ACT^2 Project Results: Maximizing Residential Energy Efficiency

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A large U.S. utility has designed, built or retrofitted two new and two existing single family homes, one new and two existing commercial sites and collected the data necessary to test the hypothesis that substantial energy savings (perhaps as high as 75% over current practice) can be achieved economically 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, for use by the utility and its customers, on the maximum energy savings possible, at or below projected competitive supply costs, by using high-efficiency end-use technologies in integrated packages acceptable to the customer.

Three of the four ACT^2 residential sites, two new single family homes and one retrofit home, are located in California's Central Valley. The designs maximized energy efficiency by installing packages of energy efficiency measures (EEMs) that reduced the size of, or eliminated the need for, mechanical cooling in a climate with 105° F typical peak day temperatures. Additional savings were achieved by improving the efficiency of appliance and lighting loads. The two new construction designs produced projected savings of 62% and 64% in total energy consumption at mature market costs competitive with new supply. The design for the retrofit house had projected savings of 61%. ACT^2 has monitored the actual energy use at all sites for up to two years and has completed EEM performance evaluations on three of the four homes.

This paper examines the integrated designs, the technologies, monitored operations and comfort at each of the Central Valley sites. The EEM performance evaluation for one new construction site and one retrofit site will be presented. The EEM performance evaluation for the second new construction site has not been completed.

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 savings might be as high 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 has scientifically tested the hypothesis for residential use by controlled demonstrations in both conventional style new construction and existing homes in California. 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 and has spent $15 million over 6 years on two new construction single-family homes, two existing single-family homes, three commercial sites and one agricultural site to test the hypothesis.

Using the results of a computer model usage comparison or actual usage data this paper examines three of the homes only, the two new construction homes and one of the existing homes. The fourth home will not be address because it is located in a less sever climate zone and while the design significantly reduced energy consumption the failure of the cooling system during the first summer and the sale of the home prior to the second summer made it impossible to complete monitoring and evaluation.

METHODOLOGY

Site Selection

New Construction Home. To select the new construction sites in California's Central Valley, California's Title 24—Building Energy Efficiency Standards (CEC 1988) residential compliance calculation submittals were reviewed for 750 to 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 are wood frame construction with slab-on-grade foundations. Consequently, any new construction home using wood frame construction and a slab-on-grade foundation in the 1500 to 2000 ft^2 (140–190 m^2) size range was considered for participation.

The first new construction site was a single family residence located in Davis, California, a community approximately 15 miles west of Sacramento, California. The nominated site was a 1656 ft^2 (155 m^2), single-story ranch-style home. The house was designed to have a 4 inch thick concrete slab-on-grade foundation, wood or stucco exterior over 2 by 4 wood framing with 16 inch stud spacing, R13 fiberglass batt insulation, dual pane windows with vinyl frames and a concrete tile roof. In the base case design 35% of the living space would have had vaulted ceiling using a non-truss system thereby increasing interior volume. The remainder of the house would have had 8 foot ceilings. A conventional ducted forced air heating system and electric air conditioning would have been installed in the house by the builder.

The second new construction site was chosen from the remaining 7 nominees. It is located in Rocklin, California, a community approximately 30 miles northwest of Sacramento. This site was chosen because the summer climate is more severe than at the Davis site. In Rocklin, daytime temperatures average 2–3 degrees (^{0}F) higher and night temperatures remain elevated thereby increasing cooling loads.

The base case house, used for comparison purposes, was a 1,683 ft^2 (158 m^2) single story model with a lot oriented on a northeast/southwest axis. The house was planned with a 4 inch thick concrete slab-on-grade foundation, wood siding over 2 by 4 wood framing with 16 inch stud spacing, R13 fiberglass batt wall insulation, dual pane windows with aluminum frames and a concrete tile roof. The living spaces were planned with 50% vaulted ceilings, which increases interior volume, and the remainder of the space having 9 and 10 foot ceilings. The builder normally installs conventional gas forced air heating and electric air conditioning systems.

Existing Home Site Selection. The existing home site was selected from a group of six existing homes all located in California's Central Valley. The homes that were considered were volunteers who were identified by referral. All homes were owner occupied single-family detached conventional wood framed structures, ranging in size from 1500 to 3000 ft^2 (140–281 m^2). Of the houses nominated, the home that was selected was considered to be the most representative of the Central Valley housing stock. Additionally, due to ease of access, general maintenance, owner enthusiasm and stability it was viewed as being the site most likely to remain in the project for the three to fours years in would take to complete monitoring and evaluation.

The existing home site is located in Stockton, a community approximately 50 miles south of Sacramento. It is a 2,200 ft^2 (206 m^2), single-story slab on grade structure that has a pool and spa and was built in 1979. The majority of the glazing is single pane with aluminum frames and faces east. The southern side of the house is heavily shaded by a neighboring two story home and the west glazing is well shaded by roof overhangs. The walls are insulated with batt insulation (R value unknown) but insulation is missing at corners and where interior wall join exterior walls. The attic had five inches of cellulose insulation. A gas-fired central forced air heating and electric air conditioning system provided space conditioning through flexible ducts located in the attic space.

Design Model Development

New Construction Home. A DOE2.1E (LBL 1991) model was created for each site using construction drawings of the base case houses, California's Title-24 Building Efficiency Standards assumptions, weather tapes adjusted for local weather conditions, and utility billing history from similar houses which had been built by the developer within the previous 18 months. The model was used to determine base case energy use for the two new construction projects. This information allowed the designers to focus their attention on the areas of highest usage first.

Existing Home. A DOE2.1E model of the existing site was also developed. The model was calibrated using one year of monitored site weather, indoor and outdoor temperatures and relative humidities, whole house usage and end-use electric and gas consumption data. The calibration of the model was done to ensure it accurately represented house performance under various conditions.

ACT^2 Design Approach

Traditional residential building practice has been based on the concept of 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 a 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 are frequently made that result in lower efficiency to reduce costs. The ACT^2 design process emphasized designing all building systems to optimize their integrated performance. Engineers worked 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 equipment sizing and performance.

