Multifamily Retrofit Conservation Programs:

Longitudinal Impact Evaluation

Debra-Laurent O. Tachibana

July 1999

Evaluation Unit
Energy Management Services Division

Seattle City Light

Copyright © 1999 (July) by Seattle City Light

Prepared by the City of Seattle – City Light Department,
Energy Management Services Division, Evaluation Unit,
700 Fifth Avenue, Suite 3100, Seattle, Washington 98104-5031
Telephone: (206) 684-3209 / Fax: (206) 684-3385

Printed on recycled paper

Seattle City Light

- The lowest cost, most reliable electricity in urban America
- Publicly owned
- Stewards of our environment

The Energy Management Services Division

- Bringing energy efficiency into every home and business in Seattle

Efficiency Services… Enhancing Our Future

Table of Contents

List of Tables & Figures

Tables

Figures

List of Terms

Building	Multifamily residential building containing five or more tenancy units
BPA	Bonneville Power Administration (federal power authority in the Pacific Northwest region)
Btu	British thermal unit (3,413 Btu per kilowatt-hour)
Common Area	The building aggregate of commercial rate house-meter data, representing the non-rentable, public portions of the building and grounds
Conversion	Window receiving new double-glazed glass units into an existing frame
DHHS	Seattle Department of Housing and Human Services (formerly DHR, Department of Human Resources)
Dwelling Area	The building aggregate of residential-rate tenant unit-meter data, representing the rentable, private portions of the building
HDD	Heating degree-days, usually from a base temperature of 65º Fahrenheit
House Meter	Commercial rate meter, typically between zero and three per building
kWh	Kilowatt-hour (1,000 Watt-hours)
Impact	Outcome of a conservation program, such as acquired energy savings
Longitudinal	Observations occurring over several time intervals after an intervention
Measure	New or replacement high-efficiency materials sponsored by a conservation program
MWh	Megawatt-hour (1,000 kilowatt-hours)
NAC	Normalized Annual Consumption; annual electricity use adjusted to a normal meteorological year, based on (30-year) average temperature conditions
Replacement	Window receiving a new frame or sash as well as new double-glazed glass units
Retrofit	Installation of new or replacement high-efficiency materials into an existing building structure (as opposed to new construction), such as new or added insulation, low U-factor windows, or low-gpm showerheads (gallons per minute)
R-value	Thermal resistance; the insulation value of individual building materials (inverse of U-value)
SCL	Seattle City Light Department
Tenant Unit	Residential apartment or condominium in a multifamily building
U-factor	Coefficient of heat transmission through a building structure, expressed in Btu/hour/ºF per square foot, also known as U-value (inverse of R-value)
Unit Meter	Residential rate meter, typically one or two per residential unit

Acknowledgments

This project was initiated in 1993 with development of an evaluation plan; the emergent design subsequently underwent revision throughout 1994-1996 as the evaluator interacted with program staff and supporting consultants. The treatment and control groups were developed in 1994, along with the initial annualized consumption data sets; data analysis proceeded in early 1995. New monthly consumption data sets were generated for the same groups in mid-1995 and subjected to extensive cleaning efforts to remedy problems observed in the initial analyses. A survey was fielded at the end of 1995, and analysis continued on throughout 1996. Completion of this report was deferred while evaluation resources were bent upon the multifamily new construction program, Super Good Cents, and later upon a Customer Service Measures evaluation for the Multifamily Conservation Programs. At long last this longitudinal impact analysis sees the light of day, bringing to fruition the efforts of numerous individuals.

The following program operators, planners, and support staff have assisted the program evaluator. They helped to develop data, review designs, and discuss intermediate work products during this five-year project: Chris Akey, Glenn Atwood, Beverly Corwin, Jim Evans, Lois Fulwider, Patricia Gibbons, Ken Katayama, Steve Lush, Daniel McLaughlin, Rodolfo Mendoza, Eugenia Morita, Richard Opara, Jean Shaffer, Terry Takeuchi, Marilou Trias, and probably a few more.

Three consulting firms also helped develop data for this evaluation: HBRS, Inc. / Hagler Bailly Consulting (Madison, Wisconsin), BRACO Services, Inc. (Seattle, Washington), and Regional Economic Research, Inc. (San Diego, California).

Executive Summary

A *longitudinal study* deals with "the growth and change of an individual or group over a period of years" (WEBSTER'S NEW COLLEGE DICTIONARY). A *program impact evaluation* focuses on outcome measures, such as energy savings from buildings treated by the program, to provide accountability. This longitudinal impact evaluation of the Multifamily Conservation Programs funded by Seattle City Light is designed to measure the changes in energy use among participating customer groups, as compared to non-participating customers. The study design maximizes the validity of impact results by including a large proportion of customers who participated in the programs over seven years.

Study Purposes: One purpose of the longitudinal impact evaluation is to track the *persistence of savings outcomes* from 1986 and 1987 pilot program participants (Cohorts A and B) over a six- to seven-year period after measures were installed. This study better determines the energy savings obtained from buildings occupied primarily by low-income tenants; findings on this impact were equivocal in an earlier study (Okumo 1991).

A second purpose of the longitudinal impact evaluation is to determine the pattern and persistence of savings from the program as it matured in 1988-1990, and as newer technology windows became prevalent in 1991-1992. Planning projections suggest that *new technology outcomes*, measured in savings on residential tenant meters, should gradually rise to a level 40% higher for 1991-92 participants (Cohorts F and G) than for 1988-1989 participants (Cohorts C and D).

A third purpose of the longitudinal evaluation is to suggest *formative changes* in program delivery or design which may improve on energy savings impacts and persistence. The question has been raised over the past five years, whether follow-on operations and maintenance services are desirable or necessary. One funding contract with the Bonneville Power Administration, now expired, called for a commitment to provide follow-on services. Another question about the transition to newer technology windows was raised in the recent companion report, entitled MULTIFAMILY RETROFIT CONSERVATION PROGRAMS: CUSTOMER SERVICE MEASURES (Tachibana, July 1998).

A fourth purpose of the longitudinal impact evaluation, at the time that it originally was designed, was to provide accurate *utility load forecast inputs*. These inputs take the form of energy savings estimates and associated errors for program participants, as well as profiles of non-participant trends.

Study Design: This report presents the results of a study conducted over a period of years on the Multifamily Conservation Programs funded by Seattle City Light. The main focus of this study has been on the persistence of energy savings from measures installed between one and seven years prior to 1993. The program participants are grouped into Cohorts (A to G) based on the year in which installation of measures was completed (1986 to 1992). Energy savings from commercial house meters are analyzed separately from residential tenant meters, to reflect the major program components: common-area lighting efficiency and dwelling-area shell integrity. Participants in the low-income program operated by the Department of Housing and Human Services (DHHS) are analyzed separately from participants in the Seattle City Light (SCL) standard-income program. Results are also aggregated to the building level, and income-levels are combined, to allow the findings to be generalized. Most results are presented by figures in the body of this report; extensive tables and detailed figures make up Appendices B and C. A detailed supplement on the research methodology may be found in Appendix A.

The data analyzed for this study are drawn mainly from utility billing records of energy consumption. Additional data developed by the evaluator are based on program files, which contain descriptive information about the buildings and measures installed. From these files could be calculated engineering estimates of expected reductions in energy use, based on each measure type and baseline conditions. A third source of information was a telephone survey conducted at the end of 1995, three to nine years after program participation. This survey inquired about changes at the multifamily residences that could influence the use of energy. A consultant fielding service completed telephone interviews with most building owners and property managers to collect information about changes in buildings, occupancy, appliances, and measures (apart from program measures) which might affect energy usage over the time period extending from 1987 through 1994.

Report Organization: Chapter 1 provides a brief overview of the program and the SCL customers who are eligible to participate. Chapter 2 describes the research methods. Chapter 3 presents descriptive findings on the participant and non-participant comparison groups. Chapter 4 provides findings on gross and net energy savings scores. Chapter 5 extends the inquiry through analysis of covariance, using several bivariate and multivariate models, to refine our understanding of program impacts. Finally, Chapter 6 recapitulates the major findings, discusses implications for the current programs, and recommends actions on each of the areas of concern brought out by the impact analysis. Following are the key recommendations that follow from the survey findings.

Longitudinal Study Group Savings: 1986-1992

Among Standard-Income participant buildings, net energy savings were about 17% of baseline for the average unit over all cohorts from 1986-1992. Among cohorts, this value ranged from 13% to 19%. On Tenant Meters, program measures saved about 15% of pre-period energy use (range: 10%-17%). Program actions saved about 31% of baseline consumption on House Meters (range: 12%-43%).

Among Low-Income participant buildings, net energy savings were about 12% of baseline for the average unit over all cohorts from 1986-1992. Among cohorts, this value ranged from 8% to 16%. On Tenant Meters, program measures saved about 10% of pre-period energy use (range: 8%-15%). Program actions saved about 19% of baseline consumption on House Meters (range: 14%-32%; not applicable to Cohort A).

Summary A: Program Energy Savings from Completed Projects, 1986-1992

Installation Year	Total Building Impact kWh per Unit		Number of Units in Completed Projects		MWh Savings from Combined Programs	
Program	Std-Inc.	Low-Inc.	Std-Inc.	Low-Inc.	First Year	Cumulative
A 1986	1,213	1,025	254	264	579	579
B 1987	1,628	1,089	399	929	1,661	2,240
C 1988	1,322	1,638	812	894	2,538	4,778
D 1989	1,534	1,015	787	891	2,112	6,889
E 1990	1,937	1,219	1,020	832	2,990	9,879
F 1991	1,696	1,038	1,232	790	2,909	12,789
G 1992	1,433	1,265	1,185	1,021	2,990	15,779

As Summary A shows, during the study years, first-year energy savings ramped up about 600 MWh in 1986 to nearly 3,000 MWh each year in 1990-1992. In 1992, energy savings from cumulative participants in the Standard-Income and Low-Income programs combined totaled nearly 15,800 MWh. This was equivalent to an average load reduction for Seattle City Light in that year of 1.9 aMW (average megawatts, including a 5.2% credit for savings on transmission and distribution).

This evaluation has found no evidence of free riders on the Multifamily Conservation Programs for standard-income and low-income buildings. The evidence for this assertion comes from energy use baselines that were examined for program participants, wait-list pre-participants (standard-income), and population nonparticipants (low-income). When seven-year data were fitted with flat trend lines (simple regression) , no significant slopes were observed. When fitted with curvilinear trend lines (polynomial regression), energy use trended slightly upward and downward, ending at levels above initial values. It is very unlikely that nonparticipants in the general population of multifamily building operators on their own are installing significant quantities of measures similar to those sponsored by the Multifamily

Conservation Programs. Few or none of the program participants have entered the program to receive financing for measures they would have installed on their own.

This evaluation has also found no evidence of spill-over effects (free drivers) from the Multifamily Conservation Programs for standard-income and low-income buildings. The evidence for this assertion is found in gross and simple net change scores that are compared among program participants, wait-list pre-participants (standard-income), population nonparticipants (low-income), and program past-participants (both income levels). Control group buildings are not using electricity in a significantly different fashion from past participants. It is very unlikely that nonparticipants in the general population of multifamily building operators have been influenced, as a direct spill-over effect of the Utility programs, to on their own install significant quantities of measures similar to those sponsored by the Multifamily Conservation Programs

This longitudinal impact study presents and discusses strong evidence for energy savings that persist up to seven years after program measure installation. There was no indication of participant free-ridership or program spill-over to nonparticipants. As newer vinyl window technology developed in the late 1980s and into the early 1990s, energy savings associated with this measure rose, although more gradually than had been hoped. Meanwhile, application of insulation measures became less frequent, and efficient showerhead measures reached the saturation point. In the last two years studied for the Standard-Income program (1991-1992), energy savings impacts from common-area lighting measures did not materialize as expected from engineering projections. And in all post-years studied, net Tenant-Meter savings among Low-Income buildings were lower than among Standard-Income buildings (although gross savings scores were quite similar). This is most likely due to the high degree to which this program has already saturated the potential market pool.

Estimates of Subsequent Program Savings: 1993-2000

To project from the impact evaluation findings to impacts in more recent years, several factors must be taken into consideration. These include common-area lighting issues (engineering estimates, realization rates, estimated lighting savings for 1998-1999), and tenant-area weatherization issues (showerhead measure penetration, building shell measure mix).

Adjusting for these factors, the average building in the 1998 Standard-Income program saves about 1,800 kWh per residential unit from tenant-area and common-are measures combined. In the Low-Income program, the average 1998 participant building saves about 1,300 kWh per residential unit from combined measures. In Low-Income buildings not installing common-area lighting measures, the average savings are about 900 kWh per unit.

Summary B: Projected Energy Savings from Completed Projects, 1993-1998

Installation Year	Total Building Impact kWh per Unit		Number of Units in Completed Projects		MWh Savings from Combined Programs	
Program	Std-Inc.	Low-Inc.	Std-Inc.	Low-Inc.	First Year	Cumulative
1993	1,840	1,338	981	847	2,938	18,717
1994	1,738	1,312	2,045	1,278	5,231	23,948
1995	1,771	1,298	2,640	1,033	6,016	29,964
1996	1,678	1,164	1,232	469	2,613	32,577
1997	1,725	1,231	1,519	725	3,513	36,090
1998	1,811	1,285	983	626	2,585	38,615

Summary B shows that the ramp-up in first-year energy savings steepened in 1994 to 5,200 MWh, and to 6,000 MWh in 1995. At that time program participation goals were cut and first-year savings dropped back down to the 2,600-3,500 MWh range in 1996-1998. In 1998, savings from cumulative participants were about 38,620 MWh, yielding an utility load reduction of 4.6 aMW from the two combined programs. These values will be used to revise projections published in the next edition of Seattle City Light's annual ENERGY CONSERVATION ACCOMPLISHMENTS report.

Ongoing Program Improvements

This longitudinal impact study of the Multifamily Conservation Programs began with several purposes.

- Produce outcome measures to provide accountability for the Standard-Income and Low-Income programs.
- Track the persistence of savings outcomes from 1986 and 1987 pilot program participants (Cohorts A and B) over a six- to seven-year period after measures were installed.
- Determining the pattern and persistence of savings from the program as it matured in 1988-1990, and as newer technology windows became prevalent in 1991-1992.
- Provide accurate utility load forecast inputs, in the form of energy savings estimates and associated errors for participants, as well as profiles of nonparticipant trends.
- Suggest formative changes in the program delivery or design that may improve on energy savings impacts and persistence.

The following recommendations address issues raised by this impact evaluation. Some of these recommendations expand on actions suggested in the companion process evaluation, "Multifamily Retrofit Conservation Programs: Customer Service Measures." Future evaluation of the Low-Income Multifamily Program would at a minimum address two major issues called out below, those being measure penetrations and market penetration.

DEVELOP OPTIONS FOR RE-DESIGN OF PROGRAM OFFERINGS IN 2001-2004

- ***Evaluate Recent Vinyl Window Replacements***

Seattle City Light should develop a strategy for following up on specific buildings receiving the current generation of vinyl-framed window products, to determine whether problems observed in 1991-1992 program installations have "shaken out" as high-efficiency ($U \leq 0.40$) products matured. Have warranty replacements for vinyl windows been significantly fewer than for the preceding aluminum and early-generation vinyl window products?

- ***Offer Vinyl Replacements to Former Aluminum-Window Participants***

Seattle City Light should investigate the economics of offering a new generation of vinyl window replacements to customers who participated in the Multifamily Conservation Programs in 1986-1990 and received aluminum window replacements or conversions. The early programs reduced heat transmission U-factors from pre-existing levels around 1.10 to post-retrofit levels around 0.72, a drop of 0.38 points (Btu/hour/°F per square foot). Current window U-factors run closer to 0.35, offering another potential drop of around 0.37 points. Certainly current windows are not twice the cost of earlier retrofits, even though savings per square foot have doubled; in fact, costs have held fairly constant over the years. New building audits for prior participants may not be necessary, since existing program files contain all relevant measurements and prior cost comparisons. Given noneconomic benefits of program measures and economic externalities of competing resources, it may be feasible to replace early aluminum window retrofits with a better-performing product, in a streamlined program format requiring customer payment upon completion of inspections (i.e., no loan financing). Seattle City Light's exposure would be limited to the cost of program administration, and perhaps some percentage of rebate or discount for measures.

- ***Offer Spot-Replacements of Failed Window Measures***

Seattle City Light should offer a simple, cost-effective rebate program to help single-family homeowners and multifamily building owners to re-fit high-efficiency windows into openings where individual aluminum or other windows have "failed". Windows fail when seals break or glass cracks, rare-gas fills are lost, moisture enters, and sometimes bacterial or mold colonies develop. The lifetimes of windows retrofit by the Multifamily Conservation Programs are ticking away, after 15 years of program operation (20 years for the single-family programs) as of 2001. About 25-35% of windows will naturally have failed by that time, and the new generation of window products offers superior energy efficiency. New audits may not be necessary, since existing program files contain all relevant measurements and prior cost comparisons. The success of this option depends on access to archived field files for the 1986-1998 programs. A rebate format should ensure a streamlined program within minimal overhead costs.

- ***Offer Rehabilitation Services***

Seattle City Light should consider, where window sills and openings have deteriorated, how rehabilitation could be incorporated into the regular Standard-Income program to increase the quality of window retrofits, the building stock, and ultimately the satisfaction of building owners. Structural deficiencies often lead to later complaints about drafts and water leakage. The Seattle City Light program should investigate installing foam over old aluminum frame perimeters, as done by the Department of Housing and Human Services program. Whenever pre-existing leakage and stains are observed by program auditors, rehabilitation to faulty or degraded wall construction should be initiated to better address owner concerns. Rehabilitation services facilitated by the City would probably require customer payments directly to contractors, due to legal limitations on "lending of credit" by City conservation programs.

EVALUATE THE REMAINING MARKET POOL FOR MULTIFAMILY RETROFIT PROGRAMS

Seattle City Light and the Seattle Office of Housing should embark on a systematic analysis of the market penetration of existing programs and remaining pools available for program services. At Seattle City Light, this investigation of the multifamily housing market should be coordinated with new revisions to the Load Forecast model. Such analysis would include at least three components.

- ***Inventory the Multifamily Market Pool (Existing & New Construction)***

Inventory the "population pool" of all existing and new-construction multifamily buildings in the City of Seattle and Seattle City Light's service area. Resources and tools include Seattle City Light's Customer Information System (CIS); the SCL Conservation Tracking System (CTS); and the King County tax assessment database (accessible through MetroScan™ software).

- ***Identify Served Buildings***

Cross-reference the inventory with records on buildings served by the Multifamily Conservation retrofit programs (SCL standard-income, DHHS low-income, SCL common-area lighting) and the Built Smart / Super Good Cents Programs for multifamily new construction. Resources and tools include program databases (such as SCL's older Rbase tracking system, the new Conservation Tracking Sytem, and DHHS's former Paradox system); and evaluator files for Standard-Income buildings (1986-1998), Low-Income buildings (1986-1992), Common-Area Lighting buildings (1993-1998), and Super Good Cents/Built Smart new construction projects (1992-1998).

- ***Analyze Unserved Buildings***

Characterize the remaining unserved market by building features, neighborhood demographics, economic development areas, and likelihood of low-income residency. Also characterize previously served buildings that may become markets for new service offerings. Estimate served and remaining market pools for existing and proposed City programs. Identify buildings for targeted marketing by each of the Multifamily Conservation Programs, including the Common-Area Lighting Program.

MODIFY DATA TRACKING FOR THE MULTIFAMILY RETROFIT PROGRAMS

Seattle City Light and the Seattle Office of Housing should collect pertinent data for projecting energy savings from the current and future programs. At the same time, certain data elements tracked in the past are likely to be unnecessary for future evaluations.

- ***Streamline Data Elements on Insulation and Windows***

Program records on insulation and window measures should continue to track information necessary to conducting program operations and management. However, it is not necessary for future evaluations to track certain data elements used in engineering projections of energy savings from insulation and window measures. These include pre-existing R-values and square footage of cavity areas in ceilings, walls, and floors, as well as similar data on insulation added by the program. U-values of windows should still be tracked in the aggregate for each building (that is, total glass square footage of each rated U-value, if more than one).

- ***Track Data Elements on Measure Mix***

The programs should continue to track, both in field files and electronic databases, information on the mix of measures installed in the tenant areas of each building. This may consist of simple flags for ceiling insulation, wall insulation, floor insulation; plus counts of showerhead replacements and faucet aerators installed. *Importantly, this should also include counts of water heater thermostat set-backs, an item which in the past has not been recorded in field files or electronic databases.* Where water heaters appear to be wired to house-meter circuits, building auditors should record this information in field files and electronic databases, to help reconcile findings on building house meters. Window retrofits should be recorded by the square footage affected.

- ***Collect Appliance Marketing Data***

Building auditors should make note of manufacture dates for existing water heaters, where accessible, for use in future marketing of efficient replacement appliances. This information should appear in the Conservation Tracking System or other electronic databases. A barrier for the programs to overcome is the labor-intensive nature of locating this information.

- ***Track Details on Common-Area Lighting***

Regarding lighting measures, all Multifamily Programs should continue to keep full records on pre-existing and replacement lighting fixtures. This includes line-by-line counts of existing lamps by location and type, accompanied by wattage and annual average hours of operation, along with counts and wattages of replacements by location and type. Tracking engineering projections for lighting continues to be important for the Multifamily Conservation Programs, as energy savings performance on house meters has not always followed expected patterns and future projections are uncertain.

- ***Evaluate Measure Penetration in Low-Income Program***

It has been suggested that current (1997-1999) differences in house-meter energy savings between the Low-Income and Standard-Income programs may be affected by a slower adoption by DHHS of LED exit sign measures. There may also have been a differential in the rate of water heater thermostat set-backs during past years. Particularly in the Low-Income Multifamily Program, a future impact evaluation would require the following information on measure penetrations (in electronic database format):

- Tracking of measure mix data elements per project;
- Tracking of complete lighting details per project; and
- Tracking the temperature differential of water heater thermostat set-backs, as well as the quantity.
- Other desirable information includes the types and cost of concurrent building repairs or rehabilitation.

Associated costs of all measures should also be collected.

1. Introduction

1.1 Overview of the Report

A *longitudinal study* deals with "the growth and change of an individual or group over a period of years" (WEBSTER'S NEW COLLEGE DICTIONARY). A *program impact evaluation* focuses on outcome measures, such as energy savings from buildings treated by the program, to provide accountability. This longitudinal impact evaluation of the Multifamily Conservation Programs funded by Seattle City Light is designed to measure the changes in energy use among participating customer groups, as compared to non-participating customers. The study design maximizes the validity of impact results by including a large proportion of customers who participated in the programs over seven years.

Study Purposes: One purpose of the longitudinal impact evaluation is to track the *persistence of savings outcomes* from 1986 and 1987 pilot program participants (Cohorts A and B) over a six- to seven-year period after measures were installed. This study will also better determine what energy savings are obtained from the buildings occupied primarily by low-income tenants; findings on this impact were equivocal in an earlier study (Okumo 1991).

A second purpose of the longitudinal impact evaluation is to determine the pattern and persistence of savings from the program as it matured in 1988-1990, and as newer technology windows became prevalent in 1991-1992. Planning projections suggest that *new technology outcomes*, measured in savings on residential tenant meters, should gradually rise to a level 40% higher for 1991-92 participants (Cohorts F and G) than for 1988-1989 participants (Cohorts C and D).

A third purpose of the longitudinal evaluation is suggest *formative changes* in the program delivery or design that may improve on energy savings impacts and persistence. The question has been raised over the past five years, whether follow-on operations and maintenance services are desirable or necessary. One funding contract with the Bonneville Power Administration, now expired, called for a commitment to provide follow-on services. Another question about the transition to newer technology windows was raised in the recent companion report, entitled MULTIFAMILY RETROFIT CONSERVATION PROGRAMS: CUSTOMER SERVICE MEASURES (Tachibana, July 1998).

