ENERGY CONSERVATION IN PUBLIC HOUSING: THE SAN FRANCISCO EXPERIENCE

Charles Goldman and Ronald Ritschard, Lawrence Berkeley Laboratory
Ronald Atkielski, San Francisco Housing Authority

ABSTRACT

The San Francisco Housing Authority, like many other public housing authorities, has faced rising energy costs in recent years. Approximately 23 percent of the Authority's $20 million 1983 operating budget was used to provide gas and electricity for the nearly 7000 conventional public housing apartments that it managed.

In 1982, the Authority began installing specified energy conservation measures financed under a zero interest loan program (ZIP) from the local utility company. The retrofit measures included attic insulation, exterior door weatherstripping, low-flow showerheads, and water heater blankets. By the end of 1983, 4082 apartments (59 percent of the Authority's units) had been weatherized at a cost of approximately $396,000.

We analyze three years of metered gas consumption data, including one year of post-retrofit data, for five family housing projects (totalling 1980 units) in an attempt to determine energy savings attributable to the retrofits. Post-retrofit energy consumption levels are 7 to 20 percent lower in the four projects that saved energy. In the fifth project, annual energy use increased by 14 percent. Overall, the Housing Authority's recent retrofit efforts in the five projects are cost-effective, with an average simple payback of 4.6 years and a cost of conserved energy of $2.50/MBtu. The Housing Authority's efforts to retain tight budgetary control over retrofit costs, which averaged only $150/unit, contributed to the program's success.

The study also examines the applicability of a building energy analysis model to multi-family buildings located in mild climates. We find that it is important to account explicitly for changes in vacancy rates in analyzing consumption patterns, particularly when evaluating the impact of retrofits in multi-family buildings with high turnover and fluctuating occupancy rates.

ENERGY CONSERVATION IN PUBLIC HOUSING: THE SAN FRANCISCO EXPERIENCE

Charles Goldman and Ronald Ritschard, Lawrence Berkeley Laboratory
Ronald Atkielski, San Francisco Housing Authority

INTRODUCTION

Improving building energy efficiency will demand increasing attention by public housing officials in this decade. Rising energy costs have created an ever-widening gap between allowable expenses and rental income collected by local housing authorities. A recent review of the topic concludes that a great potential exists for energy and cost savings in public housing.[1] Over the last decade, the U.S. Department of Housing and Urban Development (HUD) and local public housing authorities (PHAs) have sponsored major retrofit projects. In 1980, HUD awarded $23 million to 47 PHAs for modernization of their oil heating systems and another $5 million to 61 PHAs to install and test innovative energy conservation and solar measures. In addition, roughly one-quarter of the HUD modernization funds between 1975 and 1979 were used for energy conservation. Savings estimates for these programs have been based almost exclusively on engineering calculations; few evaluations of public housing retrofit efforts have relied on actual metered data.[2,3] Evaluations based on actual measured data are an important complement to engineering estimates. They provide credibility and important feedback on the accuracy of predictions, help guide retrofit investment decisions, and often raise new issues and problems that deserve further analysis.

This report is a case study of one local housing authority, San Francisco, that developed a cooperative effort with the local utility, Pacific Gas & Electric (PG&E), to finance the installation of specified energy conservation measures through a zero-interest loan program (ZIP). We analyze three years of metered consumption data, including one year of post-retrofit data, for five family housing projects (representing roughly 30 percent of dwelling units managed by the Authority) in an attempt to identify energy savings attributable to the weatherization program.* The study also explores the applicability of a building energy analysis model designed for single-family buildings to multi-family buildings located in mild climates. Analysis of conservation measures in existing multi-family buildings located in mild climates is a relatively new area. We hope that this study contributes to an increased understanding of how multi-family buildings "work" and helps focus attention on important research and policy issues.

---

* All 5 projects are master-metered although there are plans for conversion to individual meters at several sites. Space heat usage is individually metered at two other projects, Westbrook and Holly Courts (totaling 344 units); hence, they were not included in the study because the Housing Authority did not have total gas consumption.

RETROFIT AND BUILDING DESCRIPTION

Four of the five family housing projects studied are located on the east side of San Francisco, within a mile of San Francisco Bay. Each site has many relatively small (2-3 story) buildings, typically averaging 6 to 12 apartment units per building. Average per unit floor area ranges from 770 to 870 square feet among the five projects. Roughly 65 percent of the apartments are two bedroom units while one and three bedroom units each account for approximately 15 percent of the total. We found many apartments with broken or boarded windows (perhaps 3 to 5 percent of all windows) during post-retrofit site visits, suggesting that basic structural repairs are required to reduce infiltration losses. There are approximately 3.6 occupants per unit, ranging from 2.6 to 4.7 residents per unit respectively at Hayes Valley and Alice Griffith Projects.