The primary objective of the design team at all sites was to maximize energy efficiency, within economic constraints, by providing the greatest possible external and internal thermal loads reduction. The load reduction achieved was used to reduce the size of the HVAC equipment; and the highest efficiency equipment available was installed , to minimize the remaining energy consumption. These objectives were achieved by paying close attention to all aspects of the design process, resulting in an integrated design that captured savings generated by synergistic system interactions.

However, customer acceptance of the technologies was an equally important aspect of the design process. Since, for the new construction sites, the ultimate customer/home owner was not available to evaluate acceptability, the builders were interviewed throughout the process regarding EEM acceptability. For the existing site the home owners were involved in the design process. During the preliminary and final design phases, the builders and home owners were asked to review the technologies being considered as well as the design. Design features and/or technologies that the builder or the home owner considered unacceptable were removed from the design and replaced with the next most viable technology or design feature.

To determine economic competitiveness, the investment in energy efficiency measures in the homes was treated as if they were a power plant, i.e., utility discount rates and 30 year life-cycle costing were used. By this treatment, the decision to make an investment in demand-side measure was made on the same basis as for a supply-side investment, and the unit costs of both options has then been compared fairly. Since many of the candidate energy efficiency measures are just emerging, estimated mature market costs, rather than current market costs, were used to more realistically reflect each EEM's competitiveness. In addition to first costs, replacement costs over the 30 year life-cycle were included in the economic analysis. Finally a B/C ratio for each EEM was calculated. EEMs with B/C ratios greater than 1 were included in the packages. EEMs that had B/C ratios less than 1 but greater that .75 were considered on a case by case basis to ensure that important technologies were not eliminated.

Schematic Design

The first design task was to optimize building configuration and glazing location. The envelope shape, perimeter length, amount and location of the glazing were analyzed. Several alternative perimeter configurations, glazing areas and glazing placement options were varied and analyzed in an effort to balance energy use and house marketability.

Preliminary Design

The Preliminary Design phase of the project for all sites consisted of three steps:

(1) EEM Screening

(2) Multiple Package Development

(3) Design Reports

EEM Screening. A Master Technology list was reviewed for each site to identify potential EEMs. Information on specific performance, potential for providing interactive savings, and mature market pricing (an estimation of the price of a product once it is mass produced in a fully competitive market) was gathered and analyzed by the design team. Based on this information the EEMs were ranked by benefit/cost ratio.

EEM Packaging. Trying to develop a single design ran the risk of not achieving the highest level of energy efficiency. Therefore, the design team was asked to develop and compare multiple packages of EEMs and then choose the one best suited to the site, the customer and the available technologies.

The ACT^2 Design and Build Team used a sequential analysis technique (Bourne 1994) to build each of the packages from the ranked list of EEMs. EEMs were 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. Whenever the inclusion of an EEM allowed additional savings in a previously ranked EEM, those savings were attributed to the EEM higher on the curve and thereby reduced the Cost of Conserved Energy (CCE)[1] for that EEM. For 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 downsizing of the air-conditioning unit, the dollar savings would be credited to the windows this would move the windows further down the supply curve, i.e. make them more cost effective. To allow the inclusion of interesting technologies which might be above the cost of new supply, and to allow for uncertainties in mature market cost estimates, the designer were allowed to list EEMs up to 150% of the cost of new supply. The multiple packages were then reviewed by the project staff and two members of the ACT^2 Steering Committee for design validity and to determine which EEMs with costs greater than the cost of new supply would be included in the final design.

Preliminary Design Report. In preliminary design the performance and cost projections for the selected EEM package was further developed and the sequential analysis was updated. The Preliminary Design Report presented the revised package of selected EEMs, including details of the design process, architectural drawings, system schematic drawings, performance calculations, product literature and the DOE2.1E model used for design. The report was presented to the builder or the home owners for review and comment before review by the ACT^2 Steering Committee, which consisted of Amory Lovins, Art Rosenfeld, Ralph Cavanagh and utilities R&D Manager.

Final Design

The final design phase was used to incorporate the review comments of ACT^2 Steering Committee and to refine the cost and performance projections for each EEM within the selected package. The sequential analysis was updated and new supply curves were generated. The Final Design was again reviewed and approved by both the builders and the ACT^2 Steering Committee. Additionally, as part of the final design phase construction drawings were prepared and finalized, and building permits were applied for and a Commissioning Plan for the proposed EEMs was written. The plan described what was to be installed, how it was to be installed and the expected operating characteristics.

Construction and Commissioning

Construction and retrofit work was closely monitored by the project to ensure that all EEMs were installed as intended by the designers. After installation was completed a commissioning team visited the sites and tested all EEMs for proper operation. They documented what they found and what was done to correct any differences between anticipated and actual energy consumption. Wherever possible the commissioning team made necessary adjustments to achieve expected EEM performance.

Results Monitoring and Impact Evaluation

As part of the construction or retrofit process a detailed monitoring system was installed, or in the case of the Stockton retrofit site, the pre-conditions monitoring system was modified, to gather performance data on all EEMs for 12 to 24 months. In addition to the end-use data, a complete weather station measured site weather conditions, indoor temperatures in each room, and average relative humidity were monitored at 15 minute intervals.

The monitored data was used in the Impact Evaluation phase of the project to calibrate the DOE2 Design Model. Once it was demonstrated that the design model accurately represented the house performance the pre-conditions models and the design models for each site were re-run using typical meteorological year (TMY) weather. The results were then compared EEM by EEM and on a total energy basis.