A fourth purpose of the longitudinal impact evaluation, at the time that it originally was designed, was to provide accurate *utility load forecast inputs*. These inputs take the form of energy savings estimates and associated errors, for program participants, as well as profiles of nonparticipant trends.

Study Design: This report presents the results of a study conducted over a period of years on the Multifamily Conservation Programs funded by Seattle City Light. The main focus of this study has been on the persistence of energy savings from measures installed between one and seven years prior to 1993. The program participants are grouped into Cohorts (A to G) based on the year in which installation of measures was completed (1986-1992). Energy savings from commercial house meters are analyzed separately from residential tenant meters, to reflect the major program components: common-area lighting efficiency and dwelling-area shell integrity. Participants in the low-income program operated by the Department of Housing and Human Services (DHHS) are analyzed separately from participants in the Seattle City Light (SCL) standard-income program. Results are also aggregated to the building level, and income-levels are combined, to allow the findings to be generalized. Most results are presented by figures in the body of this report; extensive tables and detailed figures make up Appendices B and C. A detailed supplement on the research methodology may be found in Appendix A.

A companion volume to this report[1] describes the results of a telephone survey about changes at multifamily residences that could influence the use of energy. The subjects were nonparticipants and participants in Seattle City Light's Multifamily Conservation Programs during the years 1986-1992. The 1995-1996 Measures Survey was performed to collect data for analysis in the Multifamily Longitudinal Impact Evaluation. A consultant fielding service completed telephone interviews with 332 building owners and property managers to collect information about changes in buildings, occupancy, appliances, and measures (apart from program measures) which might affect energy usage over the time period extending from 1987 through 1994.

The 1995-1996 Measures Survey was performed primarily to collect data for analysis in the Multifamily Longitudinal Impact Evaluation. However, key data were gathered in this survey that address the quality of program measures as perceived by program participants after the passing of several years, in some cases up to a decade later.

The remainder of this chapter provides a brief overview of the program and the SCL customers who are eligible to participate. Chapter 2 describes the research methods. Chapter 3 presents descriptive findings on the participant and nonparticipant comparison groups. Chapter 4 provides findings on gross

---

[1] Tachibana, Debra-Laurent O., MULTIFAMILY RETROFIT CONSERVATION PROGRAMS: CUSTOMER SERVICE MEASURES, Evaluation Unit, Energy Management Services Division, Seattle City Light, July 1998.

and net energy savings scores. Chapter 5 extends the inquiry through analysis of covariance, using several bivariate and multivariate models, to refine our understanding of program impacts. Finally, Chapter 6 recapitulates the major findings, discusses implications for the current programs, and recommends actions on each of the areas of concern brought out by the impact analysis.

1.2 About the Programs

The Multifamily Conservation Programs (*MFCP*) began in 1986. They were preceded by a 15-building research and demonstration project in 1985. The Multifamily Conservation Programs provide financial and technical help to owners of apartment buildings with electric space heat. The types of measures that the program provides increase the efficiency of building insulation, hot water, and lighting end uses.

Seattle City Light offers three programs to retrofit existing multifamily buildings with these measures. The Low-Income Multifamily Program is funded by Seattle City Light and administered by the Department of Housing and Human Services; it offers the full range of measures. The Multifamily Conservation Program for standard (non-low) income customers is funded and operated by SCL, also offering the full range of efficiency measures. The Multifamily Common-Area Lighting Program, added in 1993, provides lighting-only measures to buildings not eligible for weatherization upgrades.

The Wave 1 and Wave 2 surveys cover the latter two components of the Multifamily Conservation Programs: whole-building retrofits of buildings occupied by standard-income tenants (sometimes called the Standard-Income Program); and buildings receiving only retrofits of common-area lighting, without regard for tenant income eligibility (the Multifamily Common-Area Lighting Program). Whole building retrofits of buildings with low-income tenants (the Low-Income Multifamily Program) were not addressed by the surveys in this report. Survey 3 on measures and building changes covers all three components of the Multifamily Conservation Programs, along with matching control groups.

The typical multifamily building retrofitted with weatherization measures through this program has five or more units and was constructed prior to 1980 when new energy efficiency building codes were adopted in the Seattle area. Participant buildings receiving weatherization measures (Standard-Income whole-building participants) usually have electric space and water heat, are three stories or less, and are not condominiums.

In contrast, participant buildings receiving only Common-Area Lighting Program modifications (lighting-only participants) can have either electric or gas space heat, can be relatively new (i.e. built after 1980), and can include condominiums.

1.2.1 PROGRAM MEASURES

The available conservation measures in the Multifamily Conservation Programs include: double-glazed replacement or conversion windows, attic or flat roof insulation, under-floor insulation, wall insulation, caulking and weather-stripping, efficient-flow showerheads, water heater wraps and temperature setbacks, pipe and duct wraps, and common-area lighting modifications. Glass-only window conversion and storm window retrofits have not been allowed since 1992 under NFRC (National Fenestration Rating Council) requirements. The actual measures installed through the program depend upon the condition of the building, feasibility and the cost-effectiveness of the recommended measures, and the owner or building manager's preferences.

The active lifetime of measures is expressed in terms of the average residual life, or the point at which approximately 50% of measures would have been retired due to failure. Failure can be physical, but can also reflect early removals due to remodeling or renovation. The active lifetime of conservation measures installed by the Multifamily Conservation Programs is assumed to be 30 years for dwelling-area measures (in the whole-building programs) and 16 years for common-area lighting (in all three programs).

1.2.2 POPULATIONS SERVED

Owners of multifamily buildings with predominantly low-income tenants, from 1986 through 1990, were referred to the Department of Human Resources (DHR) for weatherization by a program jointly administered with and funded by Seattle City Light. In 1991, the Low-Income Program was transferred to the Department of Community Development (DCD); and in 1992 it was incorporated into the Department of Housing and Human Services (DHHS). Participating building owners receive a full-cost grant, conditional upon agreement by the owner to freeze rents for a year and not to raise rents due to conservation measures for a period of four more years (this part of the covenant was changed to two years, beginning in 1998). During the period 1986-1996, owners of these buildings qualified for weatherization grants if two-thirds or more of the building tenants met low-income eligibility criteria; in late 1996 that proportion was revised to half.

In the Low-Income Program, public contractors are selected by the program and assigned to individual buildings to install the measures, while DHHS manages and pays the contractors. The Low-Income Program began to install common-area lighting measures in 1988. Competitive bidding among contractors was implemented for a limited number of projects during 1995 in an effort to reduce costs. Competitive bidding will be required for all DHHS multifamily projects in 1996.

Building owners served by Seattle City Light's Standard-Income Program with measures that include weatherization qualified for a ten-year, zero-interest loan, with five-year deferred payment and a 50%

discount for first-year payoff. In 1996 the period on this loan was reduced to six years with the first year deferred. A 50% discount for payoff during the first years remained in effect.

In the Standard-Income Program, private contractors, selected by the individual building owners or property managers, install the measures while Seattle City Light manages and pays the contractors. In 1987 through 1995, the BPA continued to reimburse some weatherization costs for low-income buildings, and in 1995 once again participants in all three programs benefited from BPA funds.

Beginning in 1993, Seattle City Light began to offer financial and technical help for common-area lighting modifications in buildings not likely to receive whole-building measures. These include oil and gas heated buildings, condominiums of all heat sources, and buildings constructed after the double-glazing code went into effect in 1980. The Common-Area Lighting Program pays for up to 70% of the installed measure cost, and offers a 70% discount for up-front payment. To date, no participants in this group have opted to take the ten-year, zero-interest loan instead; the loan option will be eliminated beginning in 1996.

Partial funding has been received from the Bonneville Power Administration (BPA) through its regional Energy Buy Back (EBB) program in 1986-1991, and through the Weatherwise funding program in 1991-1993. In 1986, the BPA reimbursed a percentage of weatherization costs, resulting in lower loan balances for standard-income building owners and defraying some program costs for low-income building grants. A new Targeted Acquisition contract was signed in March 1993 between Seattle City Light and the Bonneville Power Administration. Under this contract, the BPA funded measures installed by the Common-Area Lighting and Standard-Income (whole-building) Programs. Funding continued under the BPA Weatherwise program for measures installed by the Low-Income (whole-building) Program. Funding provided by the BPA via the Third Party Financing Agreement began in June 1994.

At the end of 1991, in the City Light service area there were 3,164 electrically-heated multifamily buildings built before 1980 that contained five or more units, for a total of 63,281 apartment and condominium units. In 25% of the buildings, at least two-thirds of the residents had incomes at or below 125% of the federal poverty level guidelines. Owners of these buildings qualified for weatherization grants through the DHHS Low-Income Multifamily Program during the period 1986-1992; owners of the other 75% of buildings qualified for Seattle City Light’s (standard-income) Multifamily Program.

The eligible population for the Multifamily Conservation Programs in 1991 thus included about 2,373 standard-income buildings (47,461 units) and 791 low-income buildings (15,820 units). Seattle City Light's goal has been to serve 29,426 standard-income units or 62% of the market pool with weatherization measures.

In addition, there were in 1991 about 2,632 buildings (52,646 units) that were built since 1980, were condominiums, or had nonelectric (gas or oil) space heat. The pool for common-area lighting measures has grown since 1991 with increasing new construction activity.

1.2.3 PROGRAM PROCESSES

The Multifamily Conservation Programs operate under three delivery methods directed to three populations: low-income buildings with electric space heat built before 1980; standard-income pre-1980 buildings with electric space heat; and nonelectric space heat or post-1980 construction needing common-area lighting measures only.

The program for standard-income buildings is conducted in seven stages:

Stage 1. The building owner applies to the program and is entered on a waiting list.

Stage 2. Seattle City Light staff performs an audit of the building and recommends measures.

Stage 3. Building owners solicit bids from qualified contractors in a group bidding process.

Stage 4. SCL staff review bids with the building owner.

Stage 5. The building owner or manager selects the successful bidder and signs work contracts.

Stage 6. SCL staff serves as the general contractor and monitors the work as measures are installed.

Stage 7. SCL staff performs a final inspection of the completed job, establishes warranties, pays off contractors, and sets up customer loan repayments.

For weatherization projects, this seven-stage process typically takes up to eight months from start to completion. For the common-area lighting projects, the process is shorter, usually requiring two to four months to complete.

The Low-Income Multifamily Program, during 1986-1994, collapsed Stages 2-5 in one process. During that period the Department of Housing and Human Services assigned projects to pre-approved contractors. This changed in 1995-1997 as the program moved toward a model similar to the Standard-Income Program, with contractors bidding competitively on whole-building jobs. Stage 7 is similar except that in the Low-Income program there are no loans or repayment of weatherization grants.

In the Multifamily Common-Area Lighting Program, during 1993-1995, lighting trade allies generated the projects brought to Seattle City Light for program contracts. The Utility's role was indirect in the early years. In 1996-1997, however, SCL staff members generated the project leads and were first out on each common-area lighting job, following stages similar to those described above. Low-income projects are referred to this program if lighting-only measures are required. The Common-Area Lighting Program has operated without waiting lists (Stage 1) in 1996-1997.

The longitudinal impact evaluation focuses on the two programs that combine measures with common-area lighting, in pre-1980 electric space-heat construction. This study does not address impacts for participants in the Multifamily Common-Area Lighting program for post-1980 construction.

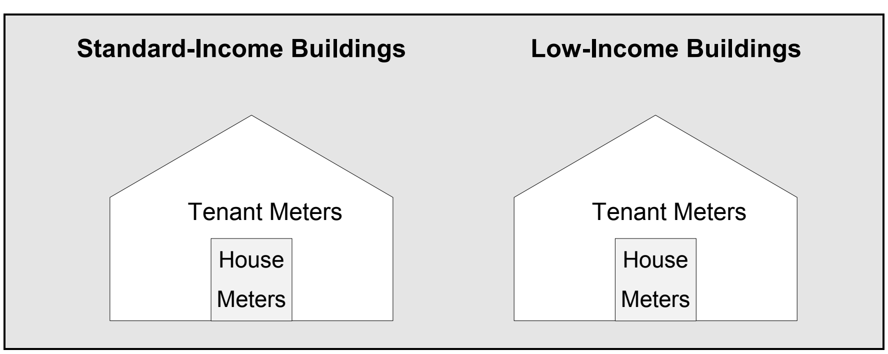
2. Research Methodology

2.1 Study Design & Sampling

Multifamily buildings use energy in two main building areas: the tenant dwelling spaces, and the common areas, consisting of entries, lobbies, stairwells, interior hallways, common laundries, parking garages, exterior walkways, and possibly swimming pools or recreational rooms. Common area energy use tends to be clustered on house meters coded for a commercial rate (Small Commercial Rate 31). Tenant area energy use is most often metered separately for each residential unit, coded for a standard rate (Residential Rate 20) or low-income rate (Residential Rate Assistance 26 or 27).

This evaluation is designed to study separately the two types of energy use, on Tenant Meters and on House Meters. It also separates participants into two groups based on the program in which customers were served. Low-income buildings are not identified from the residential rate, but rather from qualification by the Department of Housing and Human Services for a weatherization grant. Standard-income buildings are identified by participation in the Seattle City Light loan program, which does not require investigation of tenant incomes. Buildings treated by the two programs are compared with nonparticipant control group buildings to judge the level of savings that can be attributed to program participation.

Figure 2-I: Meter Data Analyzed for Dwelling and Common Areas



2.1.1 STUDY COHORTS

The treatment groups comprise buildings retrofitted by the Multifamily Conservation Programs during the calendar years 1986 through 1992. Standard-income buildings were analyzed separately from low-income buildings in a parallel design. The longitudinal evaluation allows for as many as seven years of post-weatherization electricity consumption data to be analyzed for the buildings retrofitted in 1986 (Cohort A), and as few as one post-year for buildings retrofitted in 1992 (Cohort G).

Nonparticipants (Group N) for the Low-Income program were drawn by random sampling from the county tax assessor's database, and verified by telephone for matching attributes. Standard-Income program Nonparticipants were drawn from the program's waiting list for future participation in 1994-1996.

The intention was to assess the durability of initial savings and establish energy savings effects attributable to the conservation programs. Table 2-A describes the general study design followed in this evaluation.

Table 2-A: Cohorts by Calendar Years and Post-Periods

	Calendar Year									Post-Period						
Cohorts	**85**	**86**	**87**	**88**	**89**	**90**	**91**	**92**	**93**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
A	P	M	X	X	X	X	X	X	X	X	X	X	X	X	X	X
B	P		M	X	X	X	X	X	X	X	X	X	X	X	X	
C			P	M	X	X	X	X	X	X	X	X	X	X		
D				P	M	X	X	X	X	X	X	X	X			
E					P	M	X	X	X	X	X	X				
F						P	M	X	X	X	X					
G							P	M	X	X						
N			X	X	X	X	X	X	X							

NOTES: P indicates pre-period, M is the year when measures were installed, and X indicates post-period years (comparison years for the Control Group, N). Each program participant Cohort A-G began and completed installation of all measures during the calendar year designated M.

The treatment groups represent a full census of program year participants, with the exception of buildings where weatherization work was not completed by year end, or where master-meters do not allow for disaggregation of energy use between tenant usage and common-area usage.

The next two tables describe the sample frames for participants in the Seattle City Light standard-income program (Table 2-B) and the Department of Housing and Human Services low-income program (Table 2-C). Among Standard-Income participants, 82% started and completed weatherization work within one year and had individual tenant meters. Among Low-Income participants, 58% fit a similar profile. For both programs, the number of cases in each lettered cohort may be greater or fewer than the number reported "complete" each year by program records. Cases were assigned to cohorts in a fashion that minimized "contamination" of pre-period or post-period energy use by overlaps with the installation period.

Table 2-B goes on to present the number of Standard-Income buildings for which enough program file data were available from which to calculate engineering projections of energy savings. Similar data were not available for participants in the Low-Income program. Most buildings in the 82% Standard-Income sample did have engineering data (that is, 77% of the original sample frame). A smaller group (52% of the original frame) also responded to a telephone survey about building and appliance changes in the years following participation.

One of the values of operating from a fairly complete census of participants is to reduce the amount of uncertainty about energy savings that comes from taking a sample. Changes in data processing technology have made it easier than in past years to depend less on sampling as a means of controlling study costs. When group averages are calculated for a sample, the confidence interval is often presented; this states the range of values within which the population mean may fall, given a particular sample's mean and standard deviation.

Table 2-B: Sample Frame and Sub-samples, Standard-Income Buildings

	Pgm Reported "Complete"			**with Valid Tenant Meter Data**			**with Engineering Projections**		**with Measure Survey & EEs**	
Year	**Bldgs in Year**	**Units in Year**	**Study Cohort**	**Complete Bldgs**	**Units**	***Pct of Year***	**Sample Bldgs**	***Pct of Year***	**Sample Bldgs**	***Pct of Year***
1986	24	254	**A**	23	242	*96%*	23	*96%*	15	*63%*
1987	25	399	**B**	28	466	*112*	28	*112*	22	*88*
1988	54	812	**C**	39	682	*72*	37	*69*	19	*35*
1989	33	787	**D**	35	580	*106*	34	*103*	26	*79*
1990	72	1,020	**E**	51	706	*71*	42	*58*	29	*40*
1991	66	1,232	**F**	58	1,219	*88*	56	*85*	38	*58*
1992	59	1,185	**G**	40	782	*68*	37	*63*	25	*42*
Subtotal	333	5,689		274	4,677	*82%*	257	*77%*	174	*52%*
Controls			**N**	33	429		33		33	
Total				307	5,106		290		207	

For a sample frame of 333 (the Standard-Income program's finite population size), a sample size of 178 buildings would be sufficient to ensure statistical results within a 95% confidence interval. This estimate is based on typical variances (mean and standard deviation) in energy consumption per residential unit.

The sample with tenant data (274) and the sub-sample with engineering projections (257) exceed this number, while the sample also having measure survey data is close (174). Regarding the Low-income program population, for a sample frame of 375 the sufficient sample of buildings would be 190. The number of buildings with tenant meter data (218) exceeds this number. As a result, one may have confidence that the energy use and savings observed from these samples should lie within five percent (±5%) of the population means.

Table 2-C: Sample Frame and Sub-samples, Low-Income Buildings

	Pgm Reported "Complete"			with Valid Tenant Meter Data		
Year	**Bldgs in Year**	**Units in Year**	**Study Cohort**	**Complete Bldgs**	**Units**	***Pct of Year***
1986	23	264	**A**	22	180	*96%*
1987	62	929	**B**	30	417	*48*
1988	57	894	**C**	41	742	*72*
1989	60	891	**D**	24	467	*40*
1990	62	832	**E**	43	619	*69*
1991	46	790	**F**	31	417	*67*
1992	65	1,021	**G**	27	599	*42*
Subtotal	375	5,621		218	3,441	*58%*
Controls			**N**	24	502	
Total				242	3,943	

A census approach increases certainty that the group mean is very close to the population mean, reducing dependence on confidence statements. However, this longitudinal impact evaluation is not intended to make statements about the general population eligible for the program. The results will be used primarily to project expected savings from the studied 1986-1992 cohorts into future years, and secondarily to provide a basis for projecting forward savings of 1993-1998 participants.

The longitudinal impact evaluation is designed to estimate net energy savings, based on comparisons of participants and nonparticipants. With a census approach, the question arises: Is there error in the estimation of program impacts? There is very little sampling error for the cohorts and periods studied, since nearly all participants are used in the study. Changes in the usage of participants are known for certainty up through the year 1993. That the usage of participants was higher or lower than that of a nonparticipant sample (not a census) is also known for certainty. However, the participant and nonparticipant groups may not have identical variances, due to a variety of factors including random error. This is the rational behind adding survey data to the comparison of meter read values, to control specifically for changes at the sites not captured by use of a nonparticipant control group. It is also the reason for using analysis of covariance (with pre-period energy use) in models for estimating net energy savings.

2.1.2 UNIT OF MEASUREMENT

Multifamily residential units actually comprise the original population for the Multifamily Conservation Programs and this analysis. Unit meters make the physical measurements for tenant energy use. The physical data for common-area energy use could be normalized by unit or by square foot of common-area floor area. Seattle City Light plans, load forecasts, and sets program goals in terms of tenant units. For this reason, house-meter data area normalized to the number of building tenant units, as well.

Observations of residential units within buildings do not vary independently. The interdependence within buildings is due to a variety of factors: common construction and physical characteristics; sampling bias of tenants from the population of potential tenants; and sharing of space heat through interior surfaces by conduction. This interdependence of within-building unit observations would tend to bias the variance of physical measurements upward from the variance observed between buildings as whole entities. The approach chosen for this impact evaluation pools unit-level observations within a building, derives a building centroid (average unit score), and weights this centroid by the number of units in the building.

Averaging per-unit energy use within each building was done to, in effect, homogenize within-building variance while retaining between-building (but within-group and between-group) variance. This approach is based on the assumption (pioneered in Okumo 1991) that shared walls in a multifamily structure lead to the exchange of space heat between units and an increased volume-to-surface-area ratio, both factors that decrease the independence of unit-level observations of electricity usage. Even common-area electricity use is moderately to highly correlated with the number of units in the building. Thus tests of per-building per-unit scores yields greater sensitivities to differences than tests of per-building scores. When incorporated with normalized weighting of observations by unit, this approach more accurately reflects program effects than one based only on building-level observations (which would be skewed by weighting small and large volume buildings equally).

Using a building score approach partially addresses a problem identified by Ecotope (D. Baylon) back in the 1980s, that unit-level raw data are not normally distributed, but rather follow a log-normal distribution. An explicit lognormal adjustment is not made in the models employed for this study. However, the unit-weights are normalized to keep the number of observations equivalent to the number of buildings in each group. (Not weighting the scores biases the group mean toward the smaller buildings, producing a distribution that is less representative of the overall group of units.) Thus the distribution of scores within buildings is flattened, with truncated tails, and the overall group variance is biased downward. This design allows the group building means to accurately reflect the group means of the original unit-level observations. This design also allows the calculation of standard errors that are appropriate to the comparison of building scores.

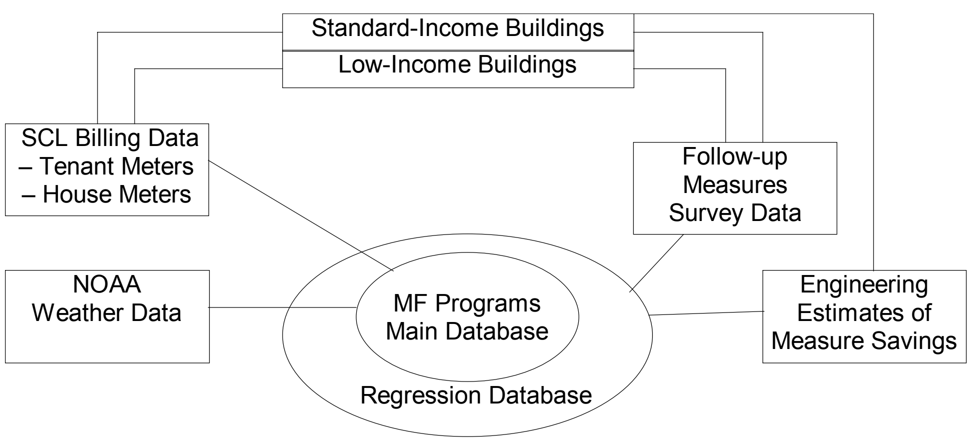
2.2 Database Development

2.2.1 OVERVIEW

The evaluation database for the Multifamily Conservation Programs longitudinal impact evaluation has four major components. As illustrated in Figure 2-II, the components are:

- Annual Energy Consumption Data (from utility bills per tenant meter and per house meter)
- Weather Data (heating-degree days calculated from average daily temperatures)
- Follow-up Survey Data (on changes in buildings and energy-using appliances)
- Expected Energy Savings Projections (from engineering features of buildings and measures installed)

Figure 2-II: Overview of Database on Multifamily Conservation Programs



The main database was constructed for all study buildings, both low-income and standard-income, including both program participants and nonparticipants. It contains records for 549 existing apartment buildings comprising 9,049 dwelling units. The regression database was constructed for standard income buildings only, as engineering projections were not available for the low-income buildings. It contains records for 290 buildings with over 4,800 dwelling units.

