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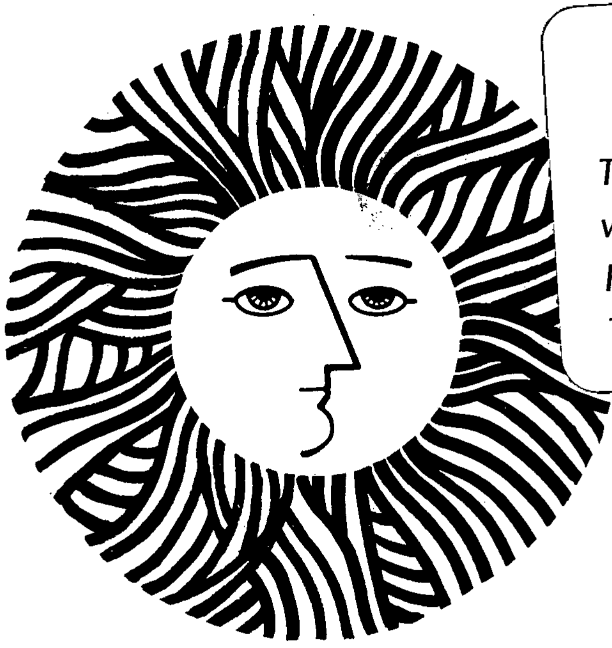

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Results of Recent Weatherization Retrofit Projects*

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ABSTRACT

Pacific Gas and Electric (PG&E) and the Bonneville Power Administration (BPA) have conducted studies in their respective service areas in order to evaluate the cost-effectiveness of certain conservation retrofits. Twenty houses in Walnut Creek, California underwent an infiltration reduction program, similar to "house doctoring." Ten of these houses also received additional contractor-installed measures. BPA retrofitted 18 houses at its Midway substation in central Washington. Retrofits made to the houses included: attic and crawlspace insulation, foundation sill caulking, storm windows and doors, increased attic ventilation, and infiltration reduction. Energy consumption and weather data were monitored before and after each set of retrofits in both projects. Leakage measurements were made by researchers from the Energy Efficient Buildings Program using blower door fan pressurization, thereby allowing calculation of heating season infiltration rates. An energy use model correlating energy consumption with outside temperature was developed in order to determine improvements to the thermal conductance of the building envelope as a result of the retrofits. Energy savings were calculated based on the results of the energy use model. As a check on these findings, the Computerized Instrumented Residential Audit (CIRA) load calculation program developed at Lawrence Berkeley Laboratory provided a theoretical estimate of the savings resulting from the retrofits. At Midway, storm windows and doors were found to save the most energy. Because the Midway houses were not very leaky at the beginning of the experiment, the infiltration reduction procedures were less effective than expected. In the Walnut Creek project, the infiltration reduction procedures did decrease the leakiness of the test houses, but the effect upon energy savings was not great.

Keywords: conservation, infiltration, insulation, retrofit, house doctoring, thermal conductance, cost-effectiveness

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INTRODUCTION

The high marginal costs of new supplies of gas and electricity are forcing many utilities to consider ways of using energy more efficiently. Residential customers consume 25% of end use energy supplied by the nation's utilities, therefore, conservation in the residential sector is a large potential source of "new" energy and a significant number of utilities have conducted projects to determine the optimum set of residential conservation retrofits for their service area [1]. Within the last two years, the Energy Efficient Buildings Program at Lawrence Berkeley Laboratory has participated in the design, implementation and analysis of two such projects: one with the Bonneville Power Administration (BPA) [2] and the other with Pacific Gas and Electric (PG&E) [3].

The BPA project, a two-stage effort, was conducted in 18 occupied, BPA-owned houses at the Midway substation near Hanford, Washington, in order to evaluate the energy savings and cost-effectiveness of several different conservation retrofit strategies: insulation of attics and crawlspaces, installation of storm windows and doors [4], and reduction of infiltration through application of some of the techniques of "house doctoring" [5,6]. The PG&E project was conducted in 40 houses in Walnut Creek, California, a suburb of San Francisco. The project was designed to measure the marginal energy savings resulting from the addition of house doctoring to an energy audit. This paper describes the results of both projects.