RESULTS

Davis Site

Description of EEMS. The Davis Site design included of 26 EEMs having a projected 62% overall energy savings and a life cycle cost savings of $3,449 using mature market economics (PG&E 1994a). While the house was well oriented on the lot, a unique form was selected for the house which minimized perimeter length and glazing area. The reduced perimeter resulted in decreased exterior wall surface area, thereby reducing overall thermal gains and losses, and the reduced glazing area decreased the heat loss in the winter. Of the two new construction sites, the Davis house provided the greatest opportunity for reducing perimeter length. The irregular shape of the base case house was changed to a rectangle, with an elongated southern elevation, reducing perimeter length by 33 feet. Glazing was concentrated on the southern elevations to maximize winter solar gains and allow architectural overhangs to shade the glazing in the summer. Total glazing area was reduced to 11% of floor area and east and west glazing were minimized. The design analysis predicted that these strategies would reduce annual space conditioning loads by 23% and reduce construction cost.

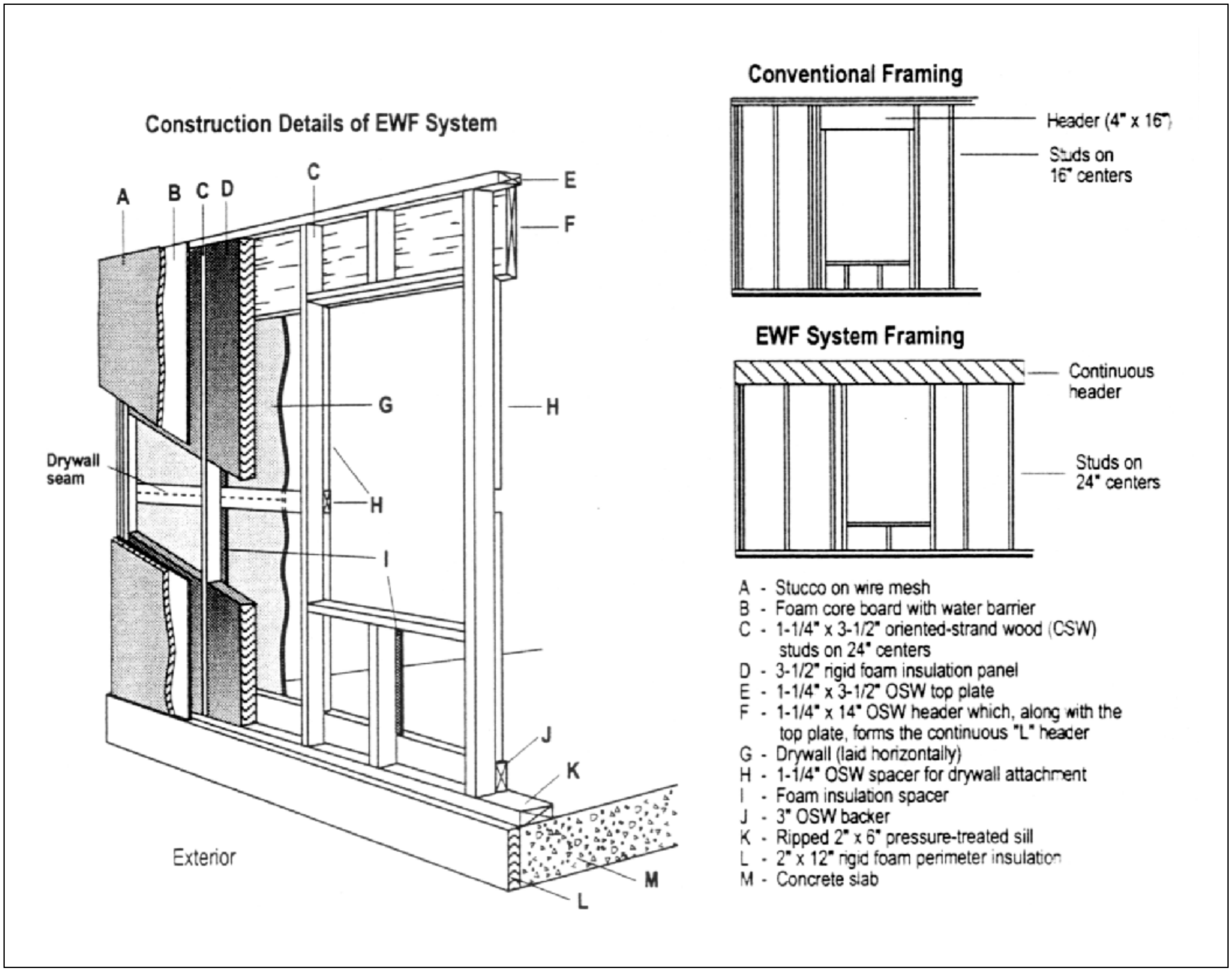
An Engineered Wall Framing (EWF) system design reduced the wood content to approximately 9% of net wall area and increased thermal resistance by using rigid foam and air gaps as shown in Figure 1.

The EWF system has a measured U-value of 0.0325 (Btu/hr-ft^2-°F) and was combined with R-38 attic insulation, a high performance glazing, insulated doors and an attic radiant barrier.

The siting, form and building envelope EEMs allowed a single high efficiency hot water heater to meet both space and domestic water heating (DHW) demand. Space heating was accomplished through a hydronic radiant floor system. Slab edge and under slab insulation were used to increase heating system efficiency. The significantly reduced cooling load made possible by the building shell EEMs made it technically and economically practical to include a ''cooling elimination'' sub-package. The need for a conventional cooling system was eliminated. This sub-package consisted of:

- increased tile floor area,

Figure 1. *Davis Site Engineered Wall Framing*



- ceiling fans,
- attic radiant barrier,
- whole house fan,
- double drywall in the living space,
- low-E gas filled glazing,
- insulated doors

The Davis house included extensive use of compact fluorescent lighting with electronic ballasts, a high efficiency dishwasher, a horizontal axis clothes washer and many other small space and non-space conditioning EEMs as listed in Table 1. The design also incorporated a high efficiency conventional refrigerator in a unique configuration which used rejected heat from the refrigerator to preheat domestic hot water.

