ACT^2 Project: Residential Maximum Energy Efficiency

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A major California utility recently began the 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 residential and commercial buildings, and in industrial and agricultural processes, at economic costs through the use of new energy efficient end-use technologies and systems.

The goal of the ACT^2 project is to provide scientific field test information on the maximum energy savings possible by using modern high-efficiency end-use technologies in integrated packages acceptable to the customer. The test will further determine if these savings can be achieved for costs at or below projected competitive supply costs. This information will be made available for use by the utility and its customers.

The initial residential projects are, an existing and a new construction, single family homes located in California's central valley. The goal of the residential design and build team is to maximize energy efficiency by designing and installing a package of Energy Efficiency Measures (EEMs). The major source of energy reduction is expected to come from reducing or eliminating the need for compressor based mechanical cooling and significantly reducing the losses inherent in traditional forced air heating systems. The remainder of the savings will come from reducing all other appliance and lighting loads.

Introduction

The advent of highly efficient end-use technologies has led energy efficiency advocates to hypothesize that large savings are possible at costs less than new energy supply. These advocates estimate that by using these technologies in integrated packages in residences the savings might be as great as 75%. The hypothesis, however, has not been thoroughly tested.

The Advanced Customer Technology Test (ACT^2) for Maximum Energy Efficiency Project is a major research and development effort that will scientifically test this hypothesis by controlled demonstrations in typical California homes. The energy saving packages of technologies can be conceived of as "negawatt power plants," (PG&E 1990) which suggests that utilities could invest in customer energy efficiency as an alternative to building new power plants and delivery systems to meet future load growth. This concept applies to residential natural gas end-use technologies as well.

In August 1990, the utility initiated this multi-year research and development project with initial funding of $10 million through 1992 (PG&E 1990). Another $9 million has been proposed for continuing the project into 1996. It is anticipated that ultimately three existing single-family homes, three new construction single-family homes and one existing multi-family residence will be used in the ACT^2 project.

The 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:

- Site investigation, prioritization and selection;
- Contracting with home owners, builders and renters;
- 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, and reporting

To determine economic competitiveness, the investment in energy efficiency measures in a customer's home 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 can then 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 EEM's competitiveness.

Project Approach

The utility invited leading U.S. experts on environment and energy efficiency to serve as a steering committee for the project. The steering committee assumed the responsibility for guiding the project staff in the design and execution of the project, to ensure valid results acceptable to the scientific and environmental communities. Working with the steering committee and other energy efficiency experts, the project team decided that the project would be governed by two primary criteria. First, the life-cycle cost for all Energy Efficiency Measures (EEMs) must be equal to or less than the cost of building new supply. Second, all aspects of the EEM package must be acceptable to the occupant.

These two criteria provided the project unique advantages and challenges. The utility economics, which are based on 30 year life-cycle costing, remove the short payback requirements imposed on most energy efficiency projects by normal commercial requirements for a 1-3 year payback. Additionally, using life-cycle cost allows ACT^2 to take advantage of potential maintenance and operational efficiencies.

The occupant acceptance requirement presents a greater challenge than the economics. The homeowner's aesthetic requirements may prove to be a significant obstacle to the designers. The occupant will also be asked to live with technologies that they may not understand and in some instances may find threatening, for example a microwave clothes dryer or microwave light bulbs. Even though the occupant acceptance requirement may limit the amount of savings that can be achieved, installing EEM packages that are not acceptable to occupants will result in savings that can not be duplicated outside the project. It is assumed that the average person can not afford to install the advanced technologies solely for the purpose of conserving energy, or if they do, they may disconnect or remove the technology due to its complexity before the end of the life cycle savings are realized.