SITE AND PROJECT DESCRIPTIONS

Midway

Midway is located in the arid southeastern part of Washington. The area experiences approximately 4,600 heating degree days (base 65 ^{o}F) per year with a low average wind velocity (7 mph). The 18 houses at the substation, built between 1945 and 1968, are wood frame, single-family, detached structures. They use only electricity as an energy source and have almost identical space heating equipment. During the project, house occupants paid a flat monthly fee for electricity. The 15 older houses were constructed with 2 inches of mineral wool insulation in the ceiling and exterior walls; the remaining three have six inches of fiberglass in the ceiling and 1.5 inch batts in the walls. The 15 older houses have double-hung wooden windows; the three newer ones, horizontal aluminum sliders. Prior to the retrofits, most of the double-hung windows had interlocking metal tracks that functioned as partial weatherstripping, and most exterior doorways had old, ineffective brass weatherstripping.

In 1978, BPA installed electric submeters in each of the 18 houses in order to monitor total electric, water heat, space heat and air conditioning energy consumption. Air temperature, wind speed and direction, and solar insolation were measured at a central site. House interior temperatures were not measured. For the purposes of the project, the 18 houses were divided into three groups, or cells (with six houses per cell), each receiving a different set of retrofits. In late 1979, BPA began its first set of conservation retrofits to Cell 2 and Cell 3 houses (Cell 1 served as a control group for Phase I), consisting of: 1) an increase in attic insulation with loose-fill fiberglass from approximately R-10 to R-30; 2) installation of R-19 fiberglass batts in the crawlspace secured to the interior perimeter of the foundation wall and, where appropriate, a vapor barrier on the crawlspace floor; 3) an increase in attic ventilation through addition of soffit and ridge vents; 4) caulking of the foundation sill plate; and 5) (Cell 3 houses only) installation of storm doors and windows. Before and after installation of the measures, a two-person team from LBL measured leakage areas in the houses using blower door fan pressurization [7].

In the fall of 1980, LBL researchers and BPA employees undertook an air infiltration reduction program similar to house doctoring in the houses of Cells 1 and 3 (with Cell 2 serving as the control). Houses in Cell 1 received approximately 22 person-hours of work, while those in Cell 3 each received about 10 person-hours. Pressurization measurements made before and after the procedure allowed an evaluation of the reduction in leakage areas resulting from the procedure. A general list of the retrofits performed in Cells 1 and 3 is presented in Table 1. Cost breakdowns for the two phases of the project are shown in Table 2.

Walnut Creek

Walnut Creek is located east of San Francisco, some 30 miles inland, with winters shorter and colder (and the summers warmer) than cities located around the San Francisco Bay. The area experiences 2,900 heating degree days per year (base 65°F), close to the average for PG&E's service territory. The housing in Walnut Creek is of reasonably uniform construction and of a type common in northern California. The houses chosen for the study, built between 1956 and 1969, were all single-story, stucco or frame detached structures with low attics and crawl-spaces. All were heated by forced-air natural gas furnaces and none contained more than nominal amounts of weatherization retrofits prior to the start of the project.

The project was conducted over the course of two heating seasons (1979-80, 1980-81). In order to measure the effect of house doctoring, four treatments were compared: 1) a PG&E "Home Energy Use Survey" that included 2 person-days of audit and house doctoring; 2) an Energy Use Survey only; 3) a "full retrofit" including house doctoring and conventional contractor retrofits; and 4) no treatment (control). Houses were chosen from a sample of 615 on three contiguous meter reading routes. Utility bills were analyzed to find houses with a good correlation between average daily gas use and local degree days. Through a detailed selection procedure, the sample was narrowed down to 40 houses, with 10 in each group. No participant was informed of the existence of the other groups in the experiment.

The house doctors spent an average of 14 person-hours in each house performing infiltration reduction procedures, installing hot water conservation devices and changing furnace filters. For legal reasons, water heater insulation and intermittant ignition devices were installed by other PG&E employees. After completion of the house doctor procedure, a Home Energy Use audit was performed. Table 1 describes the treatments received by the houses and Table 2 lists the costs of the retrofits made to the Walnut Creek house.

