Presented at the ACEEE 1986
Summer Study, Santa Cruz CA, August 1986

LBL-21886

# ANALYZING ENERGY CONSERVATION RETROFITS IN PUBLIC HOUSING:

## Savings, Cost-Effectiveness, and Policy Implications

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July 1986

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

## ABSTRACT

Annual energy costs for the U.S.'s 1.2 million public housing units exceed one billion dollars. During the last decade, the U.S. Department of Housing and Urban Development (HUD) and local public housing authorities have initiated major conservation programs. Our review of energy conservation work in public housing indicated that in spite of substantial retrofit activity, little documented information is available on energy savings from retrofits. In this paper, we calculate energy savings and economic indicators for 43 retrofits, using consumption and cost data collected from case studies, housing authorities, and utilities. These results are compared with savings from conservation measures in privately owned, multi-family housing.

Heating system controls and window measures were the two most frequent retrofit strategies in the housing projects we examined. Median energy savings are 14% of pre-retrofit consumption, or 11.2 MBtu/unit-year; savings ranged from -7% to 62%. A median payback time of 12 years showed the retrofits, as a group, to be less cost-effective than a comparable sample of retrofit efforts in privately owned, multi-family buildings. We also examine the persistence of energy savings for a small sample of buildings for which we have several years of post-retrofit utility billing data; preliminary results suggest that proper maintenance is a critical factor in sustaining energy savings after temperature control retrofits in steam-heated buildings. Finally, we discuss qualitative factors that influence the acceptability of retrofits, including effects on comfort, building appearance, and security.

# ANALYZING ENERGY CONSERVATION RETROFITS IN PUBLIC HOUSING: SAVINGS, COST-EFFECTIVENESS, AND POLICY IMPLICATIONS

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## INTRODUCTION

Approximately 3.4 million people live in the U.S. public housing system, whose 1.25 million units comprise close to 40% of all low-income, multi-family rental units, and 6% of all multi-family units (Perkins and Will, 1980; Harris, 1984). Annual energy expenses rose by 400% from 1970 to 1980 and currently exceed one billion dollars (U.S. Congress, 1984; Perkins and Will, 1980). This fuel bill now accounts for approximately 30% of the Department of Housing and Urban Development's (HUD) annual operating expenditures for public housing (Struyk, 1980). The rapid rise in energy costs is a key factor in the widening gap between building operating expenses and revenues, which are primarily derived from rents paid by tenants. This gap places an increasing strain on the operation and maintenance budgets of local housing authorities. During the last ten years, HUD initiated major retrofit programs to reduce energy consumption (and thus minimize rising energy expenses).

Although there has been major retrofit activity in public housing, little documented information is available on the measured energy savings from retrofits (Ritschard, 1985). In this study, we analyze utility bills from 38 public housing projects that implemented conservation retrofits. We briefly discuss key structural and institutional factors that are distinctive to public housing and that influence the potential for and analysis of energy savings. We also examine the persistence of energy savings for projects for which we have more than one year's worth of post-retrofit data, and discuss qualitative factors that influence the acceptability of retrofits.

## WHY STUDY PUBLIC HOUSING RETROFITS?

Public housing exists in a quite different setting from that of privately owned multi-family housing. A review of the available data suggests that average energy consumption in the typical public housing unit (of 850 $ft^2$) is much higher than in existing multi-family dwellings.* A major study commissioned by HUD estimated annual site energy use for the average public housing unit at 146 MBtu/year (1 MBtu=$10^6$ Btu) (Perkins and Will, 1980). The average multi-family unit (817 $ft^2$) consumes only 77 MBtu/year, based on measured data from the Residential Energy Consumption Survey; this is 47% less than the public housing apartment (U. S. Congress, 1984).† Structural factors, such as vintage of the building, fraction of central heating, choice of heating fuel, and household size, explain some of the difference in consumption levels. For example, half of both public housing and multi-family units were built before 1960; however, very few public housing starts have occurred since 1975, while 15% of the multi-family units were built in the post-oil-embargo era, and, as a result, benefit from more energy-efficient construction practices. A higher fraction of public housing units have central heating systems than the existing multi-family stock (52 vs. 41%). The oil-heating share is roughly comparable for each sector (20-25%), although electric space heating is more prevalent in the multi-family stock compared to

*Although some single-family dwellings are included in the public housing system, the vast majority of housing projects consist of multi-family buildings.
†The Residential Energy Consumption Survey is a representative sample of U.S. households, including those in public housing. The multi-family statistics cited here include both privately and publicly owned units; however, since public housing accounts for only 6% of multi-family units, we assume that the multi-family statistics primarily represent the characteristics of privately owned housing.

public housing (26 versus 7%), which tends to reduce site energy consumption for the sector (EIA, 1982 and 1984; Perkins and Will, 1980). The average number of persons per household is higher in public housing compared to the multi-family stock (2.9 compared to 2.3 persons per dwelling unit); household size is positively correlated with higher energy use for domestic hot water and cooking*.

The institutional setting for conservation investments in public housing is an extreme example of one of the same barriers that hinders conservation efforts in private-sector multi-family buildings. Most public housing tenants have at least part of their energy consumption included in their rent payment; only 12% of public housing tenants pay for their own electricity, while 33% pay for their own gas (OTA, 1982). Hence, household energy consumption and energy expenditures are not directly linked. In contrast, almost half of the tenants in multi-family buildings have submetered consumption for at least one energy source (48% are partially or fully sub-metered) (EIA, 1982 and 1984). There is anecdotal evidence to suggest that public housing also tends to be less well-maintained than its private counterparts, which means greater losses through the building shell and lower heating system efficiency.

## SOURCES OF DATA

We obtained information on retrofit projects from local public housing authorities (PHAs), HUD regional offices, and consultants who worked for local PHAs. We established data requirements based on analysis techniques used in the Buildings Energy Use Compilation and Analysis (BECA-B) project for existing residential buildings (Goldman, 1985). The data typically included metered energy consumption, installed retrofit measures and their cost, the price of the space heating fuel during the winter after retrofit, and a brief description of the physical characteristics of the buildings (e.g., conditioned floor area, building and heating system type). Some of this information is already compiled by PHAs in compliance with HUD regulations: project descriptions and utility billing data are regularly submitted on HUD forms 5-1885 and 5-1466B, respectively.

We attempted to obtain data from major HUD-sponsored retrofit programs, including a $23 million program for 47 PHAs to modernize oil heating systems and a $5 million innovative energy conservation and solar grants program to 61 PHAs. However, comprehensive evaluations were available from only three of 61 PHAs (Trenton NJ, Greeneville TN, and St. Paul MN) that participated in the innovative energy grants program; these three projects are included in the database (Gold, 1982; TVA, 1984; Patten, 1982). We contacted the Office of Public Housing at HUD for information on the results of retrofit efforts in 14 other PHAs that had received grants.† HUD responded that eight of these 14 had not reported any results, and one PHA had never carried out the retrofit; they provided LBL with brief progress reports from the remaining five PHAs. Ironically, as of February 1985, two of the five PHAs that submitted progress reports did not include energy use data because of delays in installing the retrofits; hence savings from the retrofits are still unknown. Our experience with innovative energy grant recipients illustrates some of the difficulties in obtaining measured data on the results of conservation activities in public housing. Moreover, it indicates that, except for a few PHAs, a serious evaluation has not been conducted of HUD's early conservation initiatives.

We contacted many local PHAs directly, in an effort to determine the scope of their recent retrofit activity, evaluation of previous efforts, and current plans. This survey indicated that various retrofits had already been implemented at nearly all of the 40 PHAs surveyed (Ritschard, 1985). Twenty-eight retrofit projects conducted by four local housing authorities met the minimum data requirements: 14 projects managed by the New York City Housing Authority, 11 projects operated by the San Francisco Housing Authority, two projects in the Phillipsburg (NJ) Housing Authority, and one project run by the St. Paul Housing Authority. We also received retrofit data on public housing projects from Princeton's Center for

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*Public housing density: The U.S. public housing system contains 1,173,000 units and 3,307,000 residents, and has a 2% vacancy rate, yielding an average density of 2.88 people/unit (Perkins and Will, 1980). Multi-family housing density: (EIA, 1982).

†We asked about PHAs that either had received a grant of significant size (greater than $75,000) or had installed heating or hot water system retrofits.

Energy and Environmental Studies and the Tennessee Valley Authority (DeCicco, 1986; TVA, 1984). In addition, a private consultant (Chaim Gold) provided LBL with information on eight retrofits in New Jersey and Philadelphia.

## METHODOLOGY

The approach used in this study includes three principal elements: 1) normalizing energy use for weather and occupant effects, 2) analysis of the level and range of energy savings and identification of factors that are associated with savings, and 3) calculation of the cost-effectiveness of conservation investments. Retrofits are analyzed by *project*, which is the HUD term for a building or group of buildings located at one site and administered as one unit. Typically, the building(s) in a project are on one meter, and building characteristic data are compiled by HUD at the project level.

Changes in weather from year to year can mask the effect of a retrofit on energy consumption for a given building. For most of the projects, we used the Princeton Scorekeeping Method (PRISM) to adjust the weather-sensitive component of space heat fuel use. PRISM is an energy analysis model that regresses energy use versus daily average temperatures to find the weather-normalized annual consumption (Fels, 1986).

Energy use of the space heat fuel at each project was normalized by the number of apartment units so we could compare energy use on a per-unit basis. We found that occupant turnover was high in some public housing projects, especially those that were poorly maintained or mostly occupied by families, and occupancy rates varied greatly over time. Hence, we divided energy use by the average number of *occupied* units during each of the pre- and post-retrofit periods (when data were available) to account for the effects of changing vacancy rates on energy consumption levels.

Labor and materials costs at the time of retrofit were converted to constant dollars (1985 $), and we calculated economic indicators, including simple payback time (SPT) and internal rate of return (IRR).[*,†] Conservation investments are amortized over the measures' expected physical lifetimes and estimated annual operation and maintenance costs are added to the initial investment.

The economic analysis assumes that one entity, either a local housing authority or HUD, paid for and received all benefits and costs associated with a retrofit. In fact, the actual distribution of benefits and costs between the various parties is much more complex and is as dependent on the financing arrangement as on the actual dollar value of the energy savings (Mills et al., 1986). Therefore, the economic indicators calculated in this paper do not represent the actual benefits to the housing authority or to HUD; they are included only to facilitate *comparisons* of the measures' cost-effectiveness. It is worth noting that roughly one-third of the retrofit projects included in this study were implemented through demonstration programs or relied heavily on the existence of tax credits; hence cost-effectiveness was not always the dominant consideration in retrofit selection.

## RESULTS

### *Building Characteristics and Retrofit Measures*

The public housing projects in this study include most building types found in the residential sector, from single-family dwellings to 1000-unit apartment complexes, although low- and high-rise multi-family dwellings predominate. Our sample has a regional bias, as projects are concentrated principally in the New York-New Jersey area and in California. Ninety percent of the projects in the data base are located in the Northeast or California, compared to 40% of the public housing stock. Retrofit data for PHAs in the Midwest and South are particularly lacking.

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[*] Definitions of economic indicators are presented in Appendix A.

[†] An energy escalation rate of 4%, representing the accepted figure at the time of most of the retrofits, is used in the economic calculations.

This compilation of retrofit activity in public housing is not intended to be representative of the entire stock, although comparison of characteristics of retrofitted buildings with stock averages offers some indication of the applicability of our results (Table I). Almost 90% of the projects in the database have central heating systems, and over 50% heat with oil. In contrast, gas is the principal space heat fuel in the public housing stock, and the stock is evenly split between central and individual unit heating systems. Of the centrally heated projects in the database, 19% have hydronic (hot water) distribution and 25% have steam distribution systems.

Retrofit strategies focused principally on reducing consumption for space heat and domestic hot water, the two largest end-uses. Table II shows the frequency with which different retrofit measures were installed in the 38 projects. (In most cases, more than one measure was installed at a project.) Retrofitting existing heating systems with improved controls was most popular, with first costs ranging from $100-450/unit. Examples of measures included in this category are thermostatic radiator vents, boiler aquastats, outdoor resets and cutouts. Window measures were also popular. For example, the New York City Housing Authority installed double-glazed, thermal-break aluminum windows in nine apartment complexes. This retrofit was fairly expensive, averaging $1070/unit in the nine buildings. Retrofits to reduce domestic hot water energy use were also common. The San Francisco Housing Authority installed solar domestic hot water systems at six projects, and wrapped hot water tanks at two other projects, while several Northeast housing authorities installed separate domestic hot water boilers. Retrofit costs ranged from $10 to almost $20,000 per unit among projects in this study; the median first cost was approximately $550/unit.

*Energy Savings*

Median annual resource energy savings were 11.2 MBtu/unit, or 14% of pre-retrofit consumption. Savings varied widely, ranging from -7% to 62%. Energy savings show some correlation with consumption prior to the retrofit (r=0.52) (Fig. 1). Projects in cold (>4500 HDD) climates have a median pre-retrofit consumption of 108 MBtu/unit, while those located in milder regions use about 57 MBtu/unit. Median savings within each climate zone are similarly split: projects in cold regions saved about 14 MBtu/unit, compared to 4 MBtu/unit in mild areas. However, good management practices can overcome the influence of climate at specific properties. For example, most projects in New York and Minnesota (over 4800 HDD/year) use less energy than some of the California and Tennessee buildings (under 3900 HDD/year). In these projects, other factors such as previous retrofit activity, building types, heating systems, operating practices, and occupant behavior must have a stronger influence on pre-retrofit energy consumption than climatic variation.

