Persistence of Savings in Multifamily Public Housing

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In a previous study of 43 retrofit cases in multifamily public housing, it was found that initial energy savings did not always persist into the second and third post-retrofit years in the cases where there were at least two years of post-retrofit data. In this study, we revisit the topic of persistence of savings in low-income multifamily buildings by collecting additional energy consumption data from many of the 43 retrofit cases analyzed in the previous work. These new data, in most cases, cover the second through fourth years of post-retrofit energy performance, weather variations, and occupancy patterns. We include only those retrofit cases where there has been no new installation of conservation measures. A utility bill analysis was conducted using the Princeton Scorekeeping Method (PRISM). The analysis considered climate variation, type of building and occupant, type of conservation measure, and pre-retrofit energy use. We found that the extent to which savings persist depended on the type of conservation measure installed. Generally, energy savings from equipment measures (i.e., heating controls, new boilers, solar hot water systems, etc.) that require ongoing maintenance were less likely to persist beyond the first post-retrofit year. Shell measures (including window replacements), on the other hand, maintained their savings over several post-retrofit years.

Introduction

Implementation of measures to increase energy efficiency in multifamily public housing will likely confront some unique and formidable barriers. Two critical issues for local housing agencies are (1) the selection of the most cost-effective retrofit measures and (2) the availability of funding to support the installation of these measures once selected. Another important issue recently identified in public housing (Greely et al. 1986) is how well the energy savings resulting from these energy conservation measures will persist over time. Greely et al. (1986) studied the energy performance and cost effectiveness of 43 retrofit cases in public housing and noted that initial energy savings did not always persist in the five cases where there were at least two years of post-retrofit data. In this paper, we revisit the topic of persistence of savings in low-income multifamily buildings by analyzing two to three years of additional utility consumption data from many of the 43 retrofit cases examined in the earlier study.

Previous research on the durability of energy conservation measures and the persistence of energy savings associated with those measures beyond the first post-retrofit year has not focused on multifamily housing, and with one exception, has not considered public housing. In most studies of retrofit performance in buildings one year of actual energy savings is compared to those predicted prior to installation of the energy efficiency measures. In some cases, the pre-retrofit case is also based on actual utility billing data. In recent years various authors (Harris and Blumstein 1982; Oliver 1988; Stoops 1990) have described the need to move away from the snapshot view of savings to a long-term approach based on monitoring and rigorous analysis. The most comprehensive analyses of persistence to date have focused on single-family residences (Heberlein et al. 1980; Brandis and Haeri 1989; Sumi and Coates 1989; White and Brown 1990) and commercial buildings (Greely et al. 1990). Energy efficiency programs for single-family and commercial buildings have been widely available for several years, and much data are available for such analyses.

Multifamily buildings also need to be considered separately from single-family construction in designing weatherization assistance programs, and as yet such attention has not occurred (Gettings and Kolb 1991). Within the multifamily housing stock, public housing presents unique problems that have been discussed elsewhere (Ritschard et al. 1986; Goldman et al. 1988). Behavioral issues, for example, can be quite important for determining actual energy savings in buildings with low-income tenants (Katrakis 1990). Apart from potential problems in financing and implementing energy efficiency programs aimed at low-income multifamily buildings, basic research remains to be done to identify appropriate measures for inclusion in such programs. Harris and Blumstein (1982), in their general review of the state of building energy efficiency, concluded that the persistence of energy savings over a multiyear period is still largely a matter of conjecture rather than based on observed data. In short, the conclusions cited by Harris and Blumstein (1982) still exist in low-income multifamily housing.

In the remaining sections of the paper we will first describe the sources of data including the specific retrofit measures installed and the description of the building characteristics. Next, we will briefly outline the methodology used to normalize the monthly utility consumption data for weather and occupancy effects. In most cases, we were able to compare four years of post-retrofit data to the one year of pre-retrofit energy use at each housing project. The results section contains information about the energy savings normalized annually by the number of apartments so that energy use on a per-unit basis can be compared among projects and similar retrofit measures. Finally, we discuss the results including which types of retrofit measure in our sample were less likely to sustain their energy savings beyond the first year after installation. We also provide some qualitative information about what might have affected the performance of energy retrofits in these public housing projects.

Sources of Data

We obtained monthly utility billing data and other pertinent information on the retrofits from the various local public housing authorities (PHAs). In a previous study (Greely et al. 1986), data from 38 housing projects were analyzed, most of which had installed one retrofit measure, but some of which had more than one, for a total of 43 retrofit cases. Since the objective of this work was to track the persistence of energy savings over time, we were interested in the monthly energy consumption, occupancy data, and the physical status of each housing project. The latter category included whether (1) new energy efficiency improvements were made since the previous study, (2) changes were made to the metering configuration (e.g., switching from master to individual meters), and (3) other structural or physical plant modifications were made that would affect the annual energy consumption patterns.

We did not include any projects in this analysis if any of the above-mentioned conditions had occurred since the 1986 study. Twenty-four of the original 38 projects met our basic requirements and are covered in this study. They include: eight projects managed by the New York Housing Authority (four projects of the original sample were eliminated because the thermostatic radiator valves installed as a conservation measure failed and were later removed), six projects operated by the Trenton Housing Authority (although two of these projects, Page Homes and Donnelly Homes were later found to be problematic because of a change in the utility metering configuration), nine projects run by the San Francisco Housing Authority (one family project, Hayes Valley B, and one senior high-rise, 2698 California, from the original study were not used because of poor data quality), and two projects managed by the Phillipsburg Housing Authority in New Jersey. In addition, we include one project (Lumley Homes) that was studied for several years by Princeton's Center for Energy and Environmental Studies and included in the earlier study. PHAs from the original study for which additional data could not be collected included the following: St. Paul MN (there were several additional retrofits performed on the buildings), Greenville TN (the Tennessee Valley Authority was no longer involved in monitoring the retrofits and energy consumption data were not available), Newark NJ (the consultant who maintained utility consumption data was not available), and Philadelphia (much of the previously studied project had been unoccupied over the study period and few new data were available). We will discuss in more detail later the data problems that continue to plague the public housing sector.