Package Operations, Comfort and Livability. During two years of monitoring, the house performed very well, meeting both the project expectations and, more importantly the comfort expectations of the homeowners. The homeowners occupied the house in December of 1993 and have had three winters and two summers in the house. The design assumption had been a thermostat setting of 68° F; after trying that setting for two months, the homeowners changed the thermostat setting to 70° F with a night setback to 65° F, stating that the 68° F temperature was too cold. During the monitoring period, the actual average winter indoor temperature never dropped below 65° F and was seldom below 70° F with the normal day time temperature in the 72° to 76°F range. The heating system provided this level of com-

Table 1. *Davis Site Sequential EEM Order*

#	Description	Economics Summary: NPV / BCR (1)	Economics Summary: LCC (2)	Annual Energy Savings: Annual Savings therms	Annual Energy Savings: Annual Savings kWh	Annual Energy Savings: Cumm. %
1	Schematic Design	$5,198	−4347	101.0	231	12
2	High R Window Frames	$ 397	−298	13.3	17	13
3	Roof Surface Char.	$ 130	−76	−4.4	86	13
4	Engineered Wall Framing	$ 677	−456	38.5	−11	17
5	Radiant Subpackage	$1,439	−154	167.7	247	35
6	Low Flow Showerheads	$ 63	0	10.1	0	36
7	High Efficiency Exhaust Fans	$ 11	0	0.0	12	37
8	Anti-Convection Valves	11.7	4	6.7	0	37
9	High Efficiency Clothes Washer	3.6	37	14.0	32	39
10	Parallel Piping	2.8	5	2.8	0	39
11	PTV Improvements	2.8	6	2.8	0	39
12	Low Flow Lavatories	2.2	19	6.7	0	40
13	Level II Lighting Improvements	2.0	50	0.0	107	41
14	High Efficiency Refrigerator	1.9	592	−13.2	1266	50
15	Level I Lighting Improvements	1.5	650	−5.0	1062	57
16	Improved Oven	1.2	9	1.7	0	58
17	Extra DHW Tank Insulation	1.1	25	4.4	0	58
18	Refrigerator Water Heater	1.0	138	18.0	18	60
19	Cooling Elimination Subpackage	0.7	292	7.4	161	62
20	Efficient Dryer Motor	0.7	63	0.0	46	62
	Total			372.5	3274	62%

Note 1: NPV listed for EEM’s with infinite BCR’s
Note 2: Life Cycle Cost

fort with an average monthly gas consumption of 19.58 therms or approximately $11.40[2] per month from November through March.

The compressor-less cooling system worked as well as the heating system. The design assumed that the majority of cooling would be accomplished by discharging the thermal mass at night; normally through natural ventilation or, during heat storms, with the whole house fan. Unfortunately, the homeowners found it impractical to leave windows open all night for ventilation due to noise from nearby agricultural operations. Consequently, they relied on the whole house fan to cool the building mass as soon as the outdoor temperature dropped below indoor temperatures. The house was able to maintain indoor temperatures at or below 78° F through both summers with the exception of a three day heat storm in June of 1995. During this period, the peak outdoor temperatures were 98°, 101° and 105° F while the indoor peak temperatures were 78°, 80° and 83° F respectively; the homeowners stated that while the house was not comfortable it was livable during the three days of the heat wave. In 1995, the monthly average energy usage for cooling (fan energy) during the six month cooling season was 24 kWh with a cost of $2.88.

EEM Performance Evaluation. The Site Data Collection and Impact Evaluation (SDCIE) contractor used measured data for the period February 1994 through January 1995 to calibrate the Davis Site DOE2 model for heating energy use. Other models were used for other end-uses. Actual hourly lighting and plug loads were used in the DOE2 model to represent internal heat gains. The result was a model that with actual weather data can predict monthly heating energy consumption for the house to within 8% of actual consumption, hourly predictions, while not achieving the 15% project tolerance, were considered acceptable.

Comparing the calibrated base case model and the calibrated design model using TMY weather indicated that the package of EEM's achieved a total energy savings of 52% above a similar Title 24 home. These savings are ten percentage points below the predicted savings of 62%. The difference between predicted and actual savings is attributed to an over estimation of base case consumption by the uncalibrated pre-conditions model.

Stanford Ranch Site

Description of EEMs. The Stanford Ranch Site design consists of 28 EEMs having a projected 64% overall energy savings and a total life cycle incremental cost of $278 using mature market economics (PG&E 1995). Like the Davis house, the Stanford Ranch house could not be reoriented on the lot; unlike the Davis house, the Stanford Ranch lot did not have good solar orientation. The rear of the house faces southeast and the front receives a significant amount of late afternoon sun. A unique form was selected for the house which minimized perimeter length and glazing area. The reduced perimeter resulted in decreased exterior wall surface area, thereby reducing overall thermal gains and losses. The reduced glazing area decreased the window contribution total house loads. Total glazing area was reduced to 14% of floor area; because of the poor orientation it was not possible to significantly reduce east and west glazing nor was it cost effective to increase roof overhangs. Even with these handicaps the design model predicted that space conditioning loads would be reduced by 18% with these perimeter and glazing modifications.