To ensure accuracy and analyze the results of the EEM packages, ACT^2 will be extensively monitoring each site. For existing residences the homes will be monitored for twelve months prior to package installation. The twelve months of end-use data will be used to construct a thermal and operational model of the home, using DOE-2.1E (LBL 1991) and to determine how much each end-use contributes to the total energy consumption of the home. This information will be used to establish the design and installation budget for each site. This budget will be equal to the amount of annual usage reduction that is achieved by the EEM package. If a residence annually consumes 10,000 kWh and the designers believe that they can achieve an efficiency improvement of 75% then the budget they have to work with is 7500 kWh multiplied by the net present value of the 30 year life-cycle cost of a kiloWatt-hour of avoided supply. If it is determined that 75% savings cannot be achieved economically then the design team will reduce the savings target until the savings can be achieved within the budget generated by those savings. Additionally, the designers are also restricted by end-use economics. For example, if pre-monitoring shows that 45% of the energy is consumed by the HVAC system then no more than 45% of the site budget can be spent to improve the efficiency of the HVAC system. Finally, each energy efficiency technology must meet the economic criteria individually.

For new construction the site budget, end-use budget and the site computer model will be developed from the plans for the house as it would have been built without ACT^2. Additionally, California's Title-24 building efficiency standards (CEC 1988), local weather data, and utility billing data for similar homes in the area will be used. This information will then be used in the design of the EEM package.

The design process for both existing and new construction homes will be the same. The ACT^2 Design and Build Team will do an initial evaluation of all potential EEMs for technical and economic feasibility. Those EEMs that pass the initial screening will be investigated in greater detail. Information on specific performance, potential for providing interactive savings, and mature market pricing will be gathered and analyzed by the design team. Based on this information the EEMs will be ranked by the Cost of Conserved Energy (CCE) and a supply curve will be built with the most cost effective measures ranked first.[1] EEMs will be added to the supply curve (Meier 1982) up to the point where the cost of the EEM is equal to 100% of the cost of new supply, measured in cents per kWh (see Figure 1). Whenever the inclusion of an EEM allows additional savings in a previously ranked EEM, those savings will be attributed to the EEM higher on the curve and thereby will reduce the CCE for that EEM. For