In Table 1 we summarize the project characteristics by PHA, including the number of apartment units, number of buildings, age of building, estimated heated floor area, and building type. In the study sample, the majority of cases have central heating systems (exceptions are individual systems at Heckman Terrace, a low-rise project in Phillipsburg, and at two larger low-rise projects in San Francisco: Alemany and Sunnydale). The fuel use is about 50% oil and 50% natural gas with only one mixed (i.e., oil and gas) fuel case (the Haverstick low-rise project in Trenton). In addition, the domestic hot water in our sample buildings was generally produced by central space heat boilers. This analysis emphasizes space and water heating use since public housing buildings generally do not contain air-conditioning equipment except in some buildings occupied by senior tenants in the southern United States.

It is also important to note that the average floor area of individual apartment units varied among the housing authorities. For example, the New York City projects averaged ~840 ft^2, while those in Phillipsburg were much larger (1103 ft^2/unit and 1524 ft^2/unit). Two size categories were also represented in San Francisco. The five senior projects averaged ~580 ft^2 and the family projects were about 845 ft^2. Since we generally compared energy use among different post-retrofit years in the same housing project, this size variation should not affect the overall conclusions of this study.

Table 1. Project Descriptions

Project		No. of Apt. Units	No. of Bldgs.	Floor Area (ft^2)	Bldg. Type	Year Built	Retrofit
Asbury Park, NJ	Lumley Homes	60	2	39,200	HR[*]	1963	Separate DHW[††]/Zone Controls/Storm Windows/ Steam traps
New York City, NY	Cypress Hills	1444	15	1,227,400	HR	1955	Window Replacement
	Paterson	1791	15	1,450,710	HR	1950	Window Replacement
	Johnson Houses	1310	10	1,061,110	HR	1948	Window Replacement
	Albany I&II	1229	9	1,032,360	HR	1956	Window Replacement
	Amsterdam Houses	1084	13	823,840	HR	1948	Window Replacement
	Carver Houses	1246	13	1,027,950	HR	1958	Window Replacement
	Sedgwick Houses	786	7	664,170	HR	1951	Window Replacement
	Gun Hill Houses	733	6	623,050	HR	1950	Window Replacement
Phillipsburg, NJ	Heckman Annex	150	24	165,480	LR[**]	1951	Rehabilitated
	Heckman Terrace	222	49	338,270	LR	1942	Rehabilitated
San Francisco, CA	3850 18th St.	107	5	59,241	HR	1970	Solar DHW
	1760 Bush St.	108	1	68,277	HR	1972	Solar DHW
	363 Noe St.	22	1	13,608	LR	1971	Solar DHW
	491 31st Ave.	75	1	44,042	HR	1973	Solar DHW
	939 Eddy St.	36	1	18,117	LR	1980	Solar DHW
	Sunnydale	767	91	666,523	LR	1942	ZIP[†] Retrofit
	Potrero Terrace	469	38	388,332	LR	1942	ZIP Retrofit
	Alemany	164	24	137,460	LR	1956	ZIP Retrofit
	Alice Griffith	256	41	215,688	LR	1962	ZIP Retrofit
Trenton, NJ	Kerney	102	5	71,400	LR	1953	Heating Controls[***]
	Campbell	81	3	63,990	LR	1953	Heating Controls
	Wilson	219	8	166,440	LR	1954	Heating Controls
	Haverstick	112	14	96,544	LR	1954	Windows/Hydropulse Boilers

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[*] HR = high rise (4 stories or more).
[**] LR = low rise (less than 4 stories).
[†] ZIP = zero interest loan (utility-sponsored) retrofit (weatherstripping, attic insulation, DHW blankets, lowflow showerheads).
[††] DHW = domestic hot water system.
[***] Heating Controls = National Pumps and Controls system.

Table 1 also shows the major categories of retrofit measures that were installed by the PHA in 1980-1984 time period. The retrofit strategies emphasized the reduction of consumption for space heating and domestic hot water, which are the two largest energy end-uses in public housing. The energy efficiency measures evaluated in this study are grouped as follows: building shell measures (e.g., attic insulation, caulking and weatherstripping, and window replacement), heating system measures (heating system replacement or retrofit, heating controls, and operations and maintenance of existing systems), and domestic hot water system measures (water heater blankets, solar hot water systems, and new domestic hot water boilers). As in the previous study (Greely et al. 1986), it should be recognized that in some cases the retrofit measures are mixed in an individual project; therefore, it is difficult to estimate the performance of a single energy conservation strategy. For example, the San Francisco ZIP (utility-sponsored zero interest loan program) retrofits included several measures: attic insulation, exterior door weatherstripping and window caulking, low-flow showerheads, and blankets for hot water systems.