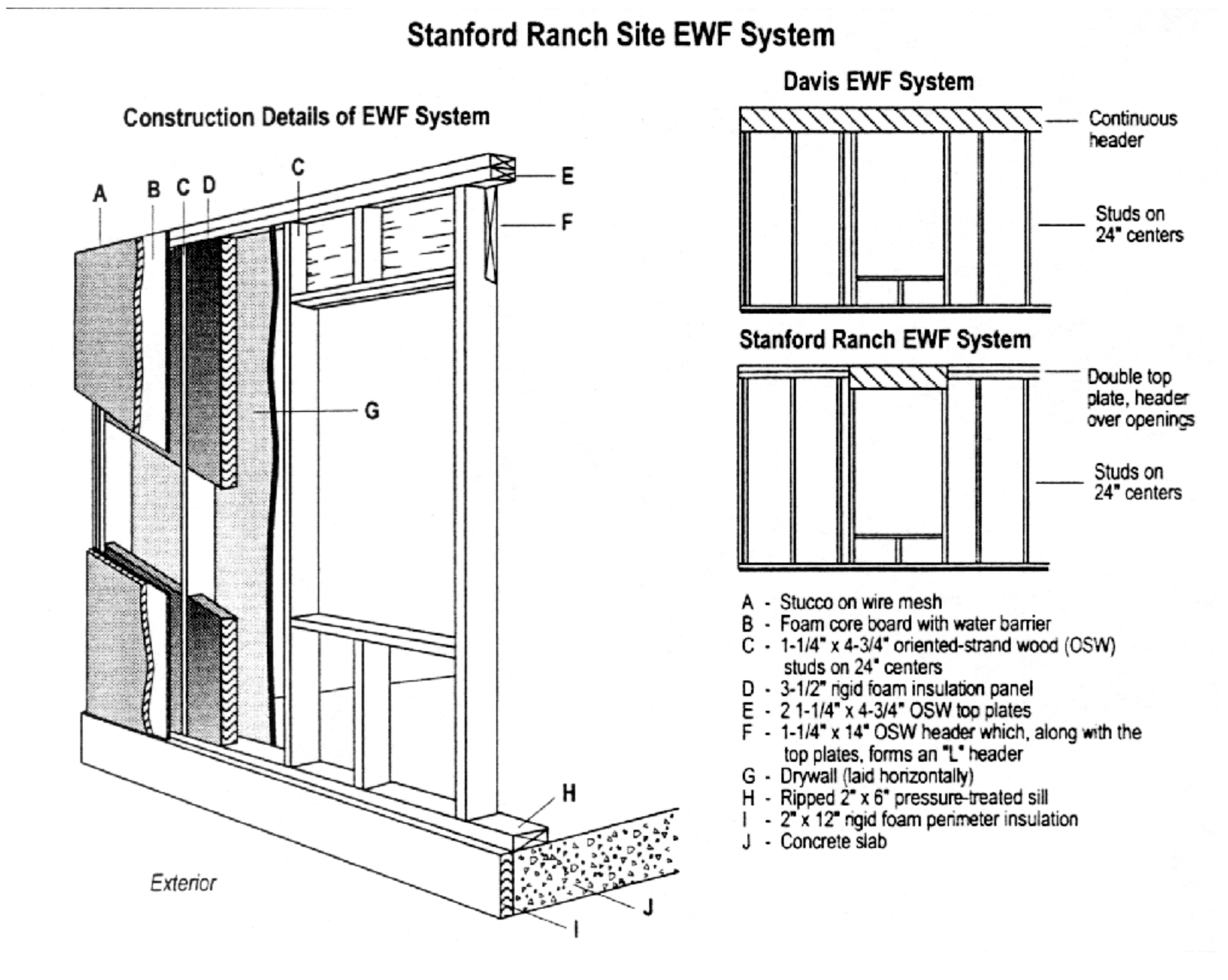
A slightly modified EWF system was incorporated into the design (see figure 2). For structural strength, the 1-1/4 by 3-1/2 inch studs were replaced by 1-1/4 by 4-3/4 inch studs on 24 inch centers, the 1-1/4 inch air space was maintained. The 1-1/4 by 16 inch continuos header was replaced with a double top plate and 1-1/4 by 16 inch headers over doors and window openings only. The interior 1-1/4 inch foam spacers were eliminated to save labor. One inch of Styrofoam insulation sheathing was added to the exterior of the framing. These changes resulted in a wall system that was less expensive to construct than the Davis site wall system and increased thermal efficiency to a calculated R-29.

The EWF system was combined with double drywall ceilings, R-38 attic insulation, high performance glazing with a high shading coefficient, insulated doors and attic radiant barrier. The greatly reduced heating and cooling loads allowed the installation of a very efficient space conditioning system which consisted of a forced air hydronic fan coil heating with a variable speed fan and a direct evaporative cooling with below slab night storage (see Figure 3).

The cooling system takes advantage of the typically increased efficiency of evaporative cooling during dry climate night conditions. Water is chilled to 60° F at night and circulated under the slab in 1000 feet of two inch plastic tubing. Evaporative cooler discharge air may be circulated through the house for ''night venting'' in response to a ''low limit'' thermostat. Cooling the ground below the slab provides thermal storage at relatively low cost. The majority of cooling is accomplished by night ventilation with the direct evaporative cooler, and passively during the day through the slab. However, during peak cooling periods when the thermostat calls for cooling, water is pumped from below the slab to a fan coil air handler and cool air is delivered to the interior spaces. This system provided overall cooling savings of 66% and reduced base case cooling demand by 4.4 KW.

Similar to the Davis site, the Stanford Ranch house included extensive use of compact fluorescent lighting with electronic

