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ABSTRACT

In response to rising energy costs and declining operating subsidies from the federal government, local public housing authorities (PHAs) and the U.S. Department of Housing and Urban Development (HUD), the agency responsible for operating and managing public housing, have become more interested in gaining an understanding of energy use patterns and the potential for energy conservation. The initial attempts by HUD to acquire this information were based principally on engineering estimates of energy use.

In this study, we analyzed energy use in 91 selected projects located over a range of U.S. climates using utility billing data. Although the study sample is not statistically representative of the public housing stock, we believe it represents the most comprehensive examination of energy consumption patterns in public housing based on measured data. We employed a two-stage analytical approach in which actual energy use is first normalized to consumption in a year with "typical" weather, followed by multiple regression analysis of different cross-sectional variables. The independent variables included structural characteristics (year built, building type, wall construction), heating system type, occupant type, and housing authority. The final regression model, which included all variables that were significant at the 5% level, explained 80% of the variation in energy use in the projects. The regression results suggest that the behavior of the PHAs is an important determinant of energy use in these projects.

Annual energy consumption of the space heat fuel was 104 MBtu/apartment unit; median energy (fuel and electricity) expenditures were found to be close to $1000/unit for our sample. We also found the following trends when the projects were disaggregated: median energy consumption in high-rise projects (greater than four stories) was 16 to 23% lower than for the low-rise projects; on average, projects heated with oil used 25-30% more energy than gas-heated ones; and senior projects used roughly 10% less energy than family buildings. When the projects in this study were compared to previous engineering estimates of consumption, they used about 10-15% less energy across all building types and climate zones. Energy use in our sample was also found to be significantly higher than consumption in the privately owned multifamily stock.

We conclude that the approach developed in this study offers a method which local housing authorities can apply to their own projects to predict energy consumption, identify problem buildings, and set energy use guidelines related to physical and demographic characteristics. It also provides HUD with an analytical tool, which, if applied to a set of projects statistically representative of the public housing stock, could be used to ensure that energy subsidies for any particular project are not insufficient or excessive.

INTRODUCTION

U.S. public housing currently provides shelter for 3.4 million low-income tenants. The program was initiated in 1937 with the passage of the U.S. Housing Act and is operated and managed by the U.S. Department of Housing and Urban Development (HUD). Local public housing authorities (PHAs) began experiencing energy-related budgetary problems during the late 1970s because of the rapid escalation of energy prices. Rent and utility costs are partially subsidized by HUD. Annual energy costs now exceed $1 billion, or one-third of the total operating subsidies, and represent 50% or more of the costs for some public housing authorities (PHAs). In recent years, HUD, like most non-defense-related federal agencies, has tried to reduce expenditures in response to tight budgetary constraints. Energy costs are a prime target for these efforts; therefore, energy use, and possibilities for energy conservation, have received increasing attention.

In this study, we analyze energy use in 91 selected projects using both utility billing data and measured consumption (fuel oil) data.* To the best of our knowledge, it represents the most comprehensive examination of energy consumption patterns in public housing based on *measured* data. We characterize energy use and costs for different subgroups of our sample. We also examine key factors that influence energy use and compare measured energy use in public housing with consumption in privately owned multifamily buildings as well as with engineering estimates of energy use in public housing.

HUD's initial attempts to understand energy consumption and the potential for conservation in public housing were based principally on engineering estimates of energy use (Perkins & Will and Ehrenkrantz Group, 1980). The reliability of engineering estimates depends principally on the sophistication and complexity of the simulation model, which can range from hand calculations to a detailed hour-by-hour simulation, as well as the accuracy of information on physical building characteristics (e.g., conditioned floor area, insulation levels), occupant behavior, and building operation. Engineering estimates of energy use engender a certain amount of skepticism; measured data provide a valuable confirmation of the reasonableness and reliability of these estimates.

Other studies, notably a study conducted by the Council of Large Public Housing Authorities (CLPHA), reported measured energy use (based on utility bills) in public housing (Sherwood et al., 1982). However, energy consumption data were aggregated by housing authority in the CLPHA study; differing building types, occupants, and heating system characteristics were combined in each PHA's energy use total. In contrast, individual public housing projects are the basic unit under analysis in this study; this allows identification of the physical and demographic characteristics (e.g., type of occupant, heating system, heating fuel, building type) that influence energy consumption. Another study based on measured energy use is currently being conducted by the North Carolina Alternative Energy Corporation (Gee, 1987). In the North Carolina study, *individually metered* energy use data and physical characteristics which vary by apartment (number of bedrooms, number of occupants) are used to predict energy use for individual apartments within a PHA. Our method was developed for *master-metered* projects, which represent the vast majority of the public housing stock; while it cannot identify excessive

* This study is part of an on-going LBL research project that seeks to improve the energy-efficiency of federally assisted housing. Previous reports have assessed the condition of the public housing stock, and identified barriers to conservation and research needs (Ritschard et al., 1986); analyzed savings and cost-effectiveness of conservation retrofits in public housing (Greely et al., 1986); and examined institutional/financial barriers to conservation in four case studies (Mills et al., 1986).

consumption by individual apartments within a project, the LBL method is useful for identifying reasonable project-level consumption.

We compiled measured data on 91 projects located over a range of U.S. climates. After adjusting annual consumption for changes in weather, we examined correlations between energy use and building and occupant characteristics, using multiple regression analysis. We also looked at patterns of consumption for different end-uses, and at how energy costs vary by type of project. Our measured consumption results are compared with engineering estimates of public housing energy use and with consumption in private multifamily buildings.

Our methodology provides a format for energy analysis suited to the planning needs of PHAs and HUD policymakers. Further work in this area could be used by HUD as a basis for establishing energy-use guidelines and to assist in evaluating PHA operating budgets and modernization applications. Energy use indices such as those developed here can also help HUD and PHAs monitor their energy consumption and design effective management initiatives.

DATA SOURCES

The study sample is not meant to be statistically representative of the public housing stock. Rather, this data compilation reflects our attempt to conduct an initial assessment of measured energy use in public housing and develop analytical techniques that could be utilized in an in-depth study with a statistically representative sample of data. We collected utility billing data for each project, as well as information on building and demographic characteristics, heating system and fuel type, and recent retrofit activity. In some cases, housing authorities were contacted directly. For example, housing authorities in San Francisco CA, Phillipsburg NJ, Philadelphia PA, Boston MA, Columbus GA, Los Angeles CA, New York NY, and St. Paul MN provided us with information on energy use and building characteristics. Some authorities have over 50% of the projects they manage included in the LBL data base, while only one or two projects are included from other cities. Often, we were able to use two standardized HUD forms, which contain data useful for energy analysis.* Additional data on specific housing projects were collected by a consultant who conducted energy audits of Northeastern PHAs and compiled raw energy use records, building descriptions, and anecdotal information on operation and maintenance practices. Princeton University's Center for Energy and Environmental Studies and HUD also provided information on several projects. Background information on the projects included in this study, and on recent retrofit efforts at individual public housing authorities, can be found in Appendix A.

APPROACH

In this section we describe the two-stage analytical approach used in this study. In the first stage, to account for the impact of climate severity in a particular year, actual energy use was normalized to consumption in a year with "typical" weather. Then, in stage two, this normalized energy use was used in examining the influence of project characteristics on consumption levels and costs.

* The first, HUD-1466B, is a standard utilities consumption and expenditures form, containing monthly data for each housing project. The second is a building characteristics data sheet, HUD-1855, containing information on building construction, vintage, and heating system characteristics.

Analysis of Energy Consumption

In all cases, we analyzed energy use 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.*

It is important to account for variations in climate when comparing energy use trends at projects in many locations and over a period of several years. Variations in weather from year to year can mask the effect of changes in building equipment or operation; therefore, we utilized techniques that adjust energy consumption to represent a typical year's weather. For more than three-quarters of the projects, we used the Princeton Scorekeeping Method (PRISM) to adjust the weather-sensitive component of space heat fuel use. PRISM is a widely used energy analysis model which regresses energy use versus degree-days calculated at the best-fit reference temperature to find the weather-normalized annual consumption (Fels, 1986). In the 16 cases where the data were of insufficient quality to use PRISM (e.g., missing billing dates, heating and cooling electricity on the same meter), consumption was weather-corrected by scaling with monthly actual and long-term average heating degree-days (base 65 °F).† Typically, project energy use of the space heat fuel (normalized annual consumption, or NAC) is expressed on either a per unit or per ft^2 basis, so that the effect of variations in project or apartment size on energy consumption can be discerned.

Characterization of Energy Consumption and Costs

We first characterized energy use and costs for our sample through disaggregation by climate zone, building type, occupant type, and space heat system and fuel type. Consumption patterns for different end-uses were also examined. Typically, we could divide consumption into its fuel and electricity components; in some cases, separately metered cooking gas data were available. Measured energy use in public housing was compared with consumption in privately owned multifamily buildings as well as with engineering estimates of energy use in public housing, to assess the accuracy of previous assumptions about public housing energy consumption.

Factors that Influence Energy Use: Multiple Regression Analysis

Energy use is influenced by many interrelated factors. Multiple regression techniques can be used on a sample of buildings to estimate the relative impact of key determinants of energy use. We formulated a regression equation using weather-normalized annual energy consumption (NAC) as the dependent variable and building and demographic characteristics, heating degree-days, and housing authority as independent variables. The magnitude and sign of the coefficients of the independent variables provide an indication of the degree to which each of these factors influence energy use in this sample of buildings. Most of the independent variables in the regression equation are "dummy variables", indicating the presence or absence of a condition (e.g., high-rise building, senior project). The variables included in the initial model were: year built, building type (high-rise versus low rise), wall construction (masonry versus frame), heating system type (central versus individual), heating distribution system (steam, water, or air), heating fuel, floor area, type of occupant (senior, family, or mixed), housing

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* Energy use data were converted to Btus using the following conversion factors: #2 oil=139,000 Btu/gallon, #4 oil=145,000 Btu/gallon, #6 oil=150,000 Btu/gallon, gas=102,000 Btu/ccf=100,000 Btu/therm, electricity=3413 Btu/kWh (site).

† Cooling and heating degree-days were similarly used to correct summer consumption at three projects where electricity use included air-conditioning.

authority, and long-term average heating degree-days. Typical values from the complete sample were assigned in the few cases (11) where information on a particular building characteristic was missing. It is also important to remember that information on building characteristics is at the project level; hence many structural factors thought to influence energy use (such as the number of windows or apartment orientation) were not considered.

The dependent variable, energy consumption (NAC), includes only gas and/or oil used for space heating, hot water, and, in 23% of the projects, cooking. Electricity consumption at each project is not included, because consumption of lights and appliances was available for only one-third of our projects. The four electrically heated projects were also excluded from the regression analysis, because space heat consumption could not be separated from that for lights and appliances. Long-term average heating degree-days (base 65 °F) are used as a proxy for the relative climatic severity at each project. Actual-year heating degree-days are not included as an independent variable in the multiple regression because year-to-year variations due to weather changes are accounted for by the energy analysis method described in the preceding section.

Minimum Data Requirements and Treatment of Projects with Multi-Year Data

The final sample of 91 projects represents roughly 50% of the original projects for which we had obtained preliminary information. The minimum requirements for inclusion of projects in the final sample were: (1) at least one year of utility billing data for the space heat fuel and (2) descriptive information on building characteristics (conditioned or total floor area, number of floors, wall material, heating system type, occupant demographics). Almost all projects were master-metered; that is, only one utility bill is issued for each project. A few projects had separately metered data on energy consumption by end use (e.g., cooking, lights and appliances).

To conduct the cross-sectional analysis, we first screened the quality of the weather-corrected PRISM results. Projects were excluded that had a standard error of the normalized annual consumption of greater than 10%, a standard error of the reference temperature of greater than 13%, or an R^2 of less than 0.8. These criteria were chosen to eliminate projects with energy data of questionable accuracy without substantially reducing the sample size. Four projects were eliminated by this procedure. We then picked one year for each project out of the periods that survived the selection process. Fifty percent of the acceptable projects had data from 1980 available; for the remainder the next closest year of data was used. This procedure created a cross-sectional "snapshot" of energy use within our sample of projects.

Reporting of "baseline" energy use in a stock of buildings is complicated by the fact that average energy consumption changes over time as buildings are retrofitted. Hence, any "baseline" is by definition dynamic, presumably declining over time as retrofit continues and new buildings (currently rather insignificant in public housing) are built to increasingly stringent thermal standards. To improve comparability across projects, we eliminated consumption periods that followed major structural retrofits from our analysis (in cases where we had information on retrofit activity). However, information about retrofit activity was not available for all projects, hence the level of retrofit and maintenance activity that preceded our analysis period undoubtedly varies among projects, and may exceed that typically occurring in the public housing stock as a whole.

RESULTS

Building and Demographic Characteristics

The 91 projects included in this study represent 1,789 buildings and 31,928 apartments and are drawn from 19 local housing authorities. All regions of the country are represented, although most of the projects are located in the Northeast (Fig. 1). The vast majority of projects in the data base are located in climates with between 4000 and 6000 heating degree-days (HUD zone 3). Only 13% are located in climates with relatively mild heating seasons (HUD zones 1 and 2) compared to 44% of the public housing stock (Table 1). Sixty percent of the projects in this study are low-rise buildings (four stories or less), a slightly lower fraction than within the overall public housing stock. Apartment size ranges from 500-1000 ft^2 in 83% of the projects. The smaller apartments are generally found in projects occupied by seniors. On average, the projects in this study tend to be older than the public housing stock (e.g., 47% were built before 1955 compared to 28% of the public housing stock). Projects built during the 1970s tend to be for seniors only, as is the case in the public housing stock. Almost 75% of the selected projects are centrally heated, a much higher fraction than in the overall stock (37%). Gas is the most common space heating fuel among our projects, followed by oil, which is much more prevalent in our sample than the overall public housing stock (44% versus 13%). In terms of demographic characteristics, the selected sample has a significant number of senior projects (32%), which parallels trends in the overall stock. Appendix B contains a detailed summary table of the characteristics of each project in the data base.

