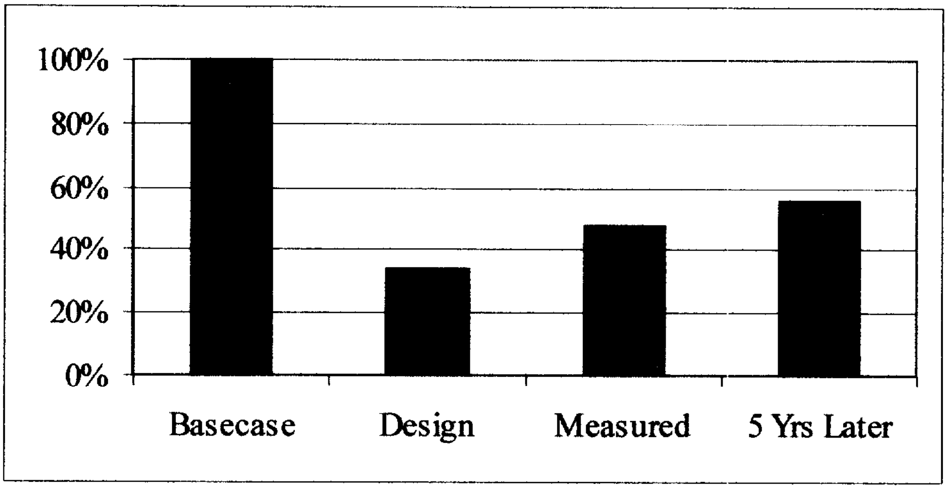
The authors roughly estimated the savings at the Sunset Building ACT^2 as it currently exists based upon the savings projections from the original EEMS. Exhibit 7 summarizes these savings in the same format presented previously in this paper.

Exhibit 7. Estimated Current of Annual EEM Energy Savings (kWh)

	Calibrated Base Case	Daylight Controls	AHU & EvapCool	Occupant Sensors	Lighting Fixtures	Chiller	South Glazing	Total Savings
Electricity Use	372,547	372,547	222,021	222,021	204,200	208,420	208,543	-
Energy Savings	-	0	150,526	0	17,821	-4,220	-123	164,004

To better present the trends in savings projections from basecase, to design, to measured, to the present the estimated percent savings is plotted in Exhibit 8

Exhibit 8. Estimated Percent of Original Energy Consumption by Phase



As discussed earlier, the difference between the design and the measured case is a result of an error in the design lighting model and differences in operating hours between the base case assumed for the design and the base case actually measured during the measurement period.

The interesting aspect of the previous two exhibits is the relatively small degradation in savings resulting from what would have appeared to be major changes at the site. The reason the reduction is small is that the features that were deactivated (i.e., occupancy sensors, daylighting, dimming) made relatively small contributions to the overall savings. The really large contributors (i.e., double indirect evaporative cooling and the T-12 to T-8 retrofit) were still in place and producing savings.

Conclusions

There are many lessons can be extracted from the process of reviewing the design, construction, monitoring, and market place performance of the ACT2 pilot project. Two conclusions are presented below for each of the three project phases, Design, Monitoring, and Market Place Performance.

Design Conclusions

1. Remember the importance of establishing a firm base case before commencing the design. Most of the issues surrounding differences between the final design predictions and the measured case resulted from lack of clarity about the base case.

2. Concentrate on the items that produce big savings and are not easily changed later by the occupants of the facility. The indirect evaporative cooling, the chiller, the T-8 lamps, and the glazing were still in place because they were not easily removed or changed.

Monitoring

1. The importance of actually monitoring energy consumption both before and after a retrofit cannot be over emphasized. Whether the reader uses the data directly and gets a rough estimate of annual energy saving or uses the data to calibrate a model to obtain higher accuracy, monitored data is critical. A good example is shown in the case of the lighting energy use of the Sunset building. The original modeler applied a calibration factor to the modeled lighting density to account for differences in lighting consumption. Monitored data showed the difference was attributable to operation hours of the lighting, not the density, greatly affecting the outcome of the analysis of energy savings.

2. Monitoring systems are also very important to diagnose or commission a facility. Observations of the monitored data rapidly uncover operational conditions outside of those called for. An example in the Sunset building was the constant speed operation of the evaporative cooling fans and the running of the evaporative condenser pump when it was not needed

Market Place Performance

1. It is not the complexity of the system that is the issue, but rather properly designing complex systems to perform in the long term. The double-indirect evaporative cooling with the high efficiency chiller and barrel were performing well in a non-research environment five years after installation (with the exception of the 1997 breakdown). This is because the systems were designed and built with robust components and control systems. The installed equipment was advanced in concept but used elements that were easily understood by technicians in the field. The contractors maintaining them obviously understood them.

2. The research project has demonstrated the energy reduction effectiveness of double indirect evaporative cooling in combination with high turndown-ratio high efficiency chillers, but little has been done to promote this technology in the market place.

Overall, both authors were pleased and impressed to see the degree to which the equipment installed under the ACT^2 pilot project has survived, given the advanced nature of the concepts.

Acknowledgments

The authors would like to acknowledge the assistance of Leslie Kramer of BVA in supplying some of the key design information required for this paper. We would like to thank the building owner Mr. Don Cameron, the Pacific Telesis facilities manager Mr. Joe Garcia, the facilities maintenance staff Mr. Dan Sealise and the staff from ComAir who currently maintain the HVAC system for the time and effort they took to supply us the information required to produce this paper.