ACT² PROJECT: MEASURING ENERGY SAVINGS

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ABSTRACT

Pacific Gas and Electric Company has initiated a major 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 initial pilot site design, focusing on how energy savings will be tracked and measured.

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 PG&E 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 project is a demand side demonstration analogous to a supply side demonstration, where near commercial advanced technologies are field-tested to determine actual economic and technical performance.

PG&E has chosen a "Learn by Doing" approach in the development of the project design, technology design methods, and measurement and monitoring techniques. The project planning is being done in parallel to a "pilot demonstration", with the hope that our planning will be responsive to lessons learned in pilot demonstration.

A design to maximize energy efficiency at the pilot demonstration site has been selected, and an energy monitoring system is being designed. The paper describes the pilot site design, the proposed monitoring system and the data processing and analysis system which will be used to collect and analyze the data.

INTRODUCTION

In 1990, Pacific Gas and Electric Co. (PG&E) established a project to determine whether the use of emerging energy-efficient end-use technologies would achieve substantial energy savings, perhaps as high as 75%.

This paper describes the project's goal and purpose, the pilot demonstration site design, the monitoring system currently installed at the pilot site to collect baseline data, and the data processing and analysis system (DPAS) which will accumulate, process and analyze the energy performance of the energy efficiency measures installed at each field site.

PROJECT OVERVIEW

The Advanced Customer Technology Test (ACT²) for Maximum Energy Efficiency project[1] is a research program of field experiments designed to scientifically test the hypothesis, proposed by many energy-efficiency advocates and environmentalists, that substantial energy-efficiency improvements can be achieved in buildings and other facilities at costs competitive with those of acquiring new electricity-generating supply. The strategy being used in the ACT² project is to demonstrate the maximum energy savings achievable by designing and installing optimized, integrated packages of energy-saving measures in a cross-section of residential and commercial buildings, as well as in industrial and agricultural sites, in PG&E's service territory. There are two major design constraints on these integrated packages: the packages must pass a test of projected cost-effectiveness and must be acceptable to the customer. The ultimate objective of the project is energy ***efficiency***, *i.e.*, "doing more with less energy," rather than energy ***conservation***, *i.e.*, "doing less with less energy," sometimes described as "freezing in the dark."

Background

PG&E is one of the largest investor-owned utilities in the United States, with 1990 revenues exceeding $9 billion. We serve an area of 94,000 mi² (244,000 km²) in central and northern California. In 1990, peak electric demand was near 20,000 MW, which was met with 15,000 MW of company-owned generation composed of hydroelectric, geothermal, nuclear, and natural gas-fired steam generation. The balance of load was met by purchases from non-utility generators, including significant wind and some solar photovoltaic generation, and from other utilities in the region.

The ACT² project is one of many ways in which PG&E is striving to reduce customer costs while pursuing a cleaner, healthier environment. We have concluded that sound environmental policy and sound business practice go together. A major focus of our cost reduction and environmental policies is improving customer energy efficiency (CEE). CEE decreases the need for energy production, thereby reducing impacts on the environment while deferring the cost of acquiring new generating resources. PG&E is relying primarily on energy efficiency with some load management as the cheapest and cleanest way to meet 2500 MW of the 3400 MW needed by the year 2000. Furthermore, the state agency regulating the electricity rates now allows California utilities to earn on investments in CEE through a shared savings incentive program. Consequently, PG&E is aggressively pursuing such investments; up to $2 billion will be spent on CEE over the next 10 years. By 2010, we project that we will have 3900 MW of CEE capacity. Ultimately, this strategy will benefit utility customers through relatively lower utility bills (perhaps higher rates, but lower consumption) and improved environmental quality.

Currently, to achieve our energy efficiency objectives, we rely on relatively simple, single energy efficiency measures (EEMs) for the most part. Some time about the mid- to late- 1990s, we will likely have to turn to the more complex approach of using integrated packages of energy-saving technologies to achieve additional energy efficiency levels consistent with our goals. ACT² will help to achieve these goals by determining the technological potential for energy efficiency, and exploring how it can be achieved and measured.

The ACT² project and other energy-efficiency research projects reflect growing concerns in the United States about the environment, dependence on imported oil, and global competition. New energy-saving technologies, like high-efficiency lighting, adjustable-speed-drive motors,

[1] Pacific Gas and Electric Company. *Facts on ACT²*. Issue 1. PG&E Research and Development Department, San Ramon, California, October 1990.