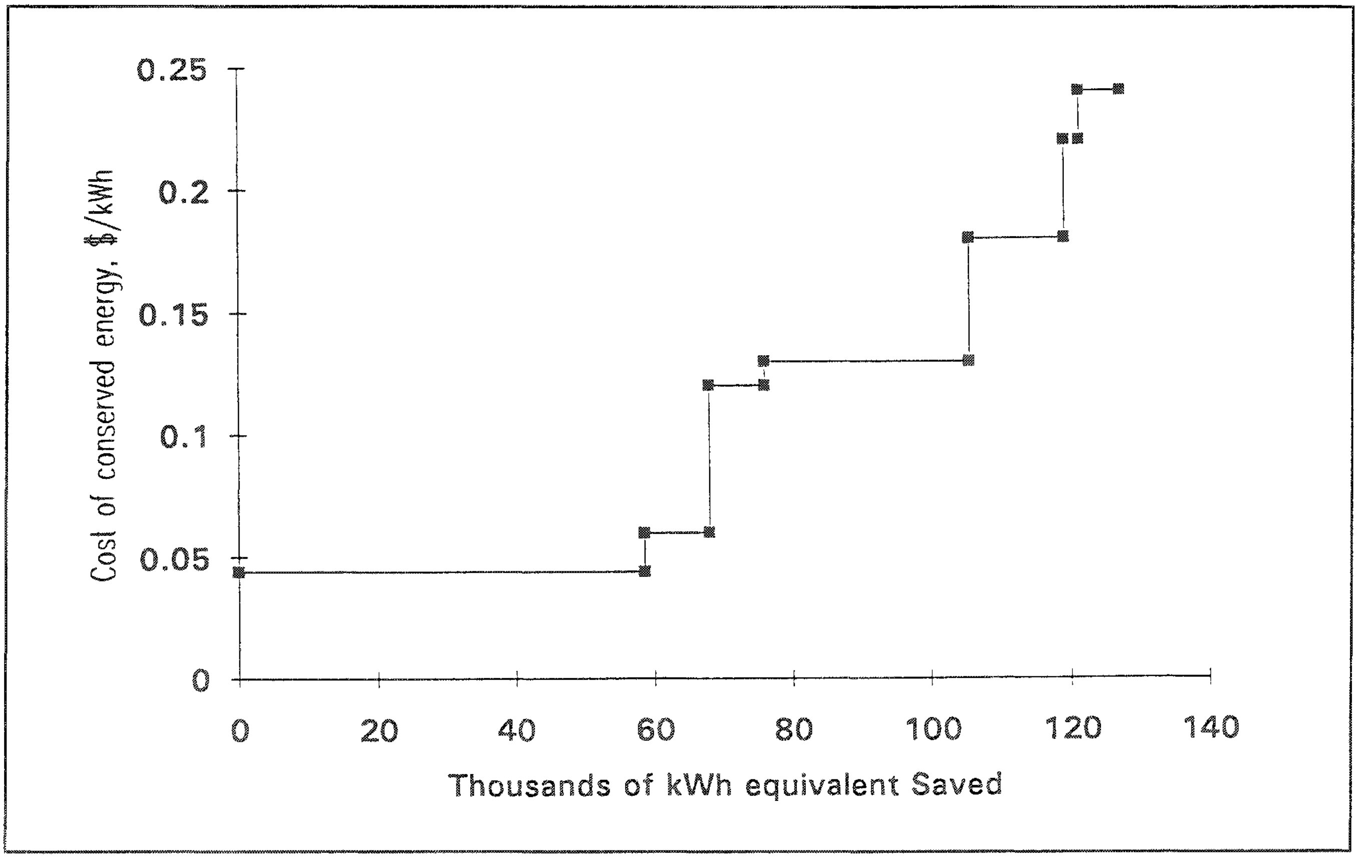

Figure 1. Sample Supply Curve

example, if high performance windows, which in California's relatively mild climate have a high CCE and are therefore high on the supply curve, allowed the down sizing of the air-conditioning unit, the dollar savings would be credited to the windows thereby moving the windows further down the supply curve. To allow the inclusion of interesting technologies which may be above the cost of new supply, and to allow for uncertainties in the mature market cost estimates, the designer will be allowed to list EEMs up to 150% of the cost of new supply. The whole package will then be reviewed by the project staff and the steering committee for design validity and to determine which EEM's with costs greater than the cost of new supply will be included in the final design.

Customer acceptance will be evaluated throughout the design process. The home owner, or builder in the case of new construction, will be interviewed regarding EEM acceptability. During the preliminary and final design phases the customer will be asked to review the technologies being considered as well as the design. Design features and/or technologies that the customer is unwilling to accept will be removed from the design and replaced with the next most efficient technology or design feature; but, if the result is too detrimental to the design, the site will be abandoned. For the design process to proceed from preliminary to final design, and then to installation, the customer must provide written approval of the design. Once the package is installed and operational the customer still has the right to require, with justification, the replacement of any technology which he or she decides is unacceptable.

Each site will be monitored for two years after the EEM package is installed. The intent of the monitoring is to measure the overall energy efficiency improvement, determine the level of interactive savings and determine effects on environmental conditions. Consequently, the project will be monitoring the individual EEMs, systems, total energy consumption and environmental conditions. During the first year ACT^2 will be responsible for operating and maintaining the EEM package. After providing the customer complete documentation and training on system operation and maintenance, the customer will assume responsibility for the systems. The purpose of the second year monitoring is to assess whether customer operation substantially effects the performance of the EEM package.