Figure 2. Stanford Ranch Site Engineered Wall Framing

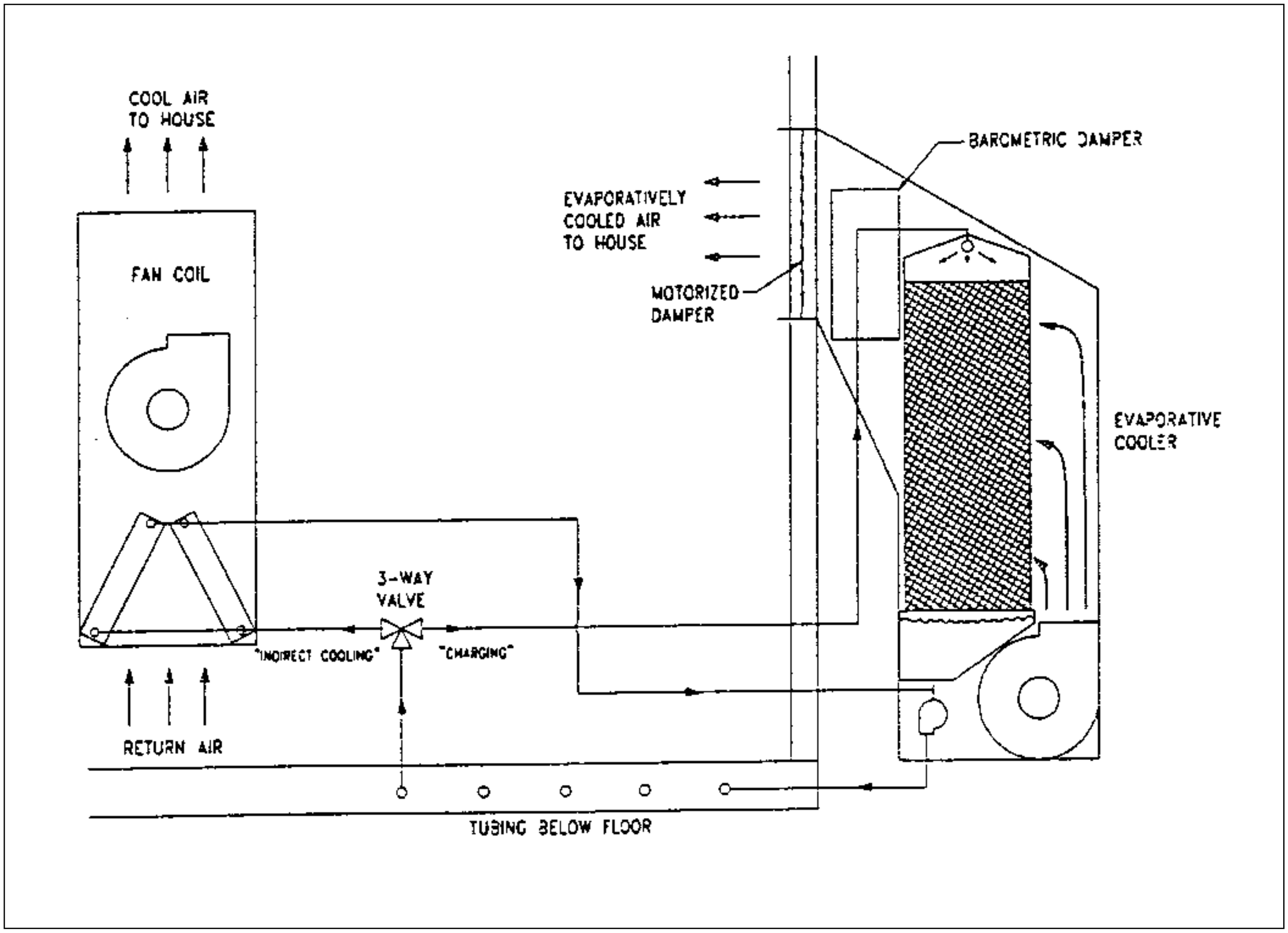


ballasts, high efficiency dishwasher, horizontal axis clothes washer and many other small space and non-space conditioning EEMs as listed in Table 2. The Stanford Ranch site was also equipped with one of the first refrigerators from the Super Efficient Refrigerator Program (SERP).

Package Operations, Comfort and Livability. The homeowner moved into the house in November of 1994 and has experienced one winter and one summer. The heating system performed up to the projects expectations. As with the Davis Site, the occupants raised the 68° F thermostat set point to 70° F with a 65° F night setback, stating that the lower temperature did not provide an acceptable level of comfort. Nevertheless, the system provided superior comfort and significant savings. The heating system was able to maintain actual indoor temperature at 70°F during the day. Even though outdoor temperatures dipped below 35°F at night, the indoor temperatures never dropped to the 65°F setback temperature; consequently, the heating system didn't operate at night. The average monthly heating usage over the seven month season was 34 kWh and 24 therms at a cost of approximately $18.48. An unexpected advantage of the system efficiency is that during normal operations the air handler's variable speed fan runs on low speed; this results in such quiet operation that the homeowner normally is not aware that the system is operating.

The evaporative cooling system had some problems during the early part of the 1994 summer. A temperature sensor malfunction kept the system from properly charging the underfloor storage and consequently the house overheated during June and July. Once the problem was corrected, the system provided an excellent level of comfort and significant energy savings. With a thermostat setpoint for cooling of 76° F during the months of August and September outdoor temperatures exceeded 105° F on 3 days, 100° F on 7 days

Figure 3. *Stanford Ranch Cooling System*



and 95° F on 15 days, the system had a peak demand of 810 watts. Total energy consumption for the indoor fan coil, which only operates when thermostat set point is reached, as shown in Figure 4, was 38.66 kWh and total cooling energy for the two months was 206.1 kWh at a cost of $24.73. Eighty-one percent (81%) the cooling was delivered by the direct evaporative cooling unit which cools in two ways. Firstly, through direct evaporative operation from 10:00 p.m. to 7:00 a.m. it exhausts and pre-cools the building mass by flushing the house (indoor temperatures can reach 65°F by 7:00 a.m.) and secondly, by passive cooling through the slab during the day.

EEM Performance Evaluation. The SDCIE contractor has completed eighteen months of data collection. The model calibration and EEM performance evaluation is scheduled for completion during the third quarter of 1996.

Stockton Site

Description of EEMs. The Stockton Site package of EEMs (see table 3) consisted of 24 separate EEMs with projected savings of 61%, a B/C ratio of 2.2, and a life cycle incremental cost of $5,746 (PG&E 1994b). The package of measures consisted of increased ceiling and duct insulation to R30 using blown-in cellulose and a box system around the ducts. The reduced heating load, which resulted from the increased insulation, allowed the heating system to be changed from forced air to hydronic baseboard and a high efficiency gas hot water heater providing both space and water heating. The cooling load was also reduced by 1 ton and a smaller more efficient air conditioning system was installed. This system consisted of a new air handler and an evaporatively precooled compressor unit.