Our results suggest that the type of measure selected has the greatest effect on the level of energy *savings*. Groups of similar retrofits are compared in Table III. (Data on individual projects are found in Appendices A and B.) Heating controls and energy management systems produced significant energy savings (17-26 MBtu/unit), and had paybacks under five years. Window replacements and retrofits saved from 5 to 16 MBtu/unit, but had payback times in excess of 12 years because of high capital costs. High-efficiency, modular, condensing-pulse combustion boilers and an incandescent-to-fluorescent lighting conversion were particularly cost-effective (with payback times around one year), although results should be interpreted very cautiously as we have only one example of each of these retrofits.

We have five examples of housing authorities that installed similar retrofits at more than one project (Fig. 2). In some cases, we can identify structural factors that account for a fraction of the observed variance in savings resulting from similar retrofits. For example, in San Francisco, five buildings received various shell measures (attic insulation, caulking and weatherstripping) and low-cost hot water retrofits (e.g., low-flow showerheads and heater blanket insulation). The projects with the highest per unit energy usage before the retrofits were installed also had the largest savings in relative and absolute terms. The project with the highest pre-retrofit usage also had improperly functioning heating system controls (e.g., time clocks were inoperable on several boilers and a number of room radiators with manual control valves were stuck in the open position).

We also have data on solar domestic hot water systems in San Francisco that were installed at six senior projects which are similar to each other in construction type and vintage. Variability in savings may be explained in part by the configuration that was required for each solar retrofit. For example, the three buildings with no energy savings had long pipe runs (and presumably greater standby losses) compared to the buildings with consumption reductions.

At the 9 New York City Housing Authority (NYCHA) apartment complexes that received window retrofits, energy savings and pre-retrofit consumption are fairly uniform, compared to the other groups of buildings. NYCHA has an extensive and long-standing energy management program with a national reputation. Elements of their program include: 1) installation of a computerized monitoring system for fuel oil consumption with baseline consumption data, objectives for fuel savings, and performance indicators to measure progress; 2) training programs to enhance technical skills of maintenance staff; and 3) systematic implementation of heating system efficiency improvements and building envelope retrofits based on detailed building audits (NYCHA, 1983). The uniform consumption levels at the buildings retrofitted with double-paned, thermal break windows is attributable, in part, to the effects of the several sets of retrofits that the buildings had already received.

*Persistence of Savings*

The effective life of a retrofit can be drastically shortened by lack of maintenance or improper operation. Most housing authorities do not track energy savings for more than a year after retrofit; however, we were able to obtain two or more years' worth of post-retrofit energy use data for five retrofits. Of these five, the two Trenton projects received heating system retrofits; attic insulation, caulking/weatherstripping, low-flow showerheads, and water heater blankets were installed at the three San Francisco projects. (We will refer to this group of retrofits as "shell" measures, since the attic insulation accounted for the bulk of costs, and presumably, of savings.) Figure 3 shows the normalized annual consumption before and after retrofit at each of these projects. Among these buildings, first-year energy savings have been more stable over time in the projects that installed shell measures compared to the projects with heating control retrofits. Post-retrofit energy use has remained constant at the Sunnydale and Potrero Terrace projects although, at Alemany, consumption has again increased to pre-retrofit levels even after adjusting for weather and the number of occupied units.

First-year energy savings were dramatic at the Campbell and Kerney projects (22 and 31%) after boiler replacement and heating control installation. However, energy use increased substantially at both projects during the second year after the retrofit, reclaiming one-tenth of the first-year savings at Kerney and one-half of the savings at Campbell. At Campbell Homes, where a third year of data was available, energy savings continued to decrease, with energy use at 92% of pre-retrofit levels. Anecdotal evidence suggests that the deterioration in energy savings at Kerney and Campbell results from inadequate maintenance, a crucial factor in older steam-heated buildings (Gold, 1985). Sufficient operating budgets and a skilled maintenance staff appear necessary to insure the persistence of initial energy savings obtained from heating system control retrofits in steam-heated buildings. HUD operating budget cutbacks hinder local housing authorities' efforts to maintain their buildings. This situation makes it difficult to recommend and implement cost-effective heating system retrofits, because energy savings over time are dependent on regular maintenance.

*Combining Retrofits with Rehabilitation*

During the last decade, most retrofit investments in public housing have been financed by HUD modernization funds, which have been traditionally used for heating plant replacements and major structural rehabilitation. A major study sponsored by the Office of Technology Assessment concluded that housing rehabilitation programs offer an excellent opportunity to make energy investments in housing when other alterations are being made and access to the structure is easier; conservation investments improve program cost-effectiveness and overall building value (Naismith, 1984; Perkins and Will, 1980). In many cases, the incremental costs of conservation features are minor compared to rehabilitation expenses, so operating expenses are reduced in return for a minimal investment. This strategy is particularly appropriate for the public housing sector, which has approximately 90,000 "chronic problem" units (i.e, buildings that are physically deteriorating and have problems with vandalism, inadequate maintenance, and poor management) that would require repair before energy conservation measures could be implemented (Perkins and Will, 1980).

A small fraction of the buildings in this study had retrofits installed as part of a larger rehabilitation effort (Table IV). Two low-rise projects in Phillipsburg NJ, which underwent extensive rehabilitation between 1980 and 1983, are good examples of retrofit/rehabilitation possibilities. Energy use decreased drastically at both projects in the year following the rehabilitation work: normalized annual consumption (NAC) declined by an average of 47%. Major structural renovations included a new exterior facade and roof, thermopane windows, wall, roof, and crawl space insulation, maximum set thermostats, and replacement of doors and storm doors. In addition, the centrally heated project (General Rehab #1) received new boiler valves and controls; gas warm-air furnaces were replaced in each of the units at the second project.

The Trenton Housing Authority used several approaches when it had to replace boilers in four of their low-rise projects. At three sites, they replaced the existing boilers with similar new equipment plus improved heating controls. (These are the same projects discussed in the sections on range and persistence of savings.) First-year savings at these projects ranged from 10 to 54 MBtu/unit. At one project, high-efficiency, modular, condensing-pulse combustion boilers were installed. The incremental expense (over the cost of replacement with ordinary boilers) of the high-efficiency boilers was $550/unit (1985 $). The large energy savings--50%--resulting from the installation repaid the incremental expense in less than one year.

The six examples discussed here are but a preliminary investigation into the energy-saving possibilities of combined rehabilitation/retrofit. The conservation opportunities present in rehabilitation work are typically not quantified since housing authorities often cannot provide data on the incremental costs of the conservation measures. However, combining efficiency investments with rehabilitation clearly gives housing authorities the opportunity to lower long-term operating costs, at a cost that is small compared to the overall rehabilitation costs.

## DISCUSSION

### *Data Limitations*

The energy consumption data collected in many public housing projects are often of uneven quality. The most common problems were associated with the typical configuration of utility metering systems (i.e., project-level rather than individual building or apartment meters) and, for oil-heated buildings, limitations in using fuel oil delivery data (e.g., unrecorded deliveries, large tank size, and more frequent readings in the heating season, all of which make it difficult to determine actual oil consumption use patterns). Retrofits that affected only some of the buildings at a project cannot be analyzed when the entire project is on one meter. In many cases, data on vacancy rates and number of occupants were not available. In addition, usage could decrease/increase because of changes in building operating conditions which may or may not be associated with the retrofits (we are most knowledgeable about operating practices for projects located in San Francisco, Trenton and Asbury Park).

### *Comparison with Results from Privately Owned Buildings*

In general, we find that there is a greater range of energy savings and cost-effectiveness in public housing projects than in a sample of retrofitted, privately owned, multi-family buildings (Goldman, 1986a). Median percentage savings are approximately the same for the two groups of buildings (15%), although the median payback time for the privately owned buildings was much shorter than that of public housing (3 vs. 12 years). The difference in cost-effectiveness can be explained in part by the fact that many public housing retrofits were part of demonstration projects, which by definition are not uniformly successful. For example, both highly successful computerized energy management systems and poorly designed solar space heat systems that required occupant operation were funded under HUD demonstration programs.

### *Qualitative and Other Impacts*

We also have anecdotal and some survey data on the qualitative impacts of a few of these retrofits. In general, public housing tenants were most concerned with comfort, building appearance, and security. Housing Authority managers in San Francisco said that tenant complaints about insufficient heat caused them to disable boiler time clocks that regulated the space heat water circulation pump, so the pump would run for 14 rather than 24 hours a day (Goldman, 1986b). In contrast, NYCHA officials reported that tenants felt that thermostatic radiator valves installed in four projects resulted in more even distribution of heat, thus improving comfort.

Trenton housing officials indicated that storm window retrofits were popular because tenants felt that it improved the overall appearance of the project. NYCHA staff also cited other positive impacts from the replacement of steel casement windows with double-glazed thermal break aluminum windows. The original windows were leaky (leading to excessive air infiltration), required substantial amounts of maintenance, and were frequently subject to glass breakage during windy weather. The Housing Authority estimated that the new windows reduced operation and maintenance costs by $30,000/year for a typical 1000-unit complex (NYCHA, 1983).

The Trenton Housing Authority had to consider some unexpected side effects after the installation of modular condensing-pulse combustion boilers at one of its projects. The high-efficiency boilers produced a great deal of noise (Gold, 1985). Fortunately, the boilers are located in a separate building far from the residences. This equipment would not be favorably received if installed in a basement boiler room near living quarters. Although information of this sort is often anecdotal, in some cases it can help building owners become aware of possible adverse effects prior to installation of similar retrofits.

## CONCLUSIONS

We stress that the retrofits studied here are selected examples of conservation efforts within the public housing system, intended to give an idea of the possibilities of conservation and the experiences of individual PHAs. Analysis of our sample of 43 retrofits shows that conservation work has produced significant energy savings in the public housing sector, but the effort has not always been cost-effective. A large number of expensive retrofits were carried out under demonstration programs, with mixed results. Preliminary results suggest that proper maintenance is a critical factor in sustaining energy savings after temperature control retrofits in steam-heated buildings. In addition, qualitative factors such as a measure's effect on comfort, building appearance, and security reportedly have a strong influence on a retrofit's acceptability, and therefore, its success.

This study represents an initial effort to summarize measured data on retrofit efforts in public housing. During this project, we have gained a thorough appreciation of the difficulties in evaluating public housing conservation retrofits. We believe that many local housing authorities and HUD still do not see the potential benefits that can be derived from an evaluation of the actual field performance of conservation strategies. Documenting measured savings requires that local housing authorities pull together historical energy use, occupancy, and economic and building characteristic data in a systematic fashion. Initiation of this process alone produces the necessary information for a crude energy management accounting system (à la NYCHA), and provides the basis for local PHAs to track energy use patterns and to set objectives for reasonable consumption levels so they can begin to regain control over their energy expenses.

## ACKNOWLEDGEMENTS

The work described in this report was funded by the Assistant Secretary for Conservation and Renewable Energy, Office of Buildings and Community Systems, Buildings Systems Division of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098. We would like to thank the housing authorities and individuals who contributed to this study, especially Chaim Gold, who provided much information on Northeastern housing authorities. Thanks also to Rick Diamond, Evan Mills, and Ed Vine for their helpful comments on earlier versions of this paper.

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**Table I. Characteristics of retrofitted projects.**

| Building Characteristic | | % of Projects in Data Base | % of Public Housing Stock[a] |
|---|---|---|---|
| Building Type: | High-Rise[b] | 47 | 30 |
| | Low-Rise | 47 | 70 |
| | Combined | 6 | -- |
| Occupant Type: | Family | 58 | 46 |
| | Senior | 22 | 33 |
| | Mixed | 6 | 21 |
| | Unknown | 14 | -- |
| Heating Plant: | Central | 89 | 51 |
| | Individual Unit | 8 | 49 |
| | Unknown | 3 | -- |
| Space Heat Fuel: | Gas | 37 | 68 |
| | Oil | 54 | 25 |
| | Electric | 3 | 7 |
| | Mixed | 6 | -- |

[a]Percentage of projects as estimated in Perkins & Will and the Ehrenkrantz Group, *An Evaluation of the Physical Condition of Public Housing Stock: Energy Conservation*, H-2850, (U.S. Department of Housing and Urban Development, March 1980), volume 4, p. 109.

[b]High-Rise = 5 stories or more.