The report by Perkins and Will and the Ehrenkrantz Group segmented the public housing stock by building and heating system type and by climate zone. We also disaggregated the 91 projects in this study by construction type, heating system equipment, and space heat fuel among five climate zones and compared the resulting matrix to that of the public housing stock (see Appendix C). Low- and high-rise projects with oil-fired central heating systems in climate zone 3 (4000-6000 HDD base 65 °F) were much larger fractions of our sample (20 and 23% respectively) than of the overall stock (3 and 4%).

Measured Energy Use (Space Heat Fuel Only)

As shown in Table 2, the median annual energy use (NAC) of the *space heat fuel only* is 104 MBtu/unit.*,† Low-rise projects in this study use 19% (on a per ft^2 basis) to 30% (on a per unit basis) more energy than high-rise projects. The 40 projects that heat with oil use 33% more energy on a square foot basis than the 46 projects that heat with gas. Differences in consumption per ft^2 between high-rise and low-rise buildings, central and individual heating systems, and oil and gas space heat are statistically significant at the 5% level. Annual energy use per apartment unit is significantly lower in the 27 senior projects compared to the 51 family projects (61 versus 114 MBtu/unit). However, apartment units in senior projects tend to be much smaller; thus the differences in annual consumption narrow when adjusted for floor area (114 $kBtu/ft^2$ for senior versus 128 $kBtu/ft^2$ for family projects).

* MBtu = 10^6 Btu, kBtu = 10^3 Btu.

† "Space heat fuel", for the projects in our sample, includes fuel used for space heat, domestic hot water, and sometimes cooking.

Table 1. Comparison of selected projects with public housing stock.

CHARACTERISTICS	LBL SELECTED PROJECTS (%)	PUBLIC HOUSING STOCK (%)*
Climate Zone		
I (<2000 HDD)	1	16
II (2000-4000 HDD)	12	28
III (4000-6000 HDD)	71	37
IV (6000-8000 HDD)	13	16
V (>8000 HDD)	2	3
Building Type		
Low-rise	60	76
High-rise	40	24
Square Footage/Apartment		
≤ 500	4	4
501-750	43	46
751-1000	40	43
> 1000	13	7
Vintage		
≤ 1945	23	13
1946-1955	24	15
1956-1965	22	16
1966-1975	25	44
> 1975	6	12†
Number of Bldgs/Project		
≤ 1	23	23
2-5	19	10
6-10	14	12
11-20	17	16
21-50	17	27
> 50	11	12
Heating System		
Individual	24	63
Central	76	37
Heating Fuel		
Oil	44	13
Gas	52	76
Electricity	4	12
Occupancy		
Families	56	46
Seniors	32	32
Mixed	12	22

* Percentage of projects as estimated in Perkins and 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.

† Since the Ehrenkrantz report was published in 1980, we used more recent figures for the vintage of the stock, from: R.G. Bratt, C. Hartman, and A. Meyerson (eds.), *Critical Perspectives on Housing,* Temple University Press, Philadelphia, PA, 1986.

Table 2. Energy use of the space heat fuel (NAC) by project characteristics.			
	Number of Projects	NAC* MBtu/Unit-Year	NAC* kBtu/ft²-Year
High-rise	35	89 ± 7	116 ± 9
Low-rise	52	116 ± 9	138 ± 8
Family tenants	51	114 ± 8	128 ± 10
Senior tenants	27	61 ± 5	114 ± 11
Mixed tenants	9	131 ± 23	165 ± 35
Central Heating	69	102 ± 8	144 ± 9
Individual Heating	18	104 ± 10	115 ± 4
Steam Distribution	36	121 ± 10	162 ± 19
Water Distribution	31	85 ± 13	137 ± 11
Oil Space Heat	40	127 ± 10	154 ± 16
Gas Space Heat	46	87 ± 8	116 ± 7
TOTAL	87	104 ±6	128 ± 7

* Median ± standard error, where standard error = interquartile range/(sample size$^{1/2}$).

The lower energy intensity of senior projects in the data base cannot be attributed to their climatic location because, on average, most of these projects are located in more severe climates (5000 HDD and above) than family projects (Fig. 2). However, the type of occupant (senior versus family) may reflect other structural differences between projects; for example, senior projects tend to be of more recent construction. We attempt to isolate the impact of such factors on energy consumption using multiple regression analysis (see below).

Measured Energy Use (Fuel and Electricity: All End Uses)

Thirty-seven of the projects reported separately metered electricity use for lighting and appliances. For these projects, the median fuel and electricity consumption was 160 kBtu/ft^2 annually, or 127 MBtu/apt. Median electricity consumption for lighting and appliances *only* was 4983 kWh/unit (17 MBtu/unit site), or 13% of total energy use. Lighting and appliance consumption ranged from 7 to 24% of total use; however, for 95% of the projects, consumption fell within 400 kWh of the median.† Projects in our sample that had electricity consumption data are located mainly in the Northeastern U.S. and Colorado.

Patterns of cooking energy use

Anecdotal evidence and submetered energy consumption data suggest that, in some cases, public housing tenants use their cooking appliances to provide supplementary space heating. Clearly this practice is not desirable and is discouraged by local housing authorities. In some cases, extended stove use may produce dangerously high levels of respiratory irritants such as nitrogen dioxide and carbon monoxide. The New York Housing Authority, for example, has issued a flyer warning tenants of the potentially lethal consequences of using their stoves for heating (NYCHA, 1983).

† The low variance in electricity consumption justifies the inclusion of the median as the electricity component for projects lacking electricity use data, for purposes of the end-use cost breakdown described later in this report (see Table 4).

Metered cooking energy use data show at least two distinct patterns: (1) projects with high cooking energy consumption throughout the entire winter, peaking during the coldest periods, and (2) projects with cooking energy peaks during the "shoulder" periods of the heating season (e.g., October, May), before and after the central heating system is turned on. In the first case, there may be inadequate provision of heat to some of the apartments throughout the entire heating season. For example, both a New Jersey (TRN008O) and California (SFN002G) project display distinct peaks in winter cooking use which track fuel use for space heating (Fig. 3).* Although increased cooking during the winter may account for *part* of the increase in cooking gas consumption, the magnitude of the winter use is often more than double summer cooking gas use. Furthermore, at the California project, the peaks are equivalent to roughly 30% of the gas consumed for *both* space heating and domestic hot water generation. One possible cause for the use of stoves for space heat in that project is that many 2-3 bedroom apartment units have only one radiator.

Another New Jersey project (JCA004O) that exhibits the second pattern, higher cooking energy use during shoulder months of the heating season, is shown in Fig. 4a. Many housing authorities in the Northeast turn on their central space heating equipment at a set date in the fall (e.g., October 15) and shut off the boilers at the end of the heating season. Often, in these projects, space heat levels during the depths of winter are ample; however, tenants may find the comfort level inadequate during the fall or spring, particularly if there is a cold spell. In project JCA004O, cooking energy use is highest during October and May, when it is 100% greater than during summer months and 20-30% greater than during other winter months.

A Trenton project (TRN004O) illustrates variability in cooking energy use that may be a by-product of uneven heating caused by a central boiler with a steam-distribution system. Cooking energy use fluctuates dramatically during the winter months between 1979 and 1982 (Fig. 4b). In 1982, the central space heat system was retrofitted with new heating controls and steam traps. Since 1983, the seasonal fluctuations in cooking fuel use have dropped markedly. Peak cooking gas consumption decreased by about half, possibly due to the more even heating made possible by the new controls.

Energy Costs

We combined current energy prices and weather-normalized energy consumption to determine baseline energy costs.† Energy prices were collected directly from the PHA or from HUD and reflect mid-1985 costs. Many housing authorities are billed for energy according to complicated rate structures; for example, Philadelphia has three electricity rates (plus demand charges), two gas rates, and variable "boiler rates" for oil. In addition, the rates often vary from project to project. In most cases, energy prices represent consumption-weighted averages for each fuel and are the *effective* rates (i.e., the ratio of total costs to total consumption for the PHA).

Typical energy prices for our sample, compared to national residential prices, are shown in Table 3.

* The seven-character project codes used in this section are our own; further information about these projects is contained in Appendices A and B.

† For projects with space heat, domestic hot water, and cooking consumption, but no electricity data for lights and appliances, we assigned the median value of "lights and appliances" consumption as the electricity component for use in the end-use breakdown, thereby increasing the sample size for this part of the analysis.

Table 3. Typical 1985 energy prices for public and U.S. residential housing.		
Energy Source	PHA Price (median)	U.S. Residential Price* (average)
Oil	\$4.62/MBtu	\$6.76/MBtu
Gas	\$5.61/MBtu	\$7.23/MBtu
Electricity (site)	\$21.80/MBtu	\$23.89/MBtu

* Source: Energy Information Administration, *Monthly Energy Review*, Washington, D.C., DOE/EIA-0035(85/06), June 1985.

Median annual energy (fuel and electricity) expenditures in 61 projects are \$983 per apartment unit. Over 60% of annual energy expenses are used to supply space heat, domestic hot water, and cooking (Fig. 5). In these projects, site electricity use is only 14% of total energy consumption; however, it accounts for 38% of energy costs. End-use estimates for this group of buildings agree closely with those obtained by the Ehrenkrantz study (88% for space heat, domestic hot water, and cooking; 12% for lights and appliances). However, Ehrenkrantz shows electricity costs as a smaller fraction of total energy expenses. This difference is due principally to the relative increase in electricity rates and decrease in oil costs since their 1980 report was written.

Annual energy expenses are 40% greater in low-rise projects than in high-rise projects; almost 50% higher in the 30 family projects compared to the 20 senior projects, and 10% higher in projects that heat with oil compared to gas (Table 4). This pattern is consistent with the energy consumption trends observed in these subgroups. However, for individually heated apartments, energy expenditures are roughly 10% higher than for projects with central heating, despite comparable consumption levels. Higher energy costs are due to to the high incidence of electricity as the space heat fuel in individually heated units. Energy costs are not correlated with climate severity, primarily due to our small sample size in some regions.

Table 4. Median energy expenses by project characteristics.		
	Number of Projects	Costs (1985 \$/Unit)
High-rise	22	734
Low-rise	39	1047
Family tenants	30	1096
Senior tenants	20	711
Mixed tenants	11	873
Central Heating	42	917
Individual Heating	19	1020
Steam Distribution	16	1022
Water Distribution	26	768
Oil Space Heat	18	1082
Gas Space Heat	38	955
Climate Zone 1 (< 2000 HDD)	1	1104
Climate Zone 2 (2000-4000 HDD)	8	828
Climate Zone 3 (4000-6000 HDD)	43	1057
Climate Zone 4 (6000-8000 HDD)	8	551
Climate Zone 5 (> 8000 HDD)	1	463

Determinants of Energy Use

We developed a multiple regression model to explore factors that contribute to variation in energy use among our sample of public housing projects. Weather-normalized annual energy consumption (NAC) per unit for space heat, domestic hot water, and cooking was used as the dependent variable, while the independent variables included structural characteristics, heating system type, occupant type, and housing authority (see Table 5). Eighty-seven projects were used in the model; four all-electric projects were excluded from the regression, because lighting use could not be separated from the end-uses we wished to include. The final regression model included all variables (and, for dummy variables, their alternates) that were significant at the 5% level (e.g., senior is significant, so family is also kept in the equation).* The coefficients for each of the dummy variables represent the amount of energy use due to that variable. This model explained 80% of the variation in energy use of the 87 sample projects ($R^2 = 0.80$). Fig. 6 compares predicted and actual energy use for this regression model.

We also tested a model in which the "housing authority" variables were not included. We decided to create such a model because the physical meaning of the PHA variables is somewhat uncertain. The regression equation without the "housing authority" dummy variables had less explanatory power ($R^2 = 0.54$) than the model which includes it ($R^2 = 0.80$).† Almost all the projects in this study are master-metered, thus many factors that affect *apartment* energy use (e.g., orientation, number of windows, number of occupants) are not readily available. An apartment-level analysis, with individual metering, could perhaps explain more of the variation in energy use by including these variables.

Of the variables we examined, the type of occupant explains most of the variation in energy consumption, as measured by change in R^2. In both models, the "senior" coefficient was negative (with values ranging between 46-85 MBtu/unit), indicating that projects occupied by seniors used less energy than either family or mixed occupancy housing (Table 5). The lower energy intensity of senior projects may be partially explained by their lower occupant density compared to family housing. The regression coefficients for projects with central heating systems and masonry buildings were positive, indicating that these factors are associated with increased energy consumption in our sample of projects. High-rise projects had a negative coefficient (with values ranging from 19 to 30 MBtu/unit-year depending on the model).

"Housing authority" variables were statistically significant at the 5% level for five PHAs, and also explained a great deal of variation in energy consumption. Results are particularly striking for the New York City Housing Authority (NYCHA), which suggest that, all else being equal, consumption at projects in New York City would be about 40 MBtu/unit less than at projects in other PHAs. This parameter estimate tends to agree with anecdotal and published information on NYCHA's activities. For example, NYCHA has one of the most aggressive energy management programs in the nation. Their program includes: (1) a computerized monitoring system for fuel oil and electricity consumption, with baseline consumption data, fuel savings targets, and performance indicators to

* Dummy variables are those that represent the presence or absence of a condition, such as "high-rise" or "low-rise".

† Another statistical indicator, the adjusted R^2, corrects for the tendency of R^2 to increase as more independent variables are added to the regression equation. As can be seen in Table 5, the adjusted R^2 is nearly as high as R^2 for both models.

Table 5. Regression equation coefficients.		
Explanatory Variable	Model with PHAs	Model without PHAs
Intercept	-1970*	73.5*
Structural:		
Year Built	1.0*	--
High-Rise[a]	-19.2*	-29.9*
Masonry[b]	38.4*	32.1*
Heating System:		
Central[c]	68.2*	39.4*
Steam Distribution[d]	-7.3	--
Water Distribution[d]	-37.8*	--
Occupancy:[e]		
Senior	-85.2*	-45.9*
Family	-5.4	1.2
Housing Authority:[f] (increasing HDD)		
Columbus, GA	-22.9	--
Las Vegas, NV	47.6	--
San Francisco, CA	21.8	--
Anne Arundel, MD	-5.3	--
New York, NY	-40.0*	--
Philadelphia, PA	21.3	--
Trenton, NJ	27.2*	--
Phillipsburg, NJ	44.2*	--
Atlantic City, NJ	10.2	--
Asbury Park, NJ	59.4*	--
Jersey City, NJ	-14.8	--
Boston, MA	74.8*	--
Denver, CO	29.2	--
Reno, NV	27.6	--
St. Paul, MN	30.6	--
R^2	0.803	0.536
Adjusted R^2	0.732	0.507
Sample Size	87	87

* Statistically significant at 5% level.
'--' Not included in equation.
[a] If not high-rise, then low-rise (4 stories or less).
[b] If not masonry, then wood-frame.
[c] If not central heating, then individual apartment heating.
[d] If not steam or water distribution, then air distribution.
[e] If not senior or family, then mixed occupancy.
[f] If not in any of these authorities, then in Newark, NJ.