Methodology

The general approach used in this study followed three major steps. First, we collected utility billing data and other pertinent information from the local housing agencies and updated our existing database on the public housing sector. In some cases (e.g., New York City Housing Authority), the data were provided directly from their main-frame computer system that tracks utility bills, occupant conditions, and energy conservation activities. At the other extreme (i.e., Phillipsburg Housing Authority), the data had been plotted separately by hand on a monthly basis, and we obtained the utility data as well as other important anecdotal information about the buildings and retrofits. We were not always able to obtain three to four consecutive years of post-retrofit data for each project in our sample. For example, the data on window replacements in New York City are missing the second year of post-retrofit data because of a change over in their computerized utility tracking system. In other locations, individual years of utility data were either missing or not complete; therefore, they were not included in the analysis. In most cases, we were able to collect two to three consecutive years of post-retrofit billing data for comparison to the pre-retrofit conditions. For the San Francisco projects we obtained six years of post-retrofit data.

Second, we normalized energy use for annual changes in weather using the Princeton Scorekeeping keeping Method (PRISM) to adjust the weather-sensitive component of the space heat fuel use. Using PRISM, monthly energy use was regressed against daily average temperatures to estimate the normalized annual consumption or NAC (Fels 1986). Daily average temperatures were obtained from the various NOAA weather stations, from which we computed heating degree-days to different reference temperatures using the 30-year normal monthly outdoor average temperatures and its standard deviation. In a previous case study of energy conservation opportunities in public housing, PRISM was found to be a useful tool for determining energy savings due to conservation measures in multifamily buildings (Goldman and Ritschard 1986). For this analysis, we only included results that were statistically significant (R-squares greater than 0.95). The standard errors for the normalized annual savings (NAC) were in the range of 1 to 4%. We used only the space heating component for the New York City projects because the statistical fits were significantly better than for the NAC savings. This approach follows that previously used by Greely et al. (1986).

The third element of the methodology was the normalization of energy use at each project by the number of apartment units so that comparisons could be made on a per-unit basis. Since the effect of vacancy rates on energy use is an important feature when estimating energy consumption levels in master-metered buildings, we divided annual energy use by the average number of occupied units during each of the pre- and post-retrofit years when data were available. With the exception of projects in Asbury Park, Phillipsburg, San Francisco, and Trenton, the availability of annual occupant vacancy rates was limited. The New York City Housing Authority, however, assured us that the majority of apartment units in their sample of projects were occupied during the analysis period.

Results

The results suggest that the level of energy savings is related to the type of conservation measure selected. In Table 2 we summarize the mean energy savings by retrofit strategy for the entire post-retrofit period (i.e., mean energy annual savings calculated over three post-retrofit years). The greatest savings (mean of 63.4MBtu[1]/unit-yr or 44%) were found in the rehabilitation-retrofit cases at two low-rise projects in Phillipsburg, NJ. The one case where high efficiency boilers were installed (Haverstick) showed mixed results with significant savings during the first two years of the post-retrofit period followed by an increased fuel use in the third year. The mean savings during the retrofit period were still substantial (33.1 MBtu/unit-yr or 16%). These results of high efficiency boiler performance, however, should be interpreted cautiously since they represent only one case. Savings from heating controls were also significant (29.6 MBtu/unit-yr or 18%). These mean annual savings included one project (Lumley Homes) where the savings did not persist after the first post-retrofit year.

The shell measures (i.e., ZIP retrofits) in San Francisco over the period of study had mean energy savings of 19.3 MBtu/unit-yr (14%), while the window replacements in the New York City Housing Authority saved 14.1 MBtu/unit-yr (21%) over the retrofit period. The least savings were found in the senior buildings in San Francisco that had installed solar domestic hot water systems. The solar systems, which showed a wide range of results among the five senior projects, had mean annual savings of only 3.9 MBtu/unit (5%) over the post-retrofit

Table 2. Mean Energy Savings By Retrofit Strategy

Retrofit Strategy	Number of Projects	Number of Apartment Units	Mean Energy Savings[a] (MBtu/unit-yr)	Mean Savings (%)
Rehab-Retrofit[b]	2	376	63.4	44
High Efficiency Boilers[cd]	1	112	33.1[e]	16
Heating Controls[e]	4	462	29.6	18
Shell Measures[f]	4	1657	19.3	14
Window Replacements[g]	8	9623	14.1	21
Solar DHW[h]	5	348	3.9	5

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[a] Mean savings calculated over retrofit period per sample (i.e., three post-retrofit years).

[b] Rehab-retrofit - thermopane windows, insulated doors, storm doors, new roofs, foundation insulation, boiler controls, new furnaces.

[c] High efficiency boilers - replacement of central boiler with high-efficiency, modular, condensing-pulse combustion boiler.

[d] Haverstick Project where savings degraded over time (37% savings to +5%).

[e] Heating controls - National Pumps and Controls System; lowered steam pressure and controller settings.

[f] Shell measures - attic insulation and caulking and weatherstripping plus low-cost hot water retrofits.

[g] Window replacements - thermal-break, double-pane windows.

[h] Solar DHW - solar domestic hot water systems.

period. Collectively, annual energy savings occurred from each retrofit strategy that was installed during the 1980-1984 period.