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and selective coatings on glazing, have led experts to project that substantial energy savings, perhaps as high as 75%, can be achieved and be cost-effective. These savings will be realized by using the most modern technologies, fully characterizing their performance, including all opportunities for savings no matter how small, and taking advantage of synergistic effects.

Projections of energy savings of this magnitude have been verified only in part, usually based on individual EEM performance. Scientifically defensible field tests of packages of these advanced technologies, integrated for maximum energy efficiency, have not yet been conducted. The ACT^2 project proposes to conduct these tests and measure the effects of component interactions on energy performance, life-cycle economics, and customer/end-user acceptance.

Project Benefits

First and foremost, the project will provide a scientific characterization of the maximum technical potential for utility customer energy efficiency, under project-specific cost-effectiveness definitions. Other major benefits include:

- providing demonstrations of modern energy-saving technologies operating successfully at customer sites, to increase utility customers' understanding of these technologies;

- identifying and developing design approaches for optimum integrated technology packages, as well as measurement and evaluation techniques, that can maximize end-use energy savings, at costs competitive with new electricity generation and new supplies of natural gas;

- providing hands-on learning about what to do and what not to do for design, installation, commissioning, measurement, evaluation and operation of new energy-saving technologies;

- revealing unforeseen benefits, like improved productivity, and problems, like deterioration of power quality; and

- providing guidance and direction for future energy-efficiency research and development (R&D).

PROJECT APPROACH

Planning and Organization

One of PG&E's environmental policies is to work with environmental groups to improve our CEE programs. We invited leading U.S. experts on environment and energy efficiency to serve as a steering committee for the ACT^2 project.[2] The committee's role is to guide the design and execution of the project to ensure valid results acceptable to the scientific and environmental communities. The committee is composed of representatives of Lawrence Berkeley Laboratory, Natural Resources Defense Council, Rocky Mountain Institute, and PG&E. PG&E's R&D department is the project manager for this multi-year effort, providing $10 million for the initial 3-year period. An additional $9 million for future years is pending regulatory approval and additional co-funding from other organizations is being pursued.

The ACT^2 mission is to provide scientific field test information 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 strategy is to demonstrate these packages in selected customer facilities, both existing and new. Each package will be optimized to maximize the energy savings subject to the constraints that the cost be less than or equal to the avoided utility costs of supply and delivery, and that it not detract from the health, productivity, *etc.*, of the customer/user. So that the costs of energy efficiency and supply can be compared, the cost of the "negawatt-hour," *i.e.*, the kWh saved, is determined by treating the investment in the energy saving package as if it were a power plant investment. The costs of natural gas savings will be determined similarly. Furthermore, since many of the candidate EEMs are just entering the market cost and are still relatively expensive, we are using "mature market" cost projections to more accurately represent the costs that will be experienced in the late 1990s.

Because of the unique character of this project, we chose a *learn-by-doing* approach for developing the project plan, energy-efficient design methods, and measurement and monitoring techniques. Overall project planning was performed concurrently with a pilot demonstration so that the planning would be responsive to lessons learned in the pilot demonstration.[3]

A pilot demonstration approach was selected because of the great risk of failure, given the high level of funding ($10 million), the high visibility of the project, and the potential negative impact of mistakes on future CEE efforts. Furthermore, host customers might be adversely affected by big mistakes, such as designs that cannot be properly installed or equipment that does not operate correctly. A pilot demonstration allows us to put technologies in the field early under tightly controlled conditions, thereby improving the likelihood that follow-on demonstrations would be properly designed, installed, operated, maintained and monitored.

PILOT DEMONSTRATION SITE DESIGN

Pilot Demonstration Building

The pilot demonstration began in 1990 in an existing office building in San Ramon, California. The site is a 22,000-ft^2 portion of the leased two-story Sunset Building occupied in part by PG&E's R&D department. The annual energy use in the test portion of the building was estimated to be 480,000 kWh and 15,000 therms. Figure 1 shows the pilot site floor plan.

The Sunset Building 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.

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[2] Pacific Gas and Electric Company. *Facts on ACT^2*. Issue 2. PG&E Research and Development Department, San Ramon, California, January 1991.

[3] Pacific Gas and Electric Company. *Facts on ACT^2*. Issue 3. PG&E Research and Development Department, San Ramon, California, March 1991.