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).

There are several possible interpretations of the meaning of the "housing authority" variables. One possible explanation is that it is a proxy for climate severity. If this were true, we would expect that PHAs in mild climates would have negative signs and possibly that coefficients would be of increasing magnitude in the more severe climates. In Table 5, PHAs are ordered by increasing number of heating degree-days. Neither of these patterns is readily apparent, therefore we believe that this is not the most plausible explanation. We think that the "housing authority" variables reflect two factors: (1) the impact of differing energy management and/or building maintenance practices and (2) systematic structural differences among the stock of buildings in various PHAs which we do not have information on. For example, some PHAs, like NYCHA, had implemented extensive structural retrofits (e.g., energy-efficient window replacements in thousands of units) several years before the baseline year of 1980, while other PHAs have been much slower to initiate major structural improvements. Furthermore, the "housing authority" variables should be interpreted with extreme caution given that, for many PHAs, only a small fraction of the projects that they manage are included in this study. Despite the limitations of our sample, we believe that there are systematic differences in PHA energy management practices that can be detected by this approach; however, a fair test would necessitate more thorough sampling techniques.

The regression results were somewhat surprising in that several variables included in the initial model and thought to be major determinants of energy use were not statistically significant at the 5% level. Specifically, these variables were apartment floor area, long-term average heating degree-days, and heating fuel. The uneven quality of the data on apartment floor area partly explains its lack of significance.* Long-term heating degree-days were probably not a significant determinant of energy use for another reason: our sample of projects did not adequately capture or reflect climatic diversity because over 70% were located in climate zone 3 (4000-6000 HDD). In addition, the "housing authority" variables were somewhat correlated with HDD, and were probably capturing some of this effect. However, HDD were still not significant at the 5% level in the model that excluded the "housing authority" variables. Fig. 2 illustrates the lack of correlation between actual energy use and climate severity for the projects in our sample.

A few variables in both models were highly correlated ($R > 0.7$). For example, "senior" and "year built" were highly correlated. This is not too surprising given that almost all senior projects were built during or after the 1960s. We tested a model in which either "year built" or "family/senior" were eliminated from the regression equation; the coefficients showed little change.

To test the robustness of the model, we re-estimated the regression equation using weather-normalized annual energy consumption (NAC) values from other years for the

* Information on floor area was not reported in a consistent fashion. Some housing authorities reported only total building floor area (including common areas), while others had data on apartment floor area (excluding common areas). In some cases, it was not possible to determine if floor area referred to conditioned space or included areas that were not heated or cooled. For a few projects, we received conflicting data from different sources on total floor area. When available, we used conditioned apartment floor area, and estimated it for the projects that reported total building floor area.

same projects (in cases where we had more than one year of energy data). The coefficients for the "housing authority" variables were the only parameters that changed significantly as a result of this substitution. This is the sort of change one would expect: while most of the physical characteristics included in the equation will not change over the years, the "housing authority" variables capture trends such as retrofit efforts or possible changes in maintenance practices.

*Comparisons With Ehrenkrantz Study**

Annual fuel consumption of projects in this study is somewhat lower than the engineering estimates for the public housing stock based on the Ehrenkrantz study, as can be seen in Table 6 (122 versus 146 MBtu/unit) (Perkins and Will, 1980). While oil and gas consumption in our sample of projects is about 20% lower than the stock estimates, metered data on electricity consumption for lighting and appliances agree closely with the Ehrenkrantz data. The relative energy consumption of low- and high-rise projects in this study is in accordance with that reported by the Ehrenkrantz study: consumption tends to be higher on a per apartment basis in low-rise buildings.

Annual electricity use is much lower in the four projects in this study that are electrically heated (10,000-12,000 kWh/unit) compared to values in the Ehrenkrantz study (25,000-50,000 kWh/unit). The Ehrenkrantz estimates of consumption in all-electric projects seem high, particularly in view of measured data from the Residential Energy Consumption Survey (RECS) which shows that average annual use for electrically heated multifamily dwellings is around 12,000 kWh/unit (EIA, 1984b). Such discrepancies may arise because, while the Ehrenkrantz sample is statistically representative of the public housing stock, its projects do not accurately represent small subsets of the stock (e.g., Ehrenkrantz's ten electrically heated projects are not representative of all electrically heated projects in the public housing stock).

Table 6. Comparison of annual energy use: LBL data base and Ehrenkrantz study.†

	LBL Data Base (median) (MBtu/apt.)	Ehrenkrantz (mean) (MBtu/apt.)
Oil & Gas	105	130
Electricity	17	16
Total	122	146
Total High-Rise	89	101
Total Low-Rise	116	164

† The LBL total use reported here differs slightly from that reported on page 7 (127 MBtu/apt.). This discrepancy exists because four all-electric projects were not included in this table, so that fuel and electricity consumption could be disaggregated.

Comparisons with multifamily stock

Privately owned and operated multifamily buildings differ significantly from public housing in many respects (Table 7). First, and foremost, energy consumption is significantly higher in public housing. The Ehrenkrantz study estimates annual site energy consumption at 146 MBtu/unit for the public housing stock, while private multifamily apartments consume only 77 MBtu/unit, based on utility billing data from the

* The Ehrenkrantz study assessed the physical condition of the public housing stock. One of four volumes is devoted to energy use; engineering estimates of energy use as a function of location, building type, and heating system type are developed.

Residential Energy Consumption Survey (Perkins & Will, 1980; U.S. Congress, 1984).* Structural features, such as heating system type and heating fuel choice partially explain the higher energy use in public housing. The public housing stock is also older, has a higher fraction of buildings with central heating systems, and includes fewer buildings with electric-resistance heating than the existing multifamily stock. Public housing also tends to have higher occupant density than private multifamily buildings (2.9 versus 2.3 occupants per household).

Table 7. Comparison of public housing with the private multifamily stock.

	PUBLIC HOUSING STOCK†	MULTIFAMILY HOUSING STOCK‡
Floor area (ft^2)	850	817
Central heating (%)	52	41
Oil heating (%)	20	25
Electric heating (%)	7	26
Occupants per household	2.9	2.3
Energy use per apartment (MBtu/yr)	146	77
Annual site energy use ($kBtu/ft^2$)	**172**	**94**

† Stock averages as estimated in Perkins & Will and the Ehrenkrantz Group, *An Evaluation of the Physical Condition of Public Housing Stock: Final Report,* H-2850, (U.S. Department of Housing and Urban Development, March 1980).

‡ Energy Information Administration, *Residential Energy Consumption Survey: Housing Characteristics 1980,* (Washington, D.C.: U.S. Government Printing Office, June 1982), DOE/EIA-0314.

Although lower than Ehrenkrantz estimates of stock consumption, measured data from selected projects in this study tend to reinforce the notion that energy use is higher in public housing than in privately owned multifamily buildings. Median per unit consumption at projects in the LBL data base is 65% higher than the RECS figure. Energy consumption normalized for floor area is 10-35% higher for projects in this study across the well-represented climate zones compared to RECS data on multifamily buildings (Table 8).

The institutional setting for public housing also contributes to its high consumption. Most public housing tenants have at least part of their energy bill included in their rent payment, and thus have little incentive to conserve; only 12% of public housing tenants have individually metered electricity, while 33% are submetered for gas (OTA, 1982). Without submetering, tenants cannot be assessed charges based on their actual consumption. In contrast, almost half of the renters in multifamily housing have their consumption submetered and are billed for at least one energy source (EIA, 1982 and 1984a).** There is anecdotal evidence to suggest that public housing also tends to be

* The Residential Energy Consumption Survey (RECS) is a statistically representative survey of U.S. households. Their multifamily statistics include both private and public housing; however, since public housing accounts for only 6% of multifamily units, we assume that the statistics primarily reflect energy use in the privately owned component.

** PHA management also has limited incentive to conserve. When a housing authority reduces its

Table 8. Average energy use by climate zone.		
HUD Climate Zone	LBL Data Base (kBtu/ft^2)	Multifamily Stock (kBtu/ft^2)
1 (< 2000 HDD)	64.2*	109.5
2 (2000-4000 HDD)	118.4	88.5
3 (4000-6000 HDD)	192.5	142.8
4 (6000-8000 HDD)	137.4	124.2
5 (> 8000 HDD)	158.1*	104.5

* LBL data base has only one project in these climate zones.

more poorly constructed and less well-maintained than its private counterparts, which means greater losses through the building shell and lower heating system efficiency.

DISCUSSION

It is important to note that many of the projects in this study are managed by PHAs that have been among the most active in attempting to reduce their energy expenditures. In some cases, they have well-developed energy management programs. Thus, energy use in this group of projects may be somewhat lower than in the public housing stock as a whole.

The results of this analysis have implications for PHAs interested in understanding the factors that affect energy consumption in their projects. Local PHAs could use these techniques to predict energy consumption, identify problem buildings, and set usage guidelines segmented by physical and demographic characteristics. Given the difficulties in interpreting the meaning of the "housing authority" variable and in developing consistent data sets across PHAs, it would be interesting to apply this technique to all the projects managed by one large PHA.

This type of analysis also provides HUD with a tool to ensure that energy subsidies and/or utility allowances for particular projects are not insufficient or excessive.† A regression model based on a statistically representative sample would allow HUD to determine typical consumption for various regions and building types. One opportunity for applying these techniques is to analyze the sample of 300 buildings that are receiving audits in a HUD-commissioned study being performed by Abt Associates (the study focuses on the modernization needs of PHAs and updates the earlier Ehrenkrantz study). The 300 building subsample (drawn from a 1000 building population that represents the public housing stock) will have one year of metered energy consumption and cost data as well as information on physical and mechanical system characteristics and population and vacancy rates. A regression model derived from this data set could provide HUD with a basis for developing energy use guidelines for projects that would take into account structural and demographic factors. In addition, it could help HUD identify "problem" projects that have excessive consumption.

energy bills, nearly all of the financial benefits are recaptured by HUD (Mills et al., 1986).

† Projects with *individual metering* are allotted utility allowances, which are given to tenants to pay for some or all of their energy consumption. Energy subsidies are given to the PHA by HUD to pay for utility costs at *master-metered* projects.

CONCLUSIONS

In this study, we examined factors that influence energy consumption levels in a group of 91 selected public housing projects. Annual energy consumption of the space heat fuel (which includes domestic hot water and some cooking consumption) was 104 MBtu/unit; median energy (fuel and electricity) expenditures were close to $1000/unit for this group of projects. Some interesting patterns emerged when the projects were segmented by building type, heating system and fuel type, and type of occupant. Median energy consumption in the high-rise projects was 16 to 23% lower than for the low-rise projects, after adjusting for floor area and the number of units, respectively. On average, the projects that heated with oil used 25% (per ft^2) - 30% (per apartment) more energy than the gas-heated projects. The senior projects used roughly 10% less energy than the family buildings, when adjusted for differences in floor area. Preliminary results from our analysis of submetered cooking energy data indicate that ranges may be used for space heating. Further investigation into the magnitude of this effect, and its causes, is warranted.

Projects in this study used approximately 10-15% less total energy across all building types and climate zones (except for buildings with electric space heat) than previous engineering estimates of consumption for the public housing stock developed in the Ehrenkrantz report. Non-heating electricity use was the same for both groups, while oil and gas consumption was about 20% lower for our sample than estimated in the Ehrenkrantz report. Lower consumption among projects in our sample may reflect the energy-conserving character of the PHAs that contributed data. Energy use in this group of projects is still significantly higher than in the privately owned multifamily stock.

We developed two multiple regression models that were able to explain between 50% and 80% of the variation in energy consumption in our sample of projects. In these projects, type of occupant was the most important factor that explained variation in energy consumption; projects occupied by seniors used less energy than family projects. The results of this analysis also suggest that the behavior of local housing authorities is an important determinant of energy use in these projects. We conclude that this two-stage analysis technique (i.e., weather-normalization of actual energy use over time to consumption in a year with "typical" weather, followed by multiple regression analysis of cross-sectional variables) may help HUD and PHAs increase their understanding of energy use patterns among projects and gain greater control of energy expenditures.