Under the ZIP program, an interest-free loan up to $1000/unit is available for six specified conservation measures. Loans may include labor costs and are repayable over an 8 year period. Initially, PG&E and Authority staff inspected a representative sample of apartment types managed by the Authority to determine which eligible measures were suitable. Housing projects with highest estimated savings were chosen first, typically townhouse apartments with accessible attics. Bid packages were prepared for each project, containing all applicable retrofit measures - attic insulation, exterior door weatherstripping, low-flow showerheads, and water heater blankets. Bids were then requested from weatherization contractors who were certified to participate in the ZIP program.

Table I gives a description of measures installed at each project in addition to a brief summary of building characteristics. Attic insulation and exterior door weatherstripping were installed at each project and two sites with individual hot water heaters received insulating blankets. Average retrofit cost per unit was around $150, ranging from $80 to 200 among the 5 projects. Inexpensive time clocks (total cost of roughly $85/boiler but only about $3/apartment unit) were installed on central boilers at three projects in October 1982. This measure was not part of the ZIP program. The time clocks were designed to regulate the space heat water circulation pump, allowing the pump to run for 14 rather than 24 hours a day. Housing Authority staff indicated that the timers were to be disconnected if tenants at a project complained about the lack of heat. Our analysis includes the effect of the boiler time clocks although savings attributable to this measure are uncertain. Recent site visits to two projects indicated that the time clocks were not working as designed. The systems either had manual override switches in effect or the on and off tripper switches were missing from the timer dial. We have been unable to obtain information on the length of time the timers were in operation after installation before being disconnected.

ANALYSIS

The basic building energy model employed in this study uses utility billing and local weather data. The model treats fuel consumption as a constant base level plus a weather-dependent heating load. Metered energy consumption

Table I. Building and retrofit description.

Project Name	No. of Units	No. of Bldgs.	Date of Const.	Style	Heating Equipment	Retrofit Measures: Attic Insul.	Shower Head	Water Heater Jacket	Weather Strip	Boiler Time Clock
Alemany	158	24	1956	Wood-frame 2 stories	Individual gas space heaters; individual gas water heaters	X		X	X	
Potrero Terrace	469	38	1942	Concrete 2-3 stories	18 central boilers; individual forced hot water systems; group gas water heaters	X	X		X	X
Sunnydale	767	91	1942	Concrete 1-3 stories	Individual gas space heaters; individual gas water heaters	X		X	X	
Alice Griffith	258	41	1962	Wood-frame 2-3 stories	5 central boilers; individual forced hot water systems; central gas water heaters	X			X	X
Hayes Valley*										
Hayes B	170	10	1963	Wood-frame 2-3 stories	2 central boilers; Individual forced hot water systems; plant gas water heaters	X			X	X
Hayes C	140	7	1963	Wood-frame 2-3 stories	2 central boilers; Individual forced hot water systems; plant gas water heaters	X			X	X
Hayes A	18	2	1963	Wood-frame 2 stories	1 central boiler, individual forced hot water systems; plant gas water heaters.	X			X	X

* Hayes Valley is actually located at three separate sites, referred to as Hayes Valley A, B and C.

Table II. Parameter estimates for San Francisco housing authority projects.

Project Name	Pre-Retrofit [Baseload]* α	[Slope]† β	T_{ref} (°F)	NAC‡	R^2	N	Post-Retrofit [Baseload]* α	[Slope]† β	T_{ref} (°F)	NAC‡	R^2	N
Alemany	273	13.9	61	127452	0.983	11	212	15.1	63	116589	0.940	14
Potrero Terrace	1175	65.1	59	525496	0.941	11	962	54.9	62	476232	0.951	14
Sunnydale	1464	101.7	56	625261	0.967	10	1252	103.5	58	588211	0.880	15
Alice Griffith	610	18.0	70	312000	0.761	9	583	13.8	75	306322	0.763	15
Hayes Valley B	306	13.7	52	116190	0.723	10	284	4.9	67	122886	0.806	10
Hayes Valley C	224	3.6	74	103598	0.839	13	295	97.2	50	126187	0.503	8
Hayes Valley A	29	0.5	68	12759	0.749	11	29	0.7	69	13776	0.696	9

* Therms/day

† Therms/°F-day

‡ Therms/Yr

data for each housing project were obtained from monthly utility bills provided by the local utility for the period from April 1981 to March 1984. Daily maximum and minimum temperatures are taken from NOAA weather station data for San Francisco Airport. Degree-day totals for reference temperatures between 50 and 75^{o}F were computed for each billing period for each housing project.

In order to compare billing periods of different lengths, we convert both the gas and temperature data to daily averages for each period. Project consumption data are analyzed using a linear model similar to the Princeton scorekeeping method:[4,5]

$$E_j = \alpha + \beta \, (DD_R)_j \qquad [1]$$

where E_j is the average daily energy consumption over period j, and DD_R is heating degree-days per day over period j (calculated using reference temperature R).