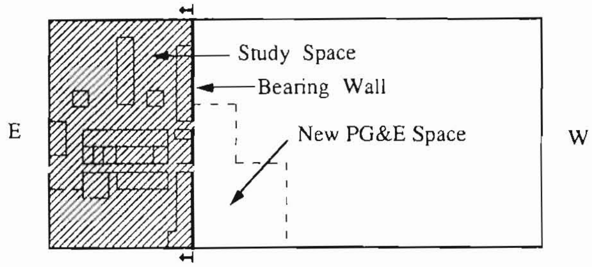

Figure 1. Pilot Demonstration Site
(Approximately 20,000 square feet)

The test space is served by three packaged rooftop variable-air-volume (VAV) air conditioning(A/C) units with common ceiling plenum air return.

Heat is provided by three rooftop forced air furnaces which supply perimeter heat only. The return air uses the same ceiling plenum as A/C units.

There are two electric panels (277/480 volt) with two 120/240 volt step down transformers for low voltage.

Natural gas is supplied at a pressure of three pounds per square inch to the furnaces and one central water heater.

The building is owned by a PG&E customer and occupied by PG&E's R&D Department.

The Design Challenge:[4,5]

To develop the approach to the pilot demonstration, the ACT[2] team discussed many options with designers and researchers from around the world. We selected a design competition because it provided a way of comparing different approaches to design and gave the competitors an incentive to be innovative.

Of 70 firms invited to participate, 11 responded. From these, we selected five firms and asked each to prepare a conceptual design for maximum energy efficiency. Each firm was paid a fixed amount for the work, so that we would own the designs and each firm would be more willing to discuss their ideas with the others.

The design firms first participated in a technology briefing to ensure that they all had up-to-date information on the latest near-commercial, energy-efficient technologies. The briefing covered HVAC design, high-efficiency lighting products and design, windows and daylighting, and high-efficiency office equipment.[6]

4 Pacific Gas and Electric Company. *Facts on ACT[2]*. Issue 4. PG&E Research and Development Department, San Ramon, California, July 1991.

5 Pacific Gas and Electric Company. *ACT[2] Design Challenge*. Report #008.1-91.13. PG&E Research and Development Department, San Ramon, California, January 1992.

6 Pacific Gas and Electric Company. *ACT[2] Technology Briefing Session Videos.*. PG&E Research and Development Department, San Ramon, California, 1991.

The firms were also provided with plans of the physical layout as well as constraints imposed by the existing structure and the building owner, followed by a walk-through of the Sunset Building. A baseline simulation model calibrated to the end-use metered data was also given to the design teams for information. The simulation results were from the DOE-2.1D building energy simulation program.[7] The design firms then had 8 weeks during which to create their conceptual designs. The design teams documented their process and conceptual designs in written reports.

In January 1991, a panel of experts in building energy efficiency was convened to decide the outcome of the design competition. Panel members included a chief HVAC designer in a large West Coast firm; a design engineer with a large public building organization; a university professor of building technology; a building researcher from a national laboratory; PG&E's corporate architect; and the building architect and mechanical engineer representing the owner of the Sunset Building.

Each design firm gave a verbal presentation to the expert panel which described how, why, and what it had done. The other design firms and the ACT[2] project team also participated. After reviewing the approaches of each firm and their proposed design concept, the panel recommended one team to design the retrofit of the pilot demonstration building. Because the other designs had interesting unique features, it also recommended that the other firms be used as consultants for the final design activities.

Overall, predicted energy savings ranged from 65% to 85%. The winning firm reviewed all five design concepts to create a final design based on the best of the concepts and approaches presented. Due to time constraints, the energy savings projections were not examined in depth, and hence these projections should be viewed as "soft" numbers.

Lessons Learned from the Design Challenge

The design challenge component of the pilot demonstration resulted in several important lessons. Some are applicable to other energy-efficiency efforts:

- Designs for large energy savings are achievable using utility economics. Four of the five firms created designs that saved more than 70% of the gas and electric energy consumption in the building.

- The design process varied somewhat across firms, and their different approaches yielded large energy savings. No specific design process is necessary to create a building design that maximizes energy savings.

- No single firm had all the good ideas; each learned something from the others' designs. The best ideas came from the experience and creativity of the designers.

- The issue of technology reliability is important for designers; they are unwilling to incorporate new products into their building designs until those products have been demonstrated to be reliable. Sizing equipment to exactly meet the load and to take advantage of synergism can also be unacceptable to building owners. Equipment sizing needs to

7 Lawrence Berkeley Laboratory. DOE-2 Supplement Version 2.1D. LBL-8706, Rev. 5. Lawrence Berkeley Laboratory, Berkeley, California, 1989.

be flexible for future unknown tenant uses and needs. Correct HVAC sizing may not make sense, even with utility economics, if all the equipment must be replaced each time a new tenant moves in. Such planned replacement may be neither reasonable nor acceptable to owners of commercial property.