**Table II. Types and costs of retrofits.**

| Retrofit Type | Number of Retrofits |
|---|---|
| Envelope: | |
| Attic Insulation | 6 |
| Caulk & Weatherstrip | 6 |
| Window Management | 3 |
| Window Replacement | 10 |
| Heating System: | |
| Heating System Replacement | 5 |
| Heating System Retrofit | 2 |
| Heating Controls | 14 |
| Energy Mangement Systems | 3 |
| Solar Space Heat | 2 |
| Operations & Maintenance | 1 |
| Domestic Hot Water System: | |
| Separate DHW Heater | 5 |
| Solar DHW | 6 |
| Lighting: | |
| Lighting Controls | 1 |
| Lighting Replacement | 1 |
| **Initial Retrofit Cost (1985 $/unit)** | **Number of Retrofits** |
| < $250 | 10 |
| $250-500 | 6 |
| $500-1000 | 9 |
| $1000-1500 | 5 |
| $1500-2000 | 5 |
| > $2000 | 3 |

| Table III. Savings and cost-effectiveness by retrofit strategy. | | | | | | |
|---|---|---|---|---|---|---|
| Retrofit Strategy | Number of Projects | Number of Units | Mean Resource Energy Savings (MBtu/unit-yr.) | (%) | Mean SPT (years) | Mean IRR |
| High-Eff. Boilers[a] | 1 | 112 | 95.4 | 50 | 0.8[b] | 1.30[b] |
| CEMS[c] | 3 | 1192 | 26.2 | 25 | 2.8 | 0.50 |
| Heating Controls | 6 | 1539 | 16.8 | 18 | 4.8 | 0.25 |
| Solar Space Heat | 2 | 77 | 9.6 | 9 | 169.8 | 0.00 |
| Windows[d] | 11 | 11261 | 9.2 | 14 | 18.2 | 0.08 |
| Lighting | 1 | 159 | 9.1 | 71[e] | 1.4 | 0.87 |
| Solar DHW | 6 | 388 | 4.2 | 8 | 73.3 | 0.01 |

[a]High-Efficiency Boilers=Replacement of central boilers with high-efficiency, modular, condensing-pulse combustion boilers.

[b]Based on incremental cost over replacement with regular boilers.

[c]CEMS=Computerized energy management systems.

[d]Windows=thermal-break, double-pane windows (9 projects); single-pane (1 project); insulated shades (1 project).

[e]Percentage of pre-retrofit *lighting* consumption only.

| Table IV. Savings and costs for rehabilitated buildings.[a] | | | | | |
|---|---|---|---|---|---|
| Retrofit | No. of Units | Pre-Retrofit Consumption (MBtu/unit) | First Year Savings (MBtu/unit) | (%) | Total Cost (1985 $/unit) |
| Phillipsburg, NJ: | | | | | |
| General Rehab #1[b] | 150 | 166.2 | 67.5 | 41 | 13767 |
| General Rehab #2 | 222 | 127.3 | 67.4 | 53 | 12766 |
| Trenton, NJ: | | | | | |
| Boiler & Controls #1[c] | 102 | 187.5 | 53.8 | 29 | 2039 |
| Boiler & Controls #2 | 81 | 198.6 | 27.9 | 14 | 3818 |
| Boiler & Controls #3 | 219 | 181.7 | 9.8 | 5 | 1556 |
| High-Efficiency Boilers[d] | 112 | 189.4 | 95.4 | 50 | 1776 |

[a]All projects consist of low-rise buildings.

[b]"General Rehab" refers to extensive renovations, including a new insulated facade and roof, thermopane windows, insulated doors and storm doors, crawl space insulation, new boiler controls and valves, and maximum set thermostats at #1, and an insulated facade, thermopane windows, new doors and storm doors, maximum set thermostats, and replacement of individual-unit gas furnaces at #2.

[c]"Boilers & Controls" refers to replacement of central boilers with similar new boilers plus heating controls. Because boiler costs do not scale linearly with the number of dwelling units, the costs per unit for this measure varies widely.

[d]"High-Efficiency Boilers" refers to replacement of central boilers with high-efficiency, modular, condensing-pulse combustion boilers.

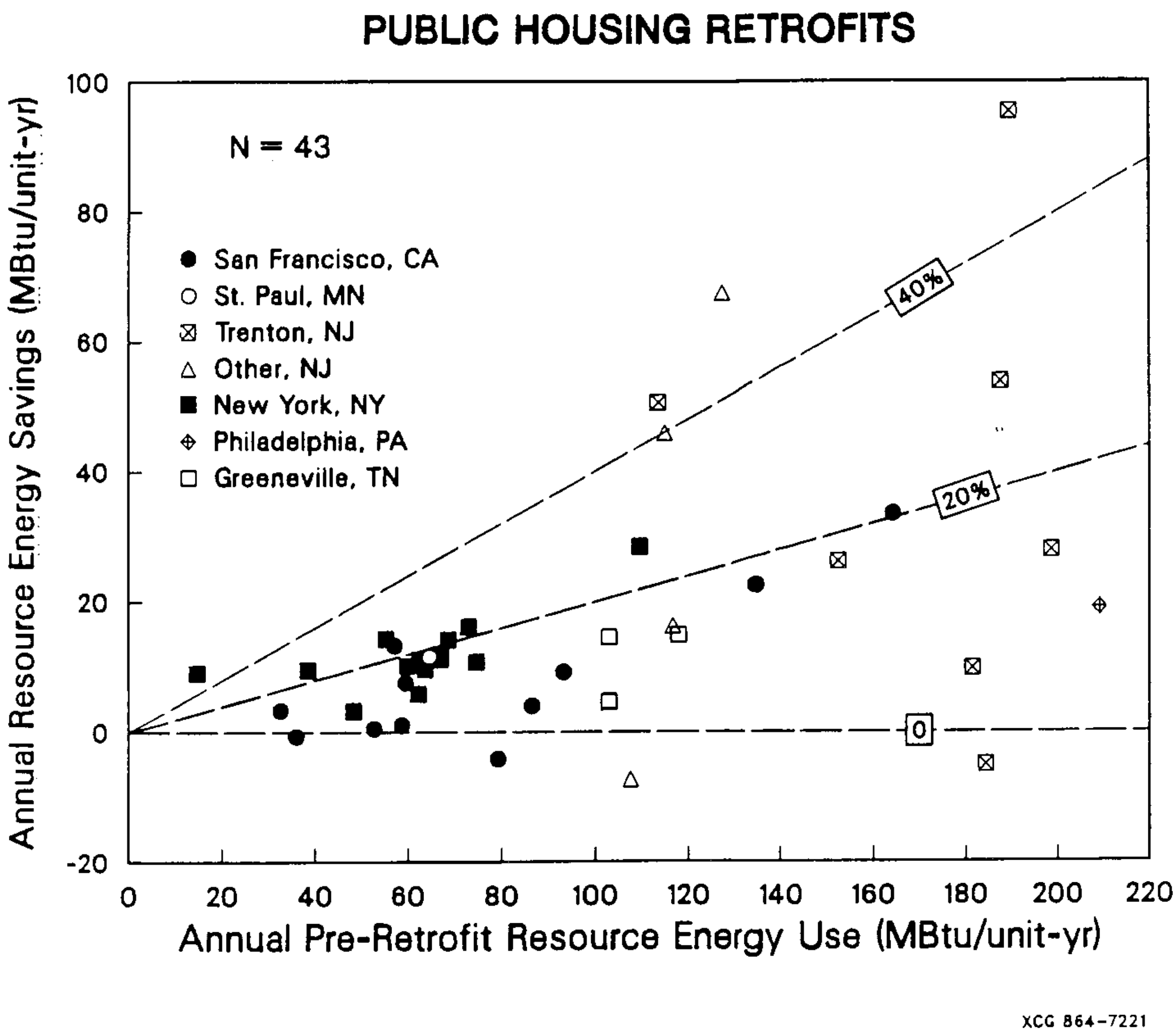
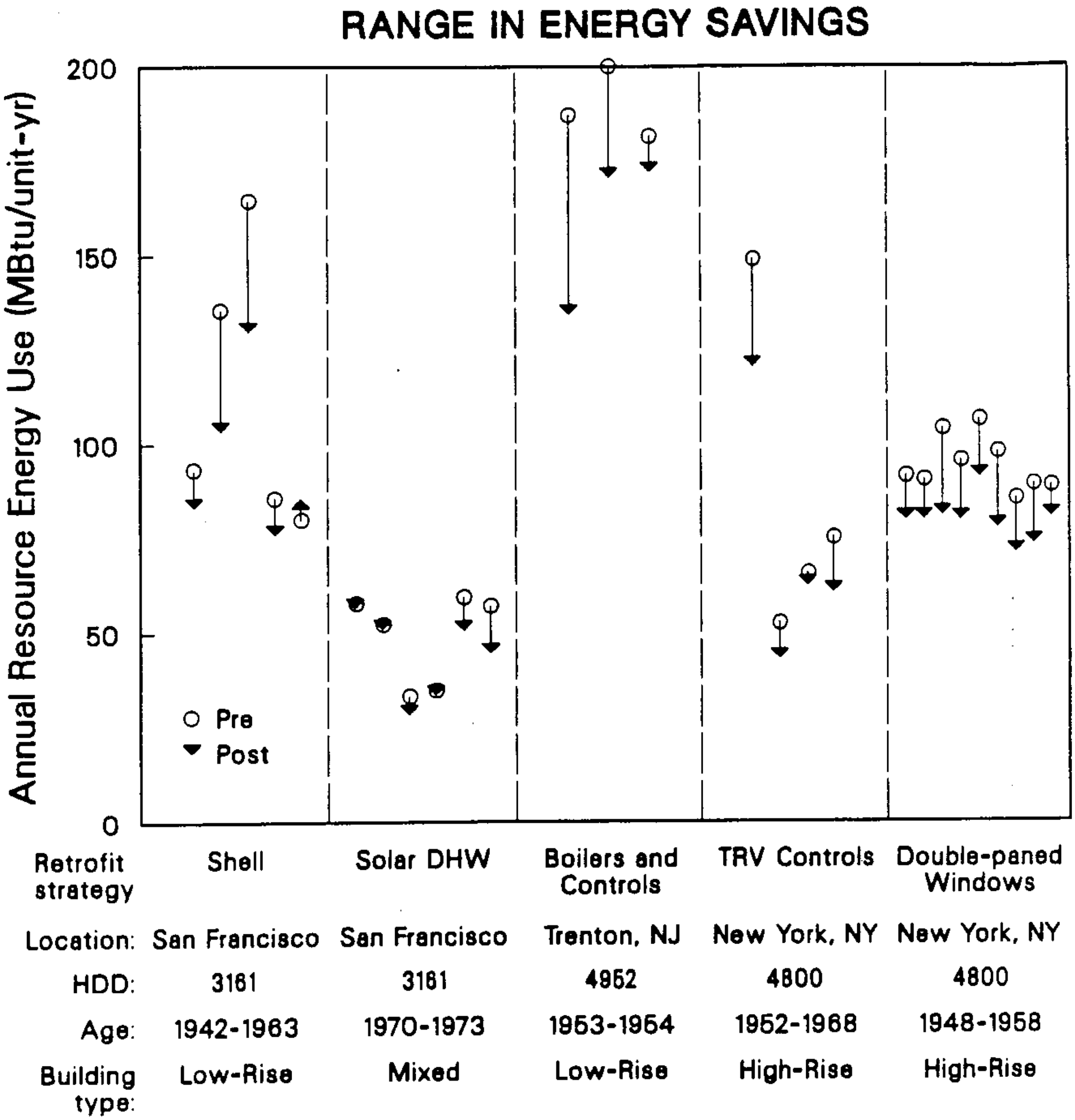



Fig. 1. Energy savings as a function of pre-retrofit consumption. Savings are somewhat correlated with pre-retrofit energy use (correlation coefficient=0.52). Electricity consumption is converted into resource energy, using 11500 Btu/kWh.




XCG 859-422 B

Fig. 2. Range in pre- and post-retrofit consumption among similar retrofits carried out at different projects. "Shell" measures include attic insulation, weatherstripping, and low-cost domestic hot water retrofits. "Solar DHW" refers to active solar domestic hot water systems. "TRV Controls" are thermostatic radiator valves. Consumption at the San Francisco projects includes energy used for space heat, domestic hot water, and cooking; the oil-heated projects in Trenton and New York include space heat and (estimated) domestic hot water use only.