ACKNOWLEDGEMENTS

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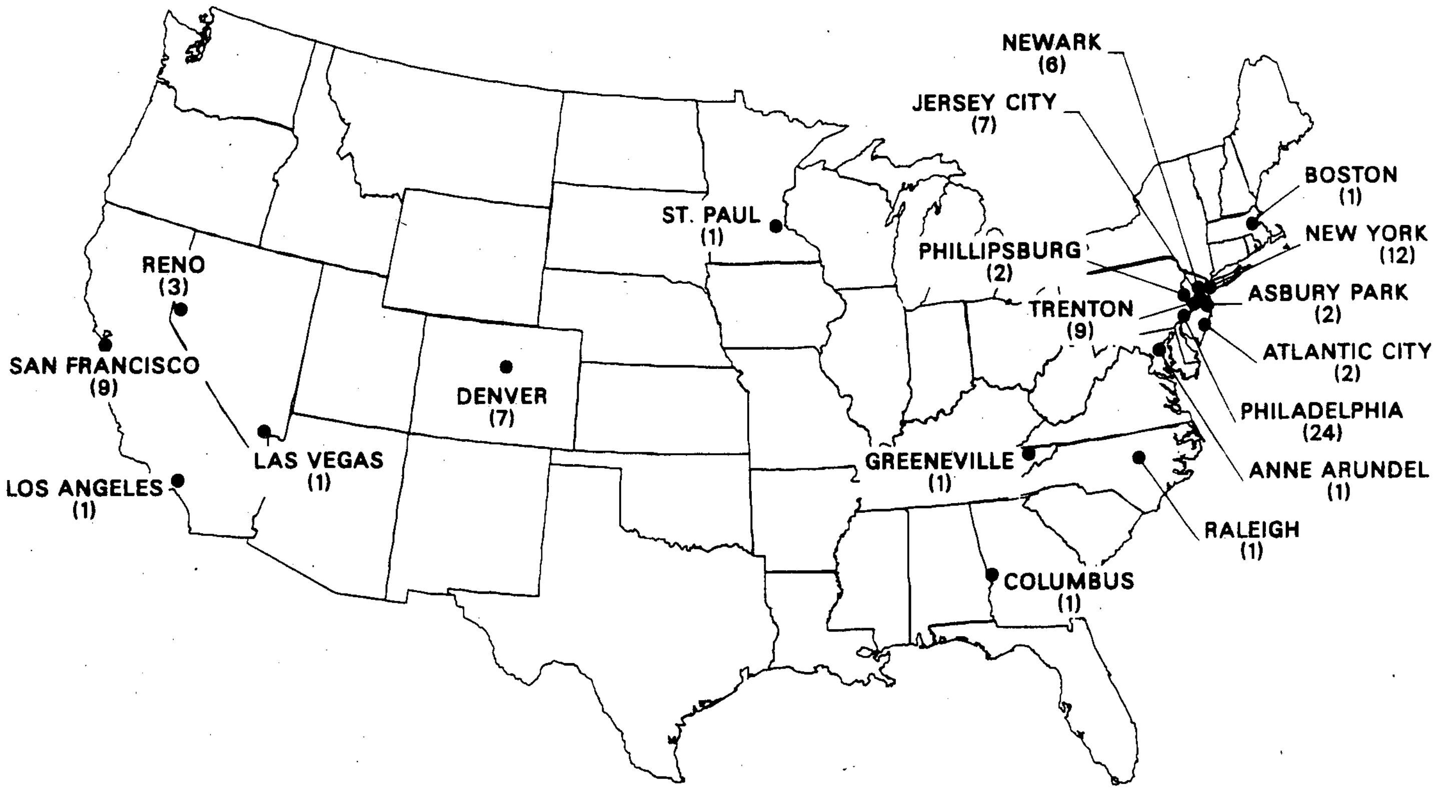
Location of Public Housing Projects in LBL Database*



XCG 8611-12248

Fig. 1. Location of public housing projects included in data base.

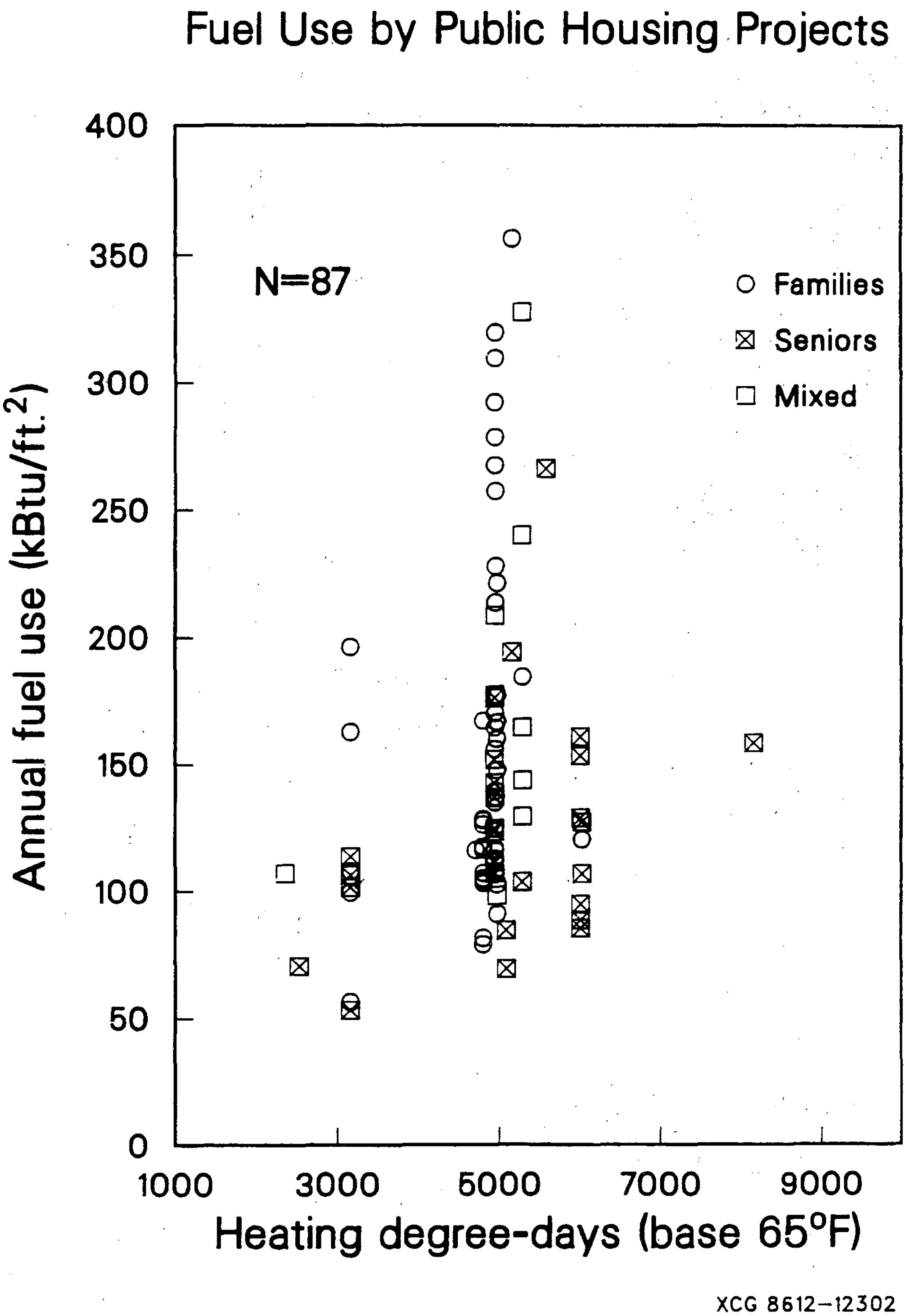
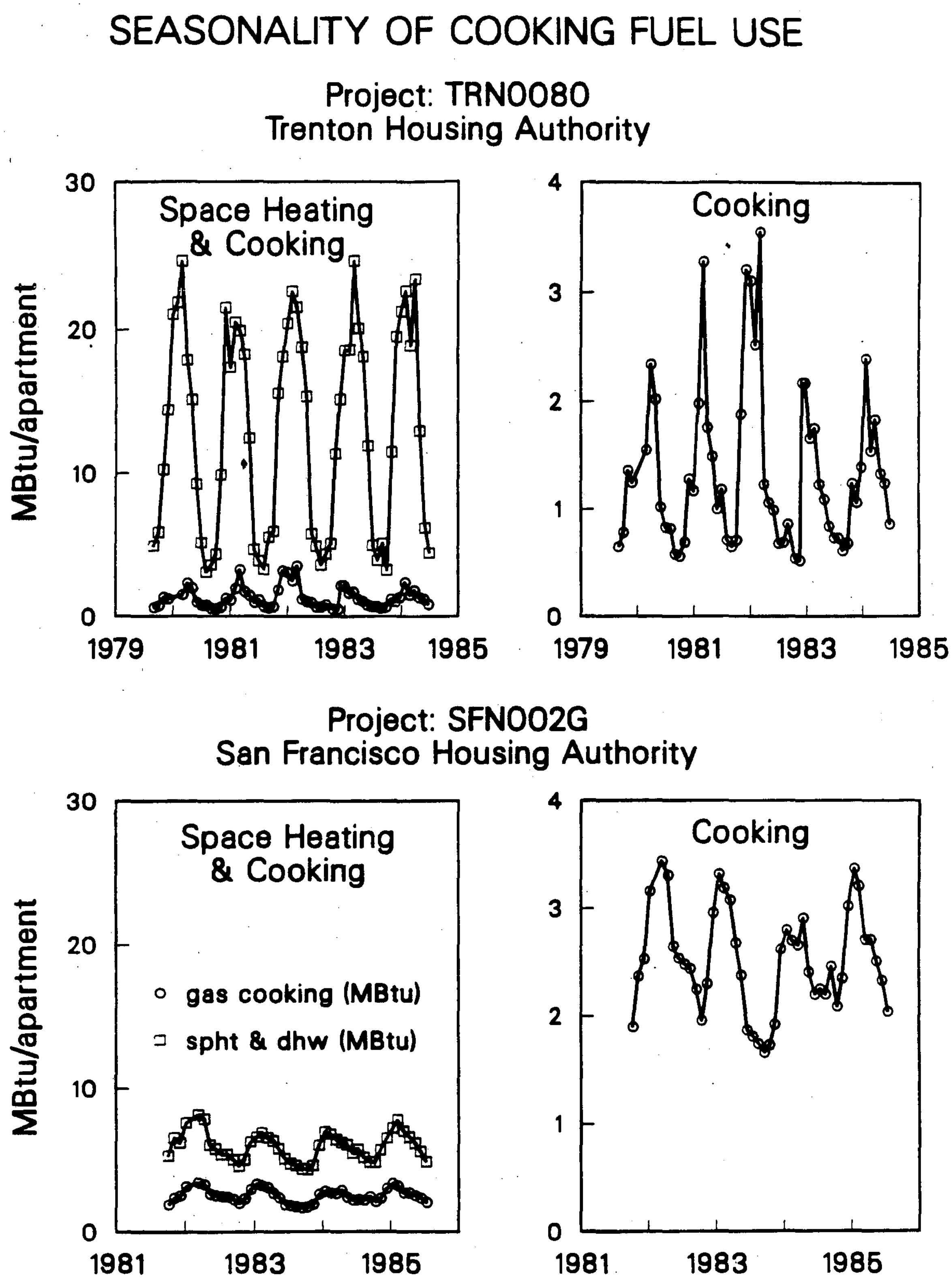


Fig. 2. Comparison of consumption of space heat fuel with heating degree-days (base 65°F), for different occupant types. Space heat fuel includes consumption for space heat, domestic hot water, and sometimes cooking.



XCG 8610-12191

Fig. 3. Seasonality of monthly cooking fuel use at projects in the Trenton Housing Authority in New Jersey and the San Francisco Housing Authority in California. Tick marks along the x-axis represent January of the indicated year. Consumption during each month has been normalized to a thirty-day billing period. Cooking fuel use at both projects increases during the winter months.

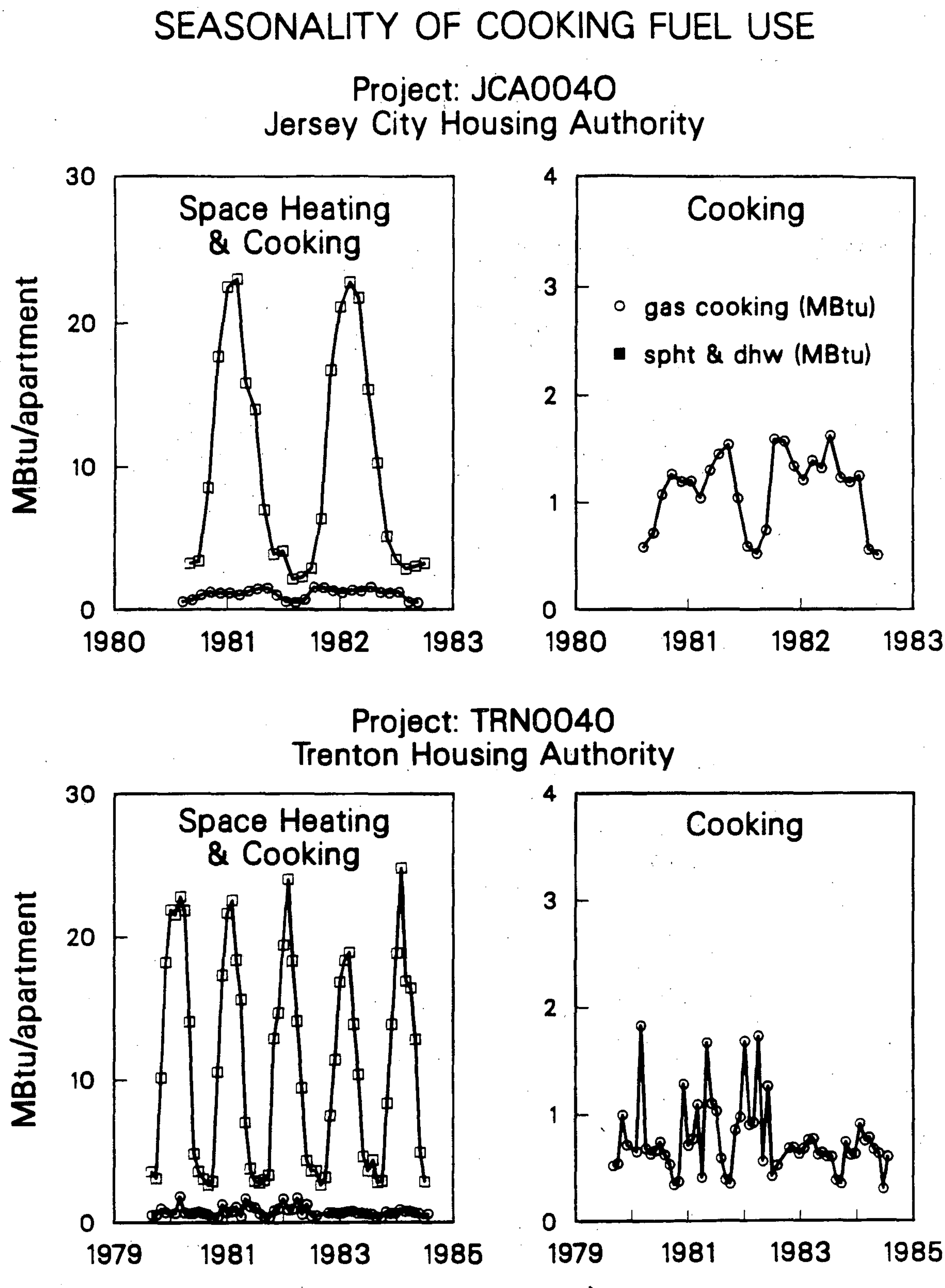


Fig. 4. (a) Monthly cooking fuel use increases during the spring and fall at a Jersey City Housing Authority project, in New Jersey. Tick marks along the x-axis represent January of the indicated year. Consumption during each month has been normalized to a thirty-day billing period. This pattern suggests that tenants use ovens to warm their apartments during cool weather if the central heating system is not operating. (b) Seasonality of cooking fuel use decreased markedly following a heating control retrofit at Donnelly Homes, in the Trenton Housing Authority in New Jersey.