The rehabilitation-retrofit strategy in Phillipsburg was clearly the most effective conservation measure in our sample. The rehabilitation consisted of installation of thermopane windows, insulated inside doors and storm doors, new roofs with 8 inches of insulation, crawlspace insulation (3 inches), boiler controls and thermostats, and replacement of warm-air furnaces at one of the projects (Heckman Terrace). Although these retrofits were expensive (over $1200/unit), the mean normalized annual savings over the period of this study (five years post-retrofit) were between 52 and 72 MBtu/unit-yr or 38 to 53%. The annual savings also persisted over this time period although there was variation (±5-10%) among the post-retrofit years (see Table 3 and Figure 1). The second post-retrofit year in both the Heckman Annex and Heckman Terrace showed less normalized energy savings than the first post-retrofit year. The annual savings at Heckman Annex increased by ~6% beginning in the third post-retrofit year and continued at that level for the next two years. We were unable to find a reasonable explanation for these annual changes. Since the Phillipsburg Housing Authority paid substantial attention to building soundness, we suspect that the annual variations were not due to the lack of maintenance. Furthermore, the Phillipsburg projects were fully occupied during the period of study (McDevitt 1992). It should be noted, however, that the annual variations among post-retrofit years may not have been significant since the standard errors during that time period also varied from 2.5 to 3%.

The Haverstick project in Trenton, which consists of 112 two-story walk-up apartments, had two retrofits installed in the 1983-1984 period. First, double-hung, single-pane windows were installed during 1983. Annual normalized energy use increased by about 3% during the first year after retrofit (Greely et al. 1986). In 1984, the Trenton Housing Authority replaced their space heat boilers and domestic hot water systems at Haverstick with Hydropulse condensing pulse-combustion boilers of high efficiency (about 91%). The first year's savings after the installation of the modular boilers (1984) were 69.8 MBtu/unit-yr or 37%. Two previous studies of this retrofit that considered

Table 3. Rehabilitation and Retrofit

PHA/Project Name		NAC/unit (MBtu/ unit-yr)	NAC Savings (MBtu/yr)	Savings (%)
Phillipsburg, NJ				
Heckman Annex	Pre	166.2		
	Post 1	98.7	67.5	41
	Post 2	102.4	63.8	38
	Post 3	95.1	71.1	43
	Post 4	94.7	71.5	43
	Post 5	94.3	71.9	43
Heckman Terrace	Pre	127.3		
	Post 1	59.9	67.4	53
	Post 2	68.5	58.8	46
	Post 3	70.3	52.0	45
	Post 4	67.3	60.0	47
	Post 5	67.8	59.5	47

only six months of data after the heating system was replaced reported a first year's energy savings of 48 to 50% (Greely et al. 1986; Gold 1987). The mean savings during the second post-retrofit year were significant (39.2 MBtu/unit-yr), but about 44% less than the first year after installation. By the third post-retrofit year, the energy savings obtained during the first year did not persist and annual normalized consumption actually increased by about 9.7 MBtu/unit-yr (see Table 4 and Figure 2). The main reason for the lack of persistence at Haverstick is the apparent lack of regular maintenance (Gold 1987). In addition, these boilers can act as condensing or non-condensing systems, depending on the temperature of the water returning to the boilers. The intake water must be at a temperature below 135°F in order to maintain condensation. When the return water exceeds 135°F, the boiler automatically converts to the non-condensing mode. Thus, no condensation in the domestic hot water (DHW) side will account for lower savings on DHW energy use. This condition may have also contributed to the lack of persistence at the Haverstick project (Gold 1989).

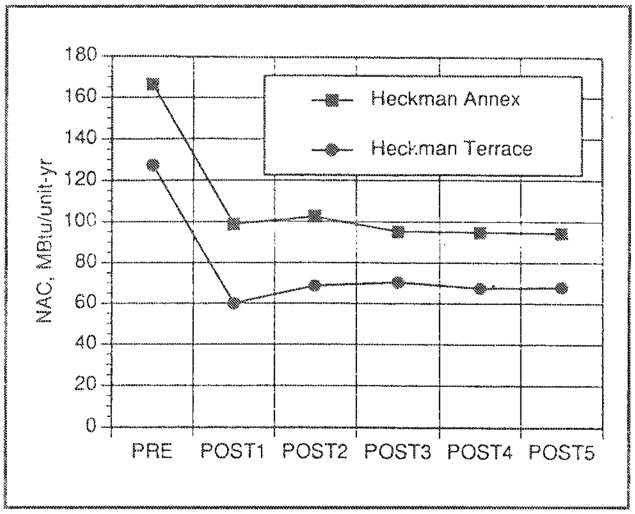

Figure 1. Rehabilitation-Retrofit

Three projects in Trenton (Campbell, Kerney, and Wilson) installed heating controls as the primary retrofit strategy. The Trenton projects are of identical construction and have similar retrofit histories through the mid-1980s. As shown in Table 5 and Figure 3, the annual energy savings based on the first post-retrofit year exhibited substantial savings in two of the three Trenton projects (57.6 MBtu/unit or 31% and 43.9 MBtu/unit or 22% at Kerney and Campbell, respectively). In the second year after the retrofit, however, savings in these two low-rise projects started to decline. In the case of the Kerney project, the savings during the second post-retrofit year were 13% less than after the initial year. This level was reduced an additional 1% in the third post-retrofit year. The persistence issue at the Campbell project was even more serious. The second post-retrofit year displayed

Table 4. High Efficiency Boilers

PHA/Project Name		NAC/unit (MBtu/unit-yr)	NAC Savings (MBtu/yr)	Savings (%)
Trenton, NJ				
Haverstick	Pre	189.4		
	Post 1	119.6	69.8	37
	Post 2	150.2	39.2	21
	Post 3	199.1	-9.7	-5

about 48% less savings than the first, and in the third post-retrofit year the savings decreased an additional 27%. On the other hand, the Wilson project had much lower energy savings in the first post-retrofit year (9.8 MBtu/unit or 5%), but these savings actually increased in the later post-retrofit years to 25.3 MBtu/unit in year 2 (14%) and 45.4 MBtu/unit (25%) in year 3. Gold (1989) has suggested that the loss of savings at the Campbell and Kerney projects resulted from a lack of proper maintenance in these older (1950s) steam-heated buildings. The increase in savings at the Wilson project was an interesting yet unexplainable finding. We were unable to determine whether the boilers at this project had received any special attention that could result in a higher persistence of savings.