Table 1: Infiltration Reduction and Other Retrofits Made to the Midway and Walnut Creek Houses

Retrofit and Location	Midway	Walnut Creek
House Interior		
Install outlet and switch plate gaskets	all houses	most houses
Caulk baseboard heaters	all	N/A
Caulk air conditioner penetration through wall	all	most
Cover air conditioner with polyethylene	some	none
Caulk circuit/fuse boxes	all	some
Caulk plumbing penetrations	all	all
Caulk electrical penetrations	all	all
Seal light fixtures	all	all
Caulk window and door frames	all	some
Weatherstrip windows and doors	all	some
Install door sweep	all	all
Attic		
Weatherstrip attic hatch	all	all
Caulk around plumbing vent pipes	some	all
Seal dropped ceilings	some	all
Stuff fiberglass into large openings	some	all
Caulk around light fixture penetrations	some	all
Caulk electrical penetrations	all	all
Seal wall/ceiling joints at top plate	some	all
Basement or Crawlspace		
Weatherstrip crawlspace hatch or basement door	all	all
Weatherstrip crawlspace vent doors	some	none
Install or repair crawlspace vent doors	some	none
Caulk plumbing penetrations	all	all
Caulk electrical penetrations	all	all
Caulk cracks in subfloor	some	none
Seal joint between foundation and sill plate	some	none
Seal top and bottom of band joist	some	none
Weatherstrip basement windows	some	none
Caulk basement window frames	some	none
Stuff fiberglass into large openings	all	all
Other		
Install low-flow showerheads and other devices	none	most
Change furnace filter	none	most
Install intermittent ignition devices	none	most
Wrap hot water heater	none	most

Table 2: Costs of Retrofit Projects

MIDWAY PROJECT

	Cell 1	Cell 2	Cell 3
Phase I Retrofits (1979-80)	None	Attic insulation; crawlspace insulation & vapor barrier; foundation sill caulking	Attic insulation; crawlspace insulation & vapor barrier; foundation sill caulking; storm windows & doors
Average cost per house	--	$1,860	$4,032
Phase II Retrofits (1980-81)	22 person-hour infiltration reduction program	None	10 person-hour infiltration reduction program
Average cost per house	$525	--	$329

WALNUT CREEK PROJECT[a]

	Group A[b]	Group B	Group C
	Infiltration reduction; hot water conservation; water heater blanket	Infiltration reduction; hot water conservation; water heater blanket	Energy audit only
Average cost per house	$367	$367	$75

a Group D acted as a "blind" control; that is, occupants were not aware of their participation in the project.

b Group A subsequently received contractor retrofits.

Costs in this table based on information received from BPA and PG&E.

ENERGY USE MODELS

Midway

To evaluate the reductions in energy consumption caused by the Midway conservation retrofits, we employed a two-parameter model based on the equation:

$$E = K(T_b - T_o) \tag{1}$$

where

$$T_b = T_i - \frac{S + G}{K}$$

and

E is the energy supplied for space heating (kWh/day);
K is the "thermal conductance parameter" of the house (kW/^oC);
S is the energy supplied by solar gain (kWh/day);
G is the energy supplied by internal sources such as people and appliances (kWh/day);
T_b is the balance temperature (^oC);
T_o is the exterior temperature (^oC); and
T_i is the interior temperature (^oC).

In this model, daily energy consumption is a linear function of the difference between the relatively constant balance and changing exterior temperatures (ΔT). K is a constant of proportionality equal to the heat loss rate of the house per degree Centigrade. T_b, the "balance temperature," is the outdoor temperature at which space heating becomes necessary.

Conservation retrofits can affect the relationship between energy use and T_o in two ways: (1) K may decrease, reflecting a lower heat loss rate per ^oC, and/or (2) assuming that T_i, S, and G remain fixed, the balance temperature of the house is reduced (as K decreases, (S + G)/K increases, and T_i - (S + G)/K decreases). The difference in the K value of the pre- and post-retrofit models is a measure of the effectiveness of the retrofits. Energy use is affected by changes in both K and the balance temperature. Internal heat contributions (G) such as appliance energy use, occupant metabolic heat and solar gain are generally important in modelling energy use. We looked for the effects of solar gain in the data by trying to find a relationship between daily energy use and solar insolation. No such relationship was discovered. We also looked for increases in non-space heating energy use during colder months, but found nothing. Occupant metabolic heat was treated as a constant background to space heating energy use.