A least-squares regression of E_j and (DD_R) with reference temperature values between 50 to 75^{o}F is run for each project. The regression with the best fit (highest R^2) is used to establish the best α, β, and reference temperature. The term α (energy use/day) is an estimate of the amount of gas use not directly influenced by the weather (i.e., baseload usage). while β is related to the building's heat loss characteristics. The term, $\beta(DD_R)$, represents an estimate of the space heating component of gas usage. We then calculate the weather-normalized annual consumption (NAC) for each project:

$$NAC = 365 * [\alpha + \beta \, (DD_R)] \; . \qquad [2]$$

The NAC is the energy consumption predicted for a year with average weather based on consumption data from any particular year. Weather in an average year (DD_R) is estimated using test reference year data from the San Francisco Airport weather station.

We also attempt to account for changes in the number of tenants in each project. Unfortunately, monthly tenant population data were not available; however, the Housing Authority did have accurate monthly information on the number of occupied units in each project. It is extremely important to include this data given the fact that significant changes in vacancy rates occurred in some projects over the three year period. We calculate the average number of occupied apartment units in each project during the pre-and-post retrofit period and then divide the NAC estimate in each period by that value, giving a normalized annual consumption per occupied unit for each project.

RESULTS AND DISCUSSION

Actual Energy Consumption

Metered energy consumption in various projects during the last three years is shown in Figures 1 through 3. Consumption data are converted to daily averages for each period but are not adjusted for variations in weather and vacancy rates. Energy consumption in projects with individual unit space heaters (Alemany and Sunnydale) more closely follows seasonal weather variations (as indicated by heating degree days - see Figure 4) than projects with central heating plants (Potrero Terrace and Hayes Valley C). Milder weather conditions prevailed in the post-retrofit period than during either of the pre-retrofit periods. There were 2522 heating degree-days (base 65°F) in the post-retrofit period compared to 3194 and 3124 HDDs during the 1981-82 and 1982-83 periods respectively (Figure 4).

Peak winter consumption is approximately 1.7 times higher than average summer use at Alemany and Sunnydale projects and is 1.2 to 1.5 times higher in the three projects with central heating facilities. The winter peak/average summer use ratio is roughly 1.6 to 1.8 for all master-metered residential customers in San Francisco (Figure 4). Hence, it appears that seasonal consumption patterns in the two projects with individual unit space heating systems are not atypical compared to other potentially similar building types in this mild climate although base level consumption dominates total demand in the three projects with central heating plants.

Gas usage for cooking increased during the winter months in two projects (Hayes Valley and Potrero Terrace) that had separately metered cooking data (Figures 2 and 3). The distinct peaks indicate that tenants are possibly using their gas ranges to supply heat during the winter. Local housing authority officials believe that this phenomenon is occurring, particularly at the Potrero Terrace project. It is also possible that residents cook at home more during the winter and holiday season. It is worth noting that "cooking" energy use accounts for a surprisingly large fraction of total gas consumption at Hayes Valley and Potrero Terrace Projects, ranging from 19 to 29 percent.

In some instances, the time-trend plots revealed questionable data. For example, energy consumption was extremely low at the Sunnydale Project in May 1982, approximately 30 percent of that observed in May 1981 or 1983 (Figure 1). Further checking revealed that the project gas meter had been vandalized and was operable during only part of the month. Data from this billing period were excluded from the regression analysis. Consumption data were particularly puzzling at the Hayes Valley C project (Figure 2). Note the flat usage levels and extremely small winter peak in 1981 and 1983. During late 1982, energy usage per day fluctuated up and down twice between August and November although there was a steady increase in heating degree-days during this period. These anomalies in usage patterns occurred just after the boilers were retrofitted with time clocks. We suspect that the newly-installed time clocks were not operating properly during this period.

NAC Parameter Estimates

Parameter estimates produced by the regression model for each housing project are shown in Table II. We ran the model using various time spans within the pre-and-post retrofit periods (N is the number of billing months included in the analysis). Some billing data were excluded, typically in the pre-retrofit period, in order to optimize model results (higher r^2 values); this resulted in only small changes (1-3 percent) in the normalized annual consumption (NAC) in each period but significantly reduced variation about the mean.

The descriptive power of this simple model is fairly good (r^2>0.88) for three projects, marginal at Alice Griffith, and unsatisfactory at Hayes Valley (possibly due to poor data).

Energy consumption declined during the post-retrofit period in all cases except the Hayes Valley projects. NAC values have not been adjusted for changes in occupancy rates. Annual savings ranged between 2 and 9 percent. Figures 5 and 6 show plots of total gas use versus degree days for Alemany and Hayes Valley. Summer consumption declined markedly in the post-retrofit period (values around 0-3 HDD/day) at Alemany, a trend also observed at Potrero Terrace and Sunnydale projects (not shown). Note the very flat heating slope and lower pre-retrofit energy use throughout the entire heating season at Hayes Valley B, reflective of a project in which energy consumption levels are largely independent of climate. It is worth noting that Hayes Valley is 7 to 10 miles from San Francisco Airport weather station, in a region noted for its micro-climates. More importantly, it is located in the middle of the city, several miles from the San Francisco Bay, and not as subject to wind and fog patterns that prevail near the Bay. Hence, site-specific weather data may improve the correlation between consumption and climate.