Heating controls were also installed in one project at the Asbury Park Housing Authority. The Lumley Homes results are more complicated because in the previous analysis conducted by Princeton's Center for Energy and Environmental Studies and reported in Greely et al. (1986), five retrofits were included and the energy bill analysis was aggregated into two groups. For this analysis, we followed the post-retrofit savings in the second group only, which included both heating controls and interior storm windows, new steam traps, and night temperature setback. According to DeCicco (1988), the effects of the heating controls contributed the most to the changes in energy consumption. Savings at Lumley Homes did not persist. During the first post-retrofit year 26.4 MBtu/unit (23%) were saved, followed in the second year by a savings of only 9.5 MBtu/unit (8%). The third year after retrofit was even worse, with an increase over pre-retrofit fuel usage of 1.5 MBtu/unit (see Table 5 and Figure 3). Since the heating control changes consisted of a series of no-cost or low-cost changes in the operation of the heating plant (lowered steam pressure and controller settings, opened radiators, and night setbacks), it appears that these measures were not maintained or checked frequently enough (or at all) so that the level of energy savings could not be maintained in these 60 apartments. DeCicco (1988) confirmed this observation.

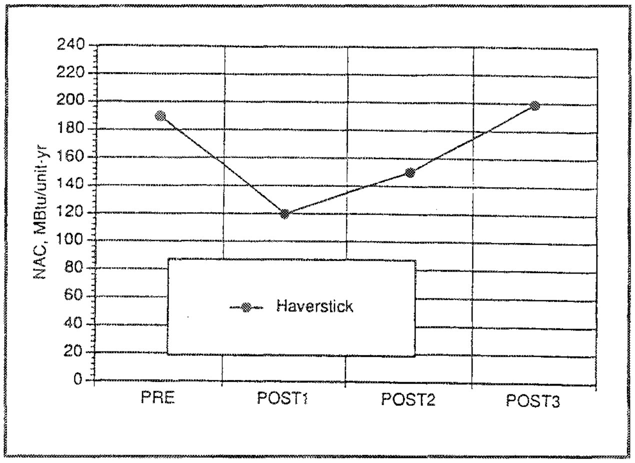

Figure 2. High Efficiency Boilers

Five projects (totalling 1822 units) in San Francisco received a mix of retrofits, termed "ZIP" retrofits, including shell measures (attic insulation, caulking and weatherstripping) and low-cost hot water measures (low-flow showerheads and water-heater blankets) in 1982. We call these "shell measures" because most of the savings resulted from the installation of attic insulation in areas where there had been no previous insulation. We were able to evaluate the performance of these retrofits in four of the five projects for six post-retrofit years. The post-retrofit performance followed a similar pattern among the projects even though the actual savings varied as shown in Table 6 and Figure 4. At one project (Alemany), the normalized energy consumption during the second and third post-retrofit years was slightly higher (up to 3%) than the pre-retrofit. By the fourth post-retrofit year, however, the annual savings began to increase or level off in all four projects (see Figure 4). Since most of the

Table 5. Heating Controls

PHA/Project Name		NAC/unit (MBtu/unit-yr)	NAC Savings (MBtu/yr)	Savings (%)
Asbury Park, NJ				
Lumley Homes	Pre	114.6		
	Post 1	88.2	26.4	23
	Post 2	105.1	9.5	8
	Post 3	116.1	-1.5	-1
Trenton, NJ				
Kerney	Pre	187.5		
	Post 1	129.9	57.6	31
	Post 2	137.4	50.1	27
	Post 3	138.1	49.4	26
Campbell	Pre	198.6		
	Post 1	154.7	43.9	22
	Post 2	175.6	23.0	12
	Post 3	181.8	16.8	8
Wilson	Pre	181.7		
	Post 1	171.9	9.8	5
	Post 2	156.4	25.3	14
	Post 3	136.3	45.4	25

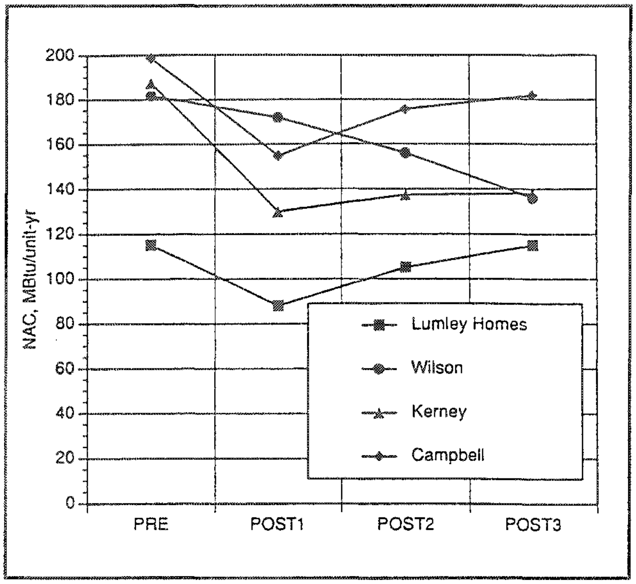

Figure 3. Heating Controls

savings at these projects are assumed to result from the installation of attic insulation, it is not surprising that the energy savings were more likely to persist than those resulting from heating system measures that must be adequately maintained over the life of the retrofit. Although the mean energy savings varied at the four projects (8%, 19%, 27%, and 29% at Alemany, Sunnydale, Alice Griffith, and Potrero Terrace, respectively), overall the savings generally persisted at each project.