Several measures addressed pool and spa consumption. An intermittent ignition device was installed on the spa heater to eliminate standing pilot light losses. More efficient pool and spa pumps were installed to reduce the demand and consumption, without affecting pool and spa operations.

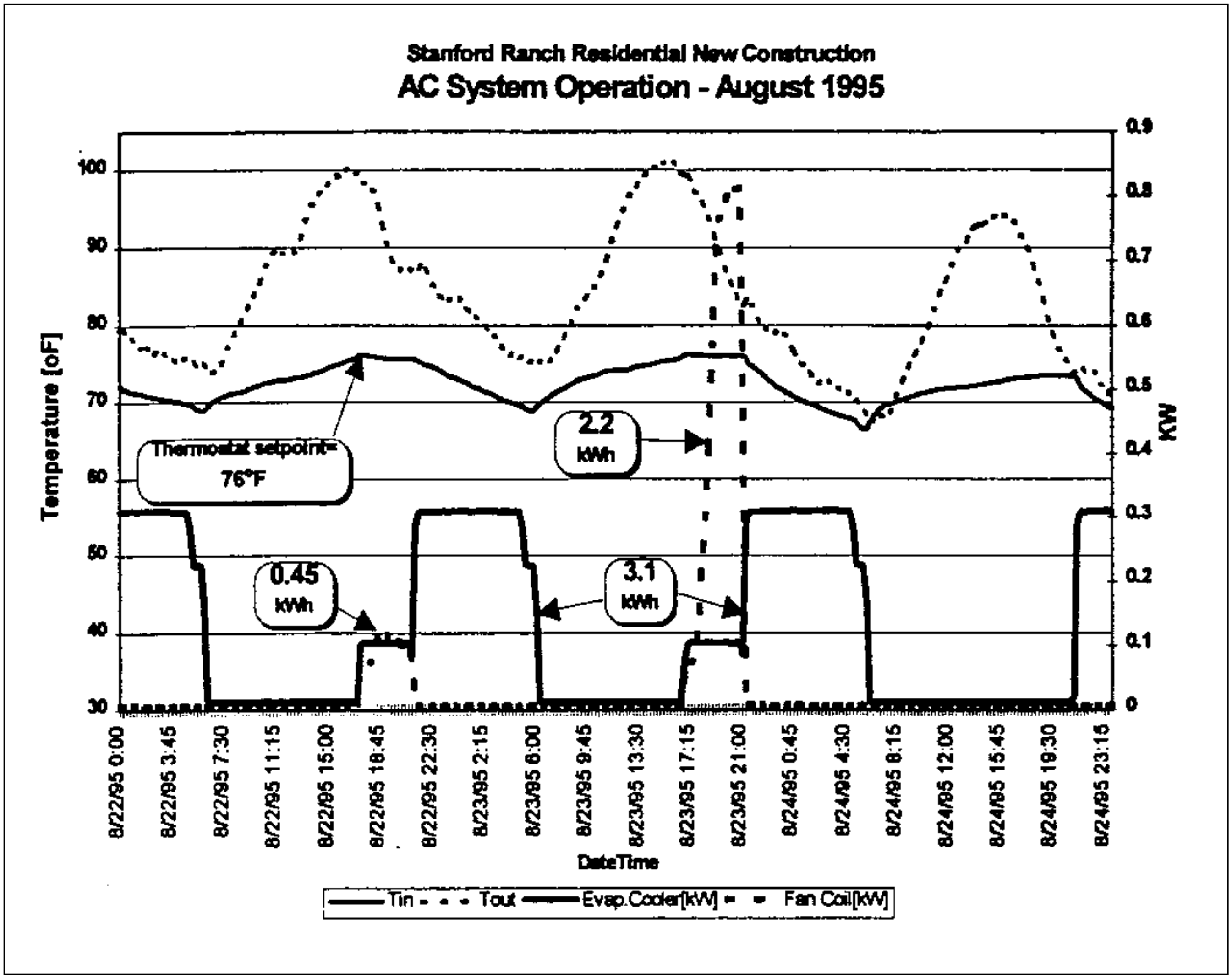
Seven EEMs were implemented to reduce the use of incandescent lighting throughout the house. T8 lamps with electronic ballasts were installed to replace incandescent or T12

Table 2. Stanford Ranch Site Sequential EEM Order

#	Description	Economics Summary: NPV / BCR (1)	Economics Summary: LCC (2)	Annual Energy Savings: Annual Savings therms	Annual Energy Savings: Annual Savings kWh	Annual Energy Savings: Cumm. %
1	Schematic Design	$2,731	−2142	62.1	207	7
2	Engineered Wall Framing	$ 509	−82	67.7	2	12
3	Low Flow Showerheads	$ 66	0	10.0	3	13
4	Light Colored Wall Surface	$ 48	−17	−2.5	48	13
5	Insulated Doors	$ 19	0	4.8	−12	14
6	High Efficiency Exhaust Fans	$ 9	0	0.0	12	14
7	Water Heater Relocation	$ 8	0	1.3	0	14
8	Tuned Glazing: S/W Low-E Cooling	58.5	2	−4.8	129	14
9	Combined Hydronic Heating	2.2	283	1200.7	−13	23
10	Anti-Convection Valves	9.2	4	5.1	0	23
11	Improved Ducts	8.9	76	33.4	500	29
12	Argon Fill (Clear Glass)	7.3	5	13.7	−53	30
13	High Efficiency Refrigerator	1.4	822	−9.2	1261	38
14	Evaporative Underfloor Cooling with Forced Air Delivery	5.4	259	0.0	1498	48
15	Outdoor Light Motion Sensor	4.6	49	0.0	239	50
16	Parallel Piping	3.9	6	3.7	0	50
17	High Efficiency Clothes Washer	3.7	33	13.9	34	52
18	Level I Lighting Improvements	2.3	382	−9.4	984	57
19	PTV Improvements	1.7	9	2.4	0	58
20	Low Flow Fixtures	1.6	30	7.7	0	58
21	Dryer Heat Recovery	1.6	27	5.9	6	59
22	High Efficiency BLower Motor and Fan	1.4	87	7.6	83	60
23	Level II Lighting Improvements	1.3	141	−2.0	212	61
24	Extra Water Heater Tank Insulation	1.1	25	4.4	0	62
25	Added Oven Insulation	1.1	9	−0.1	12	62
26	High Efficiency Dishwasher	1.1	73	6.1	42	62
27	Slab Edge Insulation	0.9	134	19.2	3	64
28	High Efficiency Dryer Motor	0.7	63	−0.4	46	64
	Total			341.3	5244	64%