Site Selection Process

After consulting experts throughout the energy efficiency community and balancing their input against available budget, it was determined that the residential portion of the project should consist of seven sites, three new construction, and three retrofit single-family residences. The seventh site would be a small, 3-5 unit, multi-family residence. The utility's service territory was divided into three climate zones: the central valley or Inland Hot zone where air-conditioning is required from June through September; the Coastal zone where air-conditioning is not required; and the Inland Cool zone where air-conditioning is not required, and for those homes that have air-conditioning, it is used only a few days each year. One new construction and one retrofit site will be located in each climate zone. The multi-family site may be located in any of the three climate zones. See Figure 2 for a map of the climate zones. Table 1 shows heating and cooling degree days for those climate zones.

The decision to choose the three climate zones was based on the need to investigate the technical potential of customer energy efficiency within the residential customer segment. ACT^2 is using these three climate zones to provide an adequate representation of the housing stock in California. The majority of the existing homes are located in the coastal and inland cool zones, while the growth in the state is concentrated in the inland hot climate zone. In selecting specific sites, the project team will attempt to choose sites that are representative of a typical new and existing home in each climate zone.

The first site selected was an existing single-family residence in Stockton, California, a central valley (Inland Hot) community. This site was chosen from a list of 10 sites which were nominated by local utility personnel. Three of the ten were screened out because they used either wood or propane as a primary or supplemental fuel. The remaining seven sites were then visited by the site inspection team. The team gathered information at each site on occupant life-style, EEM potential, ease of monitoring, energy consumption, and type of structure. Each nominee was then reviewed by the initial site inspection team and a member of the design team to determine how closely the site approximated a typical central valley existing residence. The seven nominees were ranked and a recommendation to select one was forwarded to the steering committee for review and concurrence (SBW Consulting).

The selected site is a 2200 ft^2 (205 m^2) single-story ranch-style home (slightly larger than the average central valley home). The house was built in 1979 and has a slab-on-grade foundation, wood frame construction and a pitched wood shingle roof. The house has a ducted natural gas fired forced air furnace and electric air conditioning. The ceiling height in all but the living room, which has a 10 foot vaulted ceiling, is eight feet and the windows are all clear single pane glazing. It is occupied by a husband and wife, whose children are away at college. Both the husband and wife do some work at home resulting in energy consumption per square foot similar to other candidate sites which were occupied by families with children.

To select the central valley new construction site, California Title- 24 residential compliance calculations (CEC 1988) were reviewed for 750-1000 new homes being built in the central valley during the last six months of 1991. The review determined that the average size of new homes was 1691 ft^2 (157 m^2). Further it was determined that the majority of homes built in the central valley have slab-on-grade foundations. Consequently, any new construction home using a slab-on-grade foundation in the 1500 to 2000 ft^2 (140-190 m^2) size range was considered for participation.

The new construction site was chosen from a field of 8 nominees. The nominees included one custom home, 4 high volume tract builders and 3 low volume tract or semi-custom builders from throughout the central valley. The minimum requirement for final selection was the builder's willingness to remove a candidate site from his standard construction process in order to allow for the ACT^2 design process which will add 2-3 months to the normal design process. The second consideration was the willingness of the builder/occupant to consider changes to the original design including building exterior, orientation, shell construction, interior layout, HVAC system and appliances. The final consideration was the level of quality of the homes the builder constructs.

The first new construction site is a single family residence located in Davis, California a community in the state's central valley (Inland Hot) approximately 15 miles west of Sacramento. The nominated site was a 1656 ft^2 (155 m^2), single-story ranch-style home. The house was designed to have a slab-on-grade foundation, rustic or stucco exterior and a concrete tile roof. The interior space was intended to have 35% vaulted ceiling using a non-truss system with the remainder of the house having 8 foot ceilings. The builder is willing to consider all shell and interior changes as well as new HVAC systems and household appliances. They have agreed not to attempt to sell the home prior to completion of construction and commissioning.