A consultant, Regional Economics Research, created SAS™ analysis files from the flat Billing Data files provided by Seattle City Light. They incorporated these files into the Main Database for the study, along with Weather Data and Follow-up Measures Survey data supplied by the utility. Later the consultant added Engineering Projections, also supplied by the utility evaluator, to produce the Regression Database for extended analysis. The Engineering Projections draw upon program records containing detailed audit and inspection data. These includes items such pre-existing insulation levels of attics, floors, and walls; as well as the type, location, insulating value, square footage and count of each measure installed by the program. Each of the study database components is discussed below.

2.2.2 ENERGY CONSUMPTION DATA

The Billing Database was developed from raw electricity meter-read data, which consisted of the following:

- **Index Files.** Sixteen index files that map combinations of bill-cycle:premise:meter-numbers to the evaluation building identification codes. There was one file for each of seven Low-Income Participant cohorts, seven Standard-Income Participant cohorts, a Low-Income Nonparticipant group, and a Standard-Income Nonparticipant group.
- **Meter Read Files.** Thirty-two raw electricity meter-read data files containing billing information for the eight-year period from 1987 through 1994. There was one file per year for each cohort or group of Standard-income Participants, Low-Income Participants, Standard-Income Nonparticipants, and Low-Income Nonparticipants.

In the first step, the consultant merged the index files and data files and summarized the bimonthly billing consumption data by building ID and year. The resulting data sets were compared to annualized data provided by Seattle City Light from an independent source (produced at an earlier stage of analysis), matching by building, group, and year, for tenant meters and house meters. The comparison showed that the nonparticipants did not match well at all. The consumption levels developed from the bimonthly meter data were higher than Seattle City Light's initial annualizations for almost all cases. This last issue resulted in extensive research of individual meter read data in the databases for possible data problems, to diagnose and correct anomalies.

Based on the findings, the joint project team formulated an approach to develop the final consumption databases. The underlying assumptions were that (1) data problems affected only the specific buildings for which they were identified, and (2) there was nothing wrong with the general procedures by which the nonparticipant samples were drawn and the billing data were extracted.

- If a building appeared in both participant and nonparticipant files, it was retained as a participant and dropped from the control group. This occurred infrequently, mainly due to a control building for one program having participated in the other program.
- SCL staff reviewed the retrofit dates in detail and developed a list of cohort re-assignments for all Cohorts C-G. These reassignments were based mainly on when the shell measures were installed. The “year served”, based on when a contract was written, did not accurately describe the cohort for a great many buildings having retrofits being completed in the winter months.
- Some sites with suspicious swings in the number of tenants per year were analyzed individually. Other possible data problems included incomplete numbers of records, inconsistent numbers of billing days among tenants, big changes in consumption after deletion of duplicates, etc. Tracking down these many detailed inaccuracies in the files took considerable labor on the part of the consultant and Seattle City Light.
- In general, the dwelling unit data looked fine and seemed to exhibit energy savings from pre-retrofit to post-years. Preliminary analysis indicated that appreciable savings were evident in the tenant-meter data. Given this, it did not appear necessary to conduct a dwelling unit survey on other energy-related changes during the study time period.
- The house-meter data on common-area consumption exhibited variations that could not be explained by program participation. In some cases, house meters seemed to be phased in/out over time. In other cases, consumption levels on specific meters varied sharply over time. In order to investigate reasons for these variations, a property management/ownership survey was undertaken by telephone to determine related factors and adjust the energy usage accordingly.

After implementing this approach, the Billing Databases were constructed separately for Standard-Income Tenant Meters, Standard-Income House Meters, Low-Income Tenant Meters, and Low-Income House Meters.

2.2.3 WEATHER DATA

Average daily temperature data were used to *weather normalize* the energy consumption data used in the regression analysis.[2] Annual heating degree-days were generated using deviations from a reference temperature of 65 degrees Fahrenheit. When the outdoor temperature falls below this level, space-heating systems are designed to come on to replace each degree of shortfall. One heating degree-day (HDD) is observed when the average daily temperature is 64 degrees outside, five HDD when it is 60 degrees out, and so forth. These heating degree-days may be summed on a monthly, bimonthly, or annual basis to facilitate adjustments to actual energy usage. The purpose is to levelize energy use across years with varying weather conditions, that is, to weather-normalize the consumption data. Comparisons across years of data adjusted to a normal weather year provide valid measurements of meaningful change, such as a program effect. The general formula for weather normalization adjustments to building-level electricity meter readings is:

Eq. 2-1 $$ANN\ kwh = UNADJ\ kwh + (UNITS * HDD\ dev * TEMP\ sens * RETRO\ sens)$$

where:

ANN kwh	=	Annual weather normalized energy consumption (building total kWh)
UNADJ kwh	=	Annual metered energy consumption (building total kWh)
UNITS	=	Number of tenant units in building
HDD dev	=	Normal minus actual heating degree days (base 65° F)
TEMP sens	=	Temperature sensitivity coefficient (kWh / unit / HDD_dev)
RETRO sens	=	Retrofit sensitivity reduction (RS percent)

The past energy requirements of a building are best for estimating energy use in a normal meteorological year. However, each building has its own temperature balance point which may not be equivalent to 65° F (the basis upon which heating degree-days are calculated from average daily temperatures). There are wide variations in occupant living habits that can result in large deviations from average annual energy use. Up to 50% of building heating requirements may be supplied by people, lighting, appliance use, solar gains, and thermal mass, rather than the space heating unit. Efficiency of a furnace can also vary with the time of year, because average loads on the equipment vary.

---

[2] For another application of this method used to weather normalize electricity consumption see, Okumo, Debra L., THE MULTIFAMILY CONSERVATION PROGRAM: EVALUATION OF ELECTRICITY SAVINGS AND COSTS, Evaluation Unit, Energy Management Services Division, Seattle City Light, June 1991.

Seattle City Light over the years has established empirical factors for various types of residential structures that allows the effect of 65° F heating degree-days to be adjusted for typical balance points. This temperature sensitivity coefficient applies to all buildings for which tenant-meter consumption data are to be weather-normalized. Once the building shell has been treated with high levels of insulation and high-efficiency windows, the building's response to outdoor temperatures is muted. The normalization method adjusts for this with a retrofit sensitivity factor, which reduces the temperature sensitivity factor by a set percent, also empirically determined. In the previous energy savings impact study, the temperature sensitivity coefficient was established at 0.57 kWh per HDD in Standard-Income buildings and 0.53 kWh per HDD in Low-Income buildings. After weatherization by the program, the temperature sensitivity coefficient in Participant buildings was reduced by 54% in Standard-Income buildings (RS=0.46) and by 23% in Low-Income buildings (RS=0.77).

For the present longitudinal impact evaluation, in the calculation of engineering projections, both factors expressing temperature and retrofit sensitivity have been set to singularity (=1.0). The purpose for doing this was to allow realization rate coefficients to be fitted empirically *a posteriori*, in the regression analysis phase, rather than *a priori* during calculation of engineering projections.

Table 2-D presents the annual heating degree-days for the years covered by this study. In Seattle, the long-term normal number of heating degree-days is 5,121 HDD in most years and 5,143 HDD in leap years. This typical meteorological year (TMY) is based on a thirty-year period, 1951-1980. As may be observed, all of the years 1986 through 1993 had warmer than normal weather, with the number of heating degree-days falling between 6% and 24% below a normal weather year for this city. This table also provides the deviations from normal of the heating degree-days in each year. This value is used in the calculations that adjust annual energy usage to normal-year equivalents.

Table 2-D: Annual Heating-Degree Days (HDD), Base 65 Degrees Fahrenheit

Year	1984*	1985	1986	1987	1988*	1989	1990	1991	1992*	1993
Annual HDD	5,009	5,586	4,720	4,182	4,792	4,658	4,537	4,816	3,939	4,773
% of Normal	97%	109%	92%	82%	93%	91%	89%	94%	76%	93%
HDD Deviations	+134	-465	+401	+939	+351	+463	+584	+305	+1204	+348

NOTE: * Leap years include 1984, 1988, and 1992.

2.2.4 ENGINEERING PROJECTIONS

Engineering projections of savings from the installation of program measures were constructed from data the utility evaluator extracted from program records. Seattle City Light engaged an engineer to review all lighting installation records and construct adjusted engineering projections of energy savings.

Adjustments mainly addressed the exclusion from engineering data of estimated savings due to replaced ballasts. Lighting measures were installed in common areas only (e.g., lobbies, hallways, stairwells, laundry rooms); the impacts were measured on the commercial house meters.

The SCL evaluator also created files with detailed data on the square footage of each building-shell measure installed, R-values of insulation before and after retrofit, U-values of installed windows, and number of showerheads installed. In particular, building-specific engineering savings were projected for the installation of the following measures:

- High-efficiency windows,
- Wall insulation,
- Ceiling insulation,
- Under-floor insulation,
- Efficient-flow showerheads, and
- High efficiency lighting.

Projections of expected savings from the installation of low-flow showerheads were derived from Multifamily Conservation Program records and a study on savings from efficient-flow devices completed by Seattle City Light in conjunction with the Bonneville Power Administration.[3] In particular, savings per unit for each building were derived as the product of the average number of showerheads per unit multiplied by the average savings per showerhead (200 kWh). Other hot water Program actions (such as water heater thermostat adjustments) are not reflected in the engineering projections due to lack of sufficient documentation.

The engineering projections for savings from installing high-efficiency lighting measures were developed from program records by the SCL evaluator and a consulting engineer. The calculations are based on fixture counts by previous wattage, replacement wattage (lamps and ballasts), and specified operating hours (reported or by judgment). Lighting measures were installed in common-areas only, presumably measured on house meters where present. Other lighting Program actions (such as advice on the operation of existing lighting controls) are not reflected in the engineering projections due to lack of sufficient documentation.

---

[3] Hickman, Curtis, EFFICIENT SHOWERHEAD AND FAUCET AERATOR METERING STUDY: MULTIFAMILY RESIDENCES, by SBW Consulting, Inc., for Bonneville Power Administration, Portland, Oregon, October 1994.

Appendix A to this report provides information about the equations used to calculate engineering projections of expected energy savings from thermal shell measures, based on pre-existing building and program measure characteristics. Table 2-E describes the construction characteristics behind each baseline R-value used in the calculation of engineering projections for savings.

Table 2-E: Assumed R-Values of Building Construction Baseline[4]

Shell Element	Base R Value	Base Construction Characteristics	
Windows	0.91	Flat glass 1/8” (U= 1.10)	0.91
Walls	4.10	Inside air film (still air)	0.68
		1/2” Gypsum board	0.45
		3-1/2” Air gap	1.01
		25/32” Wood sheath	0.98
		Wood bevel siding, lapped	0.81
		Outside air film (15 mph wind)	0.17
Ceiling	3.80	Inside air film (still air)	0.61
		3/4” Acoustic tile	1.78
		1/2” Gypsum board	0.45
		Building paper	0.06
		Outside air film (still air), attic gap	0.85
Floor	3.60	Inside air film (still air)	0.92
		3/4” Hardwood floor	0.68
		Vapor permeable felt paper	0.06
		25/32” Wood subfloor	0.98
		Outside air film (still air), crawl space gap	0.92

The pre- and post-installation conditions of each building reflect changes in insulation levels for each of the shell measures (new windows plus ceiling, floor, and wall insulation). Seattle City Light program and engineering staff provided the assumed baseline R-values. The added R-values from program measures were reported in program records by Utility field staff.

Buildings qualified for window retrofits had single-paned windows, assumed to have a U-value of about 1.1. Four features characterize the double-paned replacement windows: frame material (aluminum, wood, or vinyl), glass surface (plain glass or low-emissivity film), the distance between panes (3/8”, 1/2”, 5/8”, or 3/4”), and the gap fill gas (air or argon). Aluminum windows may also have a special thermal break installed between the panes. Table 2-F provides the assumed U-values assigned to windows with each combination of characteristics observed, to calculate engineering projections of savings from program participant buildings.

---

[4] ASHRAE HANDBOOK OF FUNDAMENTALS: 1972, as cited in, Riordan, Michael, “Building Heat-loss,”, ENERGY CONSERVATION, pp. 16-17; adapted in part from Anderson, Bruce with Michael Riordan, THE SOLAR HOME BOOK.

Where U-values were missing from program records, the annual mode value was substituted, as follows: Cohorts A to E, 0.75; Cohort F, 0.60; and Cohort G, 0.50.

The manufacture of window products advanced considerably during the decades of the 1980s and 1990s. Advances have included new frame materials and designs, warm edge-spacers between multiple glazings, low-conductance gas fills, and low-emissivity glass coatings.[5] Since the time when these U-factors were specified for the longitudinal impact analysis, new factors have become available based on revised laboratory testing procedures. However, the values specified in Table 2-F should be used when projections are made based on this study's findings and realization rates.

Table 2-F: Assumed U-values of Program Replacement Windows

Frame	Gap Fill	Glass	3/8”	1/2”	5/8”	3/4”
Aluminum	Air		0.81	0.75	0.69	0.63
Aluminum	Air	Thermal Break	—	0.65	0.59	—
Aluminum	Argon		0.71	0.65	0.59	—
Aluminum	Air	Low-E film	—	0.60	—	—
Vinyl	Air		—	0.60	0.54	0.48
Wood	Air		0.60	0.55	0.49	—
Aluminum	Argon	Low-E film	—	0.50	—	—
Vinyl	Argon		—	0.50	0.44	0.38
Vinyl	Argon	Low-E film	—	0.35	0.35	0.33
Wood	Argon	Low-E film	—	0.35	—	—

Windows lose indoor heat during cold weather by a combination of conduction, convection, and long-wave radiation. The U-value (or now, U-factor) represents the total heat transfer through the glazing and solid frame by these mechanisms. Heat transfers due to a temperature difference between the home interior and the outdoor side of a window. When the U-value is reduced, less energy is transmitted under a given set of inside and outside temperatures. Windows also are subject to solar heat gain. This occurs when solar radiation strikes the window glazing. Solar heat gain can partially off-set heat losses during cold weather.

Energy is also transferred when air leaks through cracks in and around the window assembly. Air moves through the window due to temperature and pressure differences between interior and outside. Air

[5] *NFRC Certified Products Directory*, Fifth Edition, National Fenestration Rating Council, Incorporated, November 1995.

leakage can take the form of infiltration (into the building) and exfiltration (out of the building). Air leakage has a smaller energy impact than does U-value, and may change over time as window seals and caulk physically wear out.

During the early and mid-1980s, windows installed by the Multifamily Conservation Programs typically had aluminum frames, and sometimes had thermal breaks between glazings. New insulating frame materials such as all-vinyl and wood-vinyl combinations reduce frame heat transfer. Insulating spacers between glazing layers (thermal breaks) are key. These new materials also reduce potential condensation problems, which occur when cold surfaces meet moisture-laden air.

Early aluminum windows used air to fill the gap between multiple glazings. However, other non-toxic gases such as argon have lower thermal conductivities. Argon-fills became dominant by the early 1990s as manufacturers strove to reduce window U-values. Low-emissivity coatings are clear to visible light but are highly reflective in the infrared portion of the light spectrum. A low-e coating on the glazing reduces radiative heat loss from the building interior. (Spectrally selective coatings can also reflect back outside the infrared portion of sunlight while transmitting visible daylight, thus controlling solar heat gain.) Low-e coatings also became prevalent by the early 1990s. In 1997, virtually all windows installed by the Multifamily Conservation Programs were vinyl-framed, argon-filled double-pane windows with a low-e coating.

Table 2-G summarizes by Cohort the average engineering projections of savings for each measure type for the treated multifamily buildings in this longitudinal study. High efficiency windows are projected to save from 755 kWh per unit in Cohort C (1988 participants) up to 1,264 kWh per unit in Cohort G (1992 participants). Wall insulation is rarely applied, with projections of savings that vary broadly from 124 kWh to 1,192 kWh per unit. Ceiling insulation is also infrequent, with savings projections ranging from 273 kWh to 628 kWh per unit. Floor insulation, when added, is projected to supply 673 kWh to 996 kWh per unit in savings. Common-area lighting is found more commonly, with savings projected at 515 kWh to 613 kWh per unit. Efficient-flow showerheads were also a common measure in these years of the Multifamily Programs, with savings projected at 200 kWh per unit when applied.

The overall effect of these projections is provided as a weighted average annual kilowatt-hours per residential unit. This average rises from about 1,700 kWh in Cohort C to about 1,900 kWh in Cohorts D through F (1989-1991 participants), hitting a high of 2,000 kWh per unit in Cohort G (1992 participants). The major source of this increase in engineering projections is the changing technology of window retrofits.

Table 2-G: Average Engineering Projections of Annual Electricity Savings by Cohort, Standard-Income Buildings (kWh in buildings having estimates)

Mean kWh per Unit *(Std. Error) N Cases*	Cohort C	Cohort D	Cohort E	Cohort F	Cohort G	Average for All Cases
High Efficiency	755	764	861	1,085	1,264	921
Windows	*(128) 33*	*(78) 32*	*(109) 42*	*(138) 54*	*(119) 37*	*206*
Wall	124	429		1,192		21
Insulation	*(0) 1*	*(735) 3*		*(131) 2*		*206*
Ceiling	307	628	273	285	407	57
Insulation	*(254) 8*	*(462) 5*	*(315) 3*	*(289) 6*	*(311) 8*	*206*
Floor	843	878	996	673	876	236
Insulation	*(307) 11*	*(306) 16*	*(190) 15*	*(247) 15*	*(613) 4*	*206*
Efficient-Flow	200	196	199	200	200	182
Showerheads	*(0) 31*	*(6) 32*	*(1) 42*	*(0) 53*	*(1) 30*	*206*
High Efficiency	515	613	566	561	589	373
Lighting	*(144) 25*	*(208) 19*	*(113) 30*	*(109) 35*	*(157) 26*	*206*
kWh per Unit	1,547	1,788	1,757	1,823	2,024	1,790
Weighted Avg. (cases)	*37*	*34*	*42*	*56*	*37*	*206*

2.2.5 FOLLOW-UP MEASURES SURVEY

Seattle City Light conducted a telephone survey in winter 1995-1996. The subjects were buildings that participated in all three Multifamily Conservation Programs during the years 1986-1992, along with comparable groups of nonparticipants. Seattle City Light's evaluator designed the survey instrument, in conjunction with consulting staff from Regional Economics Research, Inc. The Measures Survey was implemented with owners and managers of 435 buildings, of which 343 were Participants in the Multifamily Conservation Programs during the years 1986 through 1992, and 92 were comparable Nonparticipants. A consulting firm, Hagler Bailly Consulting, Inc. (successor to HBRS, Inc.), conducted the survey interviews.

Seattle City Light provided a building sample listing to the survey fielding consultant. It contained telephone numbers for building owners or property managers. The participant sample represented 72% of all the buildings weatherized in 1986-1992 by Seattle City Light's Multifamily Conservation Program for standard-income buildings, and was 59% of buildings weatherized in 1991-1992 by the SCL-funded Low-Income Multifamily Program, operated by the Department of Housing and Human Services (DHHS). All projects (100%) served in 1993 by the Multifamily Common-Area Lighting Program, some with multiple buildings per site, were surveyed. (Energy savings impacts for the Common-Area Lighting group are not addressed in this longitudinal study.) Across the three participant groups, the buildings sampled represented 71% of those completing installation of program measures during the study years.

Control groups were defined for each sub-population of Participants: Standard-Income, Low-Income, and qualified for Common-Area Lighting measures only. Nonparticipants were drawn from the control groups designed for the longitudinal impact study. All nonparticipants in the standard-income category were future participants on program waiting lists. Nonparticipants in the low-income and common-area lighting categories were drawn by random sampling from the county tax assessor's database, and verified for matching attributes. The low-income control buildings were sampled from neighborhoods with high-proportions of low-income residents. The common-area lighting control buildings were sampled from condominiums with attributes similar to program participants. A consultant (BRACO Consulting Services, Inc.) was engaged, under the direction of the utility evaluator, to develop the low-income and common-area lighting control groups, and to verify the key contact information.

Overall, 76% of the contacts in the sampling frame completed interviews. The single group with a noticeably lower response rate was the control sample drawn to represent nonparticipants in the Multifamily Common-Area Lighting Program. As many of these buildings are condominiums, it was more difficult to locate suitable and knowledgeable contact persons among home owner association officers and property management staff.

Table 2-H: Multifamily Measures Survey Response Rates

	Standard-Income Whole-Building		Low-Income Whole-Building		Common Area Lighting Only		Over-All
	Participants	Non-Participants	Participants	Non-Participants	Participants	Non-Participants	Total
Starting Sample	**239**	**32**	**65**	**28**	**39**	**32**	**435**
No Valid Listing	1	0	0	2	0	2	5
Refusal	6	5	4	3	1	2	21
Unable to Contact (7 attempts)	40	3	10	2	11	13	79
Completions	**192**	**24**	**51**	**21**	**27**	**15**	**330**
Response Rate	80%	75%	78%	75%	69%	47%	76%

The sample frame for each participant group was drawn from all buildings completing installation and inspection of program measures by the end of each study year, as documented in the ENERGY CONSERVATION ACCOMPLISHMENTS REPORT: 1977-1995. The combined participant sample frames contained 483 buildings, of which 71% were drawn for the impact evaluation sponsoring the Measures

Survey. Interviews were completed with 270 buildings, representing 79% of the sample frames and 56% of the original participant groups.

Sampling bias in the Measures Survey derives from two major sources. First are the 61 buildings for which an owner or property manager could not be reached for an interview (13% of the original population of program completions). Second are the 140 buildings not drawn into the sampling frames for a variety of reasons that made them unsuitable for the impact evaluation or impossible to contact for this survey (29% of the original population). Some reasons for excluding buildings were: electric master-meters, commingling house and tenant energy consumption; atypical construction types (e.g., concrete high-rise); multiples of buildings per project site (handled by sub-sampling); and change of ownership or management, due to death or property sale, where no knowledgeable party could be located.

The purpose of the Measures Survey was to collect data on changes at the residences that influence the use of energy. In particular, the questions related to the acquisition, replacement, and disposal of energy using equipment, changes in occupancy and building square footage, and the timing of these actions. The questions covered actions that may have affected the tenant-dwelling meters as well as the common-area meters. The collected data included:

- Change in the number of residential units at the multifamily building or in site square footage
- Changes in common-area energy use functions
- Acquisition, replacement, or removal of appliances:
  - Clothes washers, clothes dryers, dishwashers, water heaters (laundry and tenant), and other major electricity-using appliance
- Addition or removal of program-related measures:
  - High-efficiency windows; wall, ceiling, and floor insulation; efficient-flow showerheads; and common-area lighting (interior and exterior)

2.3 Research Design

The basic quasi-experimental research design for this longitudinal study addresses each program, meter type, and cohort independently. It also pools cohorts in several analyses, according to the following groupings.