# Persistence of Savings

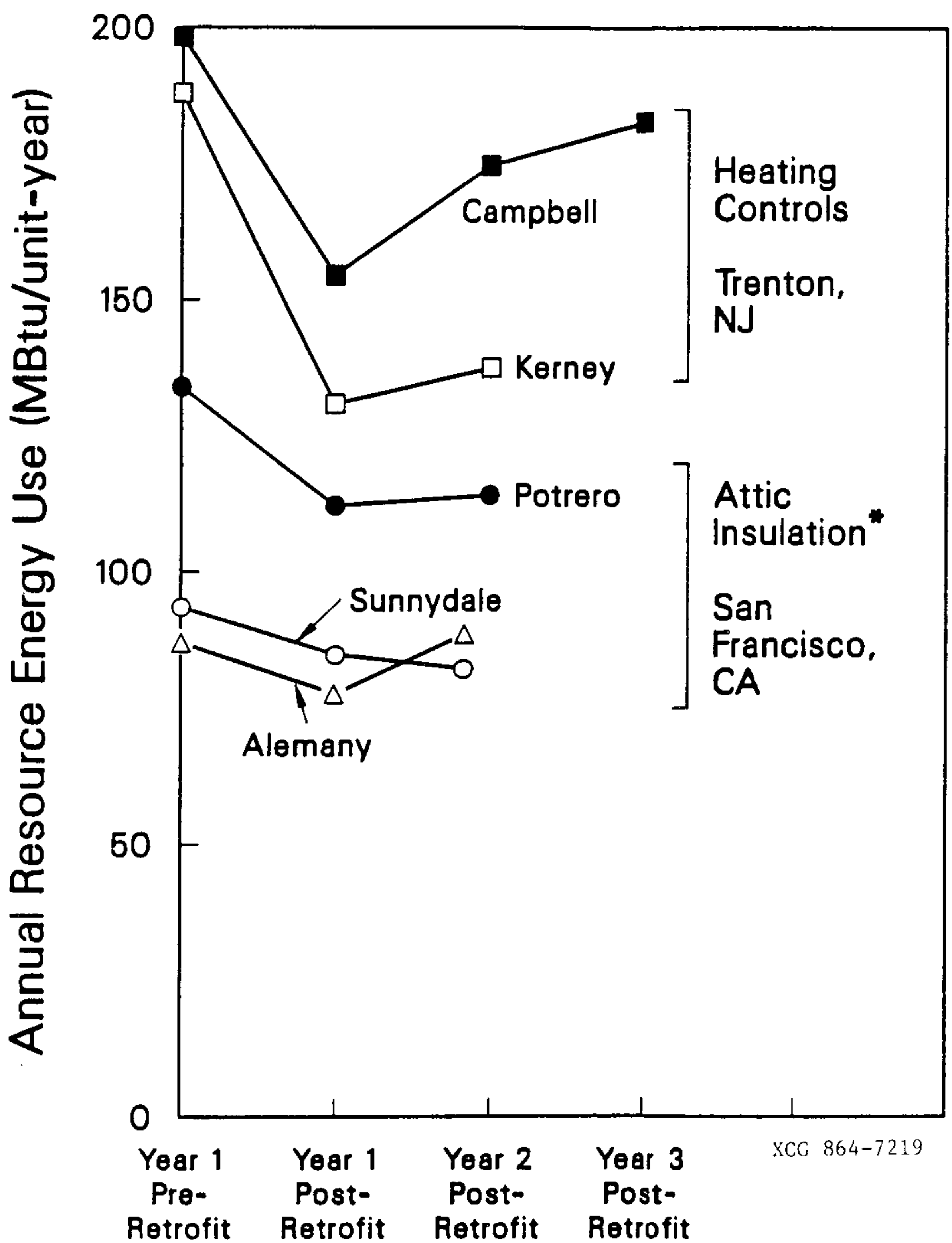



Fig. 3. Persistence of savings for projects with multiple years of post-retrofit data. Energy use increases after the first post-retrofit year at the Trenton projects; energy savings are sustained through both post-retrofit years at two of the three San Francisco projects.

*Other low-cost measures, including caulking & weatherstripping, low-flow showerheads, and domestic hot water blankets, were also installed at these projects.

## APPENDIX A: Public Housing Retrofit Database

The following tables contain results from the analysis of 43 retrofits implemented at nine U.S. housing authorities. Each retrofit is uniquely identified by a label and a retrofit intervention number. (If two separately analyzed retrofits are carried out at one property, the two retrofits have the same label but different intervention numbers.)

The following terms and abbreviations are used in the tables:

**Label:** The first letter in each label stands for the fuel used for the end-use affected by the retrofit. 'E'=electricity, 'G'=natural gas, 'M'=mixed, 'O'=oil.

**Floor Area:** Total or conditioned floor area for all of the analyzed units.

**Building Type:** 'CO'=combination of types, 'HR'=high-rise, 'LR'=low-rise, 'SF'=single-family.

**Number of Occupants Pre:** The number of occupants per dwelling unit before the retrofit.

**Type of Tenants:** 'FM'=family, 'MX'=mixed, 'SN'=senior.

**Wall Material:** 'BR'=brick, 'CB'=concrete block, 'FR'=frame, 'MA'=masonry.

**Window Type:** 'CA'=casement, 'DH'=double-hung.

**Heat System Type:** 'C'=central (one boiler room per project), 'B'=building (one boiler room per building), 'I'=individual (one heater per dwelling unit).

**Heat Distribution Type:** 'S'=steam, 'W'=water, 'F'=forced circulation.

**Domestic Hot Water (DHW) Type:** 'C'=central, 'G'=group (one boiler room for a number of buildings but not a whole project), 'B'=building, 'I'=individual, 'L'=tankless, 'T'=storage tank, 'B'=DHW produced by space heat boiler, 'R'=residential-type DHW heater separate from space heat system.

**HDD:** Long-term average heating degree-days to base 65°F.

**Climate Zone:** '1'=over 7000 HDD, '3'=4000-5499 HDD, '4'=less than 4000 HDD.

**Retrofit Measures:** 'CM'=computerized energy management system, 'CW'=caulk and weatherstrip, 'DR'=door replacement, 'HC'=heating controls, 'HR'=heating system replacement, 'HS'=heating system retrofit, 'LA'=attic insulation, 'IF'=floor insulation, 'IW'=wall insulation, 'LC'=lighting controls, 'LS'=lighting system retrofit, 'OM'=operations and maintenance, 'SH'=solar space heat, 'SR'=structural renovation, 'SW'=solar hot water, 'WH'=water-heating retrofit, 'WM'=window management, 'WR'=window replacement.

**Heat System Measures:** 'CLT'=automatic setback or clock thermostat, 'EMC'=energy mangement system with microcomputer, 'EMR'=remote computerized HVAC control, 'HRM'=replace heating plant with modular boilers, 'IHW'=insulating water heater blanket, 'LFS'=low-flow showerhead, 'OMC'=operations and maintenance on heating controls, 'OMP'=operations and maintenance on heating plant, 'RES'=outdoor reset controls, 'SHT'=separate DHW heater, 'SHW'=steam to hot water conversion, 'TRV'=thermostatic radiator vents.

**Confidence Level:** 'B+'=PRISM analysis (variable reference temperature), 'B'=regression analysis of energy data with fixed reference temperature or accurate baseload determination from summer months' bills, 'C'=annual consumption data that is weather-corrected by scaling space-heat fraction by ratio of actual to normal HDD.

**Confidence Level Cost:** 'B'=documented cost data, contractor cost of retrofit, estimated O&M costs, 'C'=adequate cost data, aggregate cost data for group of buildings or buildings that have only materials cost plus labor hours, 'F'=no retrofit cost data.

**End Uses Included:** 'F'=all end uses of space heat fuel, 'H'=space heat, 'L'=lighting, 'W'=space heat and hot water.

**Analysis Method:** 'R'=regression (PRISM) with variable reference temperature, 'S'=scaling of space heat data by annual or monthly HDD.

**Energy Use and Cost Data:** All numbers are *per dwelling unit*; electricity use is reported as kWh/dwelling unit, consumption at fuel-heated projects is expressed in MBtu/dwelling unit (1 MBtu=$10^6$ Btu). Oil and gas consumption converted to MBtus using the following conversion factors: #2 oil=0.139 MBtu/gallon, #4 oil=0.145 MBtu/gallon, #6 oil=0.150 MBtu/gallon, gas=0.102 MBtu/ccf=0.100 MBtu/therm.

NAC: Weather-normalized annual consumption, for the end-uses specified in the 'End-Uses Included' field.

**Space Heat:** Separately metered space heat consumption, or weather-dependent portion of consumption estimated in PRISM analysis.

**Baseload:** Weather-independent portion of consumption, as estimated by PRISM analysis.

**Heating Fuel Intensity:** Space heat use divided by floor area.

**Heating Factor:** Space heat use divided by floor area and long-term average heating degree-days, base 65°F.

| | |
|---|---|
| **Economic Indicators:** | All costs are in 1985 \$/dwelling unit. In the following definitions, I=capital cost of retrofit, P=local price of energy (adjusted by an energy escalation rate=4%), $\Delta$M=change in annual operations and maintenance costs, $\Delta$E=change in annual energy use (normalized, in MBtu), d=real discount rate (= 7%), n=retrofit lifetime (years). |
| **Simple Payback Time:** | $SPT = I/(\Delta E * P)$ The period required for the undiscounted cumulative value of future energy savings (at today's energy prices) to equal the initial cost of the measure in question. |
| **Payback Time Including Maintenance Costs:** | $PTMC = I/[(\Delta E * P) - \Delta M]$ Includes changes in annual operations and maintenance costs resulting from the retrofit in the calculation of payback time. |
| **Cost of Conserved Energy:** | $CCE = [I/\Delta E] * \{d/[1-(1+d)^{-n}]\}$ The ratio of the annualized investment in a retrofit to the annual energy savings caused by it. An efficient investment is one whose CCE is less than the cost of fuel. |
| **Net Present Value:** | The difference between the present value of the benefits resulting from a retrofit's lifetime energy savings and the present value of the lifetime costs of the retrofit. The best conservation investment has the highest NPV. |
| **Savings-To-Investment Ratio:** | The ratio of the present value of the benefits and costs of a conservation investment. |
| **Internal Rate of Return:** | The rate of interest which causes the discounted life-cycle costs and savings from an investment to be equal. It is useful for comparing the relative efficiency of energy conservation measures with other types of investments. |

Table A-1. Public housing retrofits: locations and building descriptions

| BLDG. LABEL | NO. OF INTER-VENTIONS | BLDG. NAME | CITY | STATE | NO. OF APT. UNITS | NO. OF BLDGS | FLOOR AREA (SQFT) | BLDG. TYPE | YEAR BUILT |
|---|---|---|---|---|---|---|---|---|---|
| E012 | 1 | 830 AMSTERDAM | NEW YORK | NY | 159 | 1 | 137535 | HR | 1965 |
| E020 | 1 | GREENEVILLE | GREENEVILLE | TN | 275 | 275 | 220000 | SF | 1968 |
| E020 | 2 | GREENEVILLE | GREENEVILLE | TN | 265 | 265 | 212000 | SF | 1968 |
| E020.1 | 2 | GREENEVILLE | GREENEVILLE | TN | 188 | 188 | 150400 | SF | 1968 |
| E020.2 | 2 | GREENEVILLE | GREENEVILLE | TN | 20 | 20 | 16000 | SF | 1968 |
| E020.3 | 2 | GREENEVILLE | GREENEVILLE | TN | 57 | 57 | 45600 | SF | 1968 |
| G032 | 1 | PROJECT A | NEWARK | NJ | 530 | 12 | 391140 | LR | 1940 |
| G035.1 | 1 | SUNNYDALE | SAN FRANCISCO | CA | 772 | 91 | 666523 | LR | 1942 |
| G035.11 | 1 | 3850 18TH ST. | SAN FRANCISCO | CA | 107 | 5 | 59241 | HR | 1970 |
| G035.12 | 1 | 1760 BUSH ST. | SAN FRANCISCO | CA | 108 | 1 | 68277 | HR | 1972 |
| G035.13 | 1 | 363 NOE ST. | SAN FRANCISCO | CA | 22 | 1 | 13608 | LR | 1971 |
| G035.14 | 1 | 2698 CALIFORNIA ST. | SAN FRANCISCO | CA | 40 | 1 | 24263 | LR | 1971 |
| G035.15 | 1 | 491 31ST AVE. | SAN FRANCISCO | CA | 75 | 1 | 44042 | HR | 1973 |
| G035.16 | 1 | 939 EDDY ST. | SAN FRANCISCO | CA | 36 | 1 | 18117 | LR | |
| G035.2 | 1 | POTRERO TERRACE | SAN FRANCISCO | CA | 469 | 38 | 388332 | LR | 1942 |
| G035.4 | 1 | ALICE GRIFFITH | SAN FRANCISCO | CA | 258 | 41 | 215688 | LR | 1962 |
| G035.5 | 1 | ALEMANY | SAN FRANCISCO | CA | 158 | 24 | 137460 | LR | 1956 |
| G035.6 | 1 | HAYES VALLEY | SAN FRANCISCO | CA | 170 | 10 | 239010 | LR | 1963 |
| G039 | 1 | LUMLEY HOMES | ASBURY PARK | NJ | 60 | 2 | 39200 | HR | 1963 |
| G039 | 2 | LUMLEY HOMES | ASBURY PARK | NJ | 60 | 2 | 39200 | HR | 1963 |
| G044.1 | 1 | HECKMAN ANNEX | PHILLIPSBURG | NJ | 150 | 24 | 165480 | LR | 1951 |
| G044.2 | 1 | HECKMAN TERRACE | PHILLIPSBURG | NJ | 222 | 49 | 338270 | LR | 1942 |
| M015 | 1 | CENTRAL/NEILL/RAVOUX | ST. PAUL | MN | 503 | 3 | 206154 | HR | 1964 |
| M016 | 1 | HAVERSTICK | TRENTON | NJ | 112 | 14 | 96544 | LR | 1954 |
| M016 | 2 | HAVERSTICK | TRENTON | NJ | 112 | 14 | 96544 | LR | 1954 |
| O002.1 | 1 | PAGE HOMES | TRENTON | NJ | 159 | 3 | 131970 | LR | 1954 |
| O002.2B | 1 | PAGE HOMES-B | TRENTON | NJ | 1500 | 3 | | LR | 1954 |
| O008.1 | 1 | BREUKELEN HOUSES | NEW YORK | NY | 42 | 1 | 37380 | HR | 1952 |
| O008.1A | 1 | BREUKELEN-A | NEW YORK | NY | 42 | 1 | 37389 | HR | 1952 |
| O008.2 | 1 | CYPRESS HILLS | NEW YORK | NY | 98 | 1 | 83300 | HR | 1955 |
| O008.2A | 1 | CYPRESS HILLS-A | NEW YORK | NY | 98 | 1 | 83300 | HR | 1955 |
| O008.3 | 1 | MARLBORO HOUSES | NEW YORK | NY | 56 | 1 | 46480 | HR | 1958 |
| O008.3A | 1 | MARLBORO HOUSES-A | NEW YORK | NY | 56 | 1 | 46480 | HR | 1958 |
| O008.4 | 1 | OCEAN HILL APTS. | NEW YORK | NY | 81 | 1 | 74520 | HR | 1968 |
| O008.4A | 1 | OCEAN HILL APTS.-A | NEW YORK | NY | 81 | 1 | 74520 | HR | 1968 |
| O009.1 | 1 | CYPRESS HILLS | NEW YORK | NY | 1444 | 15 | 233364 | HR | 1955 |
| O009.2 | 1 | BROWNSVILLE | NEW YORK | NY | 1338 | 27 | 188564 | HR | 1948 |
| O009.3 | 1 | PATERSON | NEW YORK | NY | 1791 | 15 | 1450710 | HR | 1950 |
| O009.4 | 1 | JOHNSON HOUSES | NEW YORK | NY | 1310 | 10 | 1061100 | HR | 1948 |
| O009.5 | 1 | ALBANY I & II | NEW YORK | NY | 1229 | 9 | 1032360 | HR | 1950 |
| O009.6 | 1 | AMSTERDAM HOUSES | NEW YORK | NY | 1084 | 13 | 823840 | HR | 1948 |
| O009.7 | 1 | CARVER HOUSES | NEW YORK | NY | 1246 | 13 | 1027950 | HR | 1958 |
| O009.8 | 1 | SEDGWICK HOUSES | NEW YORK | NY | 786 | 7 | 664170 | HR | 1951 |
| O009.9 | 1 | GUN HILL HOUSES | NEW YORK | NY | 733 | 6 | 623050 | HR | 1950 |
| O013 | 1 | DONNELLY | TRENTON | NJ | 376 | 85 | 292780 | LR | 1939 |
| O014.1 | 1 | KERNEY | TRENTON | NJ | 102 | 5 | 71400 | LR | 1953 |
| O014.2 | 1 | CAMPBELL | TRENTON | NJ | 81 | 3 | 63990 | LR | 1953 |
| O014.3 | 1 | WILSON | TRENTON | NJ | 219 | 8 | 166440 | LR | 1954 |
| O015 | 1 | SOUTHWARK PLAZA | PHILADELPHIA | PA | 886 | 30 | 888420 | CO | 1963 |