The reference temperature increased slightly in the post-retrofit period in four projects, though the increase is not statistically significant. The dramatic fluctuations in pre-and-post retrofit reference temperature at Hayes Valley are probably more reflective of poor data (low correlation coefficient) or inadequate model specification than to significant changes in indoor temperature. We do not have much confidence that the parameter estimates at Hayes Valley accurately characterize consumption patterns. Note that the model estimate of annual space heating use at Hayes Valley B is extremely low, from 4 to 16 percent (Table III).

End-Use Estimates

Consumption patterns in these housing projects are relatively insensitive to seasonal weather fluctuations. Weather-sensitive consumption (an estimate of space heating demand), represents only 15 to 25 percent of total usage (Table III), far lower than typical estimates of 50 percent for the space heating fraction in existing residential buildings (although reliable end-use estimates do not exist for multi-family buildings).[6] The large baseload usage suggests that domestic hot water heating consumption is quite significant; that seasonal efficiency of the heating system is low; and that heating system controls are inadequate (e.g., we observed apartment unit temperature controls frozen in the open position). Housing Authority staff indicated that, in some cases, tenants can only or chose to regulate room temperature by opening and closing windows.

Estimated annual baseload usage decreased significantly in the post-retrofit period at four projects, accounting for virtually all of the energy savings (Table III). Note that the greatest reductions in baseload consumption were at those projects (Alemany, Potrero, and Sunnydale) where hot water conserving measures had been implemented. This result suggests that hot water conservation measures (low-flow showerheads and water heater jackets) were particularly effective. We also estimated base level gas usage by scaling summer months usage to a full year. This technique yields baseload estimates that agree closely with those derived from NAC parameter estimates and provides additional evidence that non-weather-sensitive demand declined in the post-retrofit period.

Table III. Model estimates of space heating and baseload energy use.

	Pre-Retrofit [MBtu/unit-yr]			Post-Retrofit [MBtu/unit-yr]		
	Space Heating [$\beta(DD_R)$]	Baseload Estimate (365 * α)	Annualized Summer Baseload Usage*	Space Heating [$\beta(DD_R)$]	Baseload Estimate (365 * α)	Annualized Summer Baseload Usage*
Alemany	18.3	65.5	67.6	25.8	50.9	53.2
Pot. Terrace	24.6	109.2	111.1	29.9	84.0	86.0
Sunnydale	13.4	79.0	78.3	18.6	64.8	64.8
Alice Griffith	46.3	115.4	142.6	39.6	90.2	110.4
Hayes Valley B	3.1	73.6	73.6	12.9	70.1	73.9
Hayes Valley C	18.3	68.1	96.7	15.3	88.9	77.0
Hayes Valley A	12.4	58.5	63.2	18.1	58.4	64.0

* This baseload estimate is derived by taking monthly summer readings (July - September) and scaling usage per day to a full year.

Normalized Annual Consumption and Energy Savings

Table IV summarizes results for the five projects, adjusted for changes in average occupancy rates during the study period. Energy use (NAC) is normalized to the average number of occupied units in the pre-and-post retrofit period. Significant energy savings occurred in all projects with the exception of Hayes Valley where energy use actually increased by 14 percent after retrofit. Gas savings ranged from 7 percent of pre-retrofit consumption at Alemany to 20 percent at the Alice Griffith site. Those projects with the largest percentage savings also had the highest energy usage per unit before implementation of the program.

Table IV. Summary of results for SFHA zip program.

Project Name	Floor Area ft^2	Normalized Annual Consumption Before (MBtu/unit)	After (MBtu/unit)	Savings (MBtu/unit)	(%)	Cost Of Retro fit (83$)	Simple Payback (Years)	Cost of Conserved Energy D= 7% ($/MBTU)
Alemany	870	83.8	77.7	6.1	7	160	5.1	2.87
Potrero Terrace	828	133.7	113.9	19.8	15	93	0.9	0.52
Sunnydale	869	92.4	83.4	8.9	10	203	4.4	2.49
Alice Griffith	836	161.7	129.8	31.9	20	165	1.0	0.57
Hayes Valley	771	80.5	91.6	-11.1	-14	82	*	*

* Economic indicators can not be calculated when there is negative savings.

Several factors probably contribute to and partially explain the lack of savings at the Hayes Valley sites, although the results are still disappointing. The energy savings potential was lower at Hayes Valley for at least two reasons: 1) the Hayes Valley units had the lowest annual pre-retrofit energy use (80.5 MBtu/apartment) in the study sample and 2) expected savings from the same retrofit measure (e.g. attic insulation) should be less due to building characteristics. Ceiling insulation will have a greater impact on building shell characteristics in two-story apartment townhouses where every apartment has an attic, compared to three-story buildings, like Hayes Valley project, in which only one-third of the units have an attic. In addition, no hot water conservation measures were installed at the Hayes Valley sites because apartment units did not have individual water heaters or showers. Our analysis indicates that these retrofits produced significant energy savings at other projects. A recent on-site inspection at Hayes Valley also revealed that the boiler time clocks were not operable on at least one of two boilers.