Program Pilot Years: Cohorts A and B (measures installed in 1986-1987)

Program Maturity: Cohorts C to G (measures installed in 1988-1992)

- ***Early Window Technology:*** Cohorts C to E (1988-1990)
- ***New Window Technology:*** Cohorts F and G (1991-1992)

Several methods were used to calculate savings, each supplying adjustments for factors incompletely accounted for by the use of nonparticipant control groups and weather normalization. The results were compared across methods to demonstrate the most economic approach to estimating energy savings. These methods included the following:

Gross Change Scores: Post-installation minus pre-installation annual energy use

Net Change Scores:

- **Net Method I Savings:** Participant gross savings minus nonparticipant gross savings
- **Net Method II Savings:** Analysis of covariance in savings scores between participants and nonparticipants adjusting for differences in pre-period energy use levels, for each cohort and in each post-installation year (up to five)
- **Net Method III Savings:** Net Method II for pooled cohorts across each of five post-installation years

Regression Analyses: Multiple linear regression incorporating analysis of covariance due to differences in pre-period energy use levels, along with annual effects, engineering projections of expected savings, and post-period changes in appliance holdings or the building shell; using

- ***Treatment Condition:*** Dummy variables for each of five post-years (categorizing participation as yes/no)
- ***Engineering Projections:*** Building-aggregate and measure-specific values replicated for each of five post-years in place of the treatment condition “yes” values (scaling the expected effect of participation)
- ***Building Change Variables:*** Treatment condition dummies or engineering projections paired with dummy variables to indicate specific post-period changes in appliance holdings or the building shell, for particular participant and nonparticipant buildings (segregating effects from external factors)

Table 2-I: Data Years and Research Designs

Analysis Designs		**Calendar Year**									**Post-Period**						
	Cohorts	**85**	**86**	**87**	**88**	**89**	**90**	**91**	**92**	**93**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Data Source Years	A	P	M	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	B	P		M	X	X	X	X	X	X	X	X	X	X	X	X	
	C			P	M	X	X	X	X	X	X	X	X	X	X		
	D				P	M	X	X	X	X	X	X	X	X			
	E					P	M	X	X	X	X	X	X				
	F						P	M	X	X	X	X					
	G							P	M	X	X						
	N			X	X	X	X	X	X	X							
Annual Consumption	A,B	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X
PRE, POST kWh	C,D,E			X	X	X	X	X	X	X	X	X	X	X	X		
	F,G						X	X	X	X	X	X					
	N			X	X	X	X	X	X	X							
Gross Savings Score	A,B			X	X	X	X	X	X	X	X	X	X	X	X	X	X
(POST - PRE) –	C,D,E					X	X	X	X	X	X	X	X	X	X		
	F,G								X	X	X	X					
	N				X	X	X	X	X	X							
Net Savings Score	A,B			*	*	*	*	*	*	*	*	*	*	*	*	*	*
(PART– - NPART–)	C,D,E					X	X	X	X	X	X	X	X	X	X		
Net Method I	F,G								X	X	X	X					
	N																
Post 1 - 5 Ancovas	A,B																
	C,D,E					X	X	X	X	X	X	X	X	X	X		
(PART– vs NPART–)	F,G								X	X	X	X					
Net Method II	N					X	X	X	X	X							
Pooled Year 1 Ancova	A,B			X	X	X	X	X	X	X	X						
(PART– vs NPART–)	C,D,E					X	X	X	X	X	X						
Net Method III	F,G								X	X	X						
	N				X	X	X	X	X	X							
Pooled Years & Cohorts	A,B			*	*	*	*	*	*	*	*	*	*	*	*	*	*
Covariate Regressions	C,D,E					X	X	X	X	X	X	X	X	X	X		
(PARTICIPATN DUMMIES)	F,G								X	X	X	X					
(SINGLE ENG EST)	N			X	X	X	X	X	X	X							
(MULTIPLE ENG ESTS)																	

2.4 Gross & Net Savings Scores

2.4.1 OVERVIEW

Several methods were established to estimate programmatic electricity savings. The basic design is quasi-experimental using methods of partial control for extraneous effects. Comparisons are made between program participants (treatment group) and nonparticipants (control group) to isolate the changes in electricity consumption that can be attributed to the influence of the program. These methods present a picture that progressively decreases known sources of error variance in electricity use change over time for the study groups.

2.4.2 GROSS SCORES METHOD

The Gross Scores Method calculates the change in energy use from pre-period to each post-period for participating buildings. This method also first introduces an adjustment for annual variations in weather conditions across the study period. Weather affects primarily the space heating and secondarily the water heating portions of electricity use. The gross tenant meter change scores are compared without and with a weather-normalization adjustment. House meter scores are not weather normalized; although some lighting use is seasonal, it follows the schedule of solstices and equinoxes rather than outdoor temperatures.

Pre- to post-period electricity use gain scores were computed for each building. As noted before, each score represents a building centroid expressed as kilowatt-hours per average dwelling unit.

Eq. 2-2 $$GROSS\ SAVINGS = ANNUAL\ kWh_{post-period} - ANNUAL\ kWh_{pre-period}$$

where:

ANNUAL kWh = annual per building per unit metered energy consumption

2.4.3 NET SCORES, METHODS I–III

2.4.3.1 Net Scores Method I

The Net Scores Method I introduces a control group to adjust for changes across the study period due to economic and social effects in a presumably similar group of owners and tenants. These may be effects of a changing economy and electric rates, changing demographics and living habits, tenant turnover, changes in ownership, and conservation actions taken by tenants or owners/managers apart from the building's program participation. The gross tenant meter scores of both participants and nonparticipants were compared without and with a weather-normalization adjustment.

Eq. 2-3 $NET\ SAVINGS = GROSS\ SAVINGS_{participants} - GROSS\ SAVINGS_{non\text{-}participants}$

Student's t tests were also performed to assess the equivalence of pre-period energy consumption between the participant and nonparticipant groups; to judge the significance of within groups pre-to-post changes; and to decide whether any between group gain scores differences provided strong evidence of programmatic net electricity savings. Where participant and nonparticipant variances were not equivalent, the t-test for separate variances was selected; otherwise, the pooled variance t-test was applied.

2.4.3.2 Net Scores Method II

Net Method II introduces a correction for the correlation of pre- to post-period energy consumption and the contribution of this correlation to the error variance. For each post-period separately, the building scores of participants and nonparticipants are regressed against a program participation indicator (dummy code) and the pre-period score (covariate). This correction is performed because the participant (treatment) and nonparticipant (control) groups are not precisely equivalent. They were not randomly selected, are not homogeneous, and were not matched; the sizes of treatment and control groups are nonequivalent as well. Buildings also have intrinsic weather sensitivities (cf. reference temperatures) which are reflected in the pre-participation energy use level. Extraneous variance is controlled by the analysis of covariance in pre-period energy use patterns in this method (and in later design steps by introducing some specific extraneous factors as independent variables). This simple linear regression has the following specification:

Eq. 2-4 $ANNUAL\ SCORE_{post} = \alpha + \beta_1 ANNUAL\ SCORE_{pre} + \beta_2 PART$

where:

PART is a dummy-coded indicator variable = 1 if Participant, 0 if Nonparticipant

The coefficient on *PART* (that is, ϑ_2) is an estimate of net energy savings. The other terms (I and ϑ_1) represent the portion of post-period energy consumption that is correlated with pre-period baselines.

As in the previous study of these programs (Okumo 1991), preliminary results from the Net Method I analysis indicated that the treatment and control groups varied in their pre-period electricity consumption. The gain score approach of Net Method I assumes that pre-period and post-period scores bear a one-to-one relationship, which an initial examination demonstrated was not the case. Analysis of covariance allows for a degree of correlation and corrects for varying pre-period group scores. Post-period consumption can be expected to be highly correlated with pre-period consumption, more so than with any other building characteristic. The analysis of covariance approach is expected to provide a better estimate of programmatic energy savings than either the Gross Score Method or Net Scores Method I.

The sampling error resulting from an analysis of covariance also differs from the standard error calculated from the ordinary net gain score approach. The standard error term from the gain score approach includes all variance from the initial score, final score, and their intercorrelation; while the analysis of covariance error includes only the latter two forms of variance. Hence the covariance method is more sensitive and reduces further the degree of error in change estimates (McNemar 1969).

2.4.3.3 Net Scores Method III

Net Method III is a variation on Net Method I that summarizes the savings results in the first post year across clusters of cohorts. It does not incorporate the pre-period covariate score as in Net Method II. Buildings in each pooled analysis are represented by a first-year gross savings score and a dummy-coded indicator for program participation. This simple linear regression has the following specification:

Eq. 2-5 $$GROSS\,SAVINGS_{post1} = \alpha + \beta_1 PART$$

where:

PART is a dummy-coded indicator variable = 1 if Participant, 0 if Nonparticipant

2.5 Regression Analysis

The Seattle City Light evaluator established the general regression models in the research design, while consulting staff from Regional Economics Research, Inc. developed the specific multivariate linear models implemented in the longitudinal impact regression analyses. Multiple linear regression analysis was used to continue the analysis of covariance across multiple observations per building. The following Regression Methods summarize the savings results across post-period years and groups, incorporating the variance corrections of Net Method II.

2.5.1 OVERVIEW

Energy savings in the first five years after measure installation were estimated separately for Standard-Income Tenant Meters and House Meters, using multivariate linear regression analysis. In particular, two modeling approaches were used to estimate energy savings from participation in the Multifamily Conservation Program, as described below.

The unit-average values for annual energy consumption were weather-normalized for the aggregate of tenant meters in each building. Each building was represented by multiple cases, one for each post-period after measure installation. That is, Cohort C buildings were organized as five cases, one for each post-period, while Cohort G cases only appeared once for the first-post-year. The dependent variable was specified as post-period energy consumption, while independent variables included pre-period energy consumption as a covariate, along with other variables specified for each model. The aggregate of house meters in each building was averaged over the number of tenant units, but was not weather-normalized. For purposes of this study, two types of model were specified: Participation Models, and Engineering Projection Models.

Participation Model. This model type utilizes billing records, weather data, participant file information, and data derived from the follow-up survey. This general form of the model was used to estimate Tenant-Meter and House-Meter savings. One participation dummy variable appeared in the model for each of the five post-installation years. These variables were initialized as 0 (zero) for all Participant and Nonparticipant cases. Then the variables were reset to 1 (one) under the conditions specified below in Table 2-J; Nonparticipants remain coded as 0 (zero) for all Post-Year variables.

Table 2-J: Conditions for Recoding Participation Dummy Variables from Zero

Data Year by Variable	1989	1990	1991	1992	1993
Post 1	C = 1	D = 1	E = 1	F =1	G =1
Post 2	—	C = 1	D =1	E =1	F =1
Post 3	—	—	C = 1	D =1	E =1
Post 4	—	—	—	C =1	D =1
Post 5	—	—	—	—	C =1
Post 1-5	N=0	N=0	N=0	N=0	N=0

Eq. 2:6 $$ANNKWH_{it} = f\left(BASEKWH_{i}, \Delta AF_{it}, \Delta BC_{it}, \Delta OCC_{it}, \Delta CPR_{it}, PART_{it}\right)$$

where:

Δ_b = change operator for levels in period *t* minus levels in the pre-participation year (base year)

ANNKWH = annual weather normalized consumption

BASEKWH = pre-participation year (base-year) weather normalized consumption

AF = appliance features

BC = building characteristics

OCC = occupancy

CPR = conservation practices

PART = dummy coded participation indicator (treatment) variable = 1 after participation; 0 otherwise

Engineering Projection. This model type modifies the Participation Model to include data on engineering projections of savings from the program conservation measures installed. The engineering projections are positive values that reflect the expected change relative to the pre-participation baseline year for each Cohort. Models using engineering projections are calculated for House Meters (from common-area lighting measures) and for Tenant Meters (from an aggregate of effects expected from all shell measures, including insulation, windows, and showerheads). A special form of the model is applied only to Tenant Meters to disaggregate the effects by individual measure types. The engineering projection values (interval variables) are substituted into the place of the Participation Dummy values (dummy variables) described above. The advantage of this substitution is that the coefficient on the engineering variables can be characterized as a *realization rate* for projections of potential savings. The general model can be specified as

Eq. 2:7

$$ANNKWH_{it} = f\begin{pmatrix} BASEKWH_i, \Delta AF_{it}, \Delta BC_{it}, \Delta OCC_{it}, \Delta CPR_{it}, \\ PART_{it}, EINS_{it}, EWIN_{it}, ELOWFL_{it}, ELITE_{it} \end{pmatrix}$$

where:

Δ_b = change operator for levels in period *t* minus levels in the pre-participation year (base year)

ANNKWH = annual weather normalized consumption

BASEKWH = pre-participation year (base-year) weather normalized consumption

AF = appliance features

BC = building characteristics

OCC = occupancy

CPR = conservation practices

PART = participation indicator variable = 1 after participation; 0 otherwise

EINS = engineering projection of energy savings from increases in wall, ceiling and floor insulation

EWIN = engineering projection of energy savings from installation of energy-efficient windows

ESHWR = engineering projection of savings from installation of low-flow showerheads

ELITE = engineering projection of energy savings from installation of energy-efficient lighting measures

The engineering projections of savings are included in the specification to disaggregate savings across type of conservation measure. The engineering projections are positive and relative to the pre-participation or base-year for each program year. The coefficient on these engineering projections can be characterized as a realization of engineering potential savings projections. Engineering Change Form models were used to develop tenant and house meter savings.

Both types of models were also supplemented by information from the Measures Survey, with the aim of adjusted for unusual conditions that may have caused particular buildings to be *outliers*, or to confound the attribution of changes to programmatic effects. This is done because any changes in consumption from one year to the next can be characterized as a function of participation in the Multifamily Conservation Program, and engineering projections of potential savings, as well as changes in appliance stocks and features, changes in building characteristics, fluctuations in occupancy rates, and changes in conservation practices not associated with the Multifamily Conservation Program. Supplemental forms of the models incorporated only the few variables from the Measures Survey found to have explanatory power beyond program participation effects.

2.5.2 MODEL ESTIMATION FOR STANDARD INCOME TENANT METERS

The general forms of the two savings models presented above were used to estimate seven versions of savings for standard income tenant meters. The model versions differ in variable specifications and in the samples used to estimate the models. The seven estimated model versions are:

- Model I: Participation Model Full Sample, Cohorts A through G
- Model II: Participation Model Sub-sample with Engineering Projections
- Model III: Engineering Model Sub-sample with Engineering Projections
- Model IV: Measure Detail Model Sub-sample with Engineering Projections
- Model V: Participation Model Sub-sample with Engineering Projections plus Completed Follow-up Measures Survey
- Model VI: Engineering Model Sub-sample with Engineering Projections plus Completed Follow-up Measures Survey
- Model VII: Measure Detail Model Sub-sample with Engineering Projections plus Completed Follow-up Measures Survey

Models I, II, III, V, and VI were estimated for each individual Cohort C through G, and in a form that pooled all Cohorts in the sample (Model I) or sub-sample. Separate analyses were conducted for House Meters and for Tenant Meters (for which the pooled forms included Cohorts A and B as well). The models for House Meters used a single engineering projection calculated for the common-area lighting measures installed. Models IV and VII were estimated only for the Tenant Meters, because the engineering projections for the shell measures were originally calculated by measure type (windows, wall insulation, ceiling insulation, under-floor insulation, and showerheads) and could be disaggregated for these models.

These seven models are discussed below; a more detailed presentation may be found in Appendix A.

Model I, Participation Model: Full Sample, Cohorts A through G. Specification of the level form model for standard income tenant meters uses the product of a set of pre-/post-year dummy variables ($PYEAR1_{it}$ -$PYEAR5_{it}$) and a binary participation variable ($PART_i$) to indicate first- through fifth-year post participation. The estimated parameters on these binary variables (β_2, β_3, β_4, β_5, and β_6,) are the estimates of first- through fifth-year program savings. Model I was estimated using the entire sample of Standard-Income Participants and the full sample of Nonparticipants.

Model II, Participation Model: Sub-sample with Engineering Projections of Savings. The specifications presented above are used as for Model Version I. However, the model is estimated for the sub-sample of Participant buildings with engineering projections of savings and the full sample of Nonparticipants.

Model III, Engineering Model: Sub-sample with Engineering Projections of Savings. The major difference in this model from Models I and II is that the pre-/post-participation binary variables are replaced with prior engineering projections of savings. This variable enters the model as the total engineering projection of savings across all end-uses and measure types. The coefficients on the engineering savings terms (α_2, α_3, α_4, α_5, and α_6,) may be interpreted as *realization rates* in each year for the aggregate engineering projection of savings. This version of the model was estimated for the sub-sample of Standard-income Participants having available engineering projections of savings plus the full sample of Nonparticipants.

Model IV, Measure Detail Model: Sub-sample with Engineering Projections (First Year Savings Only). The major difference in this model from Model III is that first-year savings are estimated by measure type for the Tenant Meter aggregates only. This version of the model was estimated for the sub-sample of Standard-income Participants having available engineering projections of savings plus the full sample of Nonparticipants. The coefficients on the engineering projections of end-use savings (δ_4, δ_5, δ_6, and δ_7) may be interpreted as *realization rates* in the first post-year for each measure's engineering projection of savings. Only first-year savings were estimated using this version, since extending the model specification to multiple years by measure type would have introduced problems with the degrees of freedom. This version of the model was estimated for the sub-sample of Standard-income Participants having available engineering projections of savings plus the full sample of Nonparticipants.

Model V, Participation Model: Sub-sample with Engineering Projections plus Completed Measures Survey. This model is similar to Models I and II. However, variables to control for other non-program changes at the site are introduced into the model. These variables were developed from information gathered in the follow-up survey on post-installation changes in buildings, appliances, and occupancy. This version of the model was estimated for the sub-sample of Standard-income Participants having available engineering projections of savings as well as a completed Measures Survey, plus the full sample of Nonparticipants.

Model VI, Engineering Model: Sub-sample with Engineering Projections plus Completed Measures Survey. This model is similar to Model III. However, variables to control for other non-program changes at the site are introduced into the model, as in Model V. This version of the model was estimated for the sub-sample of Standard-income Participants having available engineering projections of savings as well as a completed Measures Survey, plus the full sample of Nonparticipants.

Model VII, Measure Detail Model: Sub-sample with Engineering Projections plus Completed Measures Survey (First Year Savings Only). This model is similar to Model IV. However, variables to control for other non-program changes at the site are introduced into the model, as in Models V and VI. The coefficients on the engineering projections of end-use savings (δ_4, δ_5, δ_6, and δ_7) may be interpreted as *realization rates* in the first post-year for each measure's engineering projection of savings. Only first-year savings were estimated using this version, since extending the model specification to multiple years by measure type would have introduced problems with the degrees of freedom. This version of the model was estimated for the sub-sample of Standard-income Participants having available engineering projections of savings as well as a completed Measures Survey, plus the full sample of Nonparticipants.

2.5.3 MODEL ESTIMATION FOR STANDARD INCOME HOUSE METERS

The general forms of the two savings models presented above were used to estimate five versions of savings for standard income house meters. The Model Versions differ in model specification and/or in the sample used to estimate the models. The five estimated model versions are:

- Model I: Participation Model Full Sample, Cohorts C through G
- Model II: Participation Model Sub-sample with Engineering Projections
- Model III: Engineering Model Sub-sample with Engineering Projections

- Model V: Participation Model Sub-sample with Engineering Projections plus Completed Follow-up Measures Survey
- Model VI: Engineering Model Sub-sample with Engineering Projections plus Completed Follow-up Measures Survey

These five models are discussed below; a more detailed presentation may be found in Appendix A.

Model I, Participation Model: Full Sample, Cohorts C through G. Specification of the level form model for standard income house meters uses the product of a set of pre-/post-year dummy variables ($PYEAR1_{it}$ -$PYEAR5_{it}$) and a binary participation variable ($PART_i$) to indicate first- through fifth-year post participation. The estimated parameters on these binary variables (β_2, β_3, β_4, β_5, and β_6,) are the estimates of first- through fifth-year program savings. Model I was estimated using the entire sample of Standard-Income Participants and the full sample of Nonparticipants.

Model II, Participation Model: Sub-sample with Engineering Projections of Savings. The specifications presented above are used as for Model Version I. However, the model is estimated for the sub-sample of Participant buildings with engineering projections of savings and the full sample of Nonparticipants.

Model III, Engineering Model: Sub-sample with Engineering Projections of Savings. The major difference in this model from Models I and II is that the pre-/post-participation binary variables are replaced with a prior engineering projection of savings. This variable enters the model as the engineering projection of savings from common-area lighting measures. The coefficients on the engineering savings terms (α_2, α_3, α_4, α_5, and α_6,) may be interpreted as *realization rates* in each year for the engineering projection of savings. This version of the model was estimated for the sub-sample of Standard-income Participants having available engineering projections of savings plus the full sample of Nonparticipants.

Model V, Participation Model: Sub-sample with Engineering Projections plus Completed Measures Survey. This model is similar to Models I and II. However, variables to control for other non-program changes at the site are introduced into the model. These variables were developed from information gathered in the follow-up survey on post-installation changes in buildings, appliances, and occupancy. This version of the model was estimated for the sub-sample of Standard-income Participants having available engineering projections of savings as well as a completed Measures Survey, plus the full sample of Nonparticipants.

Model VI, Engineering Model: Sub-sample with Engineering Projections plus Completed Measures Survey. This model is similar to Model III. However, variables to control for other non-program changes at the site are introduced into the model, as in Model V. This version of the model was estimated for the sub-sample of Standard-income Participants having available engineering projections of savings as well as a completed Measures Survey, plus the full sample of Nonparticipants.

2.5.4 ESTIMATION RESULTS

Differences between Model I and Model II are due to the sample for which the model is being estimated. The cause of the difference in the estimated savings between Model II and Model III is more problematic. In particular, Model II may be influenced by self-selection problems and therefore may overstate the savings. Self-selection is characterized by participants who select themselves into a program and have a higher propensity to conserve energy than the nonparticipants used as a control group. In this case the self-selection might also reflect willingness to complete a survey interview; high response rates could mitigate this type of impact. Conversely, Model III may indicate that the engineering calculations over-estimate the savings. Or, savings may occur due to changes in behavior and equipment use that are not captured by the engineering calculations on equipment changed out. Given these differences, it would be desirable to further investigate the self-selection issue and to review engineering calculation methods. Further, the differences between Model V and Model VI may have the same explanation.

Differences across samples from Participants with and without Measure Survey results (Model II and Model III versus Model V and Model VI, respectively) are not attributable solely to the change in sample. In particular, variables gleaned from the survey related to Nonparticipants are included in the model. Including Nonparticipant variables that control for the independent installation of conservation measures covered by the program transforms coefficients into *gross savings* estimates as opposed to estimates of *net savings*, as in Models I-III.

Review of Methods

The analysis of longitudinal energy savings impacts begins with three savings score methods. These methods present a picture that progressively decreases known sources of error variance in electricity use change over time for the study groups. The Gross Scores method calculated the change in use, from pre-period to each post-period for participating buildings, to estimate program impacts. This method introduced an adjustment for annual variations in weather conditions across the study period, in the examination of Tenant Meter scores. The Net Method I Scores introduced a control group to adjust for changes due to economic, social, and behavioral effects. The Net Method II analysis introduced an additional correction for the correlation of pre- to post-period energy use in individual buildings. This method adjusted for unique, pre-existing building profiles that varied independently of subsequent program or external impacts.

The final element of this examination of net energy savings is to judge whether expected increases in energy savings in fact occurred among the 1991 and 1992 participants (represented by Cohort F and Cohort G). The cohorts are clustered into two groups, Cohorts A through E representing the program with early-technology windows, and Cohorts F plus G representing the program after Class 40 windows became the norm ($U \leq 0.40$).

Finally, in the analyses that follow in Chapters 4 and 5, unit weights are used to adjust the calculation of building means and standard errors (cf. Section 2.2.1, Research Methodology: Unit of Measurement). Table 2-K and Table 2-L provide the numbers of buildings and units contained in the basic data sets, from which the normalized weights are calculated.