Although energy consumption data were available for each Midway house, we found it easiest to compare houses on the basis of an average annual energy use for each cell, normalized to a standard year and house floor area. To do this, we aggregated daily energy use for each house into seven day periods, and then normalized these quantities to floor area. The normalized seven-day energy consumption values for all houses in a cell were then added together, averaged over identical seven-day periods and plotted against outside temperature. The "thermal conductance parameter" derived from this exercise was then used to calculate annual energy consumption in the following equation:

$$E = k\,(T_b - T_o) \times (\text{floor area}) \times (\text{heating days per standard year}) \quad (2)$$

where

E is annual space heating consumption (kWh/yr.);

k is the normalized "thermal conductance parameter (K/m^2); and

all other variables are the same as previously defined.

Walnut Creek

In order to determine the effectiveness of the Walnut Creek treatments, the change in average annual energy consumption (ΔG) was calculated, based on a correlation between fuel consumption and outside temperature. Natural gas use (from utility bills) and temperature data (from a weather station seven miles away) were converted to daily averages for each billing period. The data points were fit to a two-parameter linear model:

$$E = I + C\ (DD_T) \qquad (3)$$

where

E is the average daily gas consumption (therms/day);

I is baseload gas use (therms/day);

C is the total thermal conductance of the house divided by furnace efficiency (therms/^{o}F-day);

DD_T is the average daily degree-days per day based upon a balance temperature T_b.

I represents gas use due to cooking, water heating, clothes drying etc. These sources of energy consumption have been considered independent of weather in this analysis. [C x (DD_T)] is the heating component (therms/day). C is thus the total thermal conductance of the house divided by the heating system efficiency. The balance temperature chosen for each house was that temperature that gave the largest r^2 (best fit) for the linear model for a range of values of T_b. Total annual gas consumption, G, was then calculated by the equation:

$$G = 365\ I + C\ (DD_T)_{total} \qquad (4)$$

where

C $(DD_T)_{total}$ is the total number of degree days in an average year (based upon a 30-year average ending in 1979).

G was calculated for the period before and after a particular treatment. The effect of the treatment is expressed as a percent change in G, with the uncertainty in this quantity being calculated by a method developed at Princeton University [8]. Average savings for a treatment group were calculated by weighting each individual measurement with the inverse of the variance of the measurement.

Using fan pressurization data, we calculated average heating season infiltration rates based on the LBL infiltration model and local wind and temperature data [9]. The change in heating season infiltration after treatment is one way of estimating the efficacy of the infiltration reduction portion of house doctoring. The calculation of minimum expected savings for each house doctored house was found by using the change in infiltration and the balance temperature. To this were added predicted savings for intermittent ignition devices and water heater insulation, if installed. Savings from low flow showerheads and some other measures were not included in this calculation.

RESULTS AND DISCUSSION

Midway

Tables 3 through 5 present the results of the Midway project. Table 3 presents leakage areas (in cm^2) measured during Phases I and II of the Midway project, specific leakage areas (leakage area divided by house floor area, in cm^2/m^2) and average heating season infiltration rates (in air changes per hour) derived from the leakage area measurements. As can be seen from the data, retrofits that increased the R-values of building components had negligible effects upon leakage areas, whereas measures designed to reduce infiltration--storm windows and doors and the infiltration reduction procedure--did significantly reduce leakage areas. The decrease in leakage areas due to the infiltration reduction procedure were somewhat less than might have been expected, given the amount of time spent on the procedure. (It is generally assumed that the infiltration reduction portion of house doctoring will reduce leakage areas by 20 to 40 percent, resulting in energy savings on the order of 7.5 to 15 percent [10].) This might be explained by the fact that the Midway houses were quite tight to begin with and provided little opportunity for significant tightening. Figure 1 compare pre- and post-retrofit specific leakage areas for the Midway houses with the same quantities measured for other groups of houses in North America [11]. Even before retrofitting, in terms of specific leakage area the Midway houses were among the tightest measured and compared favorably with two groups of new, energy-efficient houses in Eugene, Oregon [12] and

Rochester, N.Y. [13].