Economic Analysis

We calculated simple payback time (SPT) and the cost of conserved energy (CCE), two basic indicators of cost-effectiveness. The cost of conserved energy is defined as:[7]

$$CCE = \frac{I}{\Delta E} \cdot \frac{d}{1 - (1 + d)^{-n}} \qquad (3)$$

where I = total investment

ΔE = energy savings

d = real discount rate

n = lifetime of measure(s).

We used a real discount rate of 7 percent and assumed that the physical lifetime for the set of retrofit measures is 15 years. A conservation measure is cost-effective if its CCE is less than the price of the energy it displaces.

CCE's ranged between $0.52-2.87/MBtu in the four projects that saved energy, far lower than the average residential gas price of $5.10/MBtu paid by the Housing Authority.

Simple payback times were around one year at two projects and between 4-5 years at the other two projects. Average payback time in the five projects (weighted by number of units) is 4.6 years, an attractive investment. The Housing Authority's retrofit cost containment policy was an important factor contributing to the economic attractiveness of the weatherization effort. Retrofits costs, which averaged $150/unit, were only one-fifth of original utility estimates.[8] Competition among private contractors generated by the bid process, PG & E cost estimates based on experience with individual homes rather than multi-family buildings, and apparent economies of scale that were operative in retrofitting large tracts of similar buildings help explain this phenomenon.

CONCLUSION

Four of five family housing projects in this study show a decline in weather-normalized annual energy consumption after the implementation of various weatherization measures. Gas savings range from -14 to 20 percent of pre-retrofit consumption levels. The largest decline in consumption occurred in projects with the highest pre-retrofit energy usage. We found that reductions in baseload consumption (non-weather-sensitive) account for most of the energy savings at Sunnydale and Alemany, two projects with individual unit hot water heaters. The apparent decrease in baseload usage in these projects indicates that the measures designed to reduce hot water consumption (i.e., water heater blankets and low-flow showerheads) were particularly effective. Overall, the Housing Authority's recent retrofit efforts are cost-effective, with an average simple payback time of 4.6 years in the five projects (including Hayes Valley).

The evaluation process required collection and organization of billing, occupancy, cost, and building data from disparate sources. The data base developed can be viewed as an initial attempt to establish a useful energy management information system. For the first time, the Authority is able to systematically identify projects with high energy use per unit, a valuable tool that can be used to target future retrofit efforts. The model end-use estimates (i.e., large baseload use) also have practical impact on appropriate retrofit strategies. We suggest more detailed monitoring of dual heating systems (i.e., sub-metering of space and hot water heating) in order to obtain definitive estimates of the space heating load and demand for domestic hot water at various projects. A small research monitoring effort, in conjunction with energy audits that focus on heating system retrofits, would be useful initial steps before the Authority embarks on expensive heating system capital improvements. In the near future, we suggest a renewed effort to improve operations and maintenance practices particularly in projects with central boilers. Repairing boiler leaks, checking temperature set-backs, fixing manual controller valves on apartment unit radiators that tend to freeze up and remain open, are all low-cost actions that can produce energy savings for the Housing Authority.

Our analysis indicates that it is important to account explicitly for vacancy rates in analyzing changes in consumption patterns. For example, the average number of occupied units increased from 193 to 236 at Alice Griffith (a 258-unit project) over the three year period, a 22 percent increase. Evaluations of retrofit programs directed at single-family homes generally exclude homes in which occupancy has changed.[9] This approach is not feasible in master-metered multi-family buildings, particularly family housing projects that tend to have high turnover and fluctuating occupancy rates.

This case study also raises some interesting policy questions with regard to the suitability of existing conservation programs and financial incentives to public housing. In addition to the ZIP weatherization program, the Authority, has recently allowed an energy management firm to install solar hot water heating systems at seven senior projects in a "shared savings" venture. Existing solar and investment tax credits significantly enhance the economic viability of this effort. Yet, other cost-effective energy conservation investments, such as lighting conversions (incandescent to fluorescent), improved operations and maintenance practices, and heating system efficiency improvements, are not implemented due to institutional and organizational barriers. For example, securing adequate funding and training for boiler maintenance staff is potentially a very cost-effective conservation strategy that the Authority could pursue, yet is difficult to implement (and often a low budgetary priority) in a period of reduced operating expenses. Expensive energy-efficiency capital improvements (i.e., boiler replacement) have to be justified as part of HUD "Modernization" efforts, in which conservation potential and reduced life-cycle operating costs are secondary criteria. Conservation programs directed specifically at low-income, multi-family buildings should focus on providing technical assistance and financial incentives that direct investment towards optimal conservation retrofits. Examples of areas in which technical assistance are needed include: implementation of a long-term energy management program and strategy, development of project energy use indexes in order to identify energy-inefficient sites and to assess accurately building energy performance over time, and engineering expertise on potential heating system improvements.