Table A-2. Public housing retrofits: occupancy, building envelope, systems, and climate

| BLDG. LABEL | NO. OF INTER-VENTIONS | AVG. NO. OF OCCUP. PRE | TYPE OF TENANTS | WALL MATERIAL | WINDOW TYPE | NO. OF GLAZING LAYERS | HEAT SYSTEM TYPE | HEAT DIST. TYPE | DHW TYPE | HDD ( F) | CLIMATE ZONE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| E012 | 1 | 2.8 | FM | MA | | | C | S | | | 3 |
| E020 | 1 | 2.4 | MX | BR* | | | I | | | 3935 | 4 |
| E020 | 2 | 2.4 | MX | BR | | 2.0 | I | | | 3935 | 4 |
| E020.1 | 2 | 2.4 | MX | BR | | 2.0 | I | | | 3935 | 4 |
| E020.2 | 2 | 2.4 | MX | BR | | 2.0 | I | | | 3935 | 4 |
| E020.3 | 2 | 2.4 | MX | BR | | 2.0 | I | | | 3935 | 4 |
| G032 | 1 | | FM | MA | | | C | S | | 4857 | 3 |
| G035.1 | 1 | 3.7 | FM | CB | | | I | | I R | 3161 | 4 |
| G035.11 | 1 | | SN | CB | | | C | W | C B | 3161 | 4 |
| G035.12 | 1 | | SN | CB | | | C | | | 3161 | 4 |
| G035.13 | 1 | | SN | FR | | | C | | | 3161 | 4 |
| G035.14 | 1 | | SN | FR | | | C | | | 3161 | 4 |
| G035.15 | 1 | | SN | MA | | | C | | | 3161 | 4 |
| G035.16 | 1 | | SN | FR | | | C | | | 3161 | 4 |
| G035.2 | 1 | 3.3 | FM | CB | | | C | W F | G B | 3161 | 4 |
| G035.4 | 1 | 4.8 | FM | FR | | | C | W F | C B | 3161 | 4 |
| G035.5 | 1 | 4.0 | FM | FR | | | I | | I R | 3161 | 4 |
| G035.6 | 1 | 2.6 | FM | FR | | | C | W F | C B | 3161 | 4 |
| G039 | 1 | 1.3 | SN | CB | DH | 1.0 | C | S | CTB | 5034 | 3 |
| G039 | 2 | 1.3 | SN | CB | DH | 1.0 | C | S | CTS | 5034 | 3 |
| G044.1 | 1 | | FM | BR | | | C | | C B | 4972 | 3 |
| G044.2 | 1 | | MX | | | | I | | ITR | 4972 | 3 |
| M015 | 1 | | SN | BR | | | B | W | B B | 8159 | 1 |
| M016 | 1 | | FM | MA | CA | 1.0 | C | W | CL | 4952 | 3 |
| M016 | 2 | | FM | MA | DH | 1.0 | C | W | CL | 4952 | 3 |
| O002.1 | 1 | | FM | MA | DH | 1.0 | C | W | CTB | 4908 | 3 |
| O002.2B | 1 | | FM | | | | | | | 4911 | 3 |
| O008.1 | 1 | | FM | MA | | | C | S | | 4800 | 3 |
| O008.1A | 1 | | FM | MA | | | C | S | | 4800 | 3 |
| O008.2 | 1 | | FM | MA | | | C | S | | 4800 | 3 |
| O008.2A | 1 | | FM | MA | DH | 1.0 | C | S | | 4800 | 3 |
| O008.3 | 1 | | FM | MA | | | C | S | | 4800 | 3 |
| O008.3A | 1 | | FM | MA | | | C | S | | 4800 | 3 |
| O008.4 | 1 | | FM | MA | | | C | S | | 4800 | 3 |
| O008.4A | 1 | | FM | MA | | | C | S | | 4800 | 3 |
| O009.1 | 1 | 3.0 | FM | MA | CA | 1.0 | C | S | C B | 4800 | 3 |
| O009.2 | 1 | 3.2 | FM | MA | CA | 1.0 | C | S | C B | 4800 | 3 |
| O009.3 | 1 | 3.0 | FM | MA | CA | 1.0 | C | S | C B | 4800 | 3 |
| O009.4 | 1 | 2.8 | FM | MA | CA | 1.0 | C | S | C B | 4800 | 3 |
| O009.5 | 1 | 3.0 | FM | MA | CA | 1.0 | C | S | C B | 4800 | 3 |
| O009.6 | 1 | 2.8 | FM | MA | CA | 1.0 | C | S | C B | 4800 | 3 |
| O009.7 | 1 | 2.7 | FM | MA | CA | 1.0 | C | S | C B | 4800 | 3 |
| O009.8 | 1 | 2.5 | FM | MA | CA | 1.0 | C | S | C B | 4800 | 3 |
| O009.9 | 1 | 2.5 | FM | MA | CA | 1.0 | C | S | C B | 4800 | 3 |
| O013 | 1 | | FM | MA | DH | 1.0 | C | S | C B | 4952 | 3 |
| O014.1 | 1 | | FM | MA | DH | 1.0 | C | | C B | 4952 | 3 |
| O014.2 | 1 | | FM | MA | DH | 1.0 | C | | C B | 4952 | 3 |
| O014.3 | 1 | | FM | MA | DH | 1.0 | C | | C B | 4952 | 3 |
| O015 | 1 | | MX | MA | | | C | S | CTB | 4865 | 3 |

Table A-3. Public housing retrofits: retrofit strategies

| BLDG. LABEL | NO. OF INTER-VENTIONS | QT. | YR OF RETRO FIT | RETROFIT MEASURES | HEAT SYSTEM MEASURES | CONFI-DENCE LEVEL | CONFI-DENCE LEVEL COST | COMMENTS |
|---|---|---|---|---|---|---|---|---|
| E012 | 1 | 4 | 79 | LS | | C | C | FLOURESCENT LITE RETRO |
| E020 | 1 | 3 | 80 | IA,WM,CW | | C | C | R-19 ATTIC/STORM WINDOWS |
| E020 | 2 | 4 | 81 | WM,SH | | C | C | PASSIVE SOLAR AGGREGATE |
| E020.1 | 2 | 4 | 81 | WM | | C | C | WINDOW SHADES |
| E020.2 | 2 | 4 | 81 | SH | | C | C | SUNSPACES |
| E020.3 | 2 | 4 | 81 | SH | | C | C | WALL HEATERS |
| G032 | 1 | 3 | 82 | CM,OM,HR | SHW,EMC | C | B | HEATING CONTROLS |
| G035.1 | 1 | 4 | 82 | IA,WH,CW | IHW | B+ | B | ZIP RETROFIT |
| G035.11 | 1 | 2 | 84 | SW | | B+ | B | SENIOR SOLAR DHW |
| G035.12 | 1 | 2 | 84 | SW | | B+ | B | SENIOR SOLAR DHW |
| G035.13 | 1 | 2 | 84 | SW | | B+ | B | SENIOR SOLAR DHW |
| G035.14 | 1 | 1 | 84 | SW | | B+ | B | SENIOR SOLAR DHW |
| G035.15 | 1 | 2 | 84 | SW | | B+ | B | SENIOR SOLAR DHW |
| G035.16 | 1 | 1 | 84 | SW | | B+ | B | SENIOR SOLAR DHW |
| G035.2 | 1 | 4 | 82 | IA,WH,CW,HC | LFS,CLT | B+ | B | ZIP RETROFIT |
| G035.4 | 1 | 4 | 82 | IA,CW,HC | CLT | B+ | B | ZIP RETROFIT |
| G035.5 | 1 | 4 | 82 | IA,WH,CW | IHW | B+ | B | ZIP RETROFIT |
| G035.6 | 1 | 1 | 83 | IA,CW,HC | CLT | B+ | B | ZIP RETROFIT |
| G039 | 1 | 1 | 82 | HC,WH | RES, SHT | B+ | B | SEPARATE DHW/ZONE CTRLS |
| G039 | 2 | 1 | 84 | WM,HS | OMP,OMC | B+ | B | STORM WINDOWS/STEAM TRAPS |
| G044.1 | 1 | 1 | 83 | WM,IA,DR,IW,IF,HC,SR | OMC | B+ | B | REHAB |
| G044.2 | 1 | 1 | 82 | WM,DR,IA,HR,HC,IW,SR | | B+ | B | REHAB - MOD FUNDS |
| M015 | 1 | 1 | 81 | CM,LC | EMR | C | C | MGMT CONTROL SYS FOR PHA |
| M016 | 1 | 3 | 83 | WR | | B+ | B | THA5-8/WINDOWS |
| M016 | 2 | 3 | 84 | HR | HRM | B+ | F | THA5-8/HYDROTHERM BOILERS |
| O002.1 | 1 | 1 | 81 | HC,HS,WH | | C | B | EMCS PUBLIC HOUSING |
| O002.2B | 1 | | | | | C | B | BLIND CONTROL GROUP |
| O008.1 | 1 | 1 | 77 | HC | TRV | B | B | TRV DEMO PROJ. |
| O008.1A | 1 | | | | | B | B | TRV CONTROL BLDG. |
| O008.2 | 1 | 1 | 77 | HC | TRV | B | B | TRV DEMO PROJ. |
| O008.2A | 1 | | | | | B | B | TRV CONTROL BLDG. |
| O008.3 | 1 | 1 | 77 | HC | TRV | B | B | TRV DEMO PROJ. |
| O008.3A | 1 | | | | | B | B | TRV CONTROL BLDG. |
| O008.4 | 1 | 1 | 77 | HC | TRV | B | B | TRV DEMO PROJ. |
| O008.4A | 1 | | | | | B | B | TRV CONTROL BLDG. |
| O009.1 | 1 | 3 | 80 | WR | | C | C | WINDOW RETRO |
| O009.2 | 1 | 4 | 80 | WR | | C | C | WINDOW RETRO |
| O009.3 | 1 | 2 | 80 | WR | | C | C | WINDOW RETRO |
| O009.4 | 1 | 2 | 80 | WR | | C | C | WINDOW RETRO |
| O009.5 | 1 | 4 | 81 | WR | | C | C | WINDOW RETRO |
| O009.6 | 1 | 3 | 80 | WR | | C | C | WINDOW RETRO |
| O009.7 | 1 | 3 | 80 | WR | | C | C | WINDOW RETRO |
| O009.8 | 1 | 2 | 81 | WR | | C | C | WINDOW RETRO |
| O009.9 | 1 | 4 | 81 | WR | | C | C | WINDOW RETRO |
| O013 | 1 | 2 | 81 | HC | RES | B+ | B | THA 5-2/HEATING CTRLS |
| O014.1 | 1 | 4 | 80 | HR,HC | RES | B+ | B | THA 5-4/CTRLS & BOILERS |
| O014.2 | 1 | 2 | 80 | HR,HC | RES | B+ | B | THA 5-5/CTRLS & BOILERS |
| O014.3 | 1 | 4 | 82 | HR,HC | RES | B+ | B | THA 5-6/CTRLS & BOILERS |
| O015 | 1 | 3 | 81 | HC | RES | B+ | F | PHA 2-53/HEATING CTRLS |