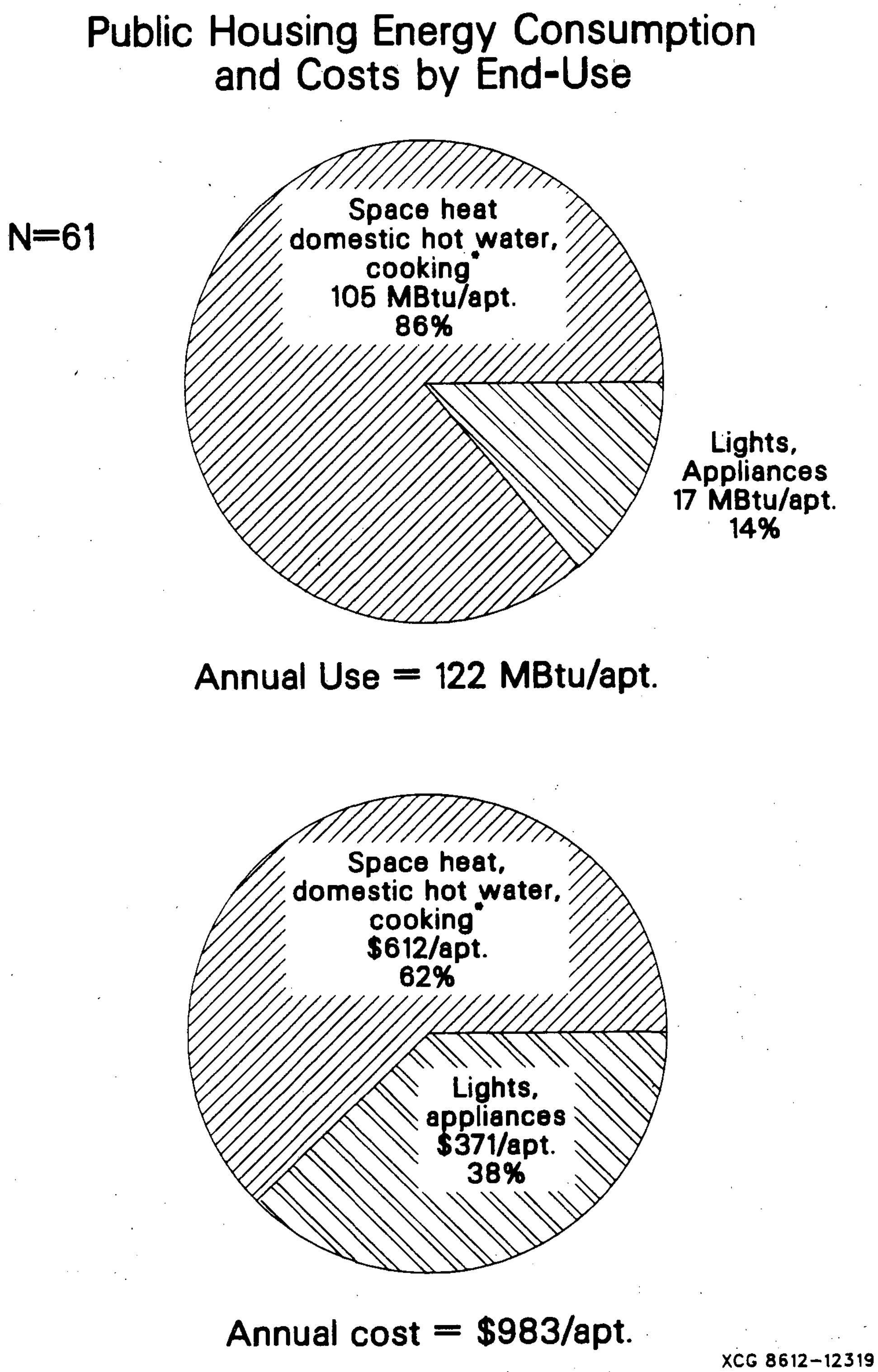


Fig. 5. Energy consumption and costs by end-use. These pies represent the 67% of our projects with data for all end-uses. Total consumption is slightly *lower* here than for the data base as a whole (122 MBtu/apt. versus 127 MBtu/apt.), because requiring that all end-uses be present excluded many oil-heated projects, which are often older and less efficient.

* Eighty-two percent of these projects use gas for cooking, and are included in "cooking". The remainder have electric ranges, whose consumption is included in "appliances".

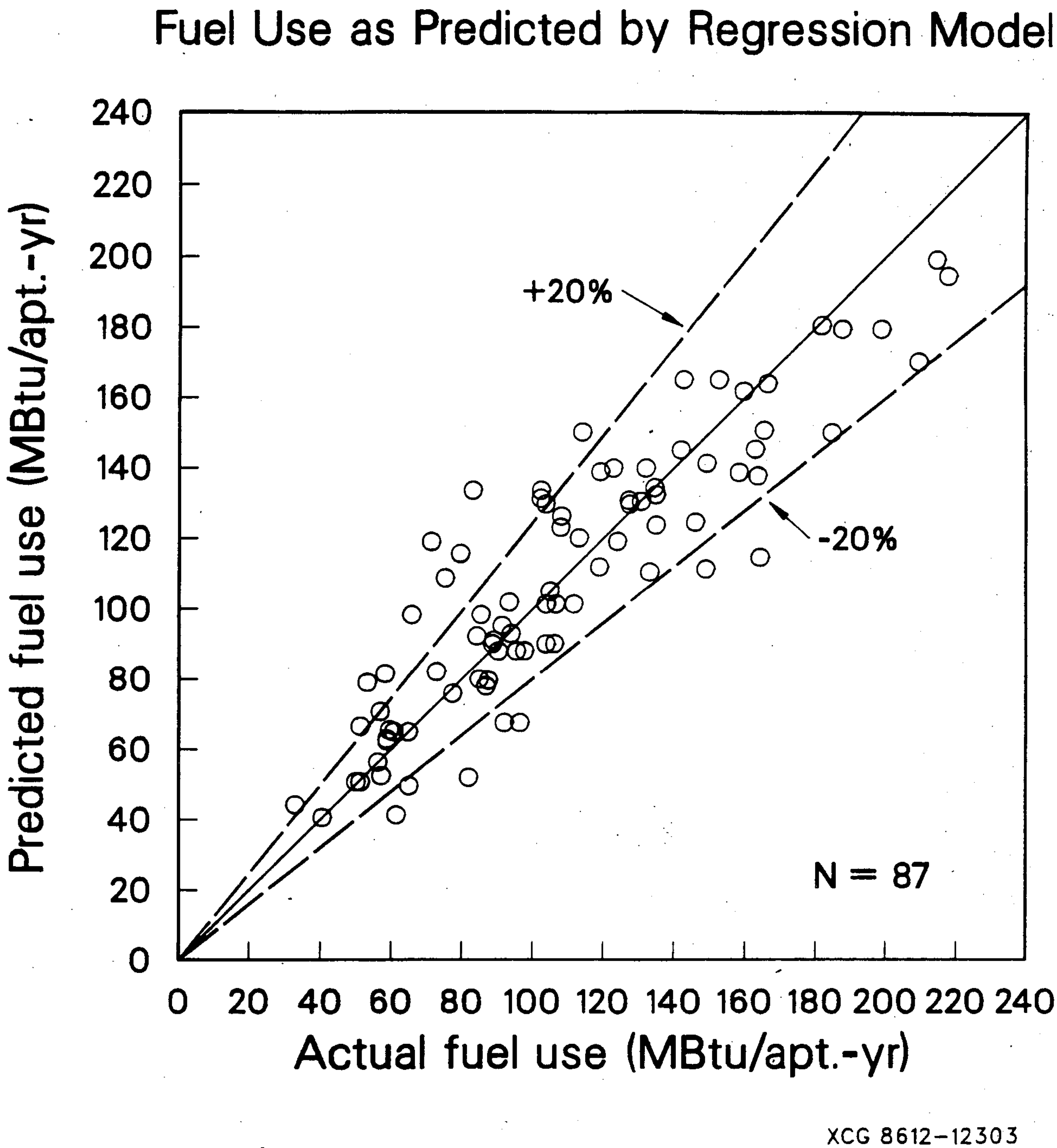


Fig. 6. Comparison of predicted versus actual energy use, for the regression model which includes the "housing authority" variables.

APPENDIX A: Public Housing Authority Descriptions

The following pages contain descriptions of the various housing authorities for which we have analyzed energy consumption. In all, the data base represents 19 PHAs, 91 projects, 1,789 buildings and 31,928 apartment units. The profiles of each housing authority contain an overview of building characteristics, occupancy, baseline energy results, and historical retrofit or energy management activities. Building vintage and number of buildings per project vary substantially within most PHAs. Here we report ranges in building age, total numbers of buildings and typical number of buildings per project. Our data sources are listed at the end of this appendix and more detailed project-specific data are provided in Appendix B. The data do not necessarily reflect the entire stock of buildings managed by any given authority because, in most cases, we only have information on a fraction of the projects.

Each project is identified with a label indicating the PHA, an identification number, and fuel used for space heating (e.g., gas (G), oil (O), mixed fuels (M), and electricity (E)). Energy consumption in the selected year is weather-corrected using the Princeton Scorekeeping Method (PRISM) unless otherwise stated. In this appendix we report the mean energy use (in annual kBtu/ft^2) for the buildings we analyzed and identify the end-uses included in the analysis. For comparison purposes, electricity is converted to site energy using 3413 Btu/kWh. The energy use data reported here as "baseline" consumption reflects only pre-retrofit energy use. Savings from retrofits installed at nearly half of these projects were analyzed in an earlier report (Greely et al., 1986). Here we briefly review the savings and cost-effectiveness of these measures.

ANNE ARUNDEL HOUSING AUTHORITY[1]

AAC001G: Glen Burnie, MD

* * *

Our baseline analysis of the Anne Arundel Housing Authority represents 200 low-rise dwelling units distributed among 30 buildings. Constructed in 1971, this project has individual gas space-heating and centralized gas water heating.

Space heating, water heating, and cooking are included in our analysis. Normalized annual consumption in 1980 was 116 MBtu/ft^2.

The Authority retrofitted with storm windows and check-metering in 1983. In March 1982, under HUD's innovative energy grant program, the Authority installed 202 high-efficiency gas furnaces. Tenants reported increased comfort levels after the retrofit.

ASBURY PARK HOUSING AUTHORITY[2,3]

ASB001G-ASB002G: Asbury Park, NJ

* * *

Our data for the Asbury Park Housing Authority represents 186 apartment units (14 buildings) in two projects, one constructed in 1941 and the other in 1963. The high-rise project is occupied by seniors and the low-rise by families. Both space heat and domestic hot water are generated centrally. At these two projects, domestic hot water consumption is responsible for 20-25% of annual gas consumption.

Mean baseline energy use was 275 kBtu/ft^2 during the 1980-1982 period. For both projects we included cooking fuel in the analysis.

In 1979, the Authority replaced deteriorating underground steam distribution piping. In late 1981 they installed new zone controls for the steam distribution system and a separate "front-end" boiler for generating summer domestic hot water at Lumley Homes. This retrofit resulted in a decrease in summertime gas consumption, but total energy use did not change after these retrofits. In 1983, storm windows and new steam traps were installed and a series of no-cost changes in the operation of the heating plant were implemented. The second retrofit yielded a 40% decrease in consumption and a two-year payback time.

ATLANTIC CITY HOUSING AUTHORITY[4]

ATC001G-ATC002G: Atlantic City, NJ

* * *

The two one-building Atlantic City Housing Authority projects were constructed in 1970 and are occupied by seniors. Space heating and domestic hot water is provided to 346 high-rise apartments by central gas boilers.

We analyzed 1980 gas consumption for all end-uses (including cooking) and found mean normalized annual consumption to be very low for this climate—77 kBtu/ft^2.

BOSTON HOUSING AUTHORITY[5]

BOS001O: Boston, MA

* * *

We analyzed a single 82-unit building operated by the Boston Housing Authority. Constructed in 1959, this high-rise senior project has centralized oil space and domestic-hot-water heating systems. The monthly consumption data for this building was of especially high quality; the building maintenance personnel record "dip-stick" readings of storage tank oil levels on a daily basis, allowing more accurate determination of when consumption takes place (normally the only record of oil consumption is delivery dates that do not necessarily correspond to consumption periods). In 1983, normalized annual consumption was 266 kBtu/ft^2.

We analyzed data for space heating and hot water consumption, including hot water for the common laundry and oil for incineration.

The Authority reports that this building has the highest level of energy consumption of the 20 buildings they operate. Within this PHA, electric stoves are known to be used for supplementary space heating, radiator controls in many apartments are frozen, and tenants often use auxiliary electric space heaters. This is one of the few PHAs we contacted that has designated a staff person to focus solely on energy management.

COLUMBUS HOUSING AUTHORITY[6]

COL001G: Columbus, GA

* * *

Our analysis of Columbus Housing Authority represents a 51-building low-rise housing project with 579 apartments. This is the oldest project in our data base, built in 1936, and is occupied by families and seniors. Individual room furnaces, hot water heaters, and ranges consume natural gas. The energy analysis for 1980 includes all end-uses of the gas.

Annual consumption is 107 kBtu/ft^2.

In 1980, the Authority installed 410 tankless water heaters through HUD's innovative energy grant program. Between 1979 and 1981, electronic ignition furnaces and ranges were installed, but we did not have sufficient data to examine consumption changes from these overlapping retrofits.

DENVER HOUSING AUTHORITY[7]

DEN001G-DEN010G: Denver, CO

* * *

We analyzed seven senior high-rise projects (954 apartments) in the Denver Housing Authority. The projects consist of one building each and range in vintage from 1968-1979, with the majority built during the late 1960s and early 1970s. Six buildings are centrally heated with gas; the remaining one has individual electric resistance heaters. Water heating is provided by central gas generators for the six buildings and individual electric heaters for the remaining one. Corridors are cooled with central air-conditioning, swamp coolers, or make-up air.