The remaining five ACT^2 sites, two additional new construction, two retrofit and a multi-family retrofit, will be selected in late 1992 or early 1993. The single-family sites

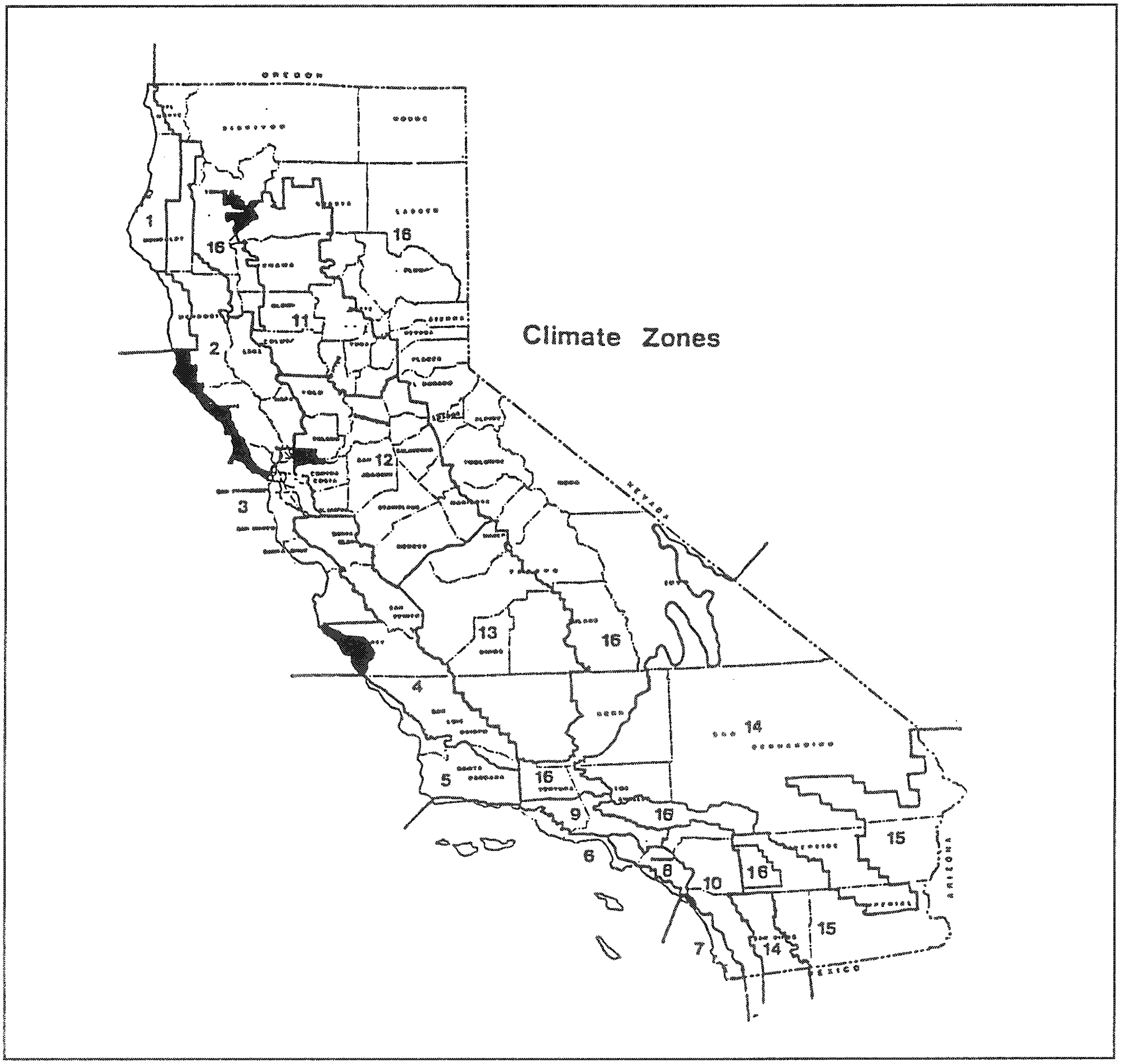

Figure 2. California Climate Zone Map

will be located in the Inland Cool and the Coastal climate zones; the multi-family site will be the last site selected.