The eight housing projects in New York City that received window replacements generally had uniform pre-retrofit energy consumption levels, on a per unit basis, compared to the other projects in our sample (see Table 7). Because of a change in computerized utility tracking at the New York City Housing Authority, we were unable to obtain the second year of post-retrofit utility data and therefore there is a break of one year at all of the projects. The original energy savings from the installation of double-hung, double pane windows persisted at all but two projects. At Johnson Houses, the first year post-retrofit

Table 6. Shell Measures/Zip Retrofits

PHA/Project Name		NAC/unit (MBtu/unit-yr)	NAC Savings (MBtu/yr)	Savings (%)
San Francisco, CA				
Sunnydale	Pre	93.2		
	Post 1	84.0	9.2	10
	Post 2	80.6	12.6	14
	Post 3	79.1	14.1	15
	Post 4	79.3	13.9	15
	Post 5	77.8	15.4	17
	Post 6	71.6	21.6	23
Potrero Terrace	Pre	134.7		
	Post 1	112.1	22.6	17
	Post 2	113.9	20.8	15
	Post 3	95.9	38.8	29
	Post 4	89.3	45.4	34
	Post 5	76.5	58.2	43
	Post 6	87.3	47.4	35
Alemany	Pre	86.6		
	Post 1	82.6	4.0	5
	Post 2	88.8	-2.2	-3
	Post 3	86.9	-0.3	-1
	Post 4	79.8	6.8	8
	Post 5	76.7	9.9	11
	Post 6	71.4	15.2	18
Alice Griffith	Pre	164.1		
	Post 1	130.6	33.5	20
	Post 2	123.9	40.2	24
	Post 3	124.8	39.3	24
	Post 4	113.6	50.5	31
	Post 5	111.6	52.5	32
	Post 6	110.9	53.2	32

savings of 11.2 MBtu/unit-yr (17%) were reduced by over 50% by the third post-retrofit year, followed by a continual decreases during each of the next three years. The degradation of energy savings was less pronounced at Carver Houses, but the original savings level of 10.2 MBtu/unit-yr decreased by about 35% during the full retrofit period with no savings in the fifth post-retrofit year. Mean energy savings generally persisted at the other New York City projects receiving window replacements as shown in Figure 5. Although the causes of deterioration in energy savings at the two projects are unknown, we can speculate that the windows may not have been properly installed or that other factors such as improper heating system controls might have caused the tenants to open their windows as a way of maintaining more optimal conditions in their apartments, a practice typical in public housing buildings.

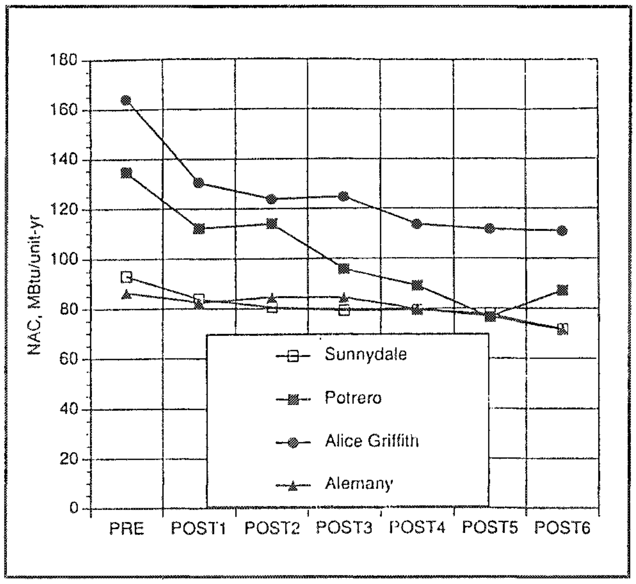

Figure 4. Shell Measures, San Francisco

The last retrofit strategy considered in this study was the installation of solar domestic hot water systems at five senior projects in San Francisco. The building construction was similar in each of these projects, but the specific configuration of each solar hot water system was different and therefore mean normalized energy savings also differed among the five projects (Table 8). For example, the savings at the Eddy property ranged from 10 to 23% over the four post-retrofit years, while the solar system at 1750 Bush resulted in savings ranging from 1 to 7%. In general the first year's savings did not persist. In three of the five projects the mean energy consumption by the third post-retrofit year was 7 to 12% higher than the pre-retrofit level (see Figure 6). In the Eddy property, the first year's savings were reduced by about 30% by the end of the second post-retrofit year and 56% by the fourth year. The variability in energy savings at these senior projects is due to the differences in the configuration of solar hot water systems and to their steady deterioration over time (Atkielski 1992).