For the gas-heated buildings we include only space heat and hot water in our analysis. The average 1983 annual consumption for these buildings was 118 kBtu/ft^2. All end-uses (including air-conditioning) are represented in the all-electric building where energy use, weather-corrected with scaling analysis, was 68 kBtu/ft^2.

Retrofit activity occurring before our analysis period involved switching from individual to central water-heating boilers at all the projects. The Solar Energy Research Institute is studying the all-electric building, focusing on energy data acquisition techniques and interviews of tenants regarding energy conservation attitudes and patterns of energy use. Preliminary findings indicate that tenants open windows and corridor doors to induce the cool air into their apartments during summer and that electric resistance heating is also left on during the summer months in some senior apartments.

GREENEVILLE HOUSING AUTHORITY[8]

GRN001E: Greeneville, TN

* * *

We analyzed one 275-unit project at the Greeneville Housing Authority. These all-electric, single-family dwellings are occupied by seniors and families. Constructed in 1968, these homes have individual electric space heating and domestic hot water heating.

All end-uses are included in our analysis; 1978 results using degree-day scaling are 44 kBtu/ft^2.

In 1980, all the homes received storm windows, attic insulation, and weatherstripping, resulting in energy savings of 13%, and a payback time of seven years. Financing was provided in part with a low-interest loan from the Tennessee Valley Authority (TVA).

In 1981, these homes received passive solar retrofits with technical assistance from the TVA Solar Applications Branch and financing from the HUD innovative energy conservation grant program. The retrofits included movable window insulation, double-glazed sunspaces, and forced-air solar air heaters at costs ranging from $400 to $20,000/unit. Educational efforts were made after tenants failed to operate the solar systems correctly. As a package, the solar retrofits saved much less energy than was predicted and had extremely long payback times.

JERSEY CITY HOUSING AUTHORITY[9]

JCA001O-JCA009O: Jersey City, NJ

* * *

Our data from the Jersey City Housing Authority represents 48 low-rise and high-rise buildings distributed among seven projects constructed between 1941 and 1966, with most built in the 1940s and early 1950s. Both senior and family tenants occupy the 2,678 apartment units in our sample.

End-uses included in our analysis of consumption include oil for space and water heating and, in three of the projects, cooking gas. One project displayed substantial seasonality in wintertime gas use, indicating possible use of stoves for space heating (see Fig. 4). Mean normalized annual consumption was 185 kBtu/ft^2.

LOS ANGELES COUNTY HOUSING AUTHORITY[10]

LAS001E: W. Hollywood, CA

* * *

One of the few warm-climate projects in our data base is located in the Los Angeles County Housing Authority. We examined a 138 unit low-rise senior building constructed in 1976. Heating is provided with individual electric heaters; domestic hot water is generated with central gas boilers.

We weather-corrected gas and electric use for water heating, space heating, cooking, and summertime air-conditioning, using monthly heating and cooling degree-days. Total energy consumption was 64 kBtu/ft^2 in 1983.

The Authority participated, along with the San Francisco Housing Authority, in a California Energy Commission project to leverage private financing with energy conservation funding assistance. In an ongoing retrofit program, the authority relamps with efficient lighting fixtures as old lamps burn out (indoors: incandescent to fluorescent, outdoors: mercury to sodium vapor lamps). To date, 90% of the lamps have been replaced under the program. In late 1984, energy-efficient refrigerators were placed at no charge in all apartments by Southern California Edison as part of a utility program aimed at low-income customers.

NEWARK HOUSING AUTHORITY[11]

NEW002O-NEW007O: Newark, NJ

* * *

We analyzed central oil heating data for six Newark Housing Authority projects, representing 70 buildings constructed between 1939 and 1946. The projects are all low-rise and contain 2,312 family apartment units. Energy audits indicate that a large number of windows are left wide-open during cold winter days. Such observations suggest that heating controls inadequately regulate apartment temperatures. One project had *no* heating controls, the boiler operators simply shut down the boilers to regulate the heat. At other projects, control sensors are located in relatively cool hallways and near windows that are often left open.

Mean normalized annual energy consumption for space-heating and hot water was 162 kBtu/ft^2 in 1980.

In 1982, the Authority installed a computerized energy management system and replaced heating systems (new boilers, underground piping, control valves, and separate gas-fired hot water generators) in a 530-unit family complex. The energy management system alone produced savings of 14% and had a payback time of three years. However, the system did require extensive maintenance by a consultant to the Authority. (If the cost of a recommended, but not purchased, $25,000/year service contract is included, the discounted payback time would be six years.)

NEW YORK HOUSING AUTHORITY[12]

NYC001E-NCY0140: New York, NY

* * *

We analyzed 118 buildings in 12 New York City housing projects, with 10-15 buildings per project. Most buildings were constructed during the late 1940s and 1950s. These 11,140 apartments are located predominantly in high-rise buildings and are all family-occupied. Space heating and domestic hot water heating are supplied from centralized oil-fired heating equipment.

Mean weather-normalized space-heating and domestic hot water energy consumption was 124 kBtu/ft^2 in 1978.

NYCHA is by far the largest authority in the country, with over 500,000 tenants and energy bills in excess of $200 million in 1982. It is also one of the most active in controlling energy costs. During the winter of 1976-77, the Authority initiated a program to determine the energy savings potential for non-electric thermostatic radiator valves (TRV) in single-zone steam heated buildings. Tenants reported increased levels of comfort; energy savings were close to 7%. The Authority also has an ongoing policy of replacing steel casement windows with double-hung, double-glazed thermal break aluminum windows for both fuel and maintenance cost savings. In nine projects, savings were roughly 18% with a 15-year simple payback time. The Authority estimates that the retrofit reduced operation and maintenance costs (through decreased painting and glass breakage) by $30/dwelling annually, lowering the discounted payback time to 11 years. Incandescent hall and stairwell lights have been replaced with 20-Watt fluorescent fixtures in 13 buildings. In the one building we analyzed, annual lighting savings were 62% and the payback time was 1.4 years, despite the initial cost of $50 per fixture. (This project is not included in the baseline analysis because heating energy data were not available.) Maintenance costs were reduced substantially due to decreased lamp replacement. In addition to these "hardware" retrofits, the Authority has conducted ongoing energy consumption monitoring and energy audits since 1974, while maintaining computerized records of historical consumption in all their projects.

NORTH LAS VEGAS HOUSING AUTHORITY[13]

VEG001G: Las Vegas, NV

* * *

We analyzed space heating and domestic hot water heating utility data for two buildings in a North Las Vegas Housing Authority project. The low-rise buildings were constructed in 1972 and house 120 senior tenants. All apartments generate their space heating and domestic hot water with individual gas appliances. The PHA has participated in a state-wide monitoring program; the State Office of Community Services tracks energy use and provides feedback to building managers.

In 1980, energy use in these buildings was 71 kBtu/ft^2.

Currently, the Authority is receiving $2.5 million in Comprehensive Improvement Assistant Program (CIAP) funds to replace existing swamp coolers with more efficient, and more comfortable, two-stage evaporative coolers. In senior buildings existing air-conditioners will be replaced with high-efficiency units. Other planned retrofits include: relamping incandescent lighting with efficient, screw-in fluorescent lamps, changes from master to individual metering, and installing high-efficiency gas furnaces.

It was difficult to gather adequate utility data for this PHA. Many of the billing records compiled by the state were incomplete, representing only common areas. In cases where tenants pay their own bills, the Authority has no record of total consumption.

PHILADELPHIA HOUSING AUTHORITY[14]

PHL001G-PHL029G: Philadelphia, PA

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The Philadelphia Housing Authority represents a diverse mixture of building types, vintage, occupancy, and heating system characteristics. In all, we have data on 24 projects, one-quarter of which consist of high-rise buildings. Roughly half contain ten or less buildings; the remainder have an average of 50 buildings. The buildings in our sample were constructed between 1940 and 1973. Seniors occupy a third of the projects. Both centralized and individual water heating systems are used; gas and oil are common fuels for these end-uses. Many projects in Philadelphia consist of both centrally heated high-rise buildings and individually heated low-rises. We excluded these "mixed" projects from our analysis.

In most cases we included space heating, water heating, and cooking in our energy analysis. Mean normalized energy use for 1980 was 143 kBtu/ft^2.

Centralized, boiler-fed DHW systems may contribute to high energy use. At one project two 5,500-gallon storage tanks supply domestic hot water to 18 separate buildings. The hot water is generated by the main boilers, operated continuously through the summer months and must be circulated long distances through underground pipelines. Vacancy rates and vandalism may also contribute to unnecessary energy consumption. In some projects, large numbers of apartments are vacant, and doors and windows are often missing, yet boiler rooms continue to supply heat to these unoccupied rooms.

In 1981, the Authority replaced non-functional outdoor reset heating controls at their 886-unit Southwark Plaza project; savings of 9.1% resulted from the retrofit. They have implemented many other retrofits over the past ten years, including roof insulation, boiler replacement, vent dampers, and heating controls, but the staff was unable to provide us with sufficient information to analyze savings from any of these measures. Fourteen projects are now instrumented with remote heating system controls that enable maintenance personnel to adjust steam temperatures and invoke night-setbacks. The Authority has replaced 3,000 gas furnaces with pulse-combustion or conventional high-efficiency units. Efforts are underway to create a computerized energy consumption tracking system. Additional efforts have been delayed due to the discontinuation of CIAP funds for energy conservation.

During FY 1981, the PHA's total utility bill (including water) represented 43% of the Authority's operating expenses. The Authority has experimented with several strategies to encourage conservation, including tenant payment of bills, state funding of weatherization, and shared savings arrangements for heating system retrofits. Little detailed evaluation has been conducted to determine the energy savings resulting from these efforts.

PHILLIPSBURG HOUSING AUTHORITY[15]

PHP001G-PHP002G: Phillipsburg, NJ

* * *

We analyzed space heating, water heating, and cooking utility bills for 73 low-rise, mixed-occupancy buildings in the Phillipsburg Housing Authority. The two projects were constructed between 1942 and 1951 and together comprise 372 apartments. Space and domestic-hot-water heating are provided by central heating equipment at one project and individual heating equipment at the other. Gas is the only fuel.

Energy consumption for the 1978-1980 period averaged 138 kBtu/ft^2 per year.

The PHA's first retrofits date from the early oil crisis, led by switching to all-gas equipment. Decreased energy consumption due to retrofits has enabled the PHA to be financially "in the black" and to allocate additional money for non-energy improvements in their buildings. The two projects analyzed here were rehabilitated and retrofitted between 1980 and 1983. Extensive 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, as well as numerous other conservation measures (three inches of crawl space insulation, maximum set thermostats, boiler controls, new boiler valves). At Heckman Terrace, 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. Savings of 41% occurred at the Annex and 53% at the Terrace apartments. Because the rehab work was so expensive (over $12,000/apartment) payback times are very long (greater than 25 years) if evaluated solely as an energy conservation measure. In this case, it was impossible to separate energy-related costs from those of the general physical improvements.

The administration plans to install a $140,000 solar pre-heating system with funding assistance from the state and a local utility plus new tankless domestic-hot-water generators using local Community Action Program and state grant funds. The Authority recently contracted a private firm to conduct blower door tests and identify sources of leakage. Estimates indicate a significant savings potential from infiltration reduction retrofits.

RALEIGH HOUSING AUTHORITY[16]

NOC001E: Raleigh, NC

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We analyzed a 30-unit low-rise building in the Raleigh Housing Authority. The building was constructed in 1972 and houses both senior and family tenants.

Space heating and domestic hot water heating are supplied by electric units in each apartment. Electricity for cooking is also included in our analysis. Consumption for 1983, determined using heating degree-day scaling, is 49 kBtu/ft^2.

The Authority is currently carrying out an experiment to test an innovative retrofit financing strategy. PHAs ordinarily make payments in lieu of taxes (PILOT) to their local governments, proportional to their net rental income (typically 10%). The demonstration involves waiving the PILOT payments for a limited period so the funds may be invested in conservation. This benefits the local government by enabling the PHA to provide higher PILOT payments (because of reduced energy costs) in the future. Based on estimated savings, selected PHAs will install retrofits with their PILOT rebates; the local utilities will also contribute to the costs because of the potential load management benefits. The North Carolina Alternative Energy Corporation has designed one retrofit under the PILOT plan, in which they will offer training in conservation techniques to Raleigh and other participating housing authorities. The Authority is currently engaged in another AEC project that will attempt to correlate apartment characteristics with individually metered energy consumption using a predictive model. The model would be useful in identifying tenants with excessive consumption and estimating tenant allowances for energy costs.

RENO HOUSING AUTHORITY[17]

REN001G-REN003G Reno, NV

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Our analysis of the Reno Housing Authority encompasses three projects constructed between 1952 and 1965. The 116 low-rise buildings contain 400 dwelling units. Two projects house seniors and all of the projects have individual gas-fired space and water heating equipment.

We analyzed data tabulated by the State Office of Community Services. Mean 1980-81 energy use was 118 kBtu/ft^2.

The Authority has installed a substantial number of retrofits including caulking & weatherstripping, low-flow showerheads, hot water heater insulation, thermostat setback devices, attic insulation, and a window-quilt insulation system. A portion of the retrofits were funded with a grant from the State of Nevada. In 1986, attic insulation in the buildings will be raised from R-19 to R-32.

SAINT PAUL HOUSING AUTHORITY[18]

STP001M: Saint Paul, MN

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We studied a three-building, high-rise project in the Saint Paul Housing Authority, representing the most severe winter climate in our sample. Constructed in 1964, these buildings house 503 senior occupants and are provided space heating and domestic hot water from central gas-fired boilers with oil back-up.

Normalized annual energy consumption in 1978 was 158 kBtu/ft^2, calculated by scaling the weather-dependent portion of total consumption with monthly heating degree-days. The analysis included space heating, water heating, cooking, and lighting & appliances.

The Authority received a HUD innovative energy conservation grant in 1980 to install a computerized energy management system at this property. Many of the existing controls were linked to the new computer, whose main functions included issuing preventive maintenance orders, reducing electrical demand charges by minimizing peak usage, providing malfunction alarms, and lighting and temperature control in common areas. Preceding this retrofit the PHA had completed an extensive conservation program. Nonetheless, annual savings from the EMCS were roughly 18%, corresponding to a four and one-half year payback period.