Table A-4. Public housing retrofits: energy savings

| BLDG. LABEL | NO. OF INTER-VENTIONS | END USES INCLUDED | ANALYSIS METHOD | NAC BEFORE | NAC SAVINGS | NAC SAVINGS (PER CENT) | SPACE HEAT BEFORE (MBTU) | SPACE HEAT SAVINGS (MBTU) | SPACE HEAT SAVINGS (PER CENT) | ANNUAL BASELOAD CONSUMP. BEFORE | BASE-LOAD SAVINGS | BASE SAVINGS (PER CENT) | HEATING FUEL INTENS. BEFORE (MBTU/ KSQFT) | HEATING FUEL INTENS. AFTER (MBTU/ KSQFT) | HEATING FACTOR BEFORE (BTU/ SQFT-DD) | HEATING FACTOR AFTER (BTU/ SQFT-DD) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | (KWH) | (KWH) | | | | | (KWH) | (KWH) | | | | | |
| E012 | 1 | L | S | 1285.0 | 793.0 | 62 | | | | 1285.0 | 793.0 | 62 | | | | |
| E020 | 1 | F | S | 10262.0 | 1292.0 | 13 | | | | | | | | | | |
| E020 | 2 | F | S | 8968.0 | 437.0 | 5 | | | | | | | | | | |
| E020.1 | 2 | F | S | 8968.0 | 399.0 | 4 | | | | | | | | | | |
| E020.2 | 2 | F | S | 8968.0 | 1265.0 | 14 | | | | | | | | | | |
| E020.3 | 2 | F | S | 8968.0 | 411.0 | 5 | | | | | | | | | | |
| | | | | (MBTU) | (MBTU) | | | | | (MBTU) | (MBTU) | | | | | |
| G032 | 1 | H | S | 162.4 | 16.3 | 10 | 116.8 | 16.3 | 14 | 45.6 | 0.0 | 0 | 158.3 | 136.2 | 32.6 | 28.0 |
| G035.1 | 1 | F | R | 93.2 | 9.2 | 10 | | | | | | | | | | |
| G035.11 | 1 | F | R | 58.8 | 1.1 | 2 | | | | | | | | | | |
| G035.12 | 1 | F | R | 52.9 | 0.6 | 1 | | | | | | | | | | |
| G035.13 | 1 | F | R | 32.9 | 3.4 | 10 | | | | | | | | | | |
| G035.14 | 1 | F | R | 36.2 | -0.6 | - 2 | | | | | | | | | | |
| G035.15 | 1 | F | R | 59.5 | 7.6 | 13 | | | | | | | | | | |
| G035.16 | 1 | F | R | 57.1 | 13.3 | 23 | | | | | | | | | | |
| G035.2 | 1 | F | R | 134.7 | 22.6 | 17 | | | | | | | | | | |
| G035.4 | 1 | F | R | 164.1 | 33.5 | 20 | | | | | | | | | | |
| G035.5 | 1 | F | R | 86.6 | 4.0 | 5 | | | | | | | | | | |
| G035.6 | 1 | F | R | 79.4 | -4.1 | - 5 | | | | | | | | | | |
| G039 | 1 | F | R | 107.8 | -7.3 | - 7 | 63.4 | -31.8 | - 50 | 44.4 | 24.5 | 55 | 97.0 | 145.7 | 19.3 | 28.9 |
| G039 | 2 | F | R | 115.1 | 45.9 | 40 | 95.2 | 69.8 | 73 | 19.9 | -23.9 | -121 | 145.7 | 38.9 | 28.9 | 7.7 |
| G044.1 | 1 | F | R | 166.2 | 67.5 | 41 | 139.3 | 72.7 | 52 | 26.9 | -5.3 | - 20 | 126.2 | 60.3 | 25.4 | 12.1 |
| G044.2 | 1 | F | R | 127.3 | 67.4 | 53 | 85.5 | 51.8 | 61 | 41.8 | 15.6 | 37 | 56.1 | 22.1 | 11.3 | 4.5 |
| M015 | 1 | W | S | 64.8 | 11.6 | 18 | | | | | | | | | | |
| M016 | 1 | F | R | 184.4 | -5.1 | - 3 | 130.6 | -6.1 | - 5 | 53.7 | 1.1 | 2 | 151.6 | 158.7 | 30.6 | 32.0 |
| M016 | 2 | F | R | 189.4 | 95.4 | 50 | 136.8 | 77.7 | 57 | 52.6 | 17.8 | 34 | 158.7 | 68.6 | 32.0 | 13.9 |
| O002.1 | 1 | W | S | 113.8 | 50.6 | 44 | 83.0 | 50.4 | 61 | | | | 100.0 | 39.3 | 20.4 | 8.0 |
| O002.2B | 1 | W | S | 116.7 | 18.4 | 16 | 116.7 | 18.4 | 16 | | | | | | | |
| O008.1 | 1 | H | S | | | | 109.8 | 28.4 | 26 | | | | 123.3 | 91.4 | 25.7 | 19.0 |
| O008.1A | 1 | H | S | | | | 110.3 | 17.0 | 15 | | | | 123.9 | 104.8 | 25.8 | 21.8 |
| O008.2 | 1 | H | S | | | | 38.8 | 9.6 | 25 | | | | 45.7 | 34.4 | 9.5 | 7.2 |
| O008.2A | 1 | H | S | | | | 36.4 | 8.5 | 23 | | | | 42.9 | 32.9 | 8.9 | 6.9 |
| O008.3 | 1 | H | S | | | | 48.5 | 3.3 | 7 | | | | 58.4 | 54.4 | 12.2 | 11.3 |
| O008.3A | 1 | H | S | | | | 45.5 | -2.2 | - 5 | | | | 54.9 | 57.5 | 11.4 | 12.0 |
| O008.4 | 1 | H | S | | | | 55.4 | 14.4 | 26 | | | | 60.2 | 44.6 | 12.5 | 9.3 |
| O008.4A | 1 | H | S | | | | 54.6 | 16.0 | 29 | | | | 59.4 | 42.0 | 12.4 | 8.8 |
| O009.1 | 1 | H | S | | | | 67.2 | 12.0 | 18 | | | | 79.1 | 64.9 | 16.5 | 13.5 |
| O009.2 | 1 | H | S | | | | 63.8 | 9.7 | 15 | | | | 82.3 | 69.8 | 17.2 | 14.5 |
| O009.3 | 1 | H | S | | | | 73.1 | 16.2 | 22 | | | | 90.2 | 70.2 | 18.8 | 14.6 |
| O009.4 | 1 | H | S | | | | 67.2 | 11.2 | 17 | | | | 83.0 | 69.1 | 17.3 | 14.4 |
| O009.5 | 1 | H | S | | | | 74.8 | 10.8 | 14 | | | | 89.0 | 76.2 | 18.6 | 15.9 |
| O009.6 | 1 | H | S | | | | 68.8 | 14.2 | 21 | | | | 90.5 | 71.8 | 18.9 | 15.0 |
| O009.7 | 1 | H | S | | | | 60.1 | 10.2 | 17 | | | | 72.8 | 60.5 | 15.2 | 12.6 |
| O009.8 | 1 | H | S | | | | 62.7 | 11.2 | 18 | | | | 74.2 | 60.9 | 15.5 | 12.7 |
| O009.9 | 1 | H | S | | | | 62.4 | 5.9 | 9 | | | | 73.4 | 66.5 | 15.3 | 13.8 |
| O013 | 1 | F | R | 152.5 | 26.1 | 17 | 118.8 | 34.5 | 29 | 33.7 | -8.3 | - 25 | 152.5 | 108.2 | 30.8 | 21.9 |
| O014.1 | 1 | F | R | 187.5 | 53.8 | 29 | 164.2 | 52.6 | 32 | 23.3 | 1.2 | 5 | 234.5 | 159.4 | 47.4 | 32.2 |
| O014.2 | 1 | W | R | 198.6 | 27.9 | 14 | 167.1 | 27.8 | 17 | 31.5 | 0.1 | 0 | 211.5 | 176.2 | 42.7 | 35.6 |
| O014.3 | 1 | W | R | 181.7 | 9.8 | 5 | 163.5 | 29.6 | 18 | 18.2 | -19.8 | -109 | 215.1 | 176.2 | 43.4 | 35.6 |
| O015 | 1 | F | R | 209.2 | 19.0 | 9 | 146.4 | 24.7 | 17 | 62.8 | -5.7 | - 9 | 146.0 | 121.3 | 30.0 | 24.9 |

## Table A-5. Public housing retrofits: cost-effectiveness

| BLDG. LABEL | NO. OF INTER-VENTIONS | COST OF RETRO FIT (85$/UNIT) | RETR. LIFE TIME | OPER. MAINT. COST ($/UNIT) | LOCAL ENERGY PRICE ($) | SIMPLE PAYBACK (YEARS) | PAYBACK WITH CAP. MAINT. COSTS (YEARS) | CCE (D=7%) | NET PRESENT VALUE ($/UNIT) | SAVINGS INVEST. RATIO | IRR |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | ($/KWH) | | | ($/KWH) | | | |
| E012 | 1 | 102 | 10 | - 5 | .070 | 1.4 | 0.7 | 0.01 | 594.9 | 6.82 | 0.87 |
| E020 | 1 | 486 | 15 | 0 | .043 | 6.9 | 6.9 | 0.04 | 362.4 | 1.75 | 0.16 |
| E020 | 2 | 1839 | 15 | 0 | .043 | 86.1 | 86.1 | 0.46 | - 1582.5 | 0.14 | 0.00 |
| E020.1 | 2 | 467 | 10 | 0 | .043 | 24.0 | 24.0 | 0.17 | - 299.9 | 0.36 | 0.00 |
| E020.2 | 2 | 19668 | 20 | 0 | .043 | 318.1 | 318.1 | 1.47 | -18745.8 | 0.05 | 0.00 |
| E020.3 | 2 | 432 | 10 | 0 | .043 | 21.5 | 21.5 | 0.15 | - 259.6 | 0.40 | 0.00 |
| | | | | | ($/MBTU) | | | ($/MBTU) | | | |
| G032 | 1 | 286 | 10 | 40 | 5.800 | 2.8 | 5.7 | 4.95 | 297.6 | 2.04 | 0.24 |
| G035.1 | 1 | 218 | 10 | 0 | 5.100 | 4.3 | 4.3 | 3.37 | 220.6 | 2.01 | 0.24 |
| G035.11 | 1 | 539 | 10 | 2 | 4.400 | 108.1 | 111.0 | 71.54 | - 510.4 | 0.05 | 0.00 |
| G035.12 | 1 | 535 | 10 | 2 | 4.400 | 196.6 | 201.9 | 130.19 | - 525.7 | 0.02 | 0.00 |
| G035.13 | 1 | 562 | 10 | 2 | 4.400 | 36.5 | 37.4 | 24.14 | - 444.6 | 0.21 | 0.00 |
| G035.14 | 1 | 623 | 10 | 2 | 4.400 | | | | - 660.9 | | 0.00 |
| G035.15 | 1 | 549 | 10 | 2 | 4.400 | 15.9 | 16.4 | 10.55 | - 267.9 | 0.51 | 0.00 |
| G035.16 | 1 | 577 | 10 | 2 | 4.400 | 9.5 | 9.7 | 6.33 | - 70.5 | 0.88 | 0.04 |
| G035.2 | 1 | 100 | 10 | 0 | 5.100 | 0.8 | 0.8 | 0.63 | 976.8 | 10.75 | 1.34 |
| G035.4 | 1 | 178 | 10 | 0 | 5.100 | 1.0 | 1.0 | 0.75 | 1419.0 | 8.99 | 1.13 |
| G035.5 | 1 | 172 | 10 | 0 | 5.100 | 7.7 | 7.7 | 6.12 | 18.6 | 1.11 | 0.09 |
| G035.6 | 1 | 88 | 10 | 0 | 5.100 | | | | - 281.3 | | 0.00 |
| G039 | 1 | 377 | 15 | 0 | 5.600 | | | | - 930.5 | | 0.00 |
| G039 | 2 | 545 | 5 | 0 | 5.600 | 2.0 | 2.0 | 2.90 | 681.0 | 2.25 | 0.45 |
| G044.1 | 1 | 13767 | 25 | 0 | 6.500 | 29.2 | 29.2 | 17.50 | - 5437.9 | 0.60 | 0.03 |
| G044.2 | 1 | 12766 | 25 | 0 | 6.500 | 25.9 | 25.9 | 16.26 | - 4076.2 | 0.68 | 0.04 |
| M015 | 1 | 350 | 10 | 0 | 5.500 | 4.5 | 4.5 | 4.29 | 310.5 | 1.89 | 0.22 |
| M016 | 1 | | 15 | 0 | | | | | | | |
| M016 | 2 | 547 | 25 | - 10 | 6.700 | 0.8 | 0.7 | 0.39 | 11072.3 | 21.25 | 1.30 |
| O002.1 | 1 | 494 | 10 | 25 | 8.269 | 1.0 | 1.4 | 1.89 | 3623.6 | 8.33 | 1.04 |
| O002.2B | 1 | | | 0 | | | | | | | |
| O008.1 | 1 | 236 | 10 | 10 | 2.517 | 2.0 | 3.0 | 1.54 | 673.2 | 3.85 | 0.49 |
| O008.1A | 1 | | | 0 | | | | | | | |
| O008.2 | 1 | 199 | 10 | 10 | 2.517 | 4.9 | 7.8 | 4.00 | 30.3 | 1.15 | 0.10 |
| O008.2A | 1 | | | 0 | | | | | | | |
| O008.3 | 1 | 156 | 10 | 10 | 2.517 | 11.2 | 19.7 | 9.75 | - 153.9 | 0.01 | 0.00 |
| O008.3A | 1 | | | 0 | | | | | | | |
| O008.4 | 1 | 214 | 10 | 10 | 2.517 | 3.5 | 5.5 | 2.81 | 188.8 | 1.88 | 0.22 |
| O008.4A | 1 | | | 0 | | | | | | | |
| O009.1 | 1 | 1339 | 20 | - 30 | 6.370 | 13.8 | 9.7 | 8.03 | 521.5 | 1.39 | 0.11 |
| O009.2 | 1 | 1639 | 20 | - 30 | 6.370 | 21.4 | 16.3 | 12.86 | - 96.5 | 0.94 | 0.06 |
| O009.3 | 1 | 1596 | 20 | - 30 | 6.370 | 11.9 | 8.8 | 7.45 | 830.2 | 1.52 | 0.12 |
| O009.4 | 1 | 1765 | 20 | - 30 | 6.370 | 19.1 | 14.6 | 12.20 | 39.8 | 1.02 | 0.07 |
| O009.5 | 1 | 1557 | 20 | - 30 | 6.370 | 19.9 | 15.3 | 10.84 | - 20.1 | 0.99 | 0.07 |
| O009.6 | 1 | 1408 | 20 | - 30 | 6.370 | 12.3 | 8.8 | 7.24 | 720.3 | 1.51 | 0.12 |
| O009.7 | 1 | 1281 | 20 | - 30 | 6.370 | 15.5 | 10.7 | 8.91 | 361.2 | 1.28 | 0.10 |
| O009.8 | 1 | 1233 | 20 | - 30 | 6.370 | 14.6 | 10.1 | 7.72 | 415.9 | 1.34 | 0.11 |
| O009.9 | 1 | 1245 | 20 | - 30 | 6.370 | 29.1 | 20.7 | 14.83 | - 241.1 | 0.81 | 0.05 |
| O013 | 1 | 458 | 20 | 40 | 7.020 | 2.1 | 4.4 | 3.19 | 2307.3 | 6.04 | 0.44 |
| O014.1 | 1 | 2039 | 20 | 60 | 5.599 | 5.5 | 7.6 | 4.69 | 2778.3 | 2.36 | 0.19 |
| O014.2 | 1 | 3818 | 20 | 45 | 5.199 | 20.3 | 23.6 | 14.53 | - 1606.3 | 0.58 | 0.02 |
| O014.3 | 1 | 1556 | 20 | 60 | 6.415 | 22.7 | 32.8 | 21.10 | - 1217.8 | 0.22 | 0.00 |
| O015 | 1 | | 20 | 0 | | | | | | | |