Design Process

Traditional residential building practice has been based on repeating what worked in the past to ensure least cost construction, rather than designing each project to take advantage of site conditions. Subcontracts for all or most of the house's systems are awarded to the low bidder and subcontractors tend not to collaborate on design or installation. This process results in systems that are oversized, to provide a margin for safety, and equipment substitutions that result in lower efficiency to keep the cost down. The ACT^2 design process emphasizes designing all building systems to optimize their integrated performance. Engineers work closely with the architects, subcontractors and builders as a team to integrate all aspects of the home and capture every opportunity to maximize efficiency, reduce costs and ensure proper sizing and performance.

Table 1. Annual Heating and Cooling Degree Days (HDD & CDD) for California Climate Zones within the ACT² Project Area

	Climate Zones							
	1	2	3	4	11	12	13	16
	Arcata	Santa Rosa	Oakland	Sunnyvale	Red Bluff	Sacramento	Fresno	Mount Shasta
HDD65	4953	3026	2840	2643	2874	2697	2647	5532
CDD65	1	952	89	220	1968	1202	1844	572

The primary objective of the design process is to maximize the energy efficiency by minimizing external and internal thermal loads on the building, use the load reduction to reduce the size of the HVAC equipment, and install the highest efficiency equipment available to minimize the remaining energy consumption. This goal is achieved by paying close attention to all aspects of the design process to produce an integrated design, that captures savings generated by synergistic system interaction. For example, by reducing the heat gain through the attic, the HVAC designer may be able to reduce the size of the air-conditioning unit.

Building Envelope

The first task is to control solar gain. The cost effectiveness of a south-facing site and building orientation to take full advantage of winter solar gain will be evaluated. The envelope and glazing systems will be selected to minimizes summer solar gain, an option that will be considered is to maximize insulation and minimize east and west glazing. A high albedo roofing tile used in conjunction with radiant barrier, ridge venting and an air space between tile and barrier may have potential for lower attic temperatures (Editor 1991). It is anticipated that these type of strategies will reduce the summer cooling loads without significantly increasing cost. The increased wall insulation together with an air tight shell, to control infiltration, and high performance windows may prove to be a valuable and cost effective way to minimize winter thermal losses.

HVAC Systems

The reduced loads achieved through envelope improvements will allow down-sizing of the HVAC systems. It is believed that the cooling loads can be reduced to the point where mechanical cooling can be eliminated or replaced by indirect/direct evaporative cooling. In order to maximize energy efficiency it is necessary to minimize duct losses. The ACT² Master Technology List describes two types of residential systems; forced air and radiant slab, among others. A radiant slab heating system will be compared with a forced air heating system and may provide a cost effective means for eliminating duct losses. If a radiant system does not prove to be cost effective then particular attention will be paid to designing a well engineered and properly sized forced air system.

Plug Loads and Appliances

The appliances for the project will be selected based on their energy efficiency and customer acceptability. By choosing the most efficient models for each end-use the designers will reduce both internal gains and end-use consumption. A horizontal axis washing machine with a high spin speed is an example of an appliance that will reduce hot water consumption and required drying energy. The use of a microwave dryer can reduce the energy required to dry clothes by an additional 26% (Comments). Remaining appliances will be chosen to minimize end-use energy consumption and reduce internal heat gains. Selecting an efficient appliance may be made more difficult by the customer acceptance criteria. The appearance and operation of the appliance will be of great concern to the home occupant.

Lighting

The lighting system will receive the same detailed attention. The most efficient light sources will be used wherever and whenever possible to reduce energy consumption and internal heat gains. Attention will also be paid to system layout and aesthetic to reduce the number of fixtures when possible without sacrificing environmental quality. Where the most efficient light source can not be used or is not acceptable to the customer, the next most efficient source will be employed. Occupancy sensors and timers will be utilized to further limit lighting energy consumption without adversely affecting comfort.