The Housing Authority has clearly adopted an innovative approach in attempting to simultaneously maintain its housing stock, reduce energy consumption, and improve tenant comfort levels. Just two years ago, the San Francisco Housing Authority faced a serious problem in obtaining funds to address any weatherization improvements. At present, it has completed the first generation of retrofits (mostly "building shell" improvements and low-cost hot water measures) on most of its projects and is now investigating new opportunities (e.g., co-generation, more solar hot water systems, heating system retrofits). The lessons learned in San Francisco can help other public housing authorities across the country who are faced with a similar dilemma: how to regain control over spiraling operating expenses yet still provide tenants with reasonable comfort and amenity levels in a period of tight budgetary constraints.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge assistance from Dorothy Dickey and Richard Diamond at Lawrence Berkeley Laboratory.

The work described in this report was funded by the Assistant Secretary for Conservation and Renewable Energy, Office of Building Energy Research and Development, Buildings Systems Division of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

REFERENCES

1. R.L. Ritschard and D. Dickey, "Energy Conservation in Public Housing: It Can Work", Energy Systems and Policy 8(3):269-291, 1984.

2. C. Gold, The Page Homes demonstration project for the application of computers to energy conservation in public housing authority projects, Bumblebee Energy Systems Inc., Trenton, NJ, Feb. 1982.

3. C. Patten, M. Sherman, and B. Shapiro, Case Studies of Successful Energy Conservation Programs in PHA's: St. Paul, Minnesota, Council of Large Public Housing Authorities, Boston, MA, December 1982.

4. G.S. Dutt, M.L. Lavine, B. Levi,, and R.H. Socolow, The Modular Retrofit Experiment: Exploring the house doctor concept. PU/CEES #130, Princeton, NJ, June 1982.

5. B.C. O'Regan, B.S. Wagner, and J.B. Dickinson, "Results of the Walnut Creek House Doctor Project", Energy, 9(1):75-86, Jan 1984.

6. J.L. Blue, Buildings Energy Use Data Book, ORNL-5552, Oak Ridge, TN, December 1979.

7. A.K. Meier, Supply Curves of Conserved Energy, LBL-14686, Lawrence Berkeley Laboratory, Berkeley, CA, May 1982.

8. San Francisco Housing Authority, Weatherization Program Report, October 1, 1983.

9. R.C. Sonderegger, "Movers and stayers: the resident's contribution to variation across houses in energy consumption for space heating," Energy and Buildings, 1:313-324, April 1978.

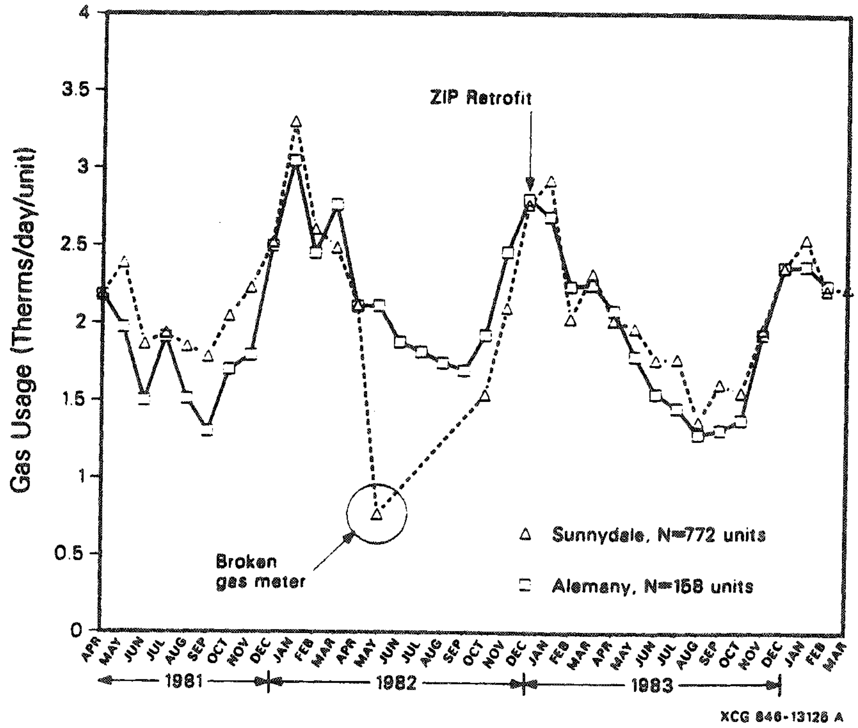

Figure 1. Gas consumption per day during each 'monthly' billing period at Alemany and Sunnydale Project.