• The use of utility economics opens an entire new world of technological options for saving energy, and designers need help in identifying and sorting through those options. In addition, architectural and engineering firms are unaccustomed to designing for "maximum energy savings." They are used to designing for a fixed energy use threshold or a fixed construction budget. It required a major overhaul of their conventional way of thinking to obtain the ACT^2 designs.

For the ACT^2 project, we found that good design firms could, if the design criteria and constraints were carefully defined, produce an energy-efficient design that maximizes energy savings. However, at the outset, designers must begin their investigations with a list of technologies that may fit the economic criteria. In addition, the baseline building energy simulation must be documented very carefully--many ot :he available models are inherently limited in dealing with innovative design solutions.

There is no single correct way to maximize energy efficiency; it takes creativity, innovation, and skill. Nevertheless, as shown in the pilot demonstration, it can be done--at least on paper.

Final Design for the Pilot Site

The following list represents the EEMs to be installed at the pilot demonstration site:

• Heating, Ventilation and Air Conditioning (HVAC) Changes: The three existing packaged air conditioning units will be removed and replaced with two air handlers. This will reduce the number of cooling zones from three to two, one on the north and one on the south. The two zones are split by the main hallway. Badly leaking portions of the existing ceiling ductwork will be sealed. The existing ceiling by-pass variable-air-volume (VAV) boxes will be retrofitted to true VAV. The actuators which control the VAV boxes will be converted to accept inputs from the new direct digital control (DDC) system. The ceiling air diffusers will be replaced with low-velocity Krantz or Thermafuser diffusers. The three existing perimeter furnaces for heating will remain in place but will now be controlled via the DDC system. Cooling will be provided primarily by an indirect evaporative cooler located on the roof and supplemented by two reciprocal compressors. The compressors are variable speed, staged units with a shared, over-sized heat exchange barrel. A single variable-speed cooling tower handles rejected heat. The cooling coils are two-row, low-face velocity, high-coolant velocity units and the air handlers are variable speed.

In addition, the system also incorporates economizers for increased efficiency.

• Lighting Changes: The current overhead lighting system is a grid system of manually switched, 4-tube, 4-foot fixtures. The existing fixtures will be retrofitted with specular reflectors, electronic ballasts, and T-8 lamps. The ballasts will be tunable to compensate for lumen depreciation and local conditions. Fixtures on the perimeter near the windows will be daylight-controlled (automatically dimmed). Large blocks of fixtures in the open areas will be controlled by occupancy sensors as will every enclosed office. The overhead fixtures will be connected to the DDC system which will turn off lights during unoccupied periods. The existing single tube, 4-foot undershelf task lights will be replaced with a combination of undershelf and swing-arm type PL compact fluorescent fixtures.

• Building Envelope Changes: The only change to the building envelope will be to re-glaze the south elevation of the test space with Cardinal TI-230, dual-pane heat mirror glazing. The existing blinds will stay in place.

Having a firm objective in mind (the project's mission), collecting baseline monitoring data for the pilot site and completing the final design for that site are worthwhile accomplishments, but do not deal with the heart of the ACT^2 Project: measuring energy savings.

MEASURING ENERGY SAVINGS: THE ACT^2 APPROACH

Technical Challenges

The Steering Committee and PG&E's Internal Review Committee have provided very specific guidance on what they felt were the important challenges to be faced by the ACT^2 Project. Three technical challenges were clearly articulated:

- Establish a scientific methodology.
- Consider all available energy efficiency technologies.
- Fully characterize the energy efficiency technologies.

The first challenge was to establish a scientific methodology for the project. If ACT^2 were conducted in a laboratory, then each Energy Efficiency Measure (EEM) could be carefully applied while all other features were held constant. While the results would be interesting, the real world of utility customers would not be reflected. Instead, PG&E decided that ACT^2 will be conducted at PG&E customer sites, occupied by customers. Consequently, many changes will be occurring simultaneously, and will need to be accounted for. The plan for the project sets forth a methodology for reliable "experimentation" in this complex *in-situ* environment.

The second challenge is to utilize all available EEMs in the design of maximum energy savings packages for each of the ACT^2 demonstration sites. There are literally thousands of firms, world-wide, which manufacture products that could be used to implement EEMs at ACT^2 demonstration sites. These firms are constantly engaged in new product development. In addition, many EEMs arise out of creative combinations of many products, site design features and operations and maintenance techniques. The design teams will need to identify and evaluate the most likely EEMs. Dozens of technical experts, the Design Assistance Team (DAT), has been assembled by PG&E which will assist the ACT^2 designers in identifying and evaluating the applicable EEMs.