Table 4 presents results obtained from the energy-use model applied to Midway. These results are presented in terms of a normalized thermal conductance parameter, K divided by cell floor area (Watts/^oC-m^2). Table 4 also compares actual (derived from the model) and estimated energy consumption and savings resulting from the conservation retrofits. Estimated energy consumption was calculated by the Computerized Instrumented Residential Audit (CIRA) developed at LBL [14]. According to the model, houses with changes to the shell--due to increased insulation or decreased infiltration--should show decreases in both normalized thermal conductance (K/floor area, in watts/^oC-m^2) and the balance temperature, but the changes observed were not always consistent with this expectation. Changes in the balance temperature were particularly puzzling and may have reflected increased indoor temperature settings. (The phenomenon of occupants increasing indoor temperatures as a response to conservation retrofits has been observed in both England and Sweden, and may have occurred here [15].) Another unexpected result was the uncertainty in energy savings in Cells 1 and 3 as a consequence of the infiltration reduction program. The estimated standard errors shown in Table 2 and Figure 3 point up the sensitivity of energy savings to small variations in k and balance temperature.

Table 5 presents the results of economic evaluations of the cost-effectiveness of the Midway retrofits. The analyses performed were net benefits, benefit-to-cost ratio, and internal rate of return [16], and the cost of conserved energy [17] adjusted to be comparable to the present retail price of energy. The economic parameters used in the analyses are shown in the tables. Also presented are the results of the economic analyses if the 15% federal energy conservation tax credit is included, and if the BPA "Energy Buy-Back Weatherization Program" is applied. Under this program, BPA will make a one-time payment to the consumer of 29.2 cents per kilowatt-hour for the estimated total kilowatt-hours saved in a single year by installed conservation measures, or the actual cost of those measures, whichever is less [18]. Using reasonably realistic economic parameters, two of the three conservation measures (attic insulation and storm windows and doors) were found to be cost-effective at an energy price slightly greater than 2.5 cents/kWh. These results should be interpreted with some caution, however, since inclusion of a salvage value can improve a measure's apparent cost-effectiveness without a concomittant increase in the homeowner's cash flow.

Walnut Creek

Tables 3 and 4 also present the results of the Walnut Creek project. Table 3 shows leakage areas (cm^2), specific leakage areas (cm^2/m^2), and average heating season infiltration rates for 30 of the 40 houses in the project. Figure 1 includes the pre- and post-retrofit quantities for these groups of houses compared to other groups of measured houses, too. Based upon the heating season infiltration rates calculated with the LBL model, infiltration was found to account for 9 to 26% of the total heating load of each house. (Infiltration typically accounts for 25 to 40% of the heating load of a house.) The small contribution of infiltration to the heat load limited the savings available from infiltration reduction.

Table 4 shows both predicted minimum savings for the house doctored group of houses and the measured change in normalized annual energy consumption for three of the four experimental groups and for the average residence in Walnut Creek. (Data collection is not complete on the extended retrofit group.) The mean savings for each of the groups are significantly different from zero, but not from each other. The control group, while not exactly the same population as the other groups showed a 7% drop in normalized annual energy consumption. This was found to be very close to the average reduction seen in all Walnut Creek residences.

The difference between the average savings resulting from house doctoring and auditing is quite small. One possible explanation is that occupants of the audited houses simply performed more of the audit recommendations than did people in the house doctored houses. The price of natural gas increased by over 50% and the price of electricity doubled during the course of the experiment and price-induced conservation undoubtedly took place. Some of the house doctored households may have