MONTHLY ENERGY CONSUMPTION
HAYES VALLEY C

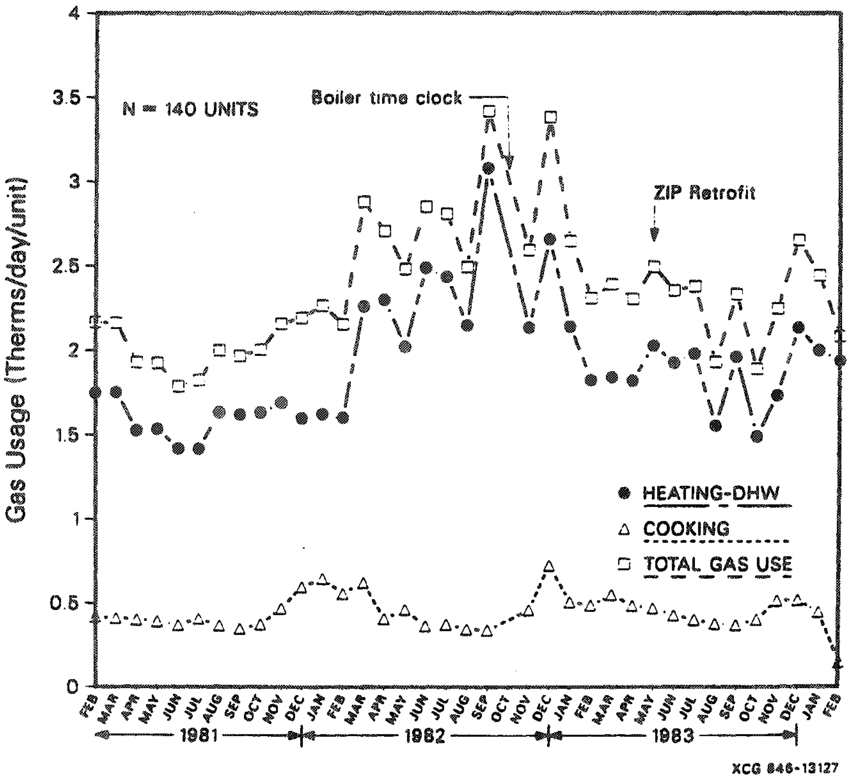

Figure 2. Gas consumption per day during each 'monthly' billing period at Hayes Valley C Project.

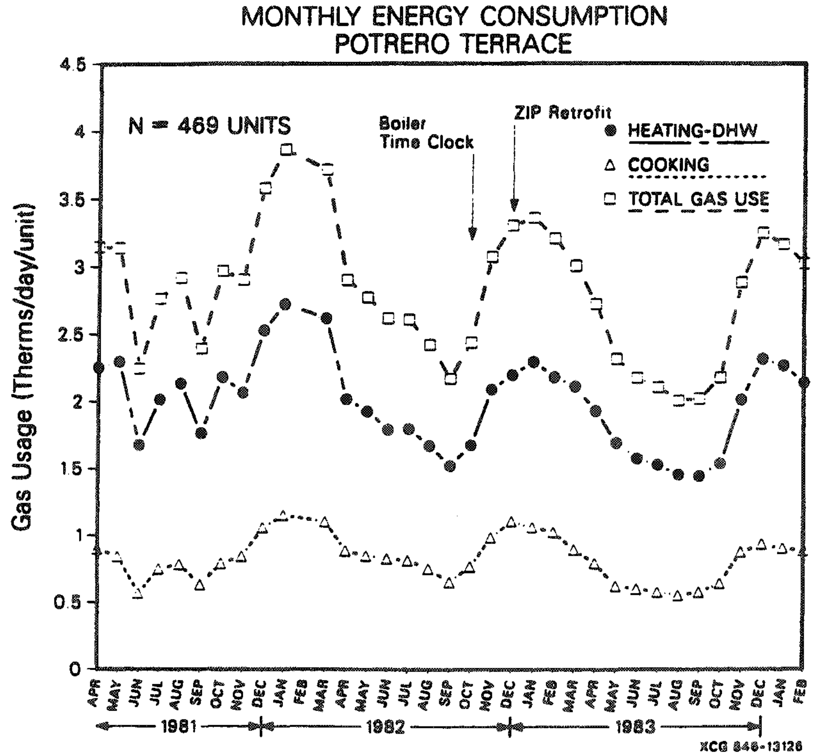

Figure 3. Gas consumption per day during each "monthly" billing period at Potrero Terrace Project.