The final challenge is to fully characterize the EEMs which are implemented at the ACT^2 demonstration sites. A

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full characterization must provide information on the reliability, service life, cost and energy performance of individual EEMs and maximum energy savings packages of EEMs. Further, the research must provide information on the impact of each EEM, and the package of EEMs, on site energy use. Both current and mature market costs must be evaluated for each EEM. In addition, a full characterization accounts for all effects that an EEM would have on each site, including effects like changes in site maintenance costs or changes in system capacity requirements. An extensive data collection system has been designed to collect and store all the data required to accomplish a full characterization of the EEMs used at ACT^2 demonstration sites.

EEM Impact Evaluation Objective

The most important question to be answered by the project is, "How much energy is saved by the EEMs implemented at each demonstration site?" The research must yield estimates of the change in site energy performance attributable to each individual EEM and the optimum package of EEMs implemented at each site. The following impact estimates are required:

1. Change in electricity consumption (kWh), by time-of-use period, and end use, which is attributable to each individual EEM and the optimum package of EEMs.

2. Change in gas consumption, by month and end use, which is attributable to each individual EEM and the optimum package of EEMs.

3. Change in peak electricity demand (kW), during the system peak period, which is attributable to each individual EEM and the optimum package of EEMs.

Changes caused by EEMs will be evaluated at both new building and retrofit demonstration sites as part of this project. For all sites, the change will be determined by comparison to the conditions that would have existed in the building if it had not been an ACT^2 demonstration site, using calibrated building simulation models. For new demonstrations, this will require the development of a model of the building that reflects how the owner *would have* built the building in the absence of ACT^2.

Data Collection Needs

Site level data must be collected to support five research activities for each ACT^2 demonstration:

1. Development of calibrated models for each site using an hourly simulation.

2. Identification of applicable Energy Efficiency Measures (EEMs) for each site.

3. Design and commissioning of EEMs at each site.

4. Evaluation of energy savings for individual and maximum energy savings packages of EEMs at each site.

5. Assessment of site environmental quality.

Development of the site data collection plan draws heavily on the experience in data collection and measurement techniques that has been gained from prior research involving the measurement of building energy performance. The plan reflects the evolution in data collection and measurement techniques that has occurred in previous and ongoing end-use metering studies such as the Seattle City Light sponsored Commercial Hourly End-Use Study (CHEUS) and Multi-Family Hourly End-Use Study (MHEUS), the BPA sponsored End-Use Load and Consumer Assessment Project (ELCAP), and the BPA Energy Edge evaluation. The plan was also influenced by the recent measurement experiences of the PG&E Commercial End-Use Metering Project (CEMP) and Appliance Metering Project (AMP).

The data collection plan for ACT^2 is distinct from baseline studies such as ELCAP and CEMP in its need to support a more thorough understanding of the performance of building energy systems and the changes that would occur in these systems as EEMs are implemented. The data collection plan for ACT^2 is also more sophisticated than the comprehensive metering studies such as Energy Edge and CHEUS/MHEUS, because the targeted levels of energy savings and the targeted technologies contemplated for ACT^2 are much more ambitious than have been attempted in prior research.

Because of the comprehensive nature of the ACT^2 data collection plan, it was necessary to supplement the experience of the research described above with the opinions of experts from around the nation who are knowledgeable in the most recent and promising techniques for measuring building energy performance. The knowledge of these experts, relevant to the data collection issues that face ACT^2, was elicited through a series of measurement workshops that were held at the PG&E's San Ramon R&D facility.

The mission statement for ACT^2 includes the requirement that only those EEMs which are "acceptable to the customer" can be included in the maximum energy savings packages that are implemented at the demonstration sites. In order to determine "acceptability," data must be collected which can be used to characterize various attributes of site environmental quality, such as indoor air quality. Site environmental quality measurement for residential and commercial buildings is a relatively new and complex discipline. As was the case for building energy performance data collection, it was necessary to assemble a panel of experts to help develop a strategy for the assessment of site environmental quality at the ACT^2 demonstration sites.

Energy Performance Measurement Strategy

Based upon the results of the measurement workshops and the experience gained from recently completed end-use research within and outside of PG&E, a measurement strategy has been developed to support the major ACT^2 activities that require measurements at each site. The measurement strategy is, in many ways, consistent with the protocol used in previous end-use research. Although the measurement strategy was constrained in several ways, such as the required use of only proven and reliable measurement techniques and the applicability to only the types of sites

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targeted for ACT², the strategy requires complex sets of data and building performance measurements. The very ambitious ACT² goal, to achieve maximum energy savings through the use of advanced EEMs, contributed to the need for a complex strategy. The ACT² goal also calls for a "scientific" assessment of the impact of these advanced EEMs, which further contributed to the need for a complex strategy.