## Appendix B: Summary of Public Housing Retrofit Projects

Appendix B contains a brief description of each retrofit project included in this study. The summary includes a description of the conservation measures that were installed, a discussion of energy savings and cost-effectiveness, and notes key adjustments to the data. Each data source is identified by a label that indicates the fuel used for space heating (e.g., gas (G), oil (O), mixed (M), and electricity (E)) along with its location and sponsor.

### GAS HEAT

*G032: Newark, NJ - Bumblebee Energy Systems* [1]

A computerized energy management system was installed by Bumblebee Energy Systems in a 530-unit family apartment complex operated by Newark Housing Authority. The system monitors indoor apartment temperatures, and supplies heat by opening and closing motorized valves depending on the average of apartment temperatures in each building. Determination of energy savings attributable to the energy management system was complicated by the fact that the central heating plant was totally refurbished during the same time period. This included installation of new boilers, underground piping, control valves, and a separate gas-fired hot water generator. Based on an analysis of several years' consumption data at four other projects, Bumblebee Management concluded that the heating plant modernization did not yield any significant savings. Any potential efficiency improvements were overshadowed by impacts stemming from the proper or improper operation and maintenance of the heating plant and control systems. They apportioned the 26% total annual savings as follows: one-half to replacement of the condensate lines (part of the modernization) and one-half to the Bumblebee energy management system. We used the 14% savings allocated to the energy management control system and the associated cost in estimating savings and cost-effectiveness (disregarding changes in consumption attributable to the refurbishment of the heating plant). An annual operating and maintenance cost of $25,000/year or $40/apartment unit was included in the economic calculations (Bumblebee's estimated cost for a service contract for the control system). The non-space heating fraction of total consumption was subtracted out using the average of the summer months usage and monthly energy usage data were normalized to a 'typical' heating season. The retrofit had a simple payback period of approximately 3 years and an internal rate of return of 39%.

*G035.1 - G035.6: San Francisco, CA - San Francisco Housing Authority* [2]

In 1982, the San Francisco Housing Authority began trying to reduce rapidly increasing energy expenses by installing attic insulation, exterior door weather stripping, low-flow showerheads, and water heater blankets in the buildings that it manages. The conservation measures were financed by the local utility's zero-interest loan program (ZIP). The Princeton Scorekeeping Method (PRISM) was used to analyze three years of utility billing data, including one post-retrofit year, at five multi-family housing projects (totalling 1822 units). All the buildings are two or three stories in height. These five projects are occupied by families and are master-metered; thus tenants do not pay utility costs directly. To adjust for occupancy effects, gas use during each billing period was divided by the number of occupied units in that period. Weather-normalized annual natural gas consumption declined by 13 percent after the retrofit at the five projects; net savings relative to a comparison group were 8 percent. Most of the energy savings resulted from reduced baseload usage. Cooking energy use was metered separately at two projects, Hayes Valley and Potrero Terrace, and accounts for a surprisingly large fraction (19 to 29 percent) of total gas consumption.

A closer examination of the individual projects shows a wide range in energy savings resulting from the ZIP retrofits:

SUNNYDALE has 772 units in 91 buildings, with all units having individual space heaters. The pre-retrofit energy-use of 93 MBtu/unit declined by 9%.

POTRERO TERRACE consists of 469 units in 38 structures with 18 central heating systems. The comparatively high pre-retrofit NAC of 135 MBtu/unit decreased by 20%.

ALICE GRIFFITH, a 258-unit project with four gas-fired central boilers supplying space heat and hot water to 41 buildings, had the highest energy consumption before the ZIP measures (164 MBtu/unit). Twenty percent savings were realized here.

Energy use at ALEMANY, another project with individual unit space heaters, declined by 11% after the retrofit from a pre-retrofit level of 87 MBtu/unit.

HAYES VALLEY is a centrally-heated project with 170 units in 10 buildings. Energy usage at this project *increased* by 5%; however, its pre-retrofit use was the lowest of all these projects: only 79 MBtu/unit.

Pre-retrofit energy use appears to be a major influence on the savings produced by the ZIP measures. Overall, the retrofit program was cost-effective, with a net present value of $399,000 or $220/unit. The Housing Authority's careful efforts to control retrofit costs, which averaged only $150/unit, contributed to the program's success.

*G035.11 - G035.16: San Francisco, CA - San Francisco Housing Authority* [3,4]

Solar domestic hot water systems were installed in the spring of 1984 at six senior properties managed by the San Francisco Housing Authority. This relatively expensive conservation option was financed by third-party investors, who own the the solar equipment and sell hot water to the Housing Authority in a micro-utility arrangement. The projects use natural gas for space heat and domestic hot water while electricity is used for cooking. Domestic hot water at each project is supplied by a central boiler.

Other minor retrofits, including low-flow showerheads and weatherstripping, were installed several months before the solar hot water system at all projects except 3850 18th Street. Due to the timing of these retrofits, it is not possible to separate out the effects of the solar hot water system, hence savings estimates include the minor retrofits. The decrease in NAC due to the weatherstripping and showerheads is assumed to be minimal, however.

Boiler time-clocks installed in October 1982 pose a more significant analytic problem. For most of the properties, pre-retrofit periods starting in November 1982 were used. For 499 31st Avenue and 939 Eddy Street, however, good PRISM fits could not be obtained for the post-October period. At these two properties, pre-retrofit periods beginning in July 1982 were used. Therefore, the savings attributed to the solar systems at these projects is most likely due to both the solar systems and boiler time-clocks.

One year of pre- and post-retrofit gas bills were used in this analysis, along with Btu readings of the energy produced by the solar systems. The number of occupied units were available for the entire analysis period; the use of energy per occupied unit, rather than energy per total number of units, significantly improved the energy savings in this group of projects.

The Btu meters showed solar production (including an assumed furnace efficiency factor of 0.6) amounting to between 8 and 13% of the pre-retrofit gas use at each of the projects. The weather-adjusted change in gas consumption indicates much more variability in system performance, however. At three projects (3850 18TH, 1760 BUSH, and 2698 CALIFORNIA), the normalized annual consumption (NAC) remained relatively unchanged before and after installation of the domestic solar hot water system. The lack of savings at 1760 BUSH, a seven-story concrete-block building completed in the early 1970's, may be due to the low tilt angle ($5^{o}$) of the collector plates. Weather-adjusted annual gas use decreased by 10 percent at 363 NOE STREET, a three-story, wood-frame building with 22 units. This property has forced-hot-water space heat, but the solar hot-water back-up is provided by separate water heaters. This building also has one DHW storage tank.

491 31ST AVENUE is a five-story masonry building with 75 apartments. It was built in 1973 and has heating systems like those at 3850 18th Street. Gas use declined by 13% after the retrofit.

939 EDDY STREET is a four-story wood-frame building containing 36 units. It was acquired by the Housing Authority in 1979. This property has steam radiators for space heating and separate water heaters for domestic hot water. Six DHW storage tanks are used here. This project produced the highest NAC savings, equivalent to 23%.

*G039: Asbury Park, NJ - Princeton Center for Energy and Environmental Studies* [5,6]

This property consists of two six-story buildings with a total of sixty units and 75 elderly occupants. Princeton University's Center for Energy and Environmental Studies has studied the gas consumption at this project for the past four years, during which several energy conservation measures have been implemented. Gas is used for space heating, domestic hot water, and cooking at Lumley Homes; monthly utility bills were used for the analysis.

The five retrofits which took place during the study period were aggregated into two groups for the calculation of energy savings. The first group (retrofit number 1) consists of new Dunham-Bush zone controls for the steam distribution system and a vacuum pump, installed in December 1981, and a separate boiler for summer domestic hot water heating (Weil-McLain boiler with an input rating of 430 kBtu/hour), installed in April 1982. The second retrofit group (retrofit number 2) includes interior storm windows and new steam traps (October 1983) and a series of no-cost changes in the operation of the heating plant (steam pressure and controller settings lowered, radiators opened, and night setback hours extended--March and April 1984).

The results of PRISM runs performed by Princeton were used to calculate the energy savings from both sets of retrofits. There was no significant change in energy use after the first retrofit group was installed. Observation of the zone controls showed that they were set to send 25% of the steam to each of the four building zones--probably not the optimal setting. The separate domestic-hot-water boiler, however, did decrease the amount of baseload energy used.

The second retrofit group showed more clear-cut energy savings, with a decrease of 40% in the normalized annual consumption and a simple payback time of 2 years.

*G044: Phillipsburg, NJ - Phillipsburg Housing Authority* [7]

Two gas-heated, low-rise housing projects, Heckman Terrace and Heckman Annex, were rehabilitated and retrofitted between 1980 and 1983. Major structural renovations, including a new insulated facade, new roofs with eight inches of insulation, thermopane windows, replacement of existing doors with insulated doors, and replacement of storm doors were carried out at Heckman Annex (G044.1), as well as numerous conservation measures (three inches of crawl space insulation, maximum set thermostats, boiler controls, new boiler valves). At Heckman Terrace (G044.2), rehab work included insulated exterior facade, thermopane windows, new doors, maximum set thermostats, and replacement of twenty-year-old gas warm-air furnaces with Lennox furnaces in each apartment.

Energy use decreased drastically at both projects following the rehabilitation work--normalized annual consumption dropped by 41% at Heckman Annex and 53% at Heckman Terrace. Because the work was so expensive (over $12000/unit), however, the rehab has very long payback times at both projects (greater than 25 years) if evaluated strictly as an energy conservation measure. The Phillipsburg Housing Authority was not able to provide LBL with costs for the conservation measures alone, nor were they able to quantify decreased maintenance costs based on the rehab. The director did cite reduced window breakage following the replacement.

## OIL HEAT

*O002: Trenton, NJ - Bumblebee Energy Systems/Trenton Housing Authority/HUD* [8]

Bumblebee Energy Systems received a HUD innovative energy conservation demonstration grant to install a temperature control system in Page Homes, an urban multi-family housing complex. Indoor temperature sensors were placed in one-third of the units, transmitting periodic readings to a micro-processor. Using this information, the computer adjusted the hot water temperature for the boiler. The hot water heat distribution system was also rebalanced and a separate gas-fired boiler was installed to meet domestic hot water requirements. Fuel savings in the complex were an impressive 44%. The pre-retrofit energy consumption was comparable to that found in other buildings operated by the housing authority yet it would be considered an 'energy guzzler' in comparison to the overall residential housing stock. The retrofit was very cost-effective with a payback time under one year and a calculated cost of conserved energy around $1/MBtu (at 14.2% capital recovery rate). Annual operation and maintenance costs were estimated at $4000/ year or $25/apt., based on Bumblebee System's service contract charges. Eight other similar apartment complexes, used as a control group, showed almost 16% savings.