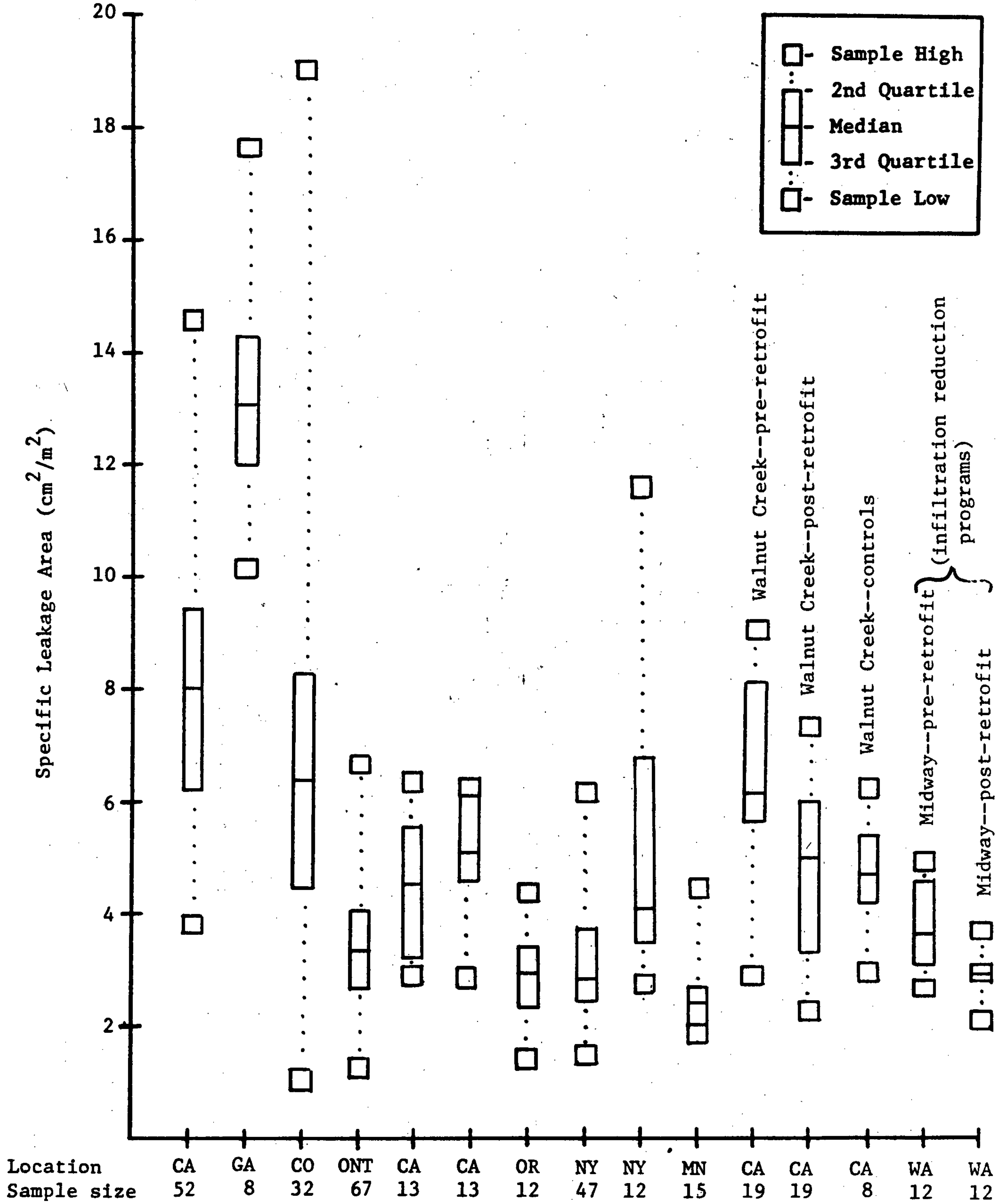

Figure 1: Specific leakage areas of retrofit houses as compared to other groups of measured houses.

Table 3: **Leakage Measurements and Predicted Heating Season Infiltration Rates**