Note 1: NPV listed for EEM’s with infinite BCR’s
Note 2: Life Cycle Cost

Figure 4. *Stanford Ranch Cooling System Operations*



fixtures. Halogen, krypton-filled lamps and compact fluorescent lamps were used throughout the house to replace incandescent lamps and fixtures. A SERP refrigerator/freezer replaced the existing side by side refrigerator/freezer.

Site Operations, Comfort and Livability. The increased attic insulation and the hydronic baseboard heating system have worked very well. The home owners have used a 70° F thermostat set point stating that the recommended 68° F set point did not provide adequate comfort. They rate the comfort level of the new system to be superior to the original forced air system. The heating system average energy consumption for the six month heating season was 80.8 therms and 47 kWh as compared to 130.28 therms and 109.5 kWh for the forced air system.

The efficiency of the cooling system and the comfort were greatly improved by the additional duct and attic insulation, the new air handler and the evaporatively pre-cooled condenser. During a three day heat wave when outdoor temperatures exceeded 100° F, indoor temperatures were maintained at or below 78°F. Total summer energy consumption for the new system was 426 kWh as compared to 1,483 kWh usage by the conventional system. Cooling peak demand was also reduced by 860 watts.

The pool and spa EEMs reduced consumption by 1,211 kWh and 85 therms. The lighting improvements were responsible for 1,296 kWh savings and the SERP refrigerator saved 1,263 kWh.

EEM Performance Evaluation. The Site Data Collection and Impact Evaluation (SDCIE) contractor used measured data for the period August 1994 through July 1995 to calibrate the Stockton Site DOE2 model, to estimate heating energy. Other models were used for other end-uses. Actual

Table 3. *Stockton Site Sequential EEM Order*

#	Description	Economics Summary		Annual Energy Savings		
		NPV / BCR (1)	LCC (2)	Annual Savings therms	kWh	Cumm. %
1	Krypton bulbs	$ 9	−5	0.0	5	0
2	Crankcase heater control	$80	0	0.0	103	0
3	Efficient computer/printer	$97	0	−2.4	101	1
4	Spa controls	23.3	20	76.0	0	4
5	Eliminate attic vent fan	19.4	5	0.0	103	4
6	Setback thermostat	19.3	72	177.7	295	12
7	Efficient dryer	10.1	10	−2.1	117	13
8	Anti-convection valves	9.2	4	5.3	0	13
9	Spa heater IID	7.3	124	145.0	0	19
10	Evaporative precondenser	6.2	52	−0.8	050	20
11	SERP referigerator	5.2	215	−36.1	1427	23
12	Ocupancy sensors	3.5	101	−12.1	458	24
13	Efficient pool pump	2.7	520	0.0	1509	30
14	Low temperature dishwashing	2.3	34	12.4	0	30
15	PTV improvements	2.2	8	2.8	0	30
16	Baseboard hydronic & condensing WH	1.6	2066	473.9	297	51
17	Halogen PARs	1.6	55	−0.7	98	51
18	Low-flow bathroom faucets	1.3	19	4.0	0	51
19	Screw-in CFLs	1.2	161	−1.8	220	52
20	T8 fluorescents with electronic ballasts	1.2	268	−4.8	376	53
21	Efficient spa pump	1.2	238	0.0	299	54
22	Linear fluorescents	1.0	318	−5.3	386	55
23	Hard-wired CFLs	1.0	510	−7.0	587	57
24	Attic/fireplace/duct improvements	.8	915	74.1	243	61
	Total			898.5	6973	61%

Note 1: NPV listed for EEM's with infinite BCR's
Note 2: Life Cycle Cost

hourly lighting and plug loads were used in the DOE2 model to represent internal heat gains. The result was a model that could predict monthly heating energy consumption to within 9% of measured, the hourly predictions, while not achieving the project's 15% tolerance, were considered acceptable.

When the calibrated pre-conditions model and the calibrated design model were re-run and compared using TMY weather it was determined the package of EEMs achieved a total energy savings of 53% above a base case home. These savings are eight percentage points below the 61% savings predicted in the Final Design Report.

CONCLUSIONS

The ACT² Project demonstrated that integrated package of EEMs provide the opportunity for achieving whole building savings which are significantly greater than those achievable through the installation of individual EEMs. For two of the three sites presented in this paper, measured savings exceeded 50% and for all three the occupants experienced improved comfort.

The ACT² Project relied on mature market economics and 30 year life cycle costing to justify the expense of the EEMs. In order for the mature market pricing of EEMs to become reality, the housing industry must embrace energy efficiency and the integrated design process and be willing to absorb initially higher costs to build a house until volume production is achieved. The housing industry in California is unwilling to do anything that increases the cost of a house one dollar without a significant market pull, and the market wants more square footage rather than greater efficiency. Therefore, the only way for the integrated design process to gain acceptance, without regulation, is to identify or develop construction techniques and efficient technologies which can provide savings without increasing the total cost of building the house. An example of this approach is ACT²'s use of a single high efficiency water heater to provide both space and water heating at an initial cost less than that of separate furnace and hot water heater.

ENDNOTES

1. The cost-of-conserved energy (CCE) is the sum of the present value of the cost, 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.

2. Energy costs are calculated based on a rate of $.12 per kWh and $.60 per therm (100,000 Btus).

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