*O008: New York, NY - NYC Housing Authority* [9]

In the winter of 1976-77, the NYC Housing Authority undertook a demonstration study program to determine the energy savings resulting from the installation of non-electric thermostatic modulating radiator valves (TRV) in steam-heated buildings controlled as a single zone. The measure was installed in multi-unit dwellings at 4 sites and changes in consumption were compared against four similar control buildings at the same sites. Daily pre-and-post retrofit space heat energy consumption values were obtained from condensate meters at the eight buildings. A conversion factor of 980 Btu/lb (assuming low pressure steam at 10 psia, 240$^{o}$F minus saturated water at atm. pressure) was used and NYCHA's estimate of 70% boiler efficiency in calculating annual energy consumption.

Significant reductions in energy usage occurred in 7 of the 8 buildings. However, causal attribution is difficult, due to such factors as the experiment's short time period (the pre and post retrofit consumption data were collected during the same heating season) and likelihood of 'independent' occupant retrofit measures and practices (i.e., apart from the study). Tenants did report increased levels of occupant comfort (more even distribution of heat in buildings). The study authors estimated energy savings of 6.8% specifically attributable to the TRV retrofit, obtained by calculating the percentage savings of the difference between three of the four study and control buildings weighted by the number of valves installed in each building. Energy savings (calculated as the difference between energy use in the study and control buildings) for the 3 successful buildings ranged from 2% to 12%. The authors ignored the results from the Ocean Hill site because the control building had greater reduction in consumption than the study building.

*O009: New York, NY - NYC Housing Authority* [10]

The New York City Housing Authority has an on-going program for replacement of steel casement windows with double-hung, double-glazed thermal break aluminum windows in order to save fuel and reduce maintenance costs. The original building windows were vulnerable to air infiltration, required substantial amounts of maintenance and were frequently subject to glass breakage during windy weather. Pre- and post-retrofit weather-adjusted fuel oil consumption were available for 9 housing projects. The window replacement retrofit achieved average savings of roughly 18 percent with a 15-year simple payback time for the 9 buildings. Energy savings at the 9 buildings ranged from 9% to 22%. The building with the smallest number of dwelling units, Green Hill (733 units), had the lowest savings, while the largest building, Paterson (1791 units), achieved the highest space-heat energy savings. The Housing Authority also estimated that the retrofit reduced operation and maintenance costs by $30/dwelling unit or $30,000/year for a typical 1000-unit complex. This lowers the payback time to roughly 11 years (assuming a 20 year lifetime and 7% real discount rate).

*0013: Trenton, NJ - Trenton Housing Authority* [11]

Donnelly Homes is a 376 unit, family project built in 1939. Two-hundred twenty-two of the dwellings are apartments in three-story buildings, while the remaining 154 units are two-story duplex houses. In 1981, the 1939 Warren Webster heating controls (judged by an on-site consultant to be mainly inoperative) were replaced with a National Pumps and Controls system (NPC). The NPC varies the pressure of the steam in the heating system, depending upon the outside temperature, by regulating control valves in each zone's supply line. This system was also used in the Kerney, Campbell, and Wilson properties of the Trenton Housing Authority. The annual cost of *properly* maintaining such a control system should not be more than 10% of the initial price. Since the old controls were not maintained at all, the change in the cost of annual maintenance is assumed to be one-tenth of the initial installed cost at each of the four projects.

The energy analysis was performed using monthly oil (space heat and domestic hot water) and gas (cooking) utility bills, for sixteen-month pre- and post-retrofit periods. Energy savings resulting from installation of the heating controls are 17%.

*0014: Trenton, NJ - Trenton Housing Authority* [12]

LBL analyzed energy savings at three properties managed by the the Trenton Housing Authority (Kerney, Campbell, and Wilson Homes). These three properties are of similar design and each received identical heating system retrofits between 1980 and 1982. All are three-story, family apartments with flat roofs and double-hung, single-glazed, aluminum frame windows that were installed in the late 1970s. Each uses oil for space heat and domestic hot water and gas as the cooking fuel. The original heating system had steel fire-tube boilers and non-functional controls. The original boilers were replaced with H.B. Smith cast-iron sectional boilers (two at each project) with Preferred Utilities horizontal rotary burners, for providing steam heat. National Pumps and Controls systems, like that installed at Donnelly (0013), replaced the original heating controls. Domestic hot water at the three properties is made using the space heat boilers. Kerney and Campbell have tankless generators which use steam; Wilson's tankless generator uses boiler hot water. Annual maintenance costs at each project were assumed to be 10% of the cost of the heating controls; we assumed that the new boilers did not add to maintenance costs.

KERNEY's 102 units were built in 1953. The control system handles the project (five buildings) as three heating zones. Boiler capacity for the new system is 6700 kBtu/hour. The analysis was performed using one pre- and two post-retrofit years of monthly oil billing data. The average energy savings from the combined boiler/control retrofit (in 1980 and 1981, respectively) is 29%.

CAMPBELL, also constructed in 1953, has 81 apartments handled as a single heating zone. Both the boilers and controls were replaced in 1980, resulting in a new boiler capacity of 6700 kBtu/hour. For this project, three years of post-retrofit oil bills were available. Average energy savings at Campbell were 14%.

WILSON is the largest property, with 219 units built in 1954. Its controls were replaced in 1981, enabling the eight buildings to be handled as four heating zones. New boilers, with a capacity of 11,700 kBtu/hour, were installed the following year. Only one year each of pre- and post-retrofit monthly oil data was available for Wilson. Energy savings here are much lower than those at Kerney and Campbell--only 5.4%. In addition, during the period when the retrofits were being performed, consumption was lower than either the pre (181 MBtu/unit) or post (172 MBtu/unit) usage. (In the intervening years, only 154 MBtu/unit and 141 MBtu/unit were used.) According to a Trenton Housing Authority consultant, during the 1981-82 heating season, only one boiler was functional. Parts of the buildings were cold because the single boiler was not sufficient to meet the heating load. This under-supply may account for the lower-than-post-retrofit energy usage during the retrofit period.

*O015: Philadelphia, PA - Philadelphia Housing Authority* [13]

Southwark Plaza is a 886-unit, family and senior citizen complex built in 1963. The property contains a mix of three 25-story highrises and 27 two- and three-story row houses. Both types of buildings are heated from a single, central boiler room. Four boilers produce steam, which is sent to remote equipment rooms, where it is converted to hot water for space heat and domestic hot water. No. 6 oil is burned in the boilers and gas is used for cooking; monthly bills for both fuels were used in this analysis.

The retrofit here, performed in 1981, consisted of replacing non-functional outdoor reset heating controls with new Honeywell outdoor reset controls (#W902A-1016 EU1). NAC savings of 9.1% resulted from the retrofit.

## MIXED HEAT

Retrofit projects were classified as 'mixed heat' for one of the following reasons: 1) buildings used more than one space heat fuel (e.g., gas and oil with typically one fuel being the primary space heat fuel and the other serves as a backup or 2) fuel-switching of the space heat fuel occurred at the same time as the retrofit.

*M015: St.Paul, MN - St. Paul Housing Authority* [14]

St. Paul Housing Authority received a HUD innovative energy conservation grant to install a computerized energy management system in three high-rise properties inhabited by elderly tenants. Many existing controls were tied into the computer. The system's main functions included issuing preventative maintenance orders, reducing electrical demand charges by minimizing peak usage, malfunction alarms, and lighting and temperature control in public areas. Prior to this retrofit, the Housing Authority had a rather extensive conservation program in operation and had undertaken many low cost/no cost retrofits (showerflow restrictors, reduced hot water temp. to 120$^{\circ}$F, insulated pipe ducts, etc.) plus various retrofits designed to improve heating system efficiencies (e.g. new burners on boilers). The system went into operation during the 1980-81 heating season. We compared fuel consumption from the 1978-79 heating season (before) to 1981-82 usage, normalizing the raw consumption and heating degree-day data to the long-term average value. According to the Housing Authority, the system also provided 404,000 KWh electricity savings in all three buildings which LBL staff converted to fuel-equivalent units and added to the pre-retrofit usage (thus increasing the overall savings). The electricity savings substantially reduced the simple payback time for the investment to roughly 4 years.

*M016: Trenton, NJ - Trenton Housing Authority* [15]

The Haverstick property consists of two-story walk-up apartments, built in 1955. The centralized boilers supplying hot water heat at Haverstick are originals, but new Preferred Utilities horizontal rotary boilers were installed in the late 1970s. Heating control is supposedly provided by a Sarcotherm outdoor-reset hydrostatic three-way mixing valve, although it does not appear to function correctly. Space heat and domestic hot water are provided by oil, while natural gas is used for cooking.

Two retrofit projects were carried out at this property. In the first, casement windows were replaced in the summer of 1983 by double-hung aluminum frames with a single glazing layer. Energy usage after the window retrofit did not significantly change, indicating that the occupants were probably opening their new windows to maintain a comfortable indoor temperature. (If heating system controls do not work, window-opening may be the only control option available to residents.)

In the second retrofit, the space heat boilers and domestic-hot-water generators were replaced with 32 Hydropulse condensing pulse-combustion boilers of high efficiency (typically 91%). These modular boilers, with a total capacity of 5000 kBtu/hour, were operational by October 1984. (These boilers are very noisy. The noise is not bothersome at Haverstick, where the equipment is in a separate boiler building, but might cause problems if located near living quarters.) Natural gas fuels the boilers, which provide both space heat and domestic hot water (eight of the modules supply hot water to a 500-gallon storage tank). Both oil and natural gas were used in the analysis. One year of monthly data was available both prior to and between the two retrofits. Six months of data after the heating system replacement have been collected so far. Because of the shortage of post-retrofit data, the energy-use characteristics of the new boiler system are not yet clearly defined, but energy savings of 50% are indicated. The total cost for this boiler replacement was $1776/unit (1985 $); however, because the boilers were in need of replacement, we use the *incremental* cost of the high-efficiency boilers over the cost of ordinary boilers in the economic calculations. The incremental cost was $547/unit, based on actual bids the housing authority received for the two alternative heating systems. Based on the incremental cost, this was the most cost-effective retrofit we found. Its simple payback time with maintenance costs was 0.7 years, the cost of conserved energy was $0.39/MBtu, and the internal rate of return was 152%.

## ELECTRIC HEAT

*E012: New York, NY - New York City Housing Authority* [16,17]

The New York City Housing Authority replaced incandescent hall and stairwell lights with 20-watt fluorescent fixtures in 13 buildings. Electricity billing data were obtained from one housing project (830 Amsterdam), indicating annual lighting energy savings of 62 percent. A cost of $50 per fixture was used in calculating retrofit cost, determined by examining the installation contracts, yet the payback time was only 1.4 years. The longer lifetime of the fluorescent bulbs led us to estimate an annual reduction in operation and maintenance costs of $5/apartment.

*E020: Greeneville, TN - Tennessee Valley Authority/HUD* [18,19]

Two hundred seventy-five all-electric, single-family homes within the Greeneville Housing Authority were selected by HUD and the Tennessee Valley Authority (TVA) to receive passive solar retrofits. Prior to the installation of the passive solar features, TVA provided the Authority with a Home Insulation Program loan to weatherize the units. They are occupied by both families and the elderly, with 25% of the residents of age 65 and over. Aggregate heating-season electricity consumption (compiled from utility bills for each of the 275 units) was used to calculate energy savings.

All 275 houses received storm windows in January 1980, R-30 attic insulation in June 1980, and weatherstripping in March 1981. Energy savings of 13% resulted from this retrofit; the payback time was 7 years.

Three different passive solar retrofits were implemented in December 1981. (Ten houses were set aside as a control group, but thermostat-limiting devices were installed in them during the retrofit period, precluding comparison of control group and study group energy use.) All of the solar retrofits had payback times in excess of 20 years. One hundred eighty-eight houses received movable inside window insulation. The Window Quilt shades have a measured R-value of 3.4. While 15% energy savings were predicted for this retrofit, savings of only 4.5% were realized. Monitoring of a sample of the houses indicated that the shades were not closed for the optimal amount of time each day, implying that the reduced savings can in part be attributed to a lack of use.

Double-glazed sunspaces, each 6 feet deep and between 10 and 22 feet in length, were added to 20 homes. The warmed sunspace air is supposed to be transferred to the living area through open doors and windows. Wall and roof vents in the sunspace were provided to prevent overheating in the summer months. Energy savings of 14% resulted from this retrofit, falling short of the predicted 27% savings. Monitoring of five dwelling units showed that the doors, windows, and vents were not being operated properly by the residents.

Forced-air solar wall heaters were installed at the remaining 57 houses. Heliopass collectors heat air which is introduced to the living space by means of a thermostatically controlled fan. Each wall heater has a collector area of 19.3 square feet. A backdraft damper covers the fan opening, preventing reverse circulation of room air through the collector at night. Energy savings of 6.3% were predicted; actual savings amounted to 4.6%. Individual monitoring of this retrofit revealed that some fans were not plugged in as long as they should have been. TVA has suggested hard-wiring of the fans as a solution that will enable solar wall heaters to achieve their full energy conservation potential.

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