The impact evaluation methodology selected for ACT² is based upon analysis techniques that require the use of an hourly simulation model that is calibrated with measured end use load data. The calibration process requires that data be collected to satisfy as many of the input requirements of the simulation model as possible. The necessary input data are collected from several sources, including an energy audit (building and tenant characteristics), professional judgment, and monitoring with a data acquisition system. A major role of site data collection is to provide data necessary to satisfy the simulation input requirements. The other major role for site data collection is to assist with the identification, design, commissioning and evaluation of the EEMs selected for each site.

Site level data relevant to the following aspects of building energy performance will be collected:

- Energy End-Use Consumption
- Building Envelope
- HVAC System Component Performance
- Equipment and Appliances
- Operations
- Site Climate

The pilot demonstration site provided the first opportunity to try out this complex strategy[8]. Baseline data for the site is needed to develop the calibrated building simulation models and to estimate the energy performance of the final design.

PILOT DEMONSTRATION SITE MONITORING

Detailed metering of the building's pre-demonstration energy consumption at the end-use level began in June 1990. Data are being collected in 30-minute intervals for heating, cooling, ventilation, lighting, plug loads, and major office equipment. Figure 2 compares summer season weekday and weekend energy use.

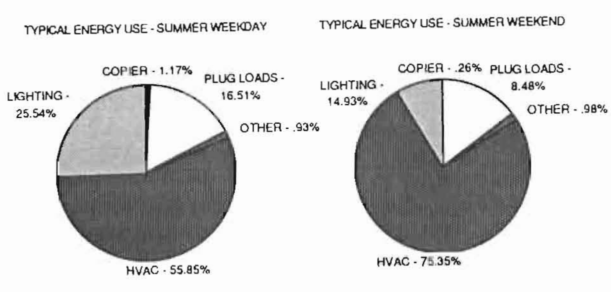

Figure 2. Comparison of Weekday and Weekend Energy Use

8 SBW Consulting, Inc., *ACT² Project Plan*. PG&E Research and Development Department, San Ramon, California, June 1991.

The building load profile is consistent with air conditioning loads dominated by internal heat gains, as the typical summer weekday energy profile shown in Figure 3 illustrates.

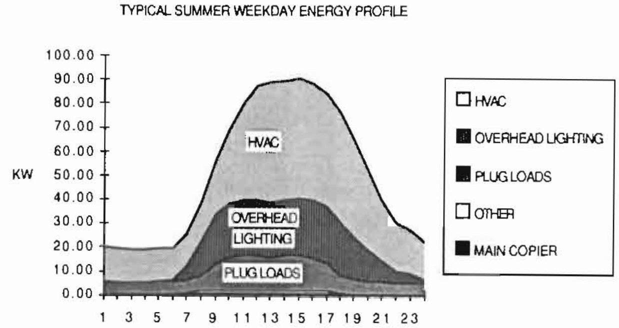

Figure 3. Typical Summer Weekday Energy Profile

Other ongoing or one-time baseline measurements include indoor temperature; indoor air quality; relative humidity; lighting quality, including lighting level, glare and flicker; power quality, including power factor and harmonics; noise level and spectrum; radon; local weather, including temperature, humidity, and solar data; and surveys of both number of occupants and their comfort. Many of these measurements are needed to characterize site environmental quality.

Results of Baseline Measurements: Indoor Air Quality Measurements

Seven possible contaminants were studied: CO, CO_2, NO_2, formaldehyde, ozone, volatile Hydrocarbons, and particulates. All measurements were within acceptable standards. No violations of any established ambient or occupational health standards were measured.

Ozone in the copy room averaged 14 ppb for a 5 1/2 hour period. The range of ozone concentrations measured was 10 to 27 ppb, with high values occurring during extended use of the photocopy machine. All other gaseous parameters were so low they were at the threshold of resolution for the analytic procedure used.

Particulates varied greatly throughout the study space, apparently due to foot traffic during the measurement period. The measurements were far below the ASHRAE recommended level of 0.365 mg/m^3 for a 24 hour period.

In terms of indoor temperature, all air temperature measurements were within the ASHRAE comfort ranges.

Radon data was also collected, and analysis of the data is currently underway.