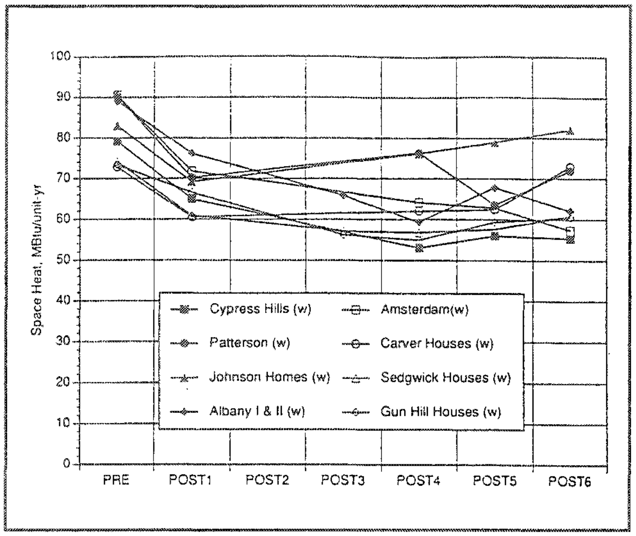

Figure 5. Window Replacement

Conclusions

Although the sample size in this study is relatively small (e.g., 24 individual housing projects, 394 multifamily buildings, ~12,500 apartment units) and is not geographically or statistically representative, it provides the most comprehensive study to date of the persistence of energy savings in low-income multifamily housing. This study extends the analysis provided previously by Greely et al. (1986) and begins to address more fully the general issue of persistence of savings. We stress that the study is still limited both by the availability of data and by the number of retrofit cases studied, but it does provide the first attempt at tracking retrofit performance over several years in public housing buildings.

We first conclude from our analysis that the extent to which savings endured depended on the type of retrofit measure installed and the level of follow-on maintenance provided. Indeed, the initial quality of the retrofit (i.e., how well it was installed) is also important, but information about this feature was not readily available. In our analysis the lack of adequate maintenance and improper operation of equipment drastically reduced the potential energy savings from the various equipment measures installed in public housing buildings. For example, first year's savings did not persist in the heating control cases in Trenton and Asbury Park, the boiler replacement at Haverstick, or the solar hot water systems in San Francisco. In each case anecdotal information suggested that proper maintenance practices were not followed after the installation of equipment measures, or that the systems deteriorated over time.

It has been noted in a previous study of public housing (Mills et al. 1987) that when energy costs rise, utility bills are often paid out of local administrative and maintenance funds leading to deferred maintenance. If this practice is widespread it may be difficult to recommend and install cost-effective heating system retrofits in public housing, since energy savings over time are dependent on regular maintenance. Heating system measures are usually the most effective way for the housing authority to save energy and dollars. On the other hand, unless these measures are properly and routinely maintained, the initial savings may deteriorate after the first year's operation.

Table 7. Window Replacements

PHA/Project Name		Space* Heat/unit (MBtu/unit-yr)	NAC Savings (MBtu/yr)	Savings (%)
New York City, NY				
Johnson Houses	Pre	67.2		
	Post 1	56.0	11.2	17
	Post 2			
	Post 3	61.6	5.6	8
	Post 4	63.9	3.3	5
	Post 5	66.6	0.6	1
	Post 6	66.0	1.2	2
Albany I & II	Pre	74.8		
	Post 1	64.0	10.8	14
	Post 2			
	Post 3	55.2	19.6	26
	Post 4	49.8	25.0	33
	Post 5	56.9	17.9	24
	Post 6	52.2	22.6	30
Amsterdam	Pre	68.8		
	Post 1	54.6	14.2	21
	Post 2			
	Post 3	48.1	20.7	30
	Post 4	47.7	21.1	31
	Post 5	43.6	25.2	37
	Post 6	41.3	27.5	40
Cypress Hills	Pre	67.2		
	Post 1	55.2	12.0	18
	Post 2			
	Post 3	45.1	22.1	33
	Post 4	47.7	19.5	29
	Post 5	47.1	20.1	30

Second, we found that energy savings were strongly correlated with pre-retrofit consumption levels: large energy users generally saved more energy after the retrofit. This condition was also reported previously in public housing buildings (Goldman and Ritschard 1986). For example in our sample, if we compare two family projects in San Francisco with similar apartment size: Alice Griffith (836 ft^2) and Alemany (870 ft^2), we find that the Alice Griffith project had a higher pre-retrofit energy consumption (164.1 MBtu/unit-yr vs 86.6 MBtu/unit-yr) and a higher savings during the first post-retrofit year (33.5 MBtu/unit-yr vs 4 MBtu/unit-yr). Similarly, if one compares two Trenton projects of similar apartment size: Campbell (790 ft^2) with high pre-retrofit

Table 7. Window Replacements (contd)

PHA/Project Name		Space* Heat/unit (MBtu/unit-yr)	NAC Savings (MBtu/yr)	Savings (%)
Paterson	Pre	73.1		
	Post 1	56.9	16.2	22
	Post 2			
	Post 3	61.8	11.3	15
	Post 4	51.5	21.6	30
	Post 5	58.3	14.8	20
	Post 6	60.3	12.8	18
Carver Houses	Pre	60.1		
	Post 1	49.9	10.2	17
	Post 2			
	Post 3	51.2	8.9	15
	Post 4	51.5	8.6	14
	Post 5	60.1	0.0	0
	Post 6	53.5	6.6	11
Sedgwick Houses	Pre	62.7		
	Post 1	51.5	11.2	18
	Post 2			
	Post 3	48.3	14.4	23
	Post 4	48.0	14.7	23
	Post 5	48.7	14.0	22
	Post 6	51.5	11.2	18
Cypress Hills	Pre	62.4		
	Post 1	56.5	5.9	9
	Post 2			
	Post 3	47.7	14.7	24
	Post 4	46.7	15.7	25
	Post 5	50.4	12.0	19
	Post 6	51.5	10.9	17

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* Space heat/unit used for New York City properties only because the statistical fits were better.

energy levels (198.6 MBtu/unit-yr) and Wilson (760 ft^2) with 181.7 MBtu/unit-year, we determine that the Campbell projects saved more energy during the first post-retrofit year (43.9 MBtu/unit-yr vs 9.8 MBtu/unit-yr).