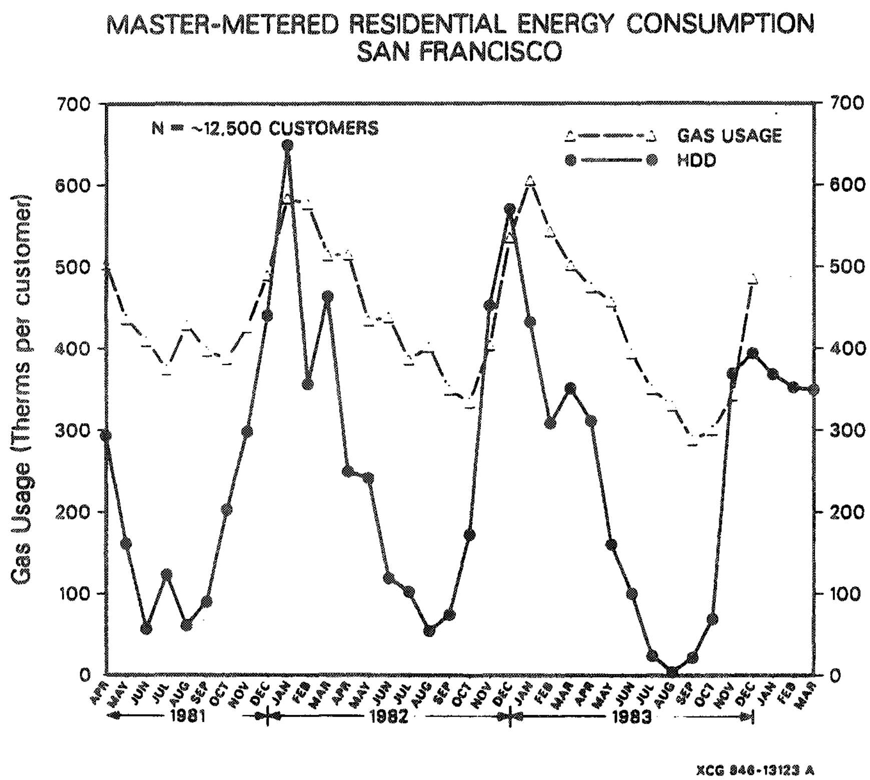

Figure 4. Monthly residential energy consumption for master-metered customers in San Francisco over the three year study period. The plot also includes monthly heating degree-days at base 65°F for San Francisco. Weather conditions in the post-retrofit period were less severe than during either of the pre-retrofit periods. [Source - Pacific Gas & Electric Economics and Statistics Department and San Francisco Airport NOAA weather station]

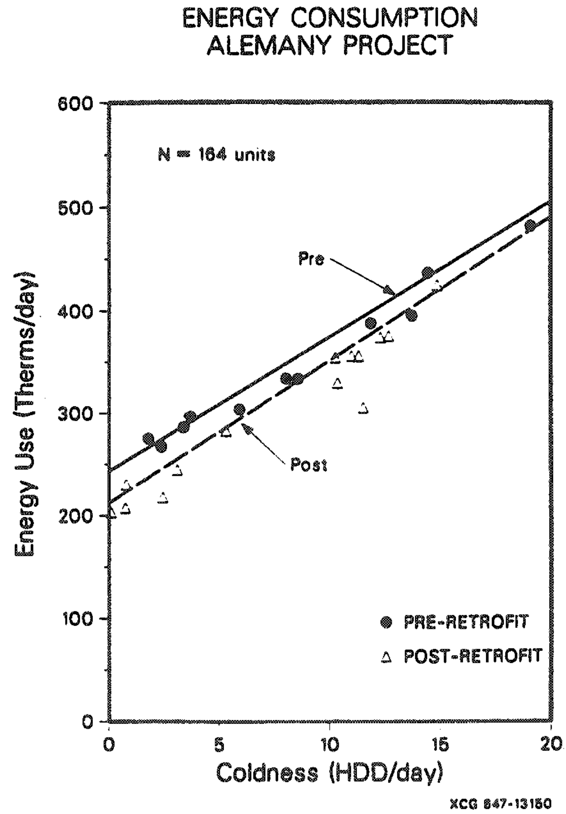

Figure 5. Scatterplot of total gas use versus heating degree-days for Alemany Project. Regression lines represent the best-fit of pre- and-post retrofit consumption data to local weather.

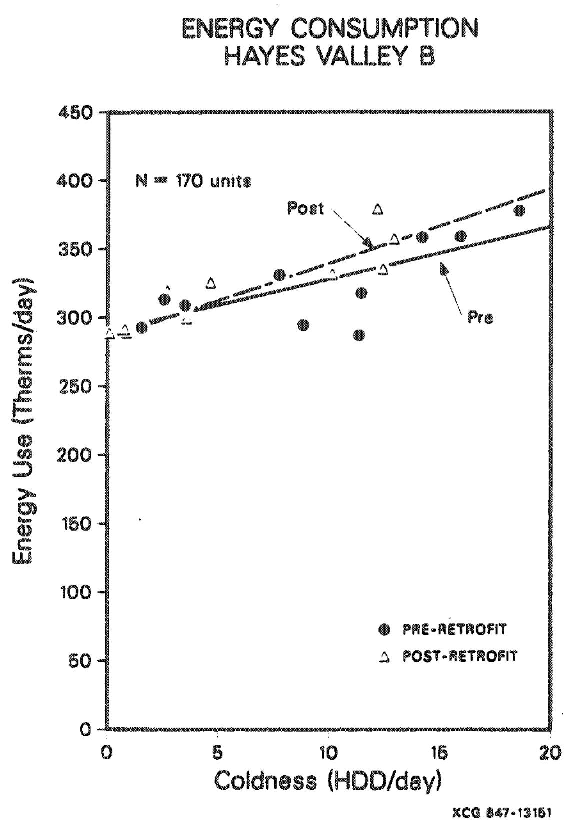

Figure 6. Scatterplot of total gas use versus heating degree-days for Hayes Valley B Project. Regression lines represent the best-fit of consumption data to local weather.