SAN FRANCISCO HOUSING AUTHORITY[19]

SFN001G-SFN016G: San Francisco, CA

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The San Francisco Housing Authority is the western-most PHA in our data base. We have analyzed utility bills for 2,067 units in 212 buildings and 9 projects. The buildings are predominantly low-rise construction, dating from 1942 to 1979. Three projects consist of individual buildings; the remainder average 35 low-rise buildings per project. Four projects are occupied by seniors; five low-rise multi-building projects are family-occupied. Gas is the primary space and water heating fuel and both central and individual heating equipment can be found among these buildings.

We analyzed space heating, water heating, and cooking for the family apartments; cooking was not included for the senior projects. Mean 1981-1982 normalized energy consumption was 111 $kBtu/ft^2$.

Cooking is metered separately at two projects and accounts for a large fraction (19 to 29%) of total gas consumption. Seasonal gas cooking data displays strong weather-dependency, indicating that stoves and ovens may be used for wintertime space-heating (see Fig. 3). This may be partly explained by the presence of only a single radiator in two- and three-bedroom apartments.

Since the early 1980s, the Authority has engaged in a substantial amount of conservation activity and has arranged innovative financing for a number of these retrofits. Many apartments received attic insulation and no-cost/low-cost retrofits under the local utilities Zero-Interest Loan Program; savings at five projects retrofitted under this program averaged 13% with payback times under three years. Additional weatherization was financed by the utility through non-profit organizations. Assistance from the California Economic Opportunity Council and windfall tax monies has also been used by the Authority for weatherization. In late 1982, timeclocks were installed on 71 boiler plants. (A number of the timeclocks had to be disabled following tenant complaints of insufficient heat). Under the California PUC's Demonstration Solar Incentives Program, the Housing Authority installed third-party financed solar hot water heating systems in seven senior projects during late 1983. Additional collectors were placed at three family projects in mid-1985. The California Energy Commission made cash contributions to leverage private investment in the solar systems. Also in 1985, public area lighting retrofits were implemented at 18 senior projects. The Authority is currently testing the efficacy of providing cash incentives to tenants who conserve energy.

More retrofit work is being planned. A project currently in the design stage would place third-party financed boiler economizers on 30 boiler plants, where heat recovered from boiler flue gasses is sold to the Authority. Replacement of existing gas distribution system lines is also in the planning process and will involve individually metering 40 buildings to avert paying for line losses in old, corroded distribution lines owned by the utility. Although the Authority enters its monthly energy consumption and costs into a computer data base they currently do not perform any analysis of this data.

TRENTON HOUSING AUTHORITY[20]

TRN001O-TRN010O: Trenton, NJ

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Our Trenton Housing Authority sample contains 1,683 apartments distributed among 79 buildings in nine projects. The predominantly low-rise buildings were constructed between 1939 and 1965 and are occupied predominantly by families. As is common for the Northeast, central oil-fired boilers provide both space heating and domestic hot water. In 1985, five projects were converted from oil to gas domestic hot water.

We analyzed utility bills that included space heating, domestic hot water, and in some cases, cooking fuels. Mean normalized annual consumption during the 1979-1981 period was 243 $kBtu/ft^2$.

Anecdotal evidence suggests that public housing tenants sometimes provide some wintertime space heating with their stovetop burners and ranges. Two Trenton projects exhibit this trend very strongly (see Fig. 3).

The Authority received a HUD innovative energy conservation demonstration grant to install a temperature control system in Page Homes. Savings of 44% were achieved and the payback time was less than one year. In 1981, heating control retrofits were installed in Donnelly Homes; resulting energy savings were 17%. Three other properties also received heating system retrofits (new controls and new boilers) in buildings whose original controls were no longer functional. First year savings ranged from 5-29%, although energy use crept up toward pre-retrofit levels 2-3 years after these heating retrofits were installed. Boilers and domestic-hot-water generators with 32 Hydropulse condensing-pulse combustion boilers with efficiencies of greater than 90% were installed at Haverstick Homes. Energy savings of roughly 50% occurred, yielding a simple payback time of 0.7 years (based on the incremental cost of the high-efficiency system over replacement with ordinary boilers).

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APPENDIX B: Public Housing Baseline Database

These tables contain results from the analysis of 91 projects at nineteen U.S. housing authorities. The following terms and abbreviations are used in the tables:

TABLE I

Label:	The first three letters in each label stand for the PHA; followed by three numbers which uniquely identify the project; the final letter represents the primary space heating fuel. 'E'=electricity, 'G'=natural gas, 'M'=mixed, 'O'=oil.
HUD Class:	Code used in the Ehrenkrantz study to identify building climate and construction characteristics. First number indicates climate zone: 1 = 0 - 2000 HDD (base 65°F), 2 = 2000 - 4000 HDD, 3 = 4000 - 6000 HDD, 4 = 6000 - 8000 HDD, 5 = 8000 + HDD; remaining columns indicate H=high-rise, L=low-rise, C=central space heating, S=individual space heating, E=electricity used for space heat, G=gas for space heat, O=oil for space heat.
Units:	Number of apartments per project.
Number of Bldgs.:	Number of buildings per project.
Meter Type:	'IM'=individually metered, 'MM'=master-metered.
Type of Tenant:	'FM'=family, 'MX'=mixed, 'SN'=senior.
Wall Material:	'BR'=brick, 'CB'=concrete block, 'FR'=frame, 'MA'=masonry.
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:	'AIR'=forced air, 'HYD'=hydronic (hot water), 'DPS'=double-pipe steam, 'SPS'=single-pipe steam.
Domestic Hot Water (DHW) Type:	'B'=building, 'C'=central, 'G'=group (one boiler room for a number of buildings but not a whole project), 'I'=individual.

TABLE II

Average Floor Area:	Average floor area per apartment, in square feet.
HDD:	Long-term average heating degree-days, base 65°F.
Analysis Method:	'R'=regression (PRISM) with variable reference temperature, 'S'=scaling of space heat data by annual or monthly degree-days.

Fall of Heating Season:	Year in which energy data begins (typically collected over a heating season).
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=139 Btu/gallon, #4 oil=145 kBtu/gallon, #6 oil=150 kBtu/gallon, gas=102 kBtu/ccf=100 kBtu/therm.
NAC:	Weather-normalized annual consumption for projects analyzed using PRISM, for the end-uses specified in the 'End Uses NAC' field.
End Uses NAC:	'F'=all end uses of space heat fuel including cooking, 'W'=space heat and hot water only.
Total Fuel Use:	Weather-normalized annual consumption for projects analyzed by scaling method, for the end-uses specified in the 'End Uses Total Fuel' field.
End Uses Total Fuel:	'F'=all end uses of space heat fuel including cooking, 'W'=space heat and hot water only.
Total Electricity Use:	Total electricity use for lights and appliances (including electric ranges where applicable); if fuel type in label is 'E', electricity used for space heat and domestic hot water also included here.
Cooking Use:	Fuel used for cooking only.
Local Oil Price :	Oil price as of mid-1985, in $/MBtu.
Local Gas Price :	Gas price as of mid-1985, in $/MBtu.
Local Electricity Price :	Electricity price as of mid-1985, in $/kWh.

Table B-1. Physical Characteristics of Projects in the LBL Data Base.

LABEL	HUD CLASS	LOCATION		YEAR BUILT	UNITS	NO. OF BLDGS	NO. OF FLOORS	METER TYPE	TYPE OF TENANT	WALL MATERIAL	HEAT SYSTEM TYPE	HEAT DIST. TYPE	DHW TYPE
AAC001G	3LSG	SEVERN	MD	1971	200	30	3	MM	FM	BR	I	AIR	B
ASB001G	3HCG	ASBURY PARK	NJ	1963	60	2	6	MM	SN	CB	C	SPS	C
ASB002G	3LCG	ASBURY PARK	NJ	1941	126	12	2	MM	FM	BR	C	DPS	C
ATC001G	3HCG	ATLANTIC CITY	NJ	1970	190	1	5	MM	SN	MA	C	HYD	
ATC002G	3HCG	ATLANTIC CITY	NJ	1970	156	1	5	MM	SN	MA	C	HYD	
BOS001O	3HCO	BOSTON	MA	1959	82	1	6	IM	SN	MA	B	SPS	B
COL001G	2LSG	COLUMBUS	GA	1936	579	51	2	MM	MX	MA	I	AIR	I
DEN001G	4HCG	DENVER	CO	1971	100	1	9	MM	SN	MA	B	HYD	B
DEN002G	4HCG	DENVER	CO	1976	200	1	9	MM	SN	MA	B	HYD	B
DEN003E	4HSE	DENVER	CO	1979	100	1	10	MM	SN	MA	I	HYD	B
DEN004G	4HCG	DENVER	CO	1979	154	1	9	MM	SN	MA	B	HYD	B
DEN006G	4HCG	DENVER	CO	1967	250	1	9	MM	SN	MA	B	HYD	B
DEN008G	4HCG	DENVER	CO	1968	50	1	9	MM	SN	MA	B	HYD	B
DEN009G	4HCG	DENVER	CO	1968	100	1	9	MM	SN	MA	B	HYD	B
GRN001E	2LSE	GREENEVILLE	TN	1968	275	275		IM	MX	BR	I	AIR	
JCA001O	3LCO	JERSEY CITY	NJ	1944	222	6	3	MM	MX	MA	C	SPS	C
JCA002O	3LCO	JERSEY CITY	NJ	1949	314	9	3	MM	MX	MA	C	SPS	C
JCA004O	3LCO	JERSEY CITY	NJ	1941	490	13	3	MM	MX	MA	C	SPS	C
JCA005O	3HCO	JERSEY CITY	NJ	1966	286	2	12	MM	SN	MA	B	SPS	B
JCA006O	3HCO	JERSEY CITY	NJ	1959	712	7	12	MM	FM	MA	C	SPS	C
JCA008O	3HCO	JERSEY CITY	NJ	1953	462	6	10	MM	MX	MA	C	SPS	C
JCA009O	3LCO	JERSEY CITY	NJ	1944	192	5	3	MM	MX	MA	C	SPS	C
LAS001E	1LSE	W. HOLLYWOOD	CA	1976	138	1	3	MM	SN	FR	I		B
NEW002O	3LCO	NEWARK	NJ	1940	236	4	3	MM	FM	BR	C	SPS	
NEW003O	3LCO	NEWARK	NJ	1939	530	12	3	MM	FM	BR	C	DPS	C
NEW004O	3LCO	NEWARK	NJ	1942	401	12	3	MM	FM	BR	B	HYD	
NEW005O	3LCO	NEWARK	NJ	1946	275	11	3	MM	FM	BR	C	SPS	
NEW006O	3LCO	NEWARK	NJ	1941	301	10	3	MM	FM	BR	C	SPS	
NEW007O	3LCO	NEWARK	NJ	1941	569	21	3	MM	FM	MA	C	SPS	
NOC001E	2LSE	RALEIGH	NC	1972	30	11		MM	MX	BR	I		I
NYC002O	3LCO	NEW YORK	NY	1952	42	1	3	MM	FM	MA	C	SPS	
NYC004O	3HCO	NEW YORK	NY	1958	56	1	7	MM	FM	MA	C	SPS	
NYC005O	3HCO	NEW YORK	NY	1968	81	1	14	MM	FM	MA	C	SPS	
NYC006O	3HCO	NEW YORK	NY	1948	1338	27	6	MM	FM	MA	C	SPS	C
NYC007O	3HCO	NEW YORK	NY	1950	1791	15	13	MM	FM	MA	C	SPS	C
NYC008O	3HCO	NEW YORK	NY	1948	1310	10	14	MM	FM	MA	C	SPS	C
NYC009O	3HCO	NEW YORK	NY	1955	1444	15	7	MM	FM	MA	C	SPS	C
NYC010O	3HCO	NEW YORK	NY	1950	1229	9	14	MM	FM	MA	C	SPS	C
NYC011O	3HCO	NEW YORK	NY	1948	1084	13	13	MM	FM	MA	C	SPS	C
NYC012O	3HCO	NEW YORK	NY	1958	1246	13	15	MM	FM	MA	C	SPS	C
NYC013O	3HCO	NEW YORK	NY	1951	786	7	15	MM	FM	MA	C	SPS	C
NYC014O	3HCO	NEW YORK	NY	1950	733	6	14	MM	FM	MA	C	SPS	C
PHL001G	3LSG	PHILADELPHIA	PA	1942	500	41	3	MM	FM	MA	I	AIR	B
PHL002O	3HCO	PHILADELPHIA	PA	1963	886	30	25	MM	MX	MA	C	SPS	C
PHL003G	3LSG	PHILADELPHIA	PA	1942	700	71	3	MM	FM	MA	I	AIR	I
PHL004G	3LSG	PHILADELPHIA	PA	1952	77	9	3	MM	FM	MA	I	AIR	I
PHL005G	3LSG	PHILADELPHIA	PA	1960	102	11	3	MM	FM	MA	I	AIR	I
PHL006G	3LCG	PHILADELPHIA	PA	1969	54	4	2	MM	SN	MA	C	HYD	C
PHL007O	3HCO	PHILADELPHIA	PA	1970	175	1		MM	SN	MA	C	SPS	C
PHL008G	3HCG	PHILADELPHIA	PA	1973	220	1	8	MM	SN	MA	C	HYD	
PHL009G	3LSG	PHILADELPHIA	PA	1959	150	14	3	MM	FM	MA	I	AIR	C

Table B-1 (continued).