Relative Humidity Measurements

Indoor RH ranges between 20% and 50% winter and 40% and 50% summer.

Outdoor RH ranges between 15% and 100%. (The 100% RH in the summer is due to early morning fog.)

Power Quality Measurements

Measurements were taken at the distribution panel, at the main copier, at one small copier and in several offices. Voltage distribution at the panel is in the range of 1.4% to

1.8% THD. The IEEE Standard #519 guideline is 5% THD. Load on the three phases is extremely unbalanced. Power factor ranges from .66 to .71. Current distortion ranged from 96% to 105%.

HVAC Efficiency

Figure 4 is a schematic of the existing HVAC. Measurements of refrigerant flow will be compared to measurements using air flow.

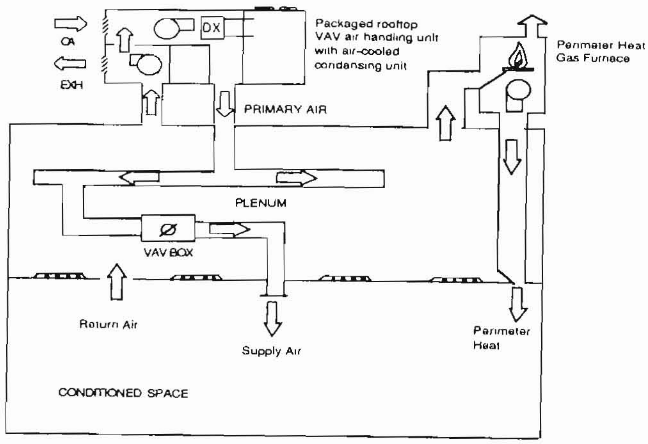

Figure 4. Existing HVAC System Schematic

The objective is to determine what portion of energy savings can be attributed to air conditioning system modifications as opposed to changes in the building envelope or heat gain changes due to more efficient lighting and different glazing.

Noise Measurements

Measurements were taken in three conference rooms, four offices and three open areas.

Noise levels measured in the conference rooms are generally at the lower range of recommended background noise, but the noise level in the largest conference room exceeds the upper range because of a noisy supply register.

Noise levels measured in the private offices are generally below or at the lower range of recommended background noise, except for one room in the upper range, again because of a noisy supply register.

Noise levels measured in the open offices are either below or within the range of recommended background noise.

Occupant Thermal Comfort Study

A thermal comfort study, designed to measure all aspects of ASHRAE Standard 55-81 and ISO 7730, was developed by staff at the University of California at Berkeley. A questionnaire was administered to 30 R&D staff members, along with actual measurements of air temperature, globe temperature, air velocity (turbulence), dew point, radiant asymmetry & illuminance at three levels. The three levels simulate a seated person's environment. The physical measurements are taken with a specially designed testing cart developed by UC Berkeley, which is placed where the occupant normally sits.

Three surveys will be taken: one before the retrofit takes place, one immediately after the construction is complete, and one six months later. The same people will be surveyed each time. During the first survey, building occupancy counts were taken at half-hour intervals for a period of three days.

DATA PROCESSING AND ANALYSIS SYSTEM

The ACT^2 Project Data Processing and Analysis System (DPAS) is the central computer system that will be used to accumulate, process and analyze all of the data collected at each demonstration site, with the exception of the data that support the assessment of site environmental quality (SEQ). DPAS will be operated by the Site Data Collection and Impact Evaluation (SDCIE) team. Although the SDCIE team will have the primary responsibility for daily operation of DPAS, the system and data products from the system will be used frequently by the ACT^2 Design and Build teams and the ACT^2 Results Communications team. DPAS has been developed by the ACT^2 Plan Implementation contractor. Once it is fully operational, it will be transferred to the ACT^2 Project SDCIE team and will be housed in their local offices.

The ACT^2 Data Processing and Analysis System (DPAS) will support the following project activities:

- Design of optimum EEM packages for each demonstration site.
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- Commissioning of EEMs at each demonstration site.
- Optimum operation of EEMs at each demonstration site.
- Evaluation of EEM impacts at each demonstration site.
- Dissemination of project results, i.e., support for results communications.

In order to meet the requirements listed above, the ACT^2 DPAS will manage data from the following sources:

- Electronic measurements taken at demonstration and control sites
- Summaries of observations made by field staff at demonstration sites and sites used to develop synthetic pre-conditions data for new building demonstrations
- Building performance simulation models
- Design Assistance Team members expert information
- PG&E's customer information system
- Climatic measurement stations

The DPAS will perform a variety of analytical and reporting functions, including:

Data Verification. This is the process by which the SDCIE team will determine whether the data collected from a site are correct. For time-series data, this is a process that must be repeated frequently and which will be automated as much as possible. However, no matter how automated the system is, SDCIE analysts will need to inspect the data in both tabular and graphical forms. DPAS will also provide those tools.