Third, we conclude that even though savings did not persist at some of the individual projects, significant median savings in the range of 5 to 44% were found over the full retrofit period with all but one of the retrofit strategies. However, the post-retrofit savings for equipment measures such as heating controls, and boiler replacements, could have been substantially higher if proper maintenance procedures were followed.

Table 8. Solar Hot Water

PHA/Project Name		NAC/unit (MBtu/unit-yr)	NAC Savings (MBtu/yr)	Savings (%)
San Francisco, CA				
3850 18th St.	Pre	58.8		
	Post 1	57.5	1.1	2
	Post 2	57.3	1.5	3
	Post 3	63.5	-4.7	-8
	Post 4	62.8	-4.0	-7
1760 Bush	Pre	52.9		
	Post 1	52.3	0.6	1
	Post 2	51.1	1.8	3
	Post 3	49.3	3.6	7
	Post 4	51.5	1.4	3
363 Noe	Pre	32.9		
	Post 1	29.5	3.4	10
	Post 2	32.0	0.9	3
	Post 3	36.6	-3.7	-11
	Post 4	33.4	-0.5	-2
491 31st Ave	Pre	59.5		
	Post 1	51.9	7.6	13
	Post 2	54.0	5.5	9
	Post 3	63.8	-4.3	-7
	Post 4	66.4	-6.9	-12
934 Eddy St.	Pre	57.1		
	Post 1	43.8	13.3	23
	Post 2	47.6	9.5	17
	Post 3	50.9	6.2	11
	Post 4	51.2	5.9	10

A fourth conclusion deals with data quality. A major problem with any study of public or other federally-assisted housing is the lack of credible data on building characteristics, energy consumption, vacancy rates, retrofit selection, and maintenance practices. In general, energy data collection and compilation are not typical administrative functions of a housing authority. Tracking utility consumption and identifying "problem" projects are usually viewed by PHA management as special programs that require additional staff and funding rather than as ongoing efforts. PHAs do provide annual project-level or Authority-level energy consumption data to the U.S. Department of Housing and Urban Development (HUD) as a normal accounting practice, but these data are generally too aggregated to provide useful insights about the energy performance of an individual building or project. Where energy consumption is monitored on a monthly basis and where "problem" projects are identified and retrofits are installed, the resulting savings of energy and dollars are significant. The two examples of this level of energy management in our study sample are New York City and Phillipsburg. In both cases, these housing

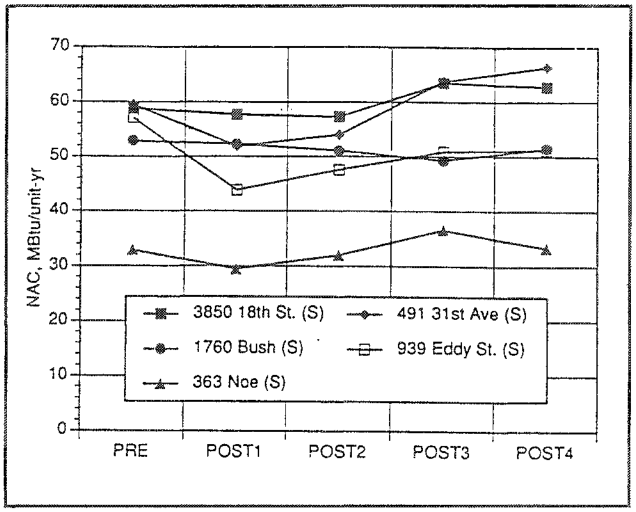

Figure 6. Solar Hot Water

authorities have taken great strides in establishing sound energy management practices.

Most engineering and economic analyses of the costs and benefits of energy retrofit measures assume that the first year's savings will continue over the lifetime of the conservation measure. The results presented here suggest that this assumption may need to be revised in light of the potential for degradation of energy savings. PHAs typically do not track energy savings beyond the first year after installation so the reported successes of any conservation program may reflect only these initial estimates. Our analysis showed that in many cases the savings may degrade in the second post-retrofit year, followed by either a continued deterioration, a leveling off, or even an increase in savings. We therefore conclude that the approach used to estimate the performance of energy conservation measures needs to be revised so that several years of post-retrofit energy performance are monitored and included in any subsequent energy and economic analyses.

Finally, the necessity for tracking monthly energy consumption to identify "problem" projects and buildings and to assist in the proper selection of retrofit measures in federally-assisted housing has been suggested elsewhere in more detail (Ritschard et al. 1986), yet HUD and most local housing authorities have made little progress in establishing a framework or policy that encourages this level of energy management. Until such a system is widely implemented, housing managers and policy makers will have great difficulty improving the energy efficiency of this large stock of federally-assisted buildings. We hope that this study will stimulate an interest both at HUD and at local PHAs to pay more attention to maintenance issues in order to ensure that savings from all retrofit measures will persist over the lifetime of the measure. We also suggest that HUD encourage energy management and establish policies that promote sound energy management practices in federally-assisted housing. Any significant change in energy use in the public housing sector will reduce the tenant's utility bills, decrease HUD's annual expenses, and provide societal benefits to federal taxpayers.

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Endnote

1. MBtu = 10^6 Btu

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