Project	Group	# of Houses	Avg. Floor Area (m^2)	Effective Leakage Area (cm^2) Pre-retrofit	Effective Leakage Area (cm^2) Post-retrofit	Specific Leakage Area (cm^2/m^2) Pre-retrofit	Specific Leakage Area (cm^2/m^2) Post-retrofit	Heating Season Infiltration Rate (ACH) Pre-retrofit	Heating Season Infiltration Rate (ACH) Post-retrofit
Midway-Phase I	Cell 1	5	117±8	484±75	491±88	4.1±0.7	4.2±0.8	0.42±0.07	0.43±0.08
	Cell 2	6	132±37	411±73	406±40	3.4±1.1	3.2±0.8	0.35±0.12	0.33±0.08
	Cell 3	6	113±10	411±107	355±126	3.5±0.8	3.2±0.9	0.36±0.08	0.33±0.10
Midway-Phase II	Cell 1	6	115±9	487±41	358±54	4.3±0.5	3.1±0.4	0.44±0.05	0.32±0.05
	Cell 2	6	Cell 2 houses not measured during Phase II						
	Cell 3	6	113±10	396±81	318±69	3.4±0.6	2.8±0.5	0.35±0.05	0.28±0.05
Walnut Creek	Group A	10	191±59	1,104±317	940±257	6.0±1.5	5.1±1.4	0.48±0.11	0.41±0.10
	Group B	9	231±44	1,495±444	969±219	6.7±2.1	4.4±1.4	0.58±0.19	0.38±0.12
	Group C[a]	8	226±29	1,153±164	n/a	4.7±1.2	n/a	0.39±0.07	n/a
	Group D		Blind controls; not measured						

a. Active control group; represented as Walnut Creek controls in Figure 1.

Figures presented in table include standard deviations.

Table 4: Energy Modelling Results and Energy Consumption Data for Retrofit Projects

MIDWAY PROJECT

Group	Year	K/unit area[a] ($W/°C-m^2$)	Balance Temp. (°C)	Actual Energy Use (kWh/yr.)	Change in Energy Use (kWh/yr.)	Predicted[b] Energy Use (kWh/yr.)	Predicted Change (kWh/yr.)
Cell 1	1978-79	2.50±0.08	19.2±0.5	19,980±1,580	--	19,470	--
	1979-80	2.74±0.11	18.1±0.6	control year	--	control year	--
22-hr. treatment	1980-81	2.24±0.14	19.5±1.0	18,130±1,680	-1,840	18,700	-770
Cell 2	1978-79	2.64±0.12	18.5±0.8	19,800±1,470	--	18,500	--
	1979-80	2.46±0.13	17.1±0.7	16,560±1,290	-3,240	14,150	-4,350
	1980-81	2.58±0.17	16.9±1.1	17,090±1,920	+530	control year	--
Cell 3	1978-79	2.45±0.10	19.6±0.8	19,650±1,330	--	18,510	--
	1979-80	1.76±0.12	16.8±1.1	11,450±1,310	-8,200	12,100	-6,410
10-hr. treatment	1980-81	1.29±0.09	21.5±1.3	11,670±1,220	+220	11,630	-470

a Uncertainty represents standard error of estimate.
b Energy use predicted by Computerized Instrumented Residential Audit [14].

WALNUT CREEK PROJECT

Group	# of Houses	Avg. Floor Area (m^2)	Normalized Annual Energy Consumption[c,d] Pre-retrofit (kWh/year)	Normalized Annual Energy Consumption[c,d] Post-retrofit (kWh/year)	Change[e] (kWh/year)
A	6	181±51	35,750 ± 10,990	31,500 ± 9,170	-4,250
B	7	231±48	39,120 ± 7,589	34,490 ± 7,060	-4,630[f]
C	6	231±27	39,440 ± 11,460	35,280 ± 8,970	-4,160
D	5	230±50 (est.)	40,350 ± 15,560	36,980 ±12,720	-3,370

c Natural gas use in therms/year converted to kWh/year with conversion of 29.3 kWh/therm.
d Uncertainty represents standard error of estimate.
e Average change for all of Walnut Creek according to PG&E records was -1,790 kWh/year.
f Predicted minimum savings based upon retroifts made to houses was 2,990 ± 1,080 kWh/year.