Exploratory Data Analysis. This is an important process by which relationships are identified in the data. For example, if the analyst expects a certain relationship between outside temperature and HVAC load, tools are needed for examining that relationship. Graphical techniques can be particularly powerful and PV WAVE, graphical software, will be used in the ACT^2 DPAS.

Simulation. The primary evaluation design tool ACT^2 will use is site energy performance simulation models, calibrated to actual end-use consumption, to estimate the impact of EEMs. In general, these are independent software packages. However, connections must be built between the output of these simulations and the input to the Life Cycle Costing calculations. Specifically, a facility ("module") for summarizing hourly simulation results to PG&E's marginal costing periods and placing these summarized results into a database that can be used in determining the impact of EEMs has been built.

Life Cycle Costing. A variety of Candidate EEM Specifications data and simulation results must be combined with PG&E-specific economic parameters to compute the levelized cost, benefit-to-cost ratio, and net-present-values of individual EEMs and EEM packages.

Reporting. The system will provide aesthetically appealing tables and graphs that can be used in Site Reports and as part of the ACT^2 Results Communications activities.

Figure 5 shows the DPAS design.

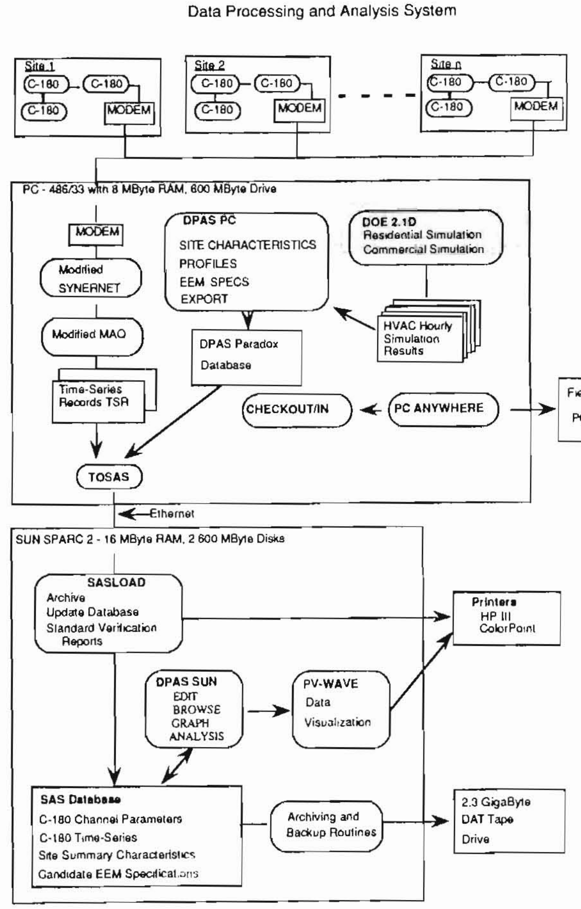

Figure 5. The Data Processing and Analysis System Design

The ACT^2 Project DPAS is a very sophisticated and complex system. Its design is based on systems used by other data collection projects and builds on the triumphs and challenges those projects faced. It is currently being tested using data from the pilot demonstration site, the Sunset Building.

FUTURE PLANS FOR ACT^2

In April 1992, retrofit construction will begin on the Sunset Building. Overall construction is expected to take approximately 4 months. At the same time, detailed energy end-use monitoring will continue so that ACT^2 will have both pre- and post-installation information on actual energy performance of the building.

In the near term, the ACT^2 team is recruiting other existing and proposed new buildings as potential demonstration sites.[9] The first-phase demonstrations will ultimately involve up to a dozen sites, the ultimate number depending on the actual cost of each demonstration, with emphasis on residential and commercial buildings. Data will be collected for two to three years to enable ongoing impact evaluations. This phase of the project will be completed by about the end of 1996.

We are currently considering whether to expand the project to another 10 to 15 sites in a second phase, to provide a better cross section of site types. To that end, 35 site types from more than 500 in PG&E's major customer sectors, residential, commercial, agricultural and industrial, have been identified and prioritized. The second phase demonstrations would start in 1993 and continue through 1998.

[9] Pacific Gas and Electric Company. *Facts on ACT^2*. Issue 5. PG&E Research and Development Department, San Ramon, California, September 1991.