Table 2-K: Number of Building Observations and Unit Weights: Gross Score & Net Methods by Program

N. Obs.	Standard-Income				Low-Income			
	Tenant Meters		House Meters		Tenant Meters		House Meters	
Cohorts	Bldgs.	Units	Bldgs.	Units	Bldgs.	Units	Bldgs.	Units
A	23	242	17	197	22	180	3	18
B	28	466	24	431	30	417	20	303
C	39	682	34	633	41	742	26	496
D	35	580	34	572	24	467	19	415
E	51	706	42	590	43	619	24	473
F	58	1,219	55	1,150	31	417	17	280
G	40	782	37	742	27	599	20	498
N	33	429	28	395	24	502	23	496
Total	307	5,106	271	4,710	242	3,943	152	2,979

Table 2-L: Number of Building Observations: Standard-Income Regression Methods

N. Obs.	Standard-Income Tenant Meters			Standard-Income House Meters		
Cohorts	*I*	*II, III, IV*	*V, VI, VII*	*I*	*II, III, IV*	*V, VI, VII*
A	23	23	15	17	2	0
B	28	28	22	24	12	0
C	39	37	19	34	25	17
D	35	34	26	34	19	14
E	51	42	29	42	30	21
F	58	56	38	55	35	25
G	40	37	25	37	26	14
N	33	33	26	28	28	28
Pooled	307	290	200	271	177	119

3. Descriptive Findings

This chapter presents basic descriptive data about the program participants:

- The mix of measures installed in each Standard-Income program year from 1986-1992, plus the current mix of measures in 1997;
- Changes in buildings and measures over the years subsequent to Standard-Income and Low-income program participation, as to building occupancy, house-meter equipment loads, and tenant-meter equipment loads;
- Annual energy consumption levels in each calendar year 1985-1993 for the four major data sources: Standard-Income Tenant Meters, Low-Income Tenant Meters, Standard-Income House Meters, and Low-Income House Meters; and,
- Annual energy consumption in the pre-participation year and each post-period for the four major data sources.

3.1 Measure Mix

Cohorts A to G installed program measures during the calendar years 1986 through 1992. The mix of measures installed in Standard-Income participant buildings during 1986-1992 is compared in Table 3-A to that of the most current program year, 1997. This information is also presented graphically in Figure 3-I and Figure 3-II. The changes over time in program measure mix are discussed here and in Chapter 5, where this information is used to generate up-to-date projections of programmatic energy savings. The Low-Income Multifamily Program kept abbreviated field-files that did not lend themselves to this type of analysis.

Table 3-A: Past and Current Mix of Measures in Standard-Income Program

Total Program Participants & Percent Installing Measure Type	A 1986	B 1987	C 1988	D 1989	E 1990	F 1991	G 1992	Now 1997
Buildings (projects)	23	28	39	35	51	58	40	77
Units	242	466	682	580	706	1,219	782	1,337
Windows	96%	93%	89%	94%	98%	96%	100%	100%
Insulation	52%	61%	38%	51%	35%	29%	32%	29%
Ceiling	*39*	*46*	*19*	*17*	*7*	*11*	*22*	—
Floor	*39*	*36*	*35*	*46*	*30*	*21*	*11*	—
Wall	*13*	*4*	*3*	*6*	*0*	*5*	*0*	—
Common-Area Lighting	9%	71%	68%	57%	70%	64%	70%	56%
Showerheads	57%	75%	84%	94%	100%	95%	81%	3%

The first thing one notices (Figure 3-I) is that the penetration of showerhead measures in the Standard-Income program increased from 1986 to peak at 100% in 1990, declined over the next two years, and dropped to nearly 0% in 1997. This adoption curve neatly reflects the saturation of high-efficiency showerheads through the Multifamily Conservation Programs and the Home Water Savers Program. The next important observation is that insulation and lighting penetrations have trended downward since the 1980s. Window measures reach virtually all program buildings, but lighting and insulation measures are much less frequently installed. The penetration of common-area lighting declined from 71% in 1987 to 56% in 1997—lower by 15%. Insulation penetration dropped more sharply, from 61% to 29%—lower by 32%. When insulation measures are broken out by building area, the incidence of wall insulation remains low (non-existent in 1990 and 1992). Ceiling and floor insulation rates vary by year but clearly declined over the seven study years, from 39% in 1986 to 11-22% in 1992. These declines in installation rates for non-window measures must modify expectations for consequent energy savings.

The savings expected from program measures were established by an earlier program evaluation of 1986 and 1987 participants (Cohorts A and B in this study), based upon prior research reported in Okumo (1991)[6] and Tachibana et al. (1997).That study found annual dwelling-area savings of 1,050 kWh per tenant unit and common-area savings of 520 kWh per unit (in buildings having house-meters and receiving lighting measures). Since 75% of buildings were observed to have house meters, the total savings per unit for 1988-1989 participants were expected to be 1,440 kWh per year.

---

[6] Okumo, Debra Laurent, THE MULTIFAMILY CONSERVATION PROGRAM: EVALUATION OF ELECTRICITY SAVINGS AND COSTS, Evaluation Unit, Energy Management Services Division, Seattle City Light, June 1991.

Figure 3-I: Mix of Measures Installed by Standard-Income Program, Cohorts A to G and Now (1997)

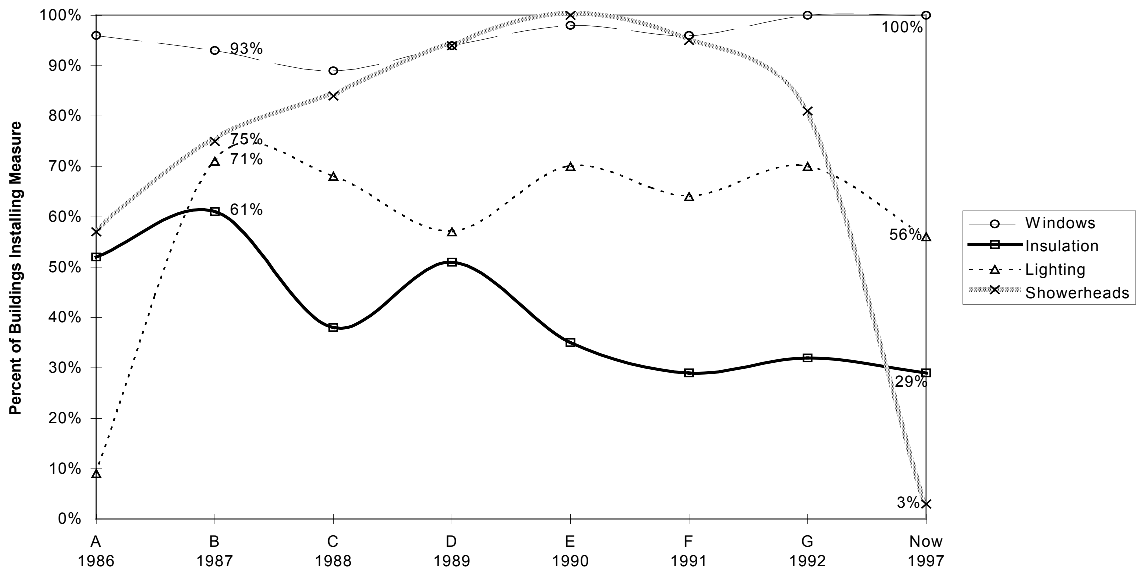
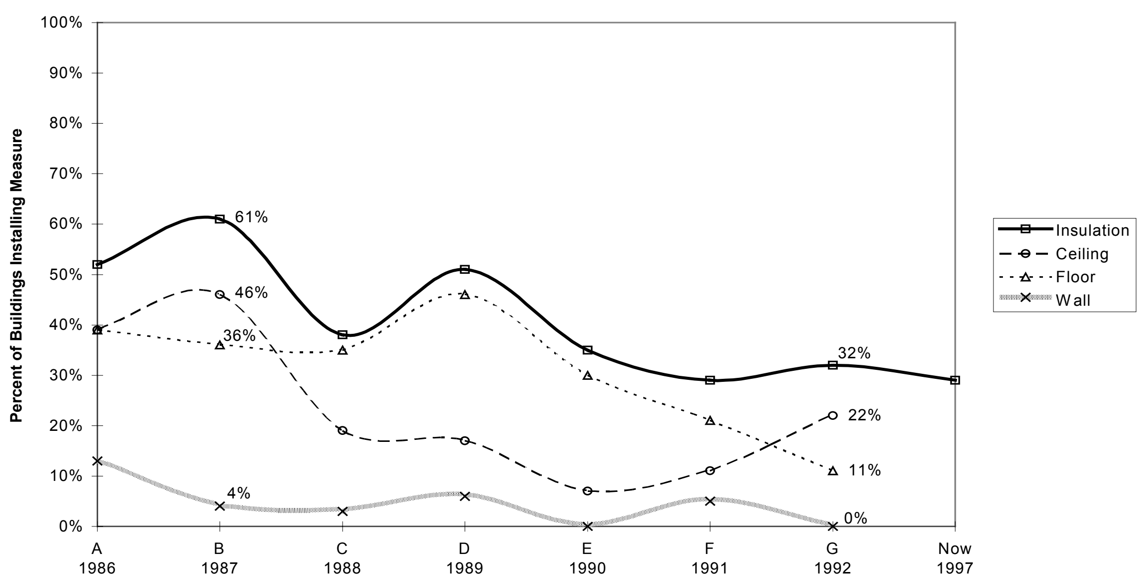


Figure 3-II: Insulation Measure Mix Installed by Standard-Income Program, Cohorts A to G and Now (1997)



In the report, ENERGY CONSERVATION ACCOMPLISHMENTS: 1977-1994[7], the penetration rate for Common-Area lighting was projected at 75% after 1987, hence savings were expected at 390 kWh per unit. Dwelling-Area space and water heat savings were expected to continue at 1,050 kWh per unit. New window technologies that reduce average U-values to ≤0.40 were expected to make incremental upward adjustments to Dwelling-Area savings after 1989.

Subsequent analysis of changes in window technology over the period 1986-1992 lead to the expectation that unit savings would be augmented by another 170 kWh in 1990, 365 kWh in 1991, and 440 kWh in 1992. These increments over the original savings observed from windows reflect increasing efficiency values of window products and a staged rate of adoption by program participants. The resulting total unit savings expected in these three years were 1,610 kWh (1990), 1,805 kWh (1991), and 1,880 kWh (1992). This analysis was performed by the Evaluation Unit and the Policy & Planning Unit of Seattle City Light, for program planning and load forecasting purposes.

Table 3-B: Expected Electricity Savings by Measure Category and Year

kWh / Unit *Penetration Rate*	**Windows**	***New Window Technol.***	**Shell Insulation**	**Shower-heads**	**Dwelling Area Subtotal**	**Common Area Lighting**	**Building Total**	**En. Cons. Accompl. Report**
At Full Penetration	815	+	185	240	1,240	520	1,760	
1986	782	0	96	137	1,015	47	1,062	1,230
1987	758	0	113	180	1,051	369	1,420	1,628
1988	725	0	70	202	997	354	1,351	1,440
1989	766	0	94	226	1,086	296	1,382	1,440
1990	799	167	65	240	1,270	364	1,634	1,610
1991	782	350	54	228	1,414	333	1,747	1,805
1992	815	440	59	194	1,509	364	1,873	1,880
1997	815	440	54	7	1,316	291	1,607	1,880

Notes: The incremental contributions of new window technologies are estimated as 170 kWh per unit in 1990, 365 kWh in 1991, and 440 kWh in 1992 and subsequent years, assuming 100% measure penetration. Actual measure penetrations were 98% in 1990, 96% in 1991, 100% in 1992, and 100% in 1997.

[7] Tachibana, Debra-L. O, et al., ENERGY CONSERVATION ACCOMPLISHMENTS: 1977-1994, Evaluation Unit, Energy Management Services Division, Seattle City Light, May 1996, pp. II-49-50.

These savings expectations need to be revised in light of the changing penetration rates for insulation and lighting measures shown in Table 3-A. When the percentage of buildings installing each measure type is taken into consideration, expected savings may be adjusted to the following values: 1,351 kWh (1988); 1,382 kWh (1989); 1,634 kWh (1990); 1,747 kWh (1991); and 1,873 kWh (1992). Following the same method, savings expected from current year participants may be only 1,607 kWh (1997). Table 3-B stipulates the measure category savings levels at a 100% penetration, and as adjusted according to actual penetration rates for program years 1986 through 1992, as well as 1997.

3.2 Changes in Program Buildings and Measures

The Measures Survey fielded in 1995-1996 provides a long-term view on program measures, taken from two years to a decade after program measure installation. The Measures Survey was performed primarily to collect data for the longitudinal impact evaluation of the Multifamily Conservation Programs. In the Measures Survey, building owners and property managers answered a series of questions about changes at the residences that could influence the use of energy. The questions covered actions that may have affected tenant dwelling (residential) meters as well as common area (commercial) meters. The survey also provided information reported in a customer service study of the 1994 program.[8]

3.2.1 CHANGES IN BUILDING OCCUPANCY

Program records show that, during the period 1986-1997, the combined Multifamily Conservation Programs served 1,360 buildings containing 24,082 residential units. The average number of units per Participant building for the combined programs is 17.7. This compares closely to the Nonparticipants randomly selected for the impact evaluation control groups, which averaged 16.3 units in size.

According to self-reports in survey interviews, Standard-Income (1986-1992) Participants sampled for the survey averaged 17.9 units per building, compared to the program average of 17.6 from 1986 through 1997. The Low-Income (1991-1992) Participants sampled for the survey were somewhat larger at 23.8 units per building, compared to the program average of 17.8 from 1986 through 1997. A review of sample records shows that 12 of the respondents represent buildings owned and operated by the Seattle Housing Authority. These public building projects have 301 tenant units and comprise 25% of units in the low-income survey respondent group.

---

[8] For more details about the Measures Survey, see the following report: Tachibana, Debra-Laurent O., MULTIFAMILY RETROFIT CONSERVATION PROGRAMS: CUSTOMER SERVICE MEASURES, Evaluation Unit, Energy Management Services Division, Seattle City Light, July 1998.

The respondents stated that the number of tenant units per building did not change between the participation year and 1995 among the Low-Income Participants interviewed for the survey. Among the Standard-Income Program Participants, three added a new dwelling unit and one building added two units (in size, these buildings are in the 9-15 unit range). Among the Nonparticipant buildings, between 1985 and 1995, one building removed two units from the tenant dwelling area and another building decreased in size by eleven units when the building was renovated in 1991. The majority of buildings in all groups were stable in size over the decade studied.

Table 3-C: Public Housing Served by Low-Income Program

Total Program Participants & Percent Public Housing	**A 1986**	**B 1987**	**C 1988**	**D 1989**	**E 1990**	**F 1991**	**G 1992**
Program Buildings (projects)	23	62	57	60	62	46	65
Program Units	264	929	894	891	832	790	1,021
Public Housing Buildings	12	0	2	0	2	8	4
Public Housing Units	94	0	140	0	132	41	234
Percent of Program Units	*36%*	*0%*	*16%*	*0%*	*16%*	*5%*	*23%*

Among Low-Income program participants, the proportion of served units in public housing projects has varied by year (see Table 3-A). In 1986, the first pilot program year, fully one-third of participating units were located in a public housing project with distinctive construction characteristics. During the second pilot year, 1987, and again in 1989 there were no City or County housing authority participants. The average proportion in other years was about 16%. Overall, about 11% of units served by the Low-Income Multifamily Program have been located in public housing projects.

According to self-reports of the owners and property managers, 16 buildings selected for the impact evaluation Control Groups participated in a Seattle City Light Program between 1990 and 1995 "for insulation, windows, or lighting." Crosschecks with program records yielded information about program participation for 12 of these buildings (75%). This information was taken into account in the impact analysis of energy usage during and after the 1993-1995 "participation" year, which occurred in each "Nonparticipant" case *after* the samples had been selected.

Of the 5 Nonparticipants selected for the Standard-Income Control Group, 4 took part in the Standard-Income Program in 1993-1995 after the impact evaluation samples were been drawn; 1 participated in the Low-Income Program in 1993. Of the 7 Nonparticipants selected for the Low-Income Control Group, 4 took part in the Low-Income Program in 1993-1995 after the impact evaluation samples were been drawn; 1 participated in the Standard-Income Program in 1993. The other two buildings could not be located on any program roster, but the owner of one had a second building that did participate in an earlier year. The speculation is that this survey respondent confused the two buildings when asked about program participation. In the end, 5-7 out of 24 Low-Income Control Group cases (21-29%) later participated in the City Light programs, along with 5 out of 33 Standard-Income Control Group cases (15%).

According to a prior Seattle City Light evaluation of multifamily building retrofits (Okumo 1991), a typical standard-income building has 789 square feet of rentable space per tenant unit. A typical privately owned low-income building has 825 square feet (public low-income housing tends to be larger at 891 square feet per unit, or approximately one 10'x10' bedroom). In addition, non-rentable square footage in common areas runs about 10-15% of total building spaces.

The combined samples drawn from program participants for the Measures Survey represent 71% of all program participants during the selected years. Contacted customers who responded to the Measures Survey comprise 79% of those sampled. The Measures Survey therefore represents more than half (56%) of all buildings that participated during the selected program years (0.71*0.79 = 0.56). This high level of representation should lend the reader confidence in the findings of the Measures Survey. However, no formal tests were made of selection bias in the response to this survey.

3.2.2 CHANGES IN HOUSE-METER LOADS

Between the program participation year and 1995, four Standard-Income Program participants report changing the common-area square footage served by the house meter. These buildings represent only 1% of the total residential units in this participant group. The types of changes added to the common area square footage (two buildings) or expanded tenant spaces into the common area (two buildings), as follows:

- Remodeled for longer hallway and stairs (18 sq. ft. added)
- Expanded lobby (40 sq. ft. added)
- Expanded some residential units (two buildings, square footage not stated)
- Made a minor change, adding a heater to the common area (1 sq. ft added in one nonparticipant building of the Standard-Income Control Group)

Table 3-D describes the types of end uses served by the commercial house meters in the multifamily buildings surveyed. The building owner or property manager was asked which equipment the building presently had in the common areas, which they believe was wired to a house meter. The electrical equipment loads are listed in descending order by frequency of occurrence. The first eight items were

acquired with individual yes/no questions; the remainder were offered by respondents to an ‘other’ category. As a result, they may under-report actual incidence, depending as they do on individual voluntary recall. The ‘other’ items are listed in decreasing frequency of occurrence.

According to these reports, while exterior lighting is universally metered on the house accounts, in some buildings interior common area lighting is either not present or, in the absence of a house meter, is served by tenant meters; a fifth of the Low-Income Program participants said ‘no’ to this item.

Most program participants have laundry systems on the house meters. These differences reflect the building types served by each program in 1994: low-income buildings are more likely to have exterior entries, and the lighting-only program serves many condominiums and larger-unit buildings with more tenant amenities in the units.

As far as changes in house meter loads since the year of program participation (or 1985 among nonparticipants), these were modest and occurred mainly in the categories of lighting and common laundry appliances. There were two exceptions, however. One Low-Income Program building had removed a tenant unit from the house meter during this period, establishing a separate residential meter for that unit. In all, 2% of the Participant buildings increased some proportion of the house-meter loads, while 1% decreased them somewhat. This compares to 3% of Nonparticipants increasing house-meter loads to some extent. As these questions were exploratory, no quantitative information is available on the magnitude of these changes.

Multifamily buildings typically experience little to no change in house meter loads over time. This suggests that energy savings from program measures should be persistent and stable over time from efficiency measures affecting house meter loads, subject to normal operations and maintenance (O&M) and the natural failure rates of installed equipment.

Of the house-meter load changes experienced by specific buildings, the following two variables were found to be significantly correlated with changes in electricity usage, beyond the effects modeled by variables established for the regression analysis models:

- Participant added clothes dryers;
- Nonparticipant added high efficiency common-area lighting.

Table 3-D: Electrical Equipment on House Meters

Percent of Buildings with Equipment	**Std.-Income** (N= 192)	**Low-Income** (N= 51)
IN COMMON AREAS:		
Exterior Lighting	100%	96%
Interior Lighting	92	80
Laundry Clothes Washers	93	88
Laundry Clothes Dryers	92	86
Laundry Water Heaters	85	80
Elevator	14	12
Tenant Water Heaters	9	26
Swimming Pool Pumps	5	4
OTHER MENTIONS:		
Intercom System	2	0
Other Pumps & Fountain	2	0
Pool Heater	1	2
Common Space Heat	1	2
Emergency & Exit Lighting *	1	2
Fire Alarms **	1	0
Electric Gate	1	0
Recreation Room	1	0
Tenant Unit	1	0
Vending Machine	1	0
Ceramic Kiln & Refrigerator	1	0
Water Boiler	0	2
Office Equipment	0	2

Notes: Replies of yes/no were requested to the first eight items; the remainder were offered by respondents to an ‘other’ category.

* Emergency and exit lighting are required by code in buildings with interior corridors, and therefore would already be included under the ‘interior common lighting’ category.

** Fire alarms are not mandatory, although smoke alarms within individual units are required equipment. Because this response was volunteered under ‘other’, more buildings may also have fire alarms.

3.2.3 CHANGES IN TENANT-METER LOADS

Table 3-E focuses on the appliances within tenant units, and changes that have occurred since the year of program participation (or since 1985, for nonparticipants). Building owners and property managers were asked whether they had removed, added, or changed out any major electrical appliances in the individual tenant units since that time. All equipment items were volunteered in response to an open-ended question about types of electrical equipment changed. The items are listed in decreasing frequency of occurrence.

The average year of participation among the survey respondents was 1989 among Standard-Income and 1991 for Low-Income. Thus the span of time covered by this question was 6 years for Standard-Income participants and 3½ years for Low-Income Participants; for Nonparticipants the span was 10 years (1995 minus 1985).

With the exception of dishwashers, the preponderance of appliance modifications in the tenant areas has been change-outs of existing appliances for newer and more efficient models. This was true for Nonparticipants as well as for Participants. Amongst the Standard-Income Program participants, however, about a third of the dishwashers described in Table 3-E were new additions, the other two-thirds being change-outs.

It is possible to estimate the proportion of appliances changed out per year, dividing the percentages in Table 3-E by the average number of years since participation. The Common-Area Lighting buildings are newer and only changed out water heaters (at the rate of 6% per year), garbage disposals (2%), and tenant unit clothes washers (2%).

Rates for the Standard-Income and Low-Income Programs were somewhat higher, the significant items being water heaters (9-12%), refrigerators (5-6%), dish washers (3-4%), and ranges (3-4%). Nonparticipants only met or exceeded the rate of 2% per year for water heaters (5%) and dishwashers (2%).

Table 3-E: Tenant Appliances Changed Out or Added Since Program Participation Year

Percent of Buildings Reporting Change	**Std.-Income** (n=192)	**Low-Income** (n=51)
Water Heaters	51%	41%
Refrigerators	34	18
Dish Washers	23	10
Ranges	21	12
Garbage Disposals	4	0
Tenant Clothes Washers	2	4
Tenant Clothes Dryers	1	2
Space Heaters	1	2
Microwave Ovens	1	0

Table 3-F specifies the type of water heat system replaced when electric water heaters were added to or changed out in the tenant units, as specified in Table 3-E. In all but one control-group case, the new electric water heaters in individual tenant units replaced (changed out) old electric water tanks. One Nonparticipant added new individual water heaters to replace an electric central water heat system. A notably smaller percentage of Participants replaced gas water heaters with electric tanks.

Table 3-F: Water Heat Type Replaced by Electric Water Heaters in Tenant Units

Percent of Buildings Reporting Change	**Std.-Income** (n=192)	**Low-Income** (n=51)
Replace Electric Water Heat Tanks (or Central System)	44%	31%
Replace Individual Nonelectric (gas) Tenant Water Heaters	5	8

Of the tenant-meter load changes experienced by specific buildings, the following two variables were found to be significantly correlated with changes in electricity usage, beyond the effects modeled by variables established for the regression analysis models:

- Participant replaced domestic water heaters in tenant units;

Nonparticipant changed out to high efficiency double-paned windows.