Table 5: Results of Economic Analyses of the Midway Retrofit Project

Attic and Crawlspace Insulation

Retrofit Cost:	$ 1,860	**Energy Savings:**	3,240 kWh/y
Amortization Period:	30 yrs.	**Maintenance Cost:**	$ 0 /yr.
Tax Credit Value:	$ 279	**BPA "Buyback Value:**	$ 946

Real Discount Rate: 4.5 %
Energy Escalation Rate: 1.8 % **Discounted Salvage Value:** $ 627

	No Tax Credit*		Tax Credit		BPA "Buyback"	
Energy Cost (¢/kWh)	2.5	5.0	2.5	5.0	2.5	5.0
Net Benefits ($)	174	1,835	453	2,114	1,120	2,781
Benefit/Cost Ratio	1.09	1.99	1.29	2.34	2.22	4.04
Internal Rate of Return (%)	5.1	10.2	6.2	11.9	10.8	19.8

*Adjusted Cost of Conserved Energy: $6.45/MBtu

Storm Windows and Doors

Retrofit Cost:	$ 2,159	**Energy Savings:**	4,960 kWh/yr
Amortization Period:	30 yrs.	**Maintenance Cost:**	$ 50 /yr.
Tax Credit Value:	$ 324	**BPA "Buyback Value:**	$ 1,448

Real Discount Rate: 4.5 %
Energy Escalation Rate: 1.8 % **Discounted Salvage Value:** $ 288

	No Tax Credit*		Tax Credit		BPA "Buyback"	
Energy Cost (¢/kWh)	2.5	5.0	2.5	5.0	2.5	5.0
Net Benefits ($)	-142	2,402	182	2,726	1,306	3,850
Benefit/Cost Ratio	0.95	1.81	1.07	2.03	1.86	3.52
Internal Rate of Return (%)	4.1	11.0	5.1	12.8	13.3	30.7

*Adjusted Cost of Conserved Energy $7.62/MBtu

22 Person-hour Infiltration Reduction Program

Retrofit Cost:	$ 525	**Energy Savings:**	1,840 kWh/yr.
Amortization Period:	10 yrs.	**Maintenance Cost:**	$ 25 /yr.
Tax Credit Value:	$ 79	**BPA "Buyback Value:**	$ 525

Real Discount Rate: 4.5 %
Energy Escalation Rate: 1.8 % **Discounted Salvage Value:** $ 0

	No Tax Credit*		Tax Credit		BPA "Buyback"	
Energy Cost (¢/kWh)	2.5	5.0	2.5	5.0	2.5	5.0
Net Benefits ($)	-323	76	-244	155	202	601
Benefit/Cost Ratio	0.55	1.10	0.62	1.24	2.02	4.04
Internal Rate of Return (%)	0	7.2	0	10.8	50+	50+

*Adjusted Cost of Conserved Energy: $13.18/MBtu felt less of a need to undertake additional efficiency or belt tightening measures than did those in the audit or control groups. This is an effect that has been observed in other conservation retrofit projects [19]. It is interesting to note that PG&E estimates an average reduction in energy use of 9.3% in houses receiving an energy audit in their system-wide program. (Since no savings were observed in the Walnut Creek houses when compared to the controls, economic analyses of the results were not calculated.)

CONCLUSIONS

The results of these projects should not be generalized to other locations or housing stocks. The Midway and Walnut Creek houses are atypical for at least one reason: the houses were initially quite tight, hence the energy savings that could be realized by the infiltration reduction efforts were not great. Clearly, infiltration reduction programs should not be undertaken in groups of houses that are found to have low leakage areas.

Economic considerations are equally important, however. The low flat monthly fee for electricity paid by residents of Midway removed any price-induced incentive to conserve. (Indeed, they consume much more electricity than the average for the BPA service region, and there is some reason to believe that the retrofits could have induced them to be even more liberal with their energy use.) On the other hand, the Walnut Creek program seemed to show that price-induced conservation is at least as important as that resulting from weatherization retrofits.

As far as house doctoring (or a similar infiltration reduction program) is concerned, the results of these two projects are mostly inconclusive. While significant reductions in leakage areas (up to 35% in some groups) were observed, corresponding reductions in energy usage were not. This suggests that house doctoring should include more than just an infiltration reduction component; it should also include, for example, hot water heater wrapping, installation of low-flow devices, furnace tune-up and occupant education. The two experiments provided little useful information for determining which houses may be tight initially. At a minimum, in any future experiments of this sort, the housing stock to be tested should be measured beforehand with a blower door in order to ensure that retrofitting programs of this sort are worthwhile.

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