Once all the building components and systems have been selected they will be reviewed to determine if any synergistic effects have created additional opportunities for reducing energy consumption. Reduced internal loads may allow further down-sizing of the cooling system. A reduction in hot water demand would provide the opportunity to reduce the hot water heater capacity or allow waste heat to provide a greater percentage of the domestic hot water needs. The final result will be a home that is the product of an integrated design process and that employs the latest, most efficient components to maximize energy efficiency.

Construction Process

The keystone of the ACT^2 construction process is continuous quality assurance from the day construction starts until building commissioning is completed. The commissioning process will also start on the first day of construction. Once construction is completed the commissioning process will continue until the home and its systems are performing as designed. Only after successful completion of commissioning will the monitoring and evaluation phase commence.

It is believed that the best design can be rendered ineffective if it is not properly carried out. If components and/or systems are installed improperly, only a commissioning process will show that the home is not operating as designed. At that point it is expensive to go back and correct the problems that good quality control procedures would have eliminated had they been in place from the beginning. Therefore, the project will strive to achieve a zero defect construction record and to meet all design criteria without corrective actions being necessary. The design and build team will be responsible for insuring quality work during the construction phase.

The construction manager, a member of the ACT^2 Design and Build Team, will brief all construction crews prior to starting each phase in which an EEM will be constructed or installed. The briefing will cover important or new construction techniques and the inspection points and criteria will be communicated so each member of the crew will know what is expected. Once construction starts the construction manager will watch the work progress and immediately correct any errors. At designated inspection points work will be stopped until the manager has inspected the work and certified proper completion.

At certain points construction will be halted to conduct specified performance tests. One such test will be performed, for new construction, when the building shell has been completed. A blower door test will be performed to determine shell tightness. If the amount of air infiltration is unacceptable, additional time will be spent identifying and eliminating leaks. Similar testing will be performed on the HVAC system components for both retrofit and new construction. At the end of construction a comprehensive set of test will be performed on both retrofit and new construction sites to characterize shell thermal performance, determine operating efficiency of the heating and cooling systems and ensure that infiltration is at or below design levels. Finally, all EEMs will be tested against the design criteria and the actual performance will be documented. Upon completion of all tests, and when the design and build team is satisfied that EEM's are performing properly, the monitoring and evaluation phase will commence.

Hurdles

The ACT^2 Project requires significant time and attention to detail to assure adherence to scientific research principles. Establishing contracts with contractors and occupants can cause significant time delays since project complexity requires detailed contracts which intimidate residential customers and extend the process.

ACT^2 has chosen to monitor and analyze the EEM packages at a level of detail which will allow the interactive effects of each end-use technology and system on the total energy consumption to be evaluated. The decision to perform detailed monitoring has resulted in a monitoring and analysis budget two to three times larger than the design and build budget. The monitoring and analysis is done for scientific purposes and therefore the costs are not considered in the economic analysis of the EEM package. However, the combined costs have seriously affected the overall project budget and reduced the number of ACT^2 residential sites.

Initially it appeared that using utility economics, which are based on 30 year life-cycle costing and a 6% discount rate, would make designing for maximum energy efficiency a relatively simple task. In actuality California's mild climate may prove to be more of a stumbling block than anticipated. The cost of heating and cooling California homes is not as significant, as it is in other parts of the U.S.; therefore, shell and glazing improvements are not as cost effective as in the more severe climates of the east coast, Midwest and south east. Innovative designs and rigorous quality assurance during construction appear necessary for the design and build team to achieve a goal as high as 75% energy savings.

Endnotes

1. The cost-of-conserved energy (CEE) is the sum of the present value of the costs times the capital recovery factor divided by the first year energy savings. The capital recovery factor converts a present-year lump sum cost to equal annual payments using an interest rate. The energy savings are in either kWh or Therms--if electricity savings are greater, then the value will be in units of kWh; otherwise, the value will be in units of Therms. Conversion from kWh to Btu is performed using the utility's average heat rate.

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