PHL010G	3LSG	PHILADELPHIA	PA	1959	24	3		MM	FM	MA	I	AIR	
PHL011G	3LCG	PHILADELPHIA	PA	1967	84	23		MM	SN	MA	C	HYD	C
PHL012O	3HCO	PHILADELPHIA	PA	1960	153	1	18	MM	FM	MA	C	HYD	C
PHL014G	3LSG	PHILADELPHIA	PA	1942	200	25		MM	FM	MA	I	AIR	
PHL015G	3LSG	PHILADELPHIA	PA	1961	22	3	2	MM	SN	MA	I	AIR	I
PHL016G	3LCG	PHILADELPHIA	PA	1966	46	4	3	MM	FM	MA	C	AIR	C
PHL017G	3LSG	PHILADELPHIA	PA	1966	177	75	3	MM	FM	MA	I	AIR	C
PHL018G	3LCG	PHILADELPHIA	PA	1971	71	1	4	MM	SN	MA	C	HYD	C
PHL019G	3LCG	PHILADELPHIA	PA	1971	72	5	2	MM	SN	MA	C	HYD	C
PHL021G	3LCG	PHILADELPHIA	PA	1955	203	22	3	MM	FM	MA	C	HYD	
PHL024G	3LCG	PHILADELPHIA	PA	1941	1324	53	4	MM	FM	MA	G	HYD	G
PHL026G	3LCG	PHILADELPHIA	PA	1940	589	62	3	MM	FM	MA	G	HYD	C
PHL027O	3HCO	PHILADELPHIA	PA	1960	576	4	13	MM	FM	MA	G	SPS	G
PHL028O	3LCO	PHILADELPHIA	PA	1955	464	58	2	MM	MX	MA	C	HYD	C
PHL029G	3LSG	PHILADELPHIA	PA	1942	994	155	3	MM	FM	MA	I	AIR	I
PHP001G	3LCG	PHILLIPSBURG	NJ	1951	150	24	2	MM	FM	BR	C	HYD	C
PHP002G	3LSG	PHILLIPSBURG	NJ	1942	222	49	2	MM	MX	MA	I	AIR	I
REN001G	4LSG	RENO	NV	1952	150	75	1	CM	FM	FR	I	AIR	I
REN002G	4LSG	RENO	NV	1965	150	16	1	CM	SN	FR	B	AIR	B
REN003G	4LSG	RENO	NV	1963	100	25	1	CM	SN	CB	I	AIR	I
SFN001G	2LSG	SAN FRANCISCO	CA	1942	772	91	2	MM	FM	CB	I	AIR	I
SFN002G	2LCG	SAN FRANCISCO	CA	1942	469	38	3	MM	FM	CB	C	HYD	G
SFN004G	2LCG	SAN FRANCISCO	CA	1962	258	41	2	MM	FM	FR	C	HYD	C
SFN005G	2LSG	SAN FRANCISCO	CA	1956	158	24	2	MM	FM	FR	I	AIR	I
SFN006G	2LCG	SAN FRANCISCO	CA	1963	170	10	2	MM	FM	FR	C	HYD	C
SFN011G	2HCG	SAN FRANCISCO	CA	1970	107	5	5	MM	SN	CB	C	HYD	C
SFN013G	2LCG	SAN FRANCISCO	CA	1971	22	1	3	MM	SN	FR	C	HYD	
SFN015G	2HCG	SAN FRANCISCO	CA	1973	75	1	5	MM	SN	MA	C	HYD	
SFN016G	2LCG	SAN FRANCISCO	CA	1979	36	1	4	MM	SN	FR	C	HYD	
STP001M	5HCG	ST. PAUL	MN	1964	503	3		MM	SN	BR	B	HYD	B
TRN001O	3LCO	TRENTON	NJ	1939	118	8	3	MM	FM	MA	C	DPS	C
TRN002O	3LCO	TRENTON	NJ	1954	112	14	2	MM	FM	MA	C	HYD	C
TRN003O	3LCO	TRENTON	NJ	1954	159	3	3	MM	FM	MA	C	HYD	C
TRN004O	3LCO	TRENTON	NJ	1939	376	21	3	MM	FM	MA	C	DPS	C
TRN005O	3LCO	TRENTON	NJ	1953	102	5	3	MM	FM	MA	C	DPS	C
TRN006O	3LCO	TRENTON	NJ	1953	81	5	3	MM	FM	MA	C	DPS	C
TRN007O	3LCO	TRENTON	NJ	1954	219	9	3	MM	FM	MA	C	DPS	C
TRN008O	3HCO	TRENTON	NJ	1964	256	12	9	MM	FM	MA	C	HYD	C
TRN010O	3HCO	TRENTON	NJ	1965	260	2	9	MM	SN	MA	C	DPS	C
VEG001G	2LSG	N. LAS VEGAS	NV	1972	120	2	3	MM	SN	FR	I	AIR	I

Table B-2. Energy Use of Projects in the LBL Data Base.

LABEL	AVG. FLOOR AREA (SQ.FT)	HDD (F)	ANALYSIS METHOD	FALL OF HEATING SEASON	NORM. ANNUAL CONSUMP (MBTU OR KWH)	END USES NAC	TOTAL FUEL USE (MBTU)	END USES TOTAL FUEL	TOTAL ELEC. USE (KWH)	COOKING USE (MBTU)	LOCAL OIL PRICE ($/MBTU)	LOCAL GAS PRICE ($/MBTU)	LOCAL ELEC. PRICE ($/KWH)
AAC001G	902	4706	R	80	104.8	F						6.180	00.074
ASB001G	555	5162	R	80	107.8	F						5.600	
ASB002G	602	5162	R	82	214.4	F						5.600	
ATC001G	593	5086	R	80	50.1	F			4577.4		5.981	6.484	00.088
ATC002G	739	5086	R	80	51.3	F			4302.1		5.981	6.484	00.088
BOS001O	505	5593	R	83	134.3	W					5.306		00.090
COL001G	526	2356	R	80	56.3	F						1.516	
DEN001G	600	6014	R	83	56.9	W			5217.7			3.412	00.050
DEN002G	600	6014	R	83	77.3	W			4896.9			3.412	00.050
DEN003E	600	6014	R	83					11874.3			3.412	00.050
DEN004G	600	6014	R	83	53.2	W			5048.0			3.412	00.050
DEN006G	600	6014	R	83	51.2	W			3364.4			3.412	00.050
DEN008G	600	6014	R	83	91.9	W			6869.0			3.412	00.050
DEN009G	600	6014	R	83	96.3	W			5558.6			3.412	00.050
GRN001E	800	3935	S	78					10262.0				00.045
JCA001O	504	5285	R	80	83.0	W			3451.0	6.2	3.039	5.670	00.070
JCA002O	482	5285	R	80	158.1	F			4982.8	13.5	3.039	5.670	00.070
JCA004O	544	5285	R	80	130.6	F			4373.3	13.3	3.039	5.670	00.070
JCA005O		5285	R	80	81.9	W			4268.0		3.039	6.940	00.070
JCA006O		5285	R	80	145.8	F			8229.6	21.9	3.039	5.670	00.070
JCA008O	938	5285	R	80	134.8	W			8384.4	14.8	3.039	5.670	00.070
JCA009O		5285	R	80	102.2	W			4269.7	9.3	3.039	5.670	00.070
LAS001E	695	1204	S	83					13067.7			3.535	00.084
NEW002O	714	4972	R	80	119.0	W					5.166	5.282	00.079
NEW003O	738	4972	R	80	163.5	W					5.166	5.282	00.079
NEW004O	900	4972	R	79	133.0	W					5.166	5.282	00.079
NEW005O	1555	4972	R	79	141.7	W					5.166	5.282	00.079
NEW006O	1194	4972	R	80	122.6	W					5.166	5.282	00.079
NEW007O	824	4972	R	80	131.9	W					5.166	5.282	00.079
NOC001E		3531	R	83					11377.6				00.080
NYC002O	890	4800	S	76			148.8	W			3.236	5.253	00.076
NYC004O	830	4800	S	76			65.7	W			2.732	5.253	00.076
NYC005O	920	4800	S	76			75.1	W			2.732	5.253	00.076
NYC006O	775	4800	S	78			90.2	W			3.236	5.253	00.076
NYC007O	810	4800	S	78			103.7	W			2.732	5.253	00.076
NYC008O	810	4800	S	78			95.3	W			2.732	5.253	00.076
NYC009O	850	4800	S	78			91.2	W			2.732	5.253	00.076
NYC010O	840	4800	S	78			106.1	W			2.732	5.253	00.076
NYC011O	760	4800	S	78			97.6	W			3.236	5.253	00.076
NYC012O	825	4800	S	78			85.2	W			2.732	5.253	00.076
NYC013O	845	4800	S	78			88.9	W			2.732	5.253	00.076
NYC014O	850	4800	S	78			88.5	W			2.732	5.253	00.076
PHL001G	789	4947	R	80	106.5	F			4603.0		5.216	6.433	00.073
PHL002O	1003	4947	R	80	209.2	W			6216.1	21.2	5.216	6.433	00.073
PHL003G	890	4947	R	80	103.7	F			4905.9		5.216	6.433	00.073
PHL004G	852	4947	R	80	118.7	F			4788.8		5.216	6.433	00.073
PHL005G	1058	4947	R	80	113.0	F			5431.1		5.216	6.433	00.073
PHL006G	595	4947	R	80	84.8	F					5.216	6.433	00.073
PHL007O	681	4947	R	81	84.0	F					5.216	6.433	00.073

Table B-2 (continued).

PHL008G	545	4947	R	80	60.7 F		5097.6		5.216	6.433	00.073
PHL009G	992	4947	R	80	123.9 F		5740.9		5.216	6.433	00.073
PHL010G	631	4947	R	80	71.2 F				5.216	6.433	00.073
PHL011G	695	4947	R	80	86.7 F		5069.2		5.216	6.433	00.073
PHL012O	882	4947	R	81	102.1 W		5506.0	22.7	5.216	6.433	00.073
PHL014G	930	4947	R	80	103.8 F		5403.2		5.216	6.433	00.073
PHL015G	449	4947	R	80	61.4 F				5.216	6.433	00.073
PHL016G	744	4947	R	80	217.7 F		10118.8		5.216	6.433	00.073
PHL017G	1000	4947	R	81	108.0 F				5.216	6.433	00.073
PHL018G	548	4947	R	80	58.7 F				5.216	6.433	00.073
PHL019G	478	4947	R	80	72.7 F		3344.2		5.216	6.433	00.073
PHL021G	919	4947	R	80	162.6 F		5914.3		5.216	6.433	00.073
PHL024G	746	4947	R	80	127.0 F		4952.8		5.216	6.433	00.073
PHL026G	664	4947	R	80	103.6 F				5.216	6.433	00.073
PHL027O	970	4947	R	80	159.4 W		4630.9	14.5	5.216	6.433	00.073
PHL028O	931	4947	R	80	165.2 W		6511.8	10.5	5.216	6.433	00.073
PHL029G	958	4947	R	80	111.5 F		4542.4		5.216	6.433	00.073
PHP001G	938	4972	R	80	166.2 F		3582.3			6.200	00.078
PHP002G	1295	4972	R	78	127.3 F				3.039	6.200	00.078
REN001G	725	6030	R	80	87.4 F					5.638	00.086
REN002G	545	6030	R	81	58.2 W		1571.0			5.638	00.086
REN003G	511	6030	R	80	65.0 W					5.638	00.086
SFN001G	863	3161	R	81	93.2 F					4.990	00.076
SFN002G	828	3161	R	81	134.7 F			32.3		4.990	00.076
SFN004G	836	3161	R	81	164.1 F					4.990	00.076
SFN005G	870	3161	R	81	86.6 F					4.990	00.076
SFN006G	1406	3161	R	81	79.4 F			15.5		4.990	00.076
SFN011G	554	3161	R	82	58.8 W					4.990	00.076
SFN013G	619	3161	R	82	32.9 W					4.990	00.076
SFN015G	587	3161	R	82	59.5 W					4.990	00.076
SFN016G	503	3161	R	82	57.1 W					4.990	00.076
STP001M	410	8159	S	78		64.8 F			5.896		00.050
TRN001O	625	4952	R	80	142.5 F		5201.0	9.4	5.932	6.664	00.087
TRN002O	862	4952	R	81	184.4 F			14.6	5.932	6.664	00.087
TRN003O	830	4952	S	80		113.8 W			5.932	6.664	00.087
TRN004O	570	4952	R	79	152.5 F			9.3	5.932	6.664	00.087
TRN005O	605	4952	R	79	187.5 W				5.932	6.664	00.087
TRN006O	621	4952	R	79	198.6 W				5.932	6.664	00.087
TRN007O	652	4952	R	79	181.7 W			14.5	5.932	6.664	00.087
TRN008O	579	4952	R	80	149.0 F		7220.9	15.7	5.932	6.664	00.087
TRN010O	531	4952	R	80	93.7 F		3892.6	5.6	5.932	6.664	00.087
VEG001G	574	2532	R	80	40.5 W					4.600	00.085

APPENDIX C: Comparison of LBL Selected Projects with the Public Housing Stock

We segmented the 91 projects in this study using a a matrix developed in the Ehrenkrantz study of the public housing stock. Projects are classified by construction type, heating system equipment, and fuel type among five climate zones (see Table C-1). Of the 60 possible cells in such a matrix, 24 contain more than 1% of the existing public housing projects. The projects in this study encompass 15 of these 24 cells. Low- and high-rise projects with oil-fired central heating systems in climate zone 3 (4-6000 HDD ^{o}F) represent a much larger fractions of our sample (20 and 23% respectively) than their composition in the overall stock (3 and 4%).

Table C-1. Percentage of U.S. public housing stock and LBL projects by climate zone and building type.

	HUD Climate Zones					
Building Type	1 (0-2000 HDD)	2 (2-4000)	3 (4-6000)	4 (6-8000)	5 (>8000)	Total
	Stock* (LBL)	Stock (LBL)	Stock (LBL)	Stock (LBL)	Stock (LBL)	Stock (LBL)
Low-rise, Sh, Oil†	**	**	1 (0)	**	**	1 (0)
Low-rise, Sh, Gas	14 (0)	21 (4)	13 (13)	2 (3)	1 (0)	51 (20)
Low-rise, Sh, Elect.	2 (1)	3 (2)	4 (0)	**	**	9 (3)
Low-rise, Ch, Oil	**	**	3 (20)	2 (0)	**	5 (20)
Low-rise, Ch, Gas	**	2 (6)	4 (9)	3 (0)	**	9 (15)
High-rise, Sh, Elect.	**	**	1 (0)	1 (1)	**	2 (1)
High-rise, Ch, Oil	**	**	4 (23)	2 (0)	**	6 (23)
High-rise, Ch, Gas	**	2 (3)	6 (5)	5 (7)	2 (1)	15 (16)
Total	16 (1)	28 (15)	36 (70)	15 (11)	3 (1)	

* Perkins and 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. 159.

† Sh = Individual space heating systems, Ch = Central space heating systems

** These cells represent less than one percent of the existing public housing projects.

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