3.3 Annual Nonparticipant Energy Use

Prior to any presentation of program impacts, it is useful to establish the baseline conditions for energy usage by multifamily buildings in Seattle City Light's service area. To begin with, in the mid-1980s basic research preceded establishment of the Multifamily Conservation Programs. A multifamily sector consumption characteristics study was undertaken on behalf of the Utility by Ecotope, a local energy engineering consultant (DeLaHunt et al. 1984). This study provides anchoring values for both Tenant-Meter and House-Meter data. It found a mean annual electricity consumption level of 8,569 kWh per unit on Tenant Meters in 1983 (n=670). Building mean electricity consumption on House Meters was 1,538 kWh per unit (n=58). About 60% of the House-Meter amount was estimated to reflect lighting end-use consumption, according to a subsequent conservation potential study (DeLaHunt et al. 1985). It follows from this finding that a program designed to cut lighting end-use consumption in half would likely reduce overall house-meter usage by about 30%. The Multifamily Conservation Programs were designed with this expectation in mind.

Residential unit electricity consumption was also measured the following year by Seattle City Light's biennial Residential Customer Characteristics Study (RCCS). In 1984 the RCCS found annual Tenant-Meter electricity usage of 8,768 kWh per unit in multifamily buildings with electric space heat. Tenant energy use levels were 8,675 kWh in 1986, 8,892 kWh in 1988,and 8,347 kWh in 1990, as measured in subsequent RCC studies (values not adjusted for annual temperature differences). These studies were not designed to measure energy usage levels on commercial house meters.

In 1990 Seattle City Light performed an impact evaluation of the pilot phase for the Multifamily Conservation Programs (Okumo 1991). Control groups for that study were drawn from *pre-participants* (buildings on waiting lists that were not served until after the post-period). In the pre-period for that study (1984-1985), Tenant-Meter electricity usage of the standard-income control group exceeded the Ecotope *nonparticipant* mean by about 8%, while the low-income control group used about 3% less than *nonparticipants*. On House Meters in 1984-1985, electricity usage of the standard-income control group exceeded the Ecotope *nonparticipant* mean by about 20%, while the low-income control group exceeded it by 44%. This suggests that the pilot phase *pre-participant* control groups had more interior common-area spaces than would be typical.

The question arises, do the Nonparticipant groups in the current study demonstrate any underlying trend in energy usage over time? That is, have multifamily buildings generally been reducing or increasing energy use over the years? This has significance because other customer sectors, such as single family homes, have been observed clearly to trend downward on energy use (by about 3% per year) due to conservation actions taken independently of utility program participation. This possibility for the multifamily sector was investigated, with the following results.

A simple linear regression line was fitted to the annual Nonparticipant energy use (weather-normalized, in the case of tenant meters) over the seven-year time period 1987-1993. The formula for a simple regression is: $\mathbf{y = I + \vartheta * x + M}$. (That is, the intercept **y** equals a constant I plus a coefficient ϑ times the independent variable **x** plus an unknown amount of error M).

The dependent variable **y** was energy use and the independent variable **x** was a number from 1 (initial year) to 7 (final year). The flat trend line observed from this analysis describes annual change in these groups that was minor, around ±1% per year (see Table 3-G). Moreover, the change moves in the opposite direction on Tenant Meters from House Meters in each customer income category (which themselves vary in opposite directions). The low R-squared values indicate that the flat-line time trends explain only about one-fourth to one-third of the variation among annual observations. These data seem to confirm that multifamily buildings not participating in the Multifamily Conservation Programs have had stable energy use that changed slightly but not significantly over time.

Table 3-G: Annual Change in Nonparticipant Energy Use, 1987-1993

kWh / year by Analysis Category	**Intercept I** (base value)	**Coefficient ϑ** (incremental change)	**R-squared** (diagnostic)	**Percentage Annual Change**
Standard-Income Tenant Meters	8,227	52.9	0.26	+0.6%
Low-Income Tenant Meters	6,840	-63.1	0.35	-1.0%
Standard-Income House Meters	2,078	-18.3	0.23	-0.9%
Low-Income House Meters	1,656	22.8	0.28	+1.3%

Comparing these values to those projected during the program planning phase (from DeLaHunt 1984), the 1987 intercept for Standard-Income nonparticipants on Tenant Meters was only 4% below the Ecotope 1983 mean, while the Low-Income nonparticipants used about 20% less than typical in the building sector. On House Meters in 1987, electricity usage of the Standard-Income nonparticipants exceeded the Ecotope 1983 mean by about 35%, while the Low-Income nonparticipants exceeded it by only 8%.

The higher than expected House-Meter usage of Standard-income Nonparticipants requires application of a net scores method to these data that provides a covariate to adjust for non-equivalency of pre-period energy use patterns (i.e., Net Method II). Tenant-Meter usage in this group appears fairly typical of the multifamily sector. The Standard-Income Nonparticipants were drawn from program waiting lists established in 1993 (buildings that participated in 1993-1995 were removed this group). As in the prior pilot phase evaluation (Okumo 1991), these control group cases constituted *pre-participants*, and some self-selection bias probably obtains. The longitudinal impact analysis makes no explicit adjustment for this type of bias.

The pilot phase evaluation revealed that Low-Income Multifamily Program participants generally have higher than sector-average energy usage. Low-income energy usage is usually higher than average due to larger tenant units, more occupants (families with children), and buildings with a lower state of construction or repair. By comparison, the finding of lower than average usage among Low-Income Nonparticipants in the present study might raise questions about their suitability as a control group. However, the Measures Survey revealed that 20% of Low-Income Control Group buildings participated in the Low-Income program within the next few years, and six years later in 1999 it is certainly possible that even more have entered one of the Multifamily Conservation Programs.

It should be remembered that the Low-Income Nonparticipants were drawn from a sample of the general building stock, not from any waiting list for the program. In fact it was difficult to constitute a control group for the Low-Income Participants due to the stage of market pool saturation by the program. Special efforts were extended to locate unserved buildings in the same neighborhoods from which program participants have been attracted. The differences observed here between Low-Income Nonparticipants and general expectations for this subsector do suggest that the unserved building population is distinctive from past participants in tenant-unit characteristics. This difference underscores the importance of applying a net scores method to Low-Income Tenant-Meter data that provides a covariate to adjust for non-equivalency of pre-period energy use patterns (Net Method II).

The simple regression approach of Table 3-G masks a more complex trend in nonparticipant energy usage, however, over the period 1987-1993. The following two figures reveal a pattern which has clear implications for interpreting the findings from this longitudinal study.

In the next two figures, polynomial trend lines have been fitted to the Nonparticipant energy use data. Examining first the Tenant-Meter annual consumption of Figure 3-III, both income categories show a clear curvilinear pattern from 1987 through 1993. These data have been weather-adjusted to a normal meteorological year. Even so, energy use trended upward from 1987 to 1990, flattened, and then dropped again by 1993.

Above each curve appear values that indicate the pre- to post-change score relevant to the corresponding participant cohort (indicated in parentheses below each year label). That is, the *gross* change score for that cohort would have this value added to calculate a *simple net* change score. The change scores are printed in bold type for Standard-Income nonparticipants, for ease of reference.

Figure 3-III: Nonparticipant Energy Use Trends on Tenant Meters

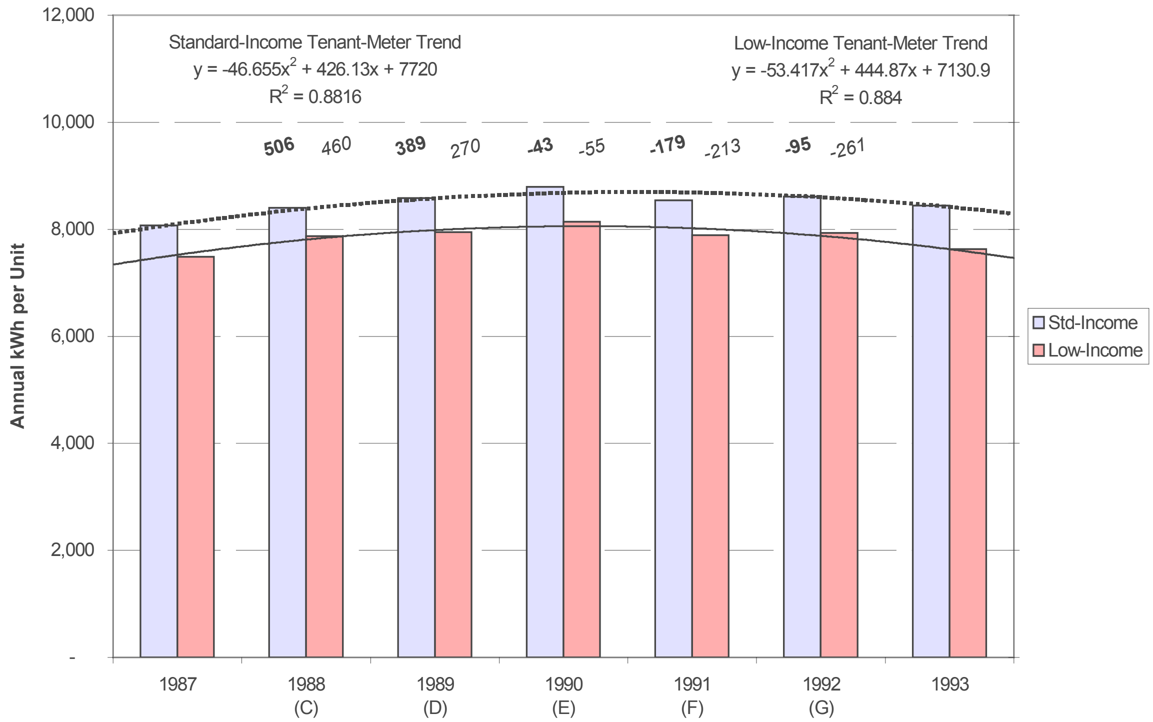
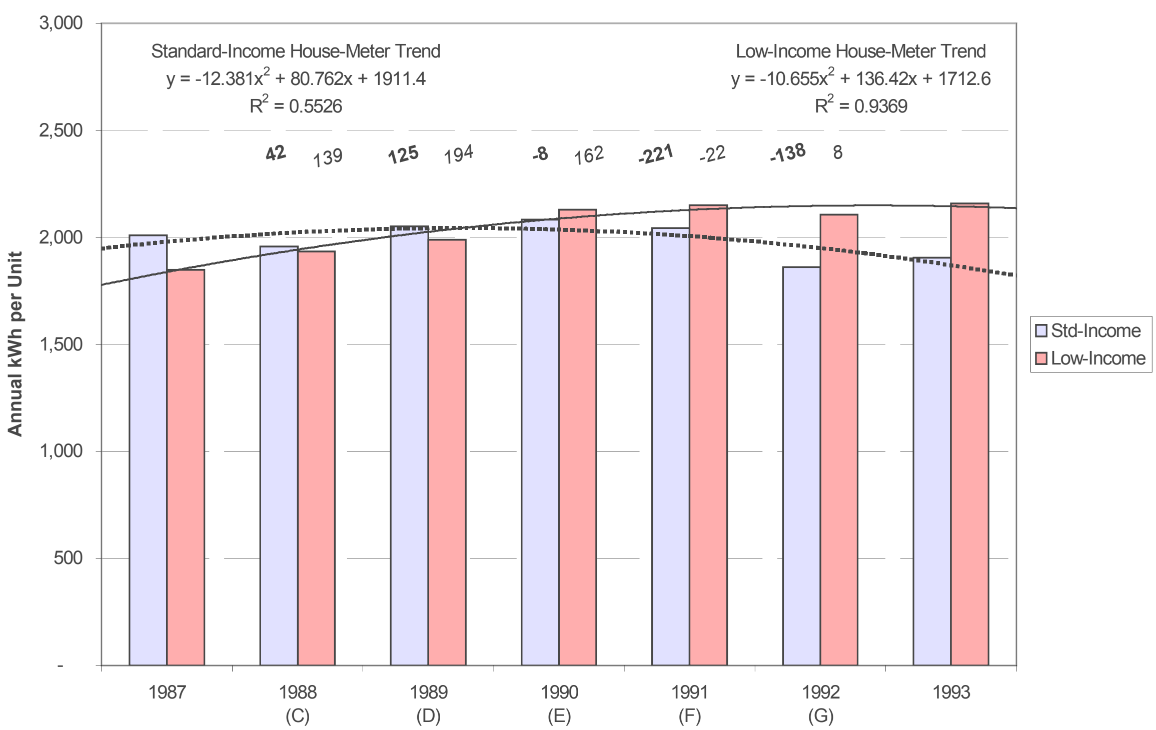


Figure 3-IV: Nonparticipant Energy Use Trends on House Meters



These values make it apparent that the underlying trend from 1987 to 1990, assumed to affect participants as well as nonparticipants, would undercut gross change scores for Cohort C and to a lesser extent Cohort D. By the same token, the underlying trend from 1990 to 1993 might be expected to overstate gross change scores for Cohort F and perhaps Cohort G. As will be discovered in the next chapter, this expectation is precisely what was observed among program participants when moving from gross to net change scores. It is possible that the downward movement in 1992-1993 relates to two phenomena: an economic slowdown in the Puget Sound region; and a regional water drought, which led many residents to comply with voluntary restraints on water usage. This latter factor, combined with Utility conservation programs in these and subsequent years, resulted in lasting reductions to average household water consumption.

Examining the House-Meter annual consumption in Figure 3-IV, both income categories also show clear curvilinear patterns from 1987 through 1993 (note that the y-axis is expanded for clarity). Given the lower absolute levels of electricity use per unit, these patterns are muted compared to those of the Tenant-Meter data. These data are not weather-adjusted to a normal meteorological year. Among Standard-income nonparticipants, energy usage was flat from 1987 to 1990 and then trended downward to 1993. Low-income nonparticipant energy usage trended upward from 1987 to 1990 and then held steady to 1993.

Again, above each curve appear values that indicate the pre- to post-change score relevant to the corresponding participant cohort (indicated in parentheses below each year label). That is, the *gross* change score for that cohort would have this nonparticipant value added to calculate a *simple net* change score. The change scores are printed in bold type for Standard-Income nonparticipants, for ease of reference. These values make it apparent that the underlying trend from 1987 to 1990, assumed to affect participants as well as nonparticipants, would undercut gross change scores among Low-Income Participants for Cohort C, to a lesser extent Cohort D. By the same token, the underlying trend from 1990 to 1993 might be expected to overstate gross change scores for Standard-Income Cohort F and perhaps Cohort G. As will be discovered in the next chapter, this expectation is precisely what was observed among program participants.

The fitting of polynomial curves to the Nonparticipant data goes a long way toward underscoring why it is necessary not only to use control groups in an energy savings impact analysis, but also why statistical methods to control extraneous variance are necessary as well. Gross savings scores are useful to determine whether program measures are operating to reduce energy use in participant buildings. Gross scores can be compared to engineering estimates to suggest realization rates (with embedded missing variables such as heat-loss parameters and measure penetrations). However, the presentation of net scores using analysis of covariance provides the best indication of effects that may be attributed to the program intervention, independent of underlying trends in energy-using behavior. This method is designed to adjust for effects of the changing economy, energy rates, occupant demographics, living habits, tenant turnover, building ownership, independent conservation actions, and unique building sensitivity to outside temperatures.

3.4 Annual Participant Energy Use

In the year before program measures were installed, the participant cohorts exhibited the following energy use baselines. On Tenant Meters, Standard-Income participants averaged 8,073 kWh per unit before program retrofits while Low-Income participants used 9,113 kWh per unit (1,040 kWh more, or about 113%). On House Meters, adjusted to total units per building, Standard-Income participants average 1,325 kWh per unit before program retrofits while Low-Income participants used 1,661 kWh per unit (336 kWh more, or about 125%). Overall, combining both meters, Low-Income building electricity consumption was 1,376 kWh per unit higher (115%) than the average Standard-income building.

Table 3-H: Baseline Participant Energy Use by Program and Meter Type

Measured kWh/Unit Energy Consumption (First Year Pre-Retrofit)	Cohort A 1986 Partici-pants	Cohort B 1987 Partici-pants	Cohort C 1988 Partici-pants	Cohort D 1989 Partici-pants	Cohort E 1990 Partici-pants	Cohort F 1991 Partici-pants	Cohort G 1992 Partici-pants
Standard-Income							
House Meter Usage	1,610	1,570	1,844	1,473	1,787	1,376	1,824
in Pct. of Units	*81%*	*92%*	*93%*	*99%*	*84%*	*94%*	*95%*
Adjusted House-Meters	1,311	1,452	1,712	1,309	1,366	924	1,516
Tenant Meter Usage	7,968	7,525	7,987	8,711	8,592	8,082	7,549
Building Average Usage	9,279	8,977	9,699	10,020	9,958	9,006	9,065
Low-Income							
House Meter Usage	6,289*	1,803	2,121	1,380	3,121	1,341	3,171
in Pct. of Units	*10%*	*73%*	*67%*	*89%*	*76%*	*67%*	*83%*
Adjusted House-Meters	629	1,310	1,418	1,226	2,385	900	2,636
Tenant Meter Usage	11,519*	9,150	9,079	8,140	9,946	9,488	8,043
Building Average Usage	12,147	10,460	10,497	9,366	12,331	10,388	10,679

* See Section 4.1 for more on Low-Income Cohort A.

Nonparticipant baselines have already been discussed. The final section of this chapter shows the energy use levels of each individual Participant cohort relative to the Nonparticipant control groups (see Figure 3-V to Figure 3-XII). The first set of four figures shows energy consumption by calendar year. The second set of four figures shows energy use relative to the pre-period and post-treatment years for each cohort.

Annual Energy Consumption by Calendar Year

Figure 3-V: Standard-Income Tenant Meters

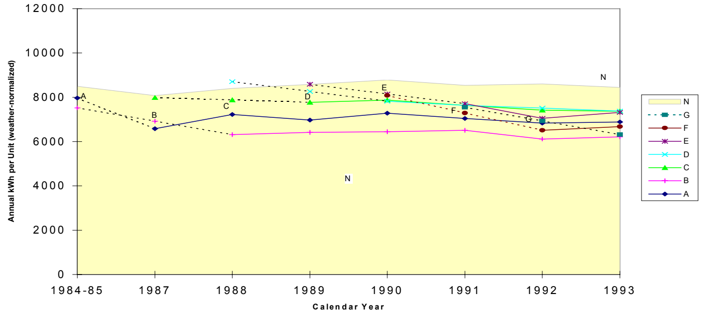


Figure 3-VI: Low-Income Tenant Meters

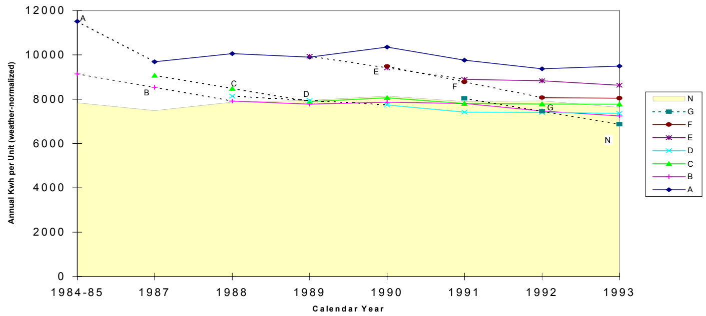


Figure 3-VII: Standard-Income House Meters

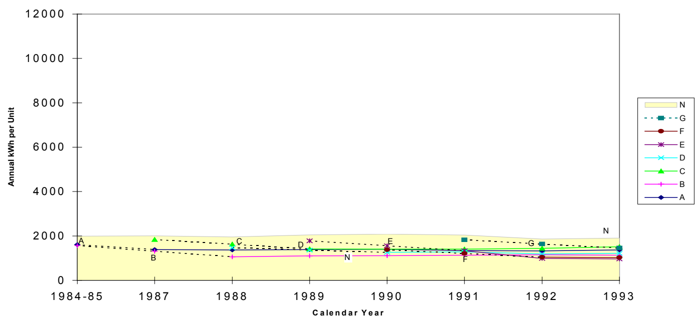
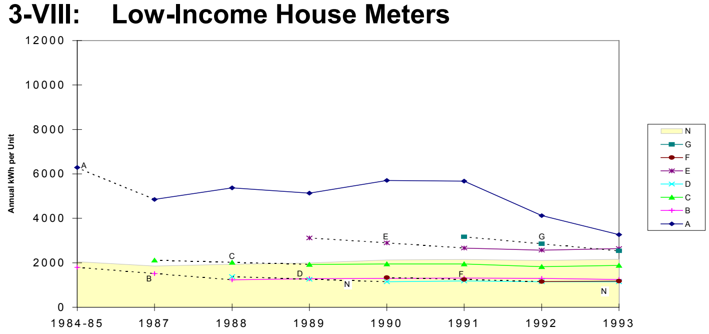


Figure 3-VIII: Low-Income House Meters



This page contains four graphic figures to allow comparisons among Standard-Income and Low-Income buildings on Tenant-Meter and House-Meter energy use. These figures are greatly reduced; larger versions appear in Appendix C of this report.

The shaded area of each graph shows the average use level of program nonparticipants (Group N) over the nine-year span extending from 1985 through 1993. The seven lines on each graph depict the energy use of each study Cohort A through G. The line is solid during the post-installation period for each cohort, and dotted between the pre-period and first-post year (a two-year span that includes the installation year).

One observes from these figures that energy use per unit is greater on Tenant Meters than on House Meters, by a factor of about four. In the Standard-Income samples, post-period energy use is clearly lower than the shaded area representing Nonparticipants, while pre-period use lies close to the top of the shaded area. The Low-Income samples, on the other hand, describe a Nonparticipant group with lower usage than the treatment cohorts in most years.

However, it is not readily apparent from these graphs whether there is a coherent pattern among cohorts from year to year, and how this pattern relates to the control group usage.

Annual Energy Consumption by Period

Figure 3-IX: Standard-Income Tenant Meters

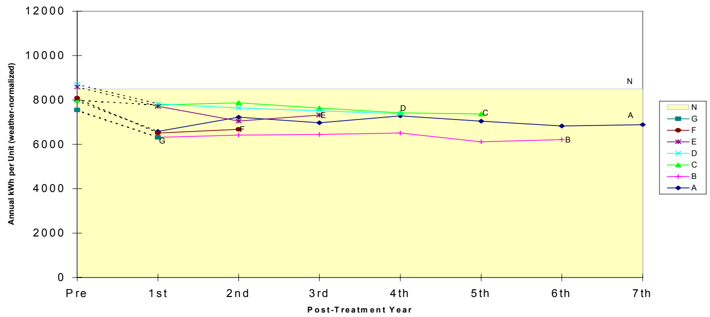


Figure 3-X: Low-Income Tenant Meters

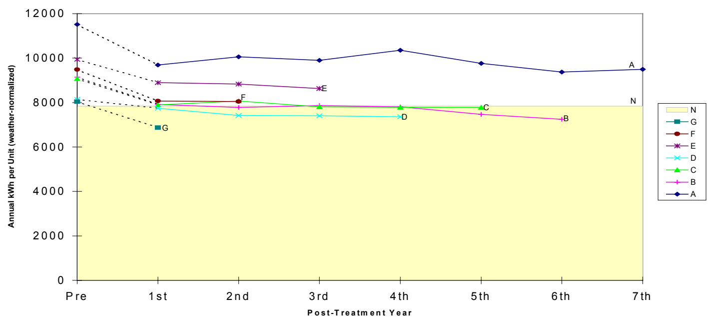


Figure 3-XI: Standard-Income House Meters

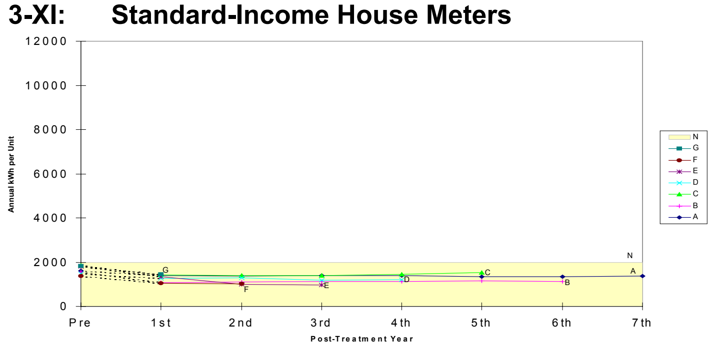
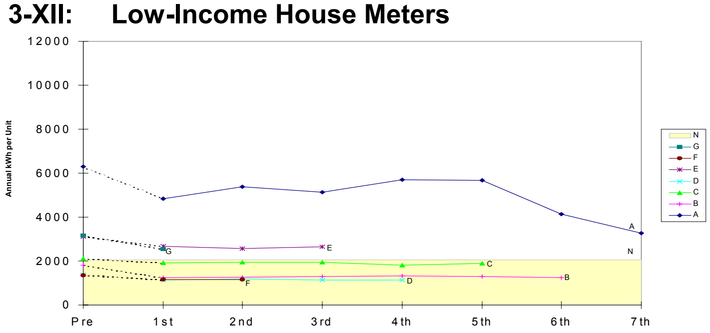


Figure 3-XII: Low-Income House Meters



This page also contains four graphic figures to allow comparisons among Standard-Income and Low-Income buildings on Tenant-Meter and House-Meter energy use. These figures are greatly reduced; larger versions appear in Appendix C of this report.

The seven lines on each graph depict the energy use of each study Cohort A through G. The line is solid during the post-installation periods ("1st" through "7th") for each cohort, and dotted between the pre-period ("Pre") and first-post year.

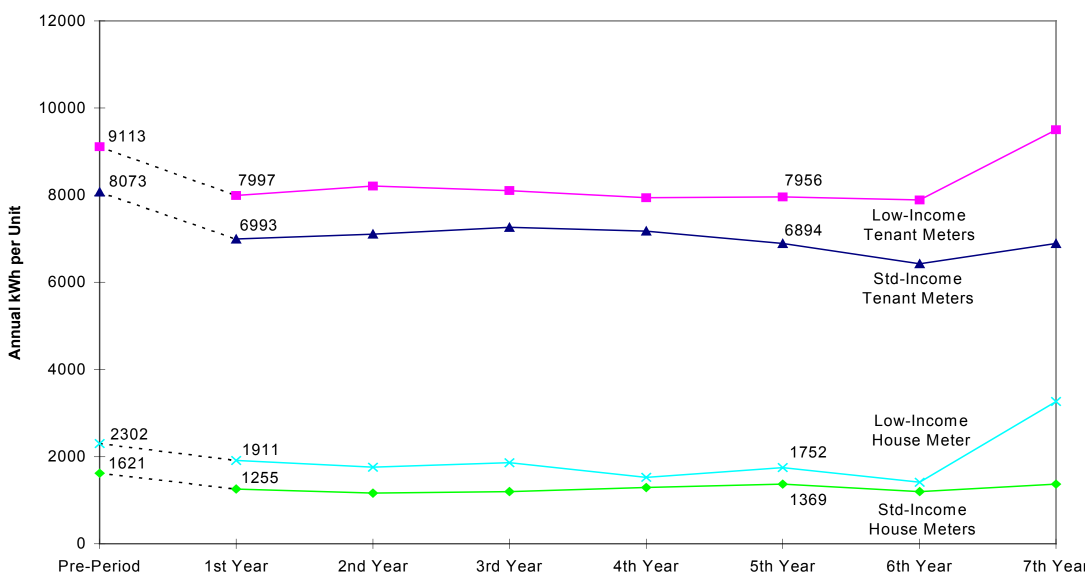
One may see that the Standard-Income cohorts all start with higher energy usage in the Pre-period, near Nonparticipant levels, and drop below during the Post-periods, continuing along a fairly level course for up to seven years after measure installation.

Most Low-Income cohorts, by contrast, start at a level clearly higher than Nonparticipants, and drop down to the shaded level after measure installation. There is also clearly a higher usage level across all years for the first treatment group, Cohort A, and to a lesser extent for the fifth group, Cohort E. House-Meter usage also shows a second drop for Cohort A from the fifth to seventh Post-years. This drop coincides with a strong push to install water-efficiency measures in public housing and to rehabilitate these structures.

Regarding Tenant-Meter energy usage, take note that the Standard-Income Participants, Standard-Income Nonparticipants, and Low-Income Nonparticipants all begin in 1984-85 with energy levels around 8,000 kWh per unit. The Low-Income Participants, by comparison, begin with energy usage that is clearly much higher, reflecting perhaps their particular need for the load and bill reductions offered by the Multifamily Conservation Programs.Group averages can reveal the underlying pattern more clearly than these detailed figures, however. Therefore the subsequent graphic, Figure 3-XIII, shows the weighted group averages across seven cohorts for seven post-treatment years, along with the pre-treatment annual energy usage.

Figure 3-XIII reveals the expected negatively sloped line between the Pre-period and first Post-year (savings), and apparent persistence of savings through at least the fifth Post-year (see the value labels). On Tenant Meters between the fourth and sixth years, the line does slope downward slightly for the Standard-Income and Low-Income Participants. It is the evaluator's opinion that observed changes from the sixth to seventh Post-years should be not be generalized to reflect on the Program, as the upward movement reflects only one atypical group (Cohort A) and a small number of cases. In the case of Low-Income House Meters, some of these buildings received showerheads retrofits through a subsequent program. For this and other reasons, later analyses focus mainly on the first five years after measure installation.

Figure 3-XIII: Annual Energy Consumption by Period, Weighted Average for Cohorts A to G



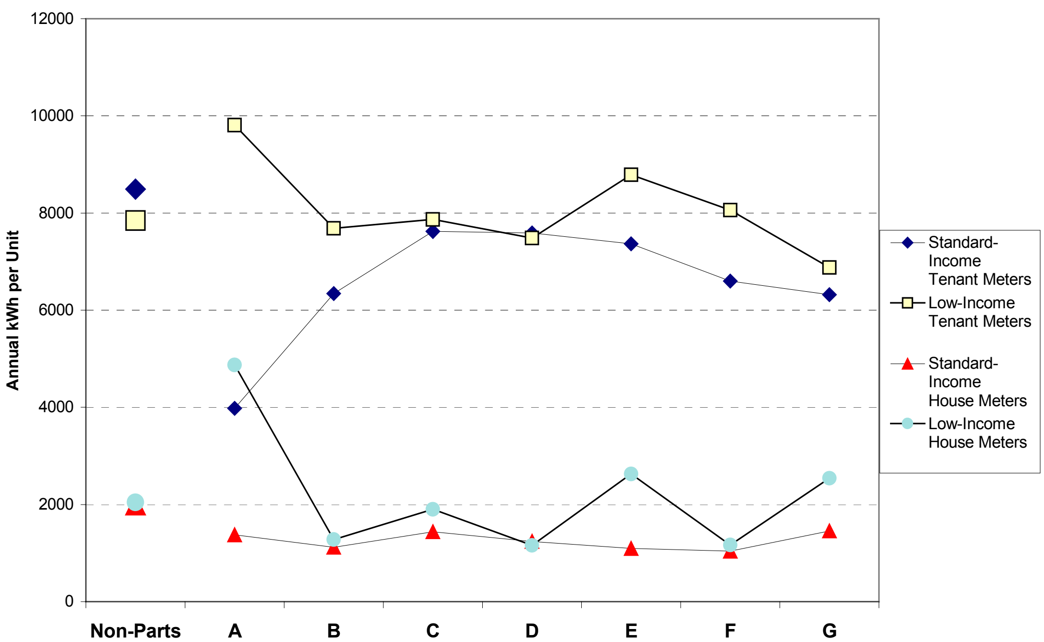
In all comparisons that follow, it must be remembered that all groups (Standard-Income, Low-Income, Participant, and Nonparticipant) have baseline energy consumption distributions that diverge from the normal. In all groups, median values are higher than mean values. However, the Low-Income Participants have the largest standard deviation of the mean, reflected in a wider gap between median and mean (a skewed distribution). Net Method II, with its analysis of covariance,was devised to compensate for these differences in baseline distributions. The Standard-Income Participants and Standard-Income Control Group (future-participants) have identical distributions (i.e., mean and standard deviation) on Tenant Meter data. The Low-Income Participants and Low-Income Control Group (nonparticipants) have distributions that vary significantly on both means and standard deviations.

4. Gross & Net Score Impact Results

4.1 Gross Energy Savings Scores

Figure 4-I illustrates two Nonparticipant groups on the left side ("Non-Parts"). The taller pair of points represents seven-year averages of 8,444 kWh per Standard-Income tenant unit and 7,631 kWh per Low-Income tenant unit. The weighted average of these programs is 8,141 kWh per year from Tenant Meters. The lower overlapping pair represents average house-meter usage of 2,158 kWh per unit among Standard-Income buildings and 1,905 kWh per unit among Low-Income buildings. The weighted average of these programs is 2,018 kWh per year from House Meters. The Nonparticipant points are followed by a line linking usage of each Participant Cohort (A-G). These points show annual energy consumption by a cohort averaged across all available post-retrofit years (seven for Cohort A, six for Cohort B, down to one for Cohort G).

Figure 4-I: Average Annual Energy Consumption Over 1–7 Years (Nonparticipants vs. Cohorts After Program Participation)



The midpoint of the Nonparticipant seven-year average period illustrated in Figure 4-I is 1990. The 1990 Residential Customer Characteristics Survey (RCCS) also provides nonparticipant comparison values for the post-participation tenant-meter findings reported here (Cohorts A to G). In the RCCS, a random survey of multifamily building units with electric space and water heat yielded an estimated 8,347 kWh of electricity consumed per tenant unit in 1990 (with a standard deviation of 4,166 kWh). Comparison values are not available from the RCCS for house-meter data.

Table 4-A: Gross Score Changes of Nonparticipants by Meter Type

Measured kWh/Unit Energy Savings (Pre to Post Period)	1987 to 1989 {C}	1988 to 1990 {D}	1989 to 1991 {E}	1990 to 1992 {F}	1991 to 1993 {G}
Standard-Income					
House Meter Change	(42)	(125)	8	222	138
in Pct. of Units	*92%*	*92%*	*92%*	*92%*	*92%*
Adjusted House-Meters	(39)	(115)	7	204	127
Tenant Meter Change	(506)	(388)	44	179	94
Building Average Change	(545)	(503)	51	383	221
Low-Income					
House Meter Change	(138)	(194)	(163)	22	(7)
in Pct. of Units	*99%*	*99%*	*99%*	*99%*	*99%*
Adjusted House-Meters	(137)	(192)	(161)	22	(7)
Tenant Meter Change	(459)	(270)	55	213	260
Building Average Change	(596)	(462)	(106)	235	253

The table above (Table 4-A) shows the change scores among Nonparticipants for each first-year Participant comparison to the relevant Cohort. Increases in energy usage from pre-period to post-period are given in parentheses to reflect “negative savings” by Nonparticipants. Decreases in energy use from pre-to-post period are cited as positive values to correspond with how Participant savings are shown in all tables and figures of this report. The average change score over these comparison years was nearly identical for Standard-Income and Low-Income Nonparticipants. The values differed by only 60 kWh per unit between the two control groups.

Among both Standard-Income and Low-Income Nonparticipants, energy consumption increased significantly in the average building during the pre-to-post comparison periods for Cohort C and Cohort D, by about 500 kWh per unit. Energy usage dropped somewhat in the comparison periods for Cohort F and Cohort G, by about 200-300 kWh per unit, during a period of economic slowdown and regional drought. This reflects an overall swing of about 770-850 kWh per unit in the Nonparticipant rate of change over five years of program operation, from high acceleration in 1988 to relative deceleration in

1991-1992. These Nonparticipant patterns would tend to drive Participant *net* energy savings up for the first two cohorts and down for the latter cohorts, relative to *gross* energy savings scores.

Detailed tables in Appendix B provide gross savings scores for each Participant Cohort in each post-installation year. Each table contains relevant statistics, such as group medians, means, and standard errors for the pre-period and each post-period. The gross savings scores are examined with Student's t-test (one-tailed). Savings are represented as a percentage of baseline energy use, accompanied by a 95% confidence interval and correlation coefficient.

The general findings on group mean savings are summarized briefly in the following set of graphical figures (see Figure 4-II to Figure 4-V). Note that the Low-Income graphs of gross savings scores show upward trends in the sixth and seventh years after program retrofits for Cohort A and Cohort B. In fact, gross scores for Cohort A House-Meters range above all other cohorts in the first three years as well. This requires some explanation.

In 1990 Seattle City Light performed an impact evaluation of the pilot phase for the Multifamily Conservation Programs (Okumo 1991). The pilot phase extended for two years, 1986-1987, and these two program years are represented by Cohort A and Cohort B of the present longitudinal study. Participants in the first program year, Cohort A, seem to present a profile distinctive from that of later year cohorts.

To re-iterate some background, Chapter 3 cited a multifamily sector consumption characteristics study that was undertaken on behalf of the Utility by Ecotope, a local energy engineering consultant (DeLaHunt et al. 1984). This study provides anchoring values for both Tenant-Meter and House-Meter data. It found a mean annual electricity consumption level of 8,569 kWh per unit on Tenant Meters in 1983 (n=670). Building mean electricity consumption on House Meters was 1,538 kWh per unit (n=58).

As measured by the present longitudinal study, baseline (pre-retrofit) Tenant-Meter electricity usage of the standard-income Cohort A exceeded the Ecotope *nonparticipant* mean by about 8%, while the low-income Cohort A exceeded it by 42%. On House Meters, baseline electricity usage of the standard-income Cohort A was 23% below the Ecotope *nonparticipant* mean, while the low-income Cohort A exceeded it by 20%. These values differ from those reported previously (Okumo 1991) because an improved data source identified meters that had not been accumulated in the pilot phase evaluation database. These findings suggest that Cohort A low-income participant buildings had larger units and/or more occupants that would be typical for the sector as a whole, and more interior common-area spaces than was typical (half were units in public housing projects). The Cohort A standard-income participants, meanwhile, had typical Tenant-Meter usage but probably less interior common-area square footage and/or fewer end uses (many being “motel style” buildings with direct exterior entries to the units).

Annual Energy Savings by Period: Gross Scores

Figure 4-II: Standard-Income Tenant Meters

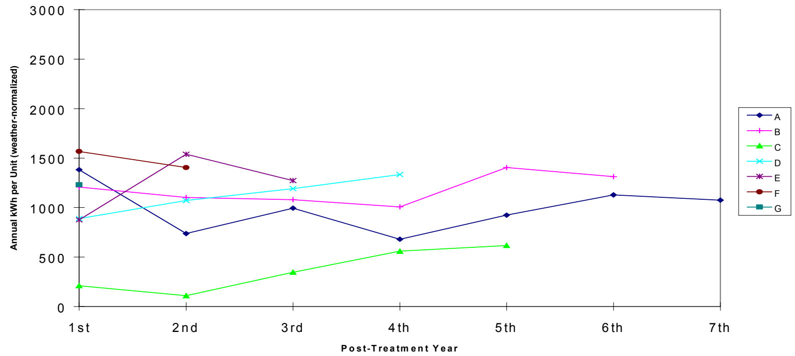


Figure 4-III: Low-Income Tenant Meters

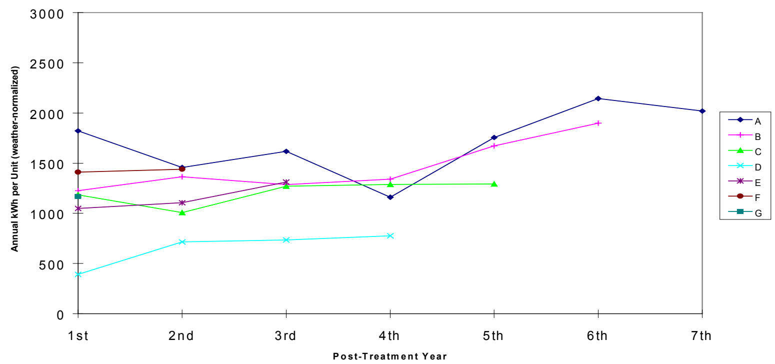


Figure 4-IV: Standard-Income House Meters

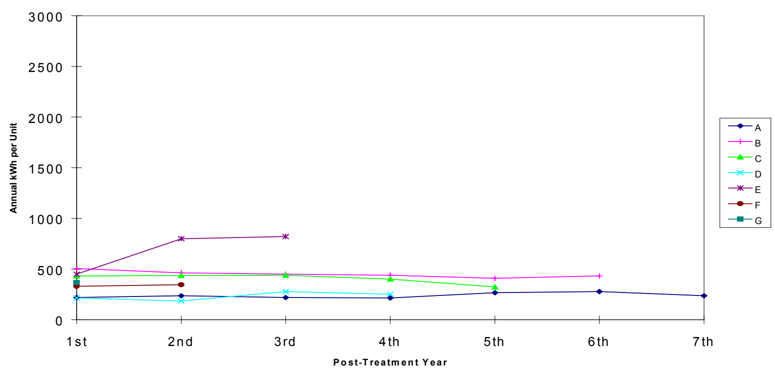
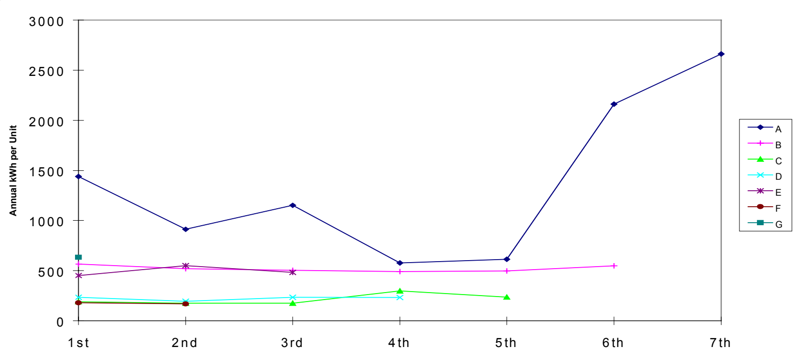


Figure 4-V Low-Income House Meters



This page contains four graphic figures to allow comparisons among Standard-Income and Low-Income buildings on Tenant-Meter and House-Meter gross energy savings. These figures are greatly reduced; larger versions appear in Appendix C of this report.

One observes that Tenant Meter savings cluster in a range mainly between 800 and 1,500 kWh per unit, although each program has one cohort with scores in the 0 to 500 range. There is year-to-year variation that apparently is not smoothed by adjusting data to a normal weather year.

Results on House Meters show more consistency, ranging between 250 and 500 kWh per unit, with the exception of Cohort A among the Low-Income Participants. The trends for House Meters are clearly flat over the post-installation years. These results represent savings in buildings with house meters (a subset of buildings studied).

Gross savings scores can mask effects driven by underlying changes in appliances, behaviors, and economic factors. For this reason, a Nonparticipant control group is introduced in the following methods to represent and adjust for these changes.

Lastly, as stated before, Low-Income Cohort A buildings participated in a 1992-1993 showerhead replacement program, and some public housing units received additional rehabilitation services.

The preceding four figures show gross savings scores for each individual participant cohort, which have unequal numbers of buildings and units. Figure 4-VI, below, shows the weighted group averages across seven cohorts for seven post-treatment years, to reveal the underlying pattern more clearly. This graph shows a clear confluence of results in the first two Post-years for Tenant Meters, around 1,100 kWh per unit, which gradually diverges in subsequent years. This divergence is driven by very large impacts in Low-Income Cohort A and Cohort B, especially in the later years when efficient-flow showerheads may have been installed by a subsequent Seattle City Light program. (Only Cohort A has seven years of post-retrofit data, and only Cohort A plus Cohort B have six years of post-data). Measure penetration levels dipped in Standard-Income Cohort C for windows and insulation.

The House Meter results are nearly identical over a five-year span, starting around 380 kWh in the first Post-year and ending at about 345 kWh per unit in the fifth Post-year. At this point the two programs diverge, reflecting the unusual Low-Income Cohort A's effect.

When only the more recent Cohorts D-G are examined, the Standard-Income program shows higher gross energy savings (by about 200 kWh per unit) than the Low-Income program on Tenant Meters, and identical savings across programs on House Meters. The overall impact is a discrepancy between programs of 200 kWh per unit in gross energy savings, according to the Gross Scores method.

Figure 4-VI shows weighted average gross savings scores across seven cohorts of program participants. These scores represent the majority of units in low-income buildings (61%) and standard-income buildings (82%) that participated in the Multifamily Conservation Programs. The following table states the average first-year *gross* savings for each of the seven cohorts. Building level savings are stated as kWh per unit, calculated as the sum of average Tenant Meter savings plus House Meter savings adjusted for the percentage of residential units in buildings having house meters. Table 4-B shows the variability among program years around the averages shown above.

Figure 4-VI: Annual Energy Savings by Period, Gross Score, Weighted Average for Cohorts A to G

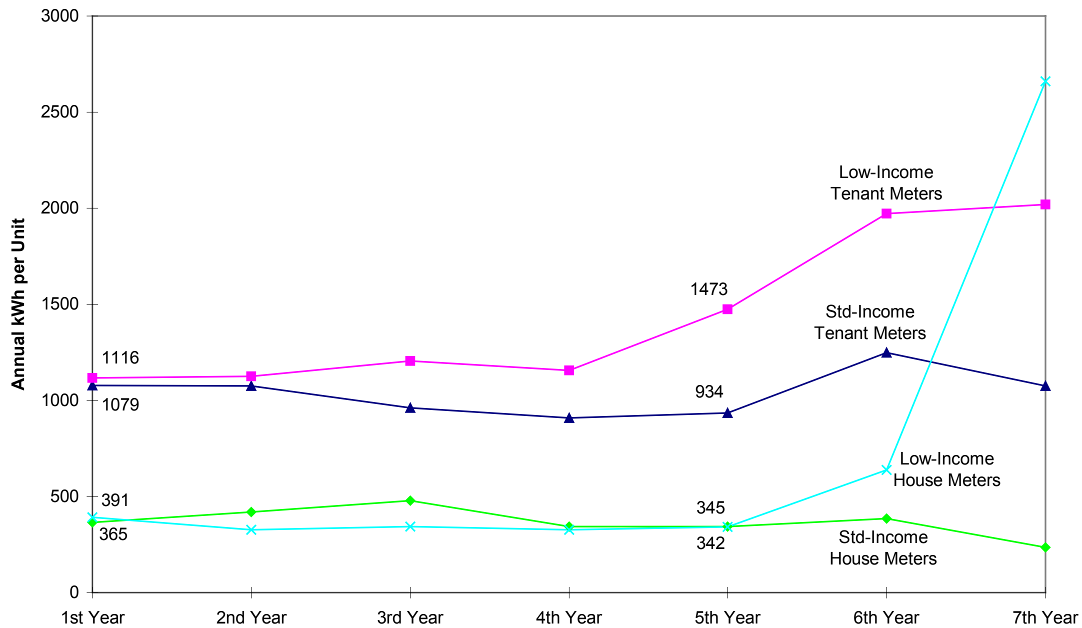


Table 4-B: Gross Score First Year Savings by Program and Meter Type

Measured kWh/Unit Energy Savings (First Year Post-Retrofit)	Cohort A 1986 Partici-pants	Cohort B 1987 Partici-pants	Cohort C 1988 Partici-pants	Cohort D 1989 Partici-pants	Cohort E 1990 Partici-pants	Cohort F 1991 Partici-pants	Cohort G 1992 Partici-pants
Standard-Income							
House Meter Savings	220	506	433	216	449	331	367
in Pct. of Units	*81%*	*92%*	*93%*	*99%*	*84%*	*94%*	*95%*
Adjusted House-Meters	178	466	403	214	377	311	349
Tenant Meter Savings	1,382	1,207	211	889	875	1,567	1,232
Building Average Savings	1,560	1,673	614	1,103	1,252	1,878	1,581
Low-Income							
House Meter Savings	1440	566	192	235	451	180	634
in Pct. of Units	*10%*	*73%*	*67%*	*89%*	*76%*	*67%*	*83%*
Adjusted House-Meters	144	413	129	209	343	121	526
Tenant Meter Savings	1,821	1,227	1,184	392	1,050	1,411	1,168
Building Average Savings	1,965	1,640	1,313	601	1,393	1,532	1,694

4.2 Net Savings Score Method I

4.2.1.1 Nonparticipant Comparisons

Detailed tables in Appendix B also provide net savings scores for each cohort in each post-installation year. Each table contains relevant statistics, such as group medians, means, and standard errors for the pre-period and each post-period, for both program participants and nonparticipants. The net savings scores are examined with Student's t-test (one-tailed). Savings are represented as a percentage of baseline energy use, accompanied by a 95% confidence interval and correlation coefficient. A Student's t-test (two-tailed) appears with each table, to judge the pre-period equivalency of the participant cohort and nonparticipant group. The general findings on group mean savings are summarized briefly in the following set of graphical figures.

The figures on the next page show net savings scores for each individual participant cohort, which have unequal numbers of buildings and units. Once again one sees that, apart from Cohorts C, the Standard-Income Tenant Meters cluster in the 1000-1400 kWh range while the Low-Income Tenant Meters cluster lower around 700-1200 kWh. Figure 4-XI, following, shows the weighted group averages across five cohorts for five post-treatment years, to reveal the underlying pattern more clearly.

As with the gross scores, this graph shows a clear confluence of results in the Post-years for Tenant Meters, extending from the first through fourth years, around 1,130 kWh per unit, which then diverges in the fifth year. The House Meter results are higher by nearly 200 kWh for Low-Income participants than for Standard-Income participants, in the first and fifth Post-years.

Figure 4-XI shows weighted average gross savings scores across seven cohorts of program participants. The following table states the average first-year *net* savings for each of the seven cohorts. Building level savings are stated as kWh per unit, calculated as the sum of average Tenant Meter savings plus House Meter savings adjusted for the percentage of residential units in buildings having house meters.

When only the more recent Cohorts D-G are examined, the Standard-Income Program shows higher savings (by about 300 kWh per unit) than the Low-Income Tenant Meters and lower savings (by about 100 kWh per unit) on House Meters. The overall impact is a discrepancy between programs of 125 kWh per unit in net energy savings, according to Net Method I.

Annual Energy Savings by Period: Net I Scores

Figure 4-VII: Standard-Income Tenant Meters

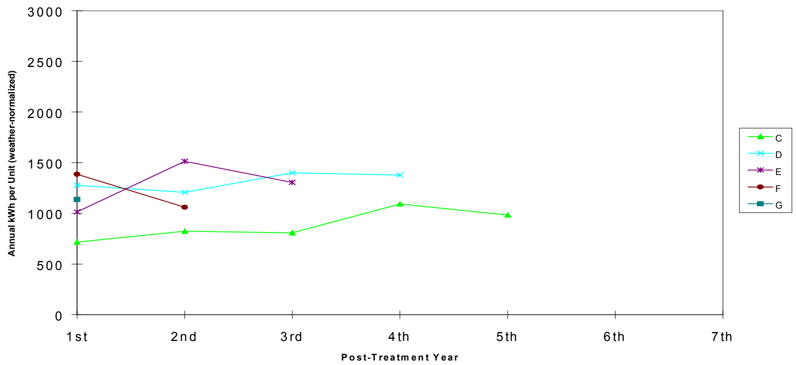


Figure 4-VIII: Low-Income Tenant Meters

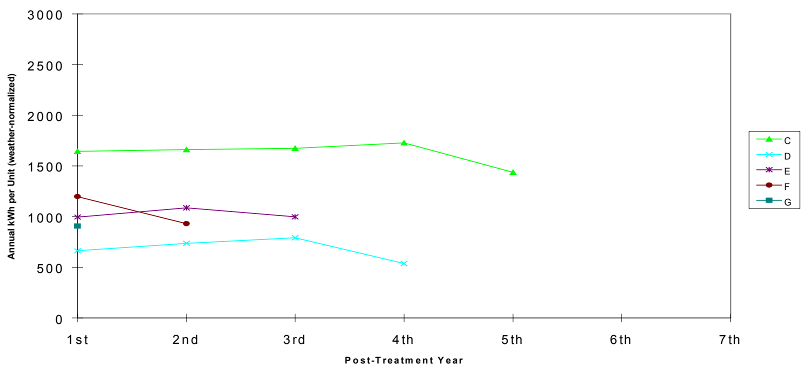


Figure 4-IX: Standard-Income House Meters

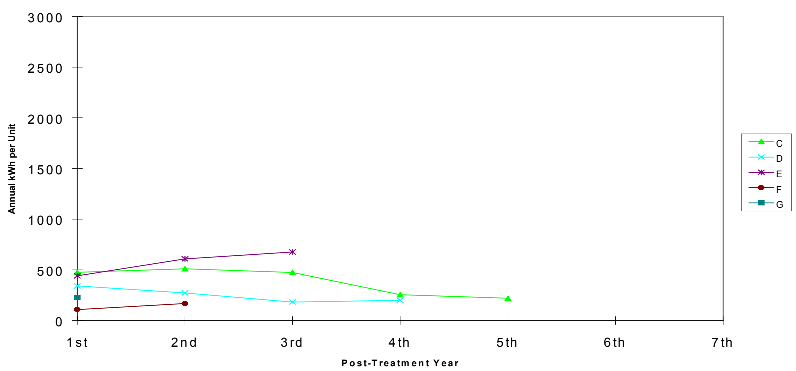
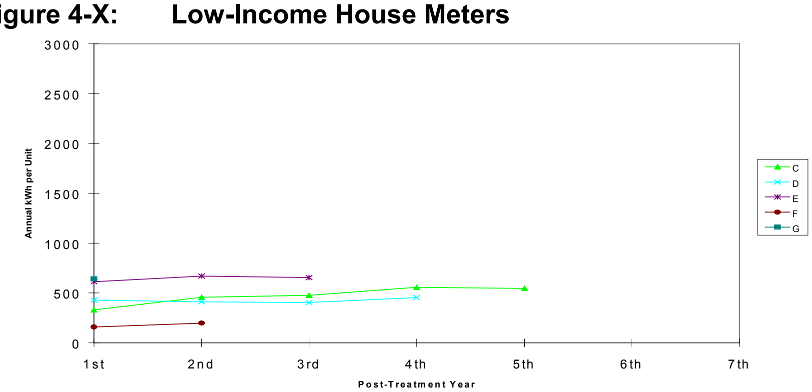


Figure 4-X: Low-Income House Meters



This page contains four graphic figures to allow comparisons among Standard-Income and Low-Income buildings on Tenant-Meter and House-Meter net energy savings (Method I). Cohorts A and B are dropped from this analysis because Nonparticipant data were not developed for their pre-periods. These figures are greatly reduced; larger versions appear in Appendix C of this report.

One observes that Tenant Meter savings cluster in a range between 700 kWh and 1,600 kWh per unit. No longer does any cohort lie below the 500 kWh level. There is less year-to-year variation among cohorts than on the gross savings scores, but still cohorts vary.

Results on House Meters show slightly less consistency among Standard-Income participants than on the gross scores. In both programs, results range between 200 kWh and about 600 kWh per unit. The trends for House Meters still seem fairly flat over the post-installation years.

The Nonparticipant control groups represent and adjust for effects driven by underlying changes in appliances, behaviors, and economic factors.

Figure 4-XI: Annual Energy Savings by Period, Net Method I, Weighted Average for Cohorts A to G

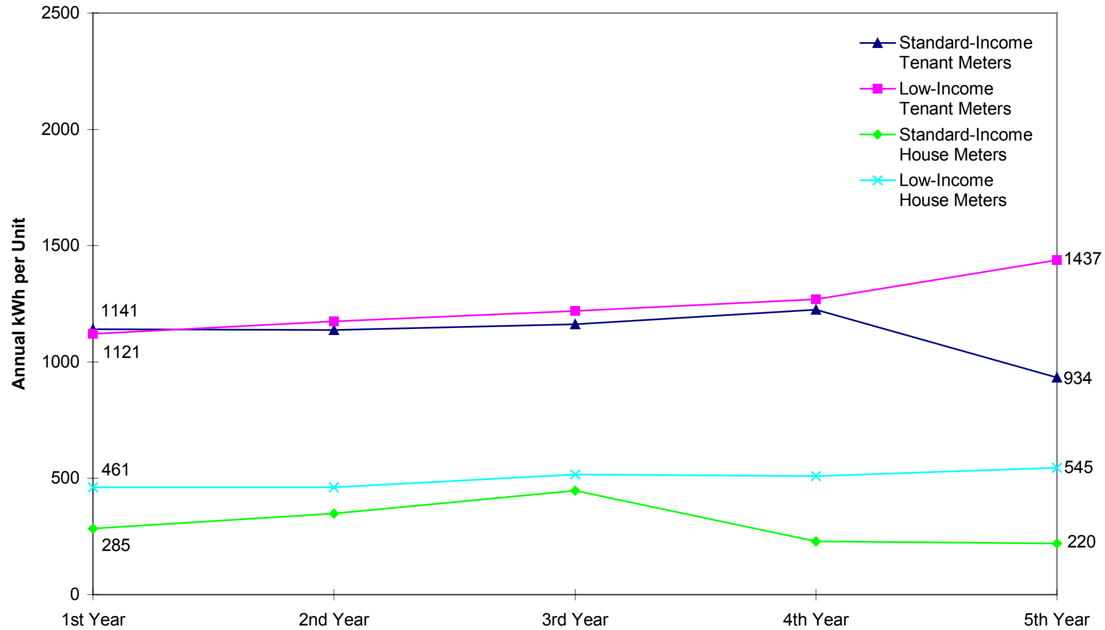


Table 4-C: Net Method I First Year Savings by Program and Meter Type

Measured kWh/Unit Energy Savings (First Year Post-Retrofit)	Cohort C 1988 Participants	Cohort D 1989 Participants	Cohort E 1990 Participants	Cohort F 1991 Participants	Cohort G 1992 Participants
Standard-Income					
House Meter Savings	476	341	441	109	228
in Pct. of Units	*93%*	*99%*	*84%*	*94%*	*95%*
Adjusted House-Meters	443	338	370	102	217
Tenant Meter Savings	717	1,278	1,015	1,388	1,137
Building Average Savings	1,160	1,616	1,385	1,490	1,354
Low-Income					
House Meter Savings	331	429	614	158	641
in Pct. of Units	*67%*	*89%*	*76%*	*67%*	*83%*
Adjusted House-Meters	222	382	467	106	532
Tenant Meter Savings	1,643	663	995	1,198	907
Building Average Savings	1,865	1,045	1,462	1,304	1,439

Table 4-C shows the variability among program years around the averages shown above. As was telegraphed by the discussion of Nonparticipant change scores, the net savings scores demonstrate strong gains over gross scores for Cohort C and Cohort D, while they show relative declines for Cohort F and Cohort G. The effect is to smooth the trends over program cohorts in observed energy savings impacts during the first year post-retrofit.

4.2.1.2 Past-Participant Comparisons

There is another way to calculate simple net savings than by using control groups of *pre-participants* or general population *nonparticipants*. This method was first used in the Pacific Northwest by the Bonneville Power Administration in an evaluation of the single-family Residential Weatherization Program (Oates 1993). The evaluation pioneered a new concept of using two comparison groups, one being a group of *past participants*. In the Residential Weatherization (RW) program there was some reason to believe that nonparticipants were installing weatherization measures on their own. Nonparticipant impacts could be interpreted as spillover effects (*free-drivers*) of the highly-saturated regional RW program. These actions might result in gross energy savings increasing over time among nonparticipants. If participant gross energy savings remained constant, net energy savings would decline. On the other hand, future participants drawn from such a nonparticipant group could become *free-riders* receiving program incentives for otherwise intended actions.

Energy changes in a comparison group generally are taken to represent price-induced conservation, as well as the impacts of change in demographics, economics, appliance holdings, and energy-using behavior. In a comparison group of past participants, there would be little remaining opportunity to purchase more measures of the type the program sponsors. However, another type of spillover can occur among former program participants. Their good experience with a utility conservation program may encourage them to try other conservation actions in subsequent years. In the case of the Multifamily Conservation Programs, this type of nonprogrammatic action would not involve weatherization or common-area lighting measures, but might include change-outs to higher efficiency appliances, in-unit lighting, or behavioral changes in the use and disposal of water and solid waste. These actions might result in increased gross energy savings over time among former participants. Such changes are difficult to attribute to the Utility programs. Nonetheless, care must be taken that valid impacts such as these are not subtracted from gross energy savings for participants when calculating net energy impacts.

Seattle City Light's evaluation was not designed to use a second comparison group, but the opportunity presents itself due to the number of program cohorts being studied simultaneously. The Past-Participant Net Method requires examining energy use change in prior cohorts that have post-installation data for the same two years being compare pre-to-post for a more recent cohort. For example, Cohort G has pre-retrofit data for 1991 and post-retrofit data for 1993; Cohort E has post-retrofit data for those same two years. Subtracting the Cohort E change score from the Cohort G change score yeilds a net savings score for Cohort G. Similarly, Cohort F has pre-retrofit data for 1991-1992 and post-retrofit data for 1993; Cohort D has post-retrofit data for those same three years. The contrasts for Cohorts C-G were examined for Tenant Meters and House Meters among the Standard-Income and Low-Income groups.

Figure 4-XII to Figure 4-XIV compare the results of the Nonparticipant Net Method I with the Past-Participant Net Comparison, for each program and meter type. (The Standard-Income control group was actually drawn from pre-participants, while the Low-Income control group was drawn from the nonparticipant sector at large). Table 4-D presents the Net Method I results from the Past-Participant comparisons for Cohorts C-G.

When only the more recent Cohorts D-G are examined, the Standard-Income program shows higher savings (by about 200 kWh per unit) than the Low-Income program on Tenant Meters and somewhat higher savings (by about 70 kWh per unit) on House Meters. The overall impact is a discrepancy between programs of 270 kWh per unit in net energy savings, according to the Net I Past-Participant comparison method.

Responses to the regional drought and economic slowdown in 1991-1993 were apparent on the Tenant Meters of *nonparticipants* in the Low-Income and Standard-Income programs, in the amount of 350-550 kWh per unit, or -4% to -6% of previous energy usage. Identical declines in energy use during the period of regional drought and economic slowdown were apparent on the Tenant Meters of *past participants* in the Low-Income and Standard-Income programs, in the same amount of 350-550 kWh per unit, or -5% to -7% of previous energy usage.

These findings suggest a reason for increased Tenant Meter energy savings among Standard-Income Participants (all cohorts) during post-installation Years 1-5, that being a general response to the regional drought conditions and economic slowdown of 1991-1993.

Among Low-Income Participants, a similar is only seen in Cohort A and Cohort B, while later cohorts show no change over time. It is important to note that the observed declining consumption may not reflect an enduring response, as water economic conditions change again in subsequent years.

Responses to the regional drought and economic slowdown in 1991-1993 were also apparent on the House Meters of *nonparticipants* in the Low-Income and Standard-Income programs. Low-Income nonparticipants flattened a previous +16% trend in usage (about 300 kWh per unit), while Standard-Income nonparticipants showed declining usage in the amount of 180 kWh per unit, or -9% of previous energy usage.

Figure 4-XII: Tenant-Meter Net I Comparison: Nonparticipants and Past Participants

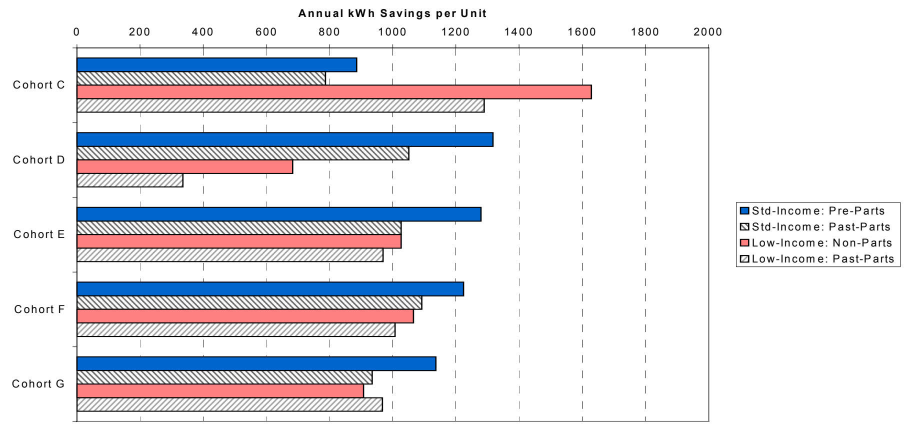


Figure 4-XIII: House-Meter Net I Comparison: Nonparticipants and Past Participants

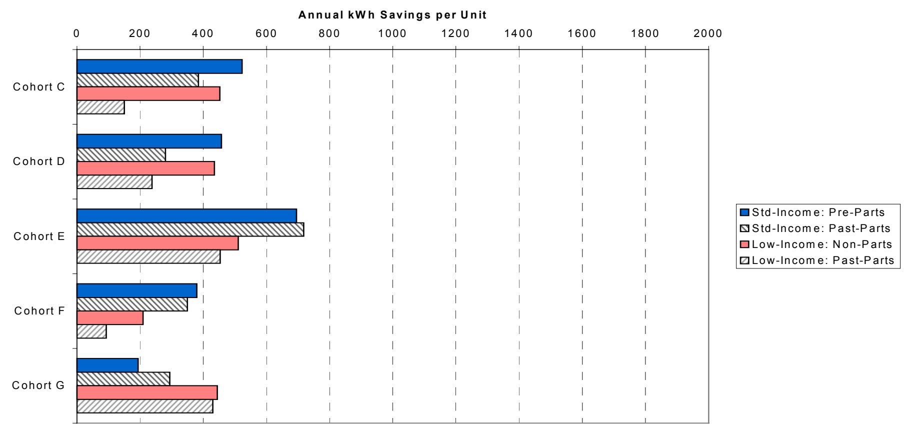


Figure 4-XIV: Total-Building Net I Comparison: Nonparticipants and Past Participants

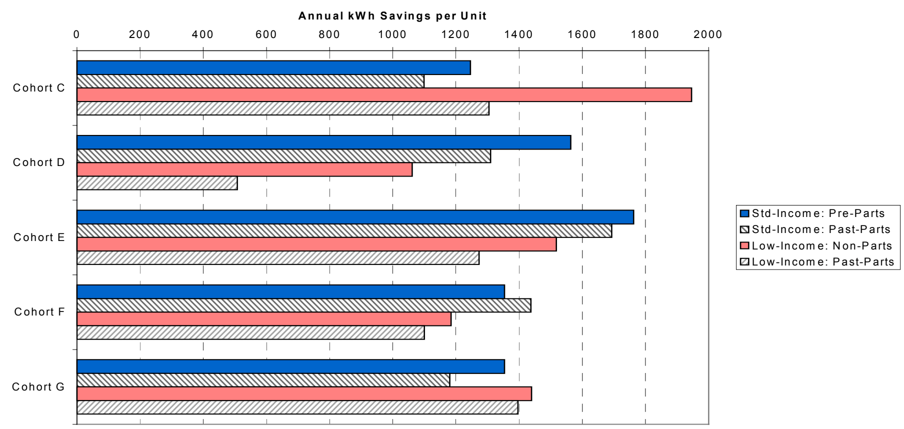


Table 4-D: Past-Participant Net Method I Comparison, First Year Savings by Program and Meter Type

Measured kWh/Unit Energy Savings (First Year Post-Retrofit)	Cohort C 1988 Participants	Cohort D 1989 Participants	Cohort E 1990 Participants	Cohort F 1991 Participants	Cohort G 1992 Participants
Standard-Income					
House Meter Savings	384	280	718	350	294
in Pct. of Units	*93%*	*99%*	*84%*	*94%*	*95%*
Adjusted House-Meters	312	259	666	345	245
Tenant Meter Savings	787	1,051	1,027	1,092	935
Building Average Savings	1,099	1,310	1,694	1,437	1,180
Low-Income					
House Meter Savings	150	238	454	105	562
in Pct. of Units	*67%*	*89%*	*76%*	*67%*	*83%*
Adjusted House-Meters	15	173	304	93	430
Tenant Meter Savings	1,290	335	969	1,007	967
Building Average Savings	1,305	508	1,272	1,100	1,396

Very muted responses to the regional drought and economic slowdown were suggested on the House Meters of *past participants* in the Low-Income and Standard-Income programs. Both groups flattened previous upward trends in energy usage (with modest rises of +6%, or about 70 kWh per unit).

The following summarization focuses on the new-technology Cohorts E through G. While specific cohort results vary, the overall effect of the Past-participant comparison is a drop of annual total savings by about 50 kWh per unit among Standard-Income Participants and a drop of about 120 kWh per unit among Low-Income Participants, relative to Net Method I findings using Nonparticipant control groups. The effect of using *past participants* for comparison under the Net I Method is thus very modest relative to *pre-participants* or *nonparticipants*. In a sampling-based methodology, the magnitude of difference would be lost in the “noise” of natural variance. The Nonparticipant control groups, as discussed earlier, showed a decelerated rate of energy use increase in 1990-1993 relative to the 1987-1990 period, when energy use was rising markedly. This corresponds to an economic slowdown and regional drought that have probably affected energy-using acquisitions and behaviors. The findings from this comparison between past-participant and nonparticipant impacts suggests that there are few if any spillover effects (free drivers) attributable to the Multifamily Conservation Programs.

4.3 Net Savings Score Method II

See Appendix B for tables that provide Method II net savings scores for each cohort in each post-installation year. This analysis is performed by simple linear regression incorporating as a covariate the pre-period energy usage. The purpose of Net Method II is to adjust for pre-existing patterns of energy use that differentiate buildings and confound the calculation of net savings attributable to the program intervention. Each table contains statistics such as the group mean and standard error for each post-period. Savings are represented as a percentage of baseline energy use, accompanied by a 95% confidence interval. The tables also provide for each analysis the R-squared value, degrees of freedom, and F-test of significance. The general findings on group mean savings are summarized briefly in the following set of graphical figures.

The four figures on the next page show adjusted net savings scores for each individual participant cohort, which have unequal numbers of buildings and units. Figure 4-XIX, following, shows the weighted group averages across five cohorts for five post-treatment years, to reveal the underlying pattern more clearly. As with the Gross scores and Net Method I scores, this graph shows a clear confluence of results in the Post-years for Tenant Meters. Savings of 1,000-1,200 kWh in the first Post-year are succeeded by a similar savings range in the fifth Post-year. The House Meter results begin at a common point around 380 kWh in the first Post-year, rise together to about 500 kWh in the third Post-year, and then separate, ending with a 300 kWh difference between programs by the fifth year after measure installation.

Figure 4-XIX shows weighted average gross savings scores across seven cohorts of program participants. The following table states the average first-year *net* savings for each of the seven cohorts, as measured by Net Method II. Building level savings are stated as kWh per unit, calculated as the sum of average Tenant Meter savings plus House Meter savings adjusted for the percentage of residential units in buildings having house meters. Table 4-E shows the variability among program years around the averages shown above.

When only the more recent Cohorts D-G are examined, the Standard-Income program shows higher savings (by about 470 kWh per unit) than the Low-Income program on Tenant Meters, and identical savings across programs on House Meters. The overall impact is a discrepancy between programs of 470 kWh per unit in net energy savings, according to Net Method II.

Relative to Net Method I, the Net Method II savings scores demonstrate some dampening of effects, as in Standard-Income Cohort F and Low-Income Cohort C. This occurs because innate variance of the Nonparticipants differs from that of Participants in the affected cohorts.

Annual Energy Savings by Period: Net II Scores

Figure 4-XV: Standard-Income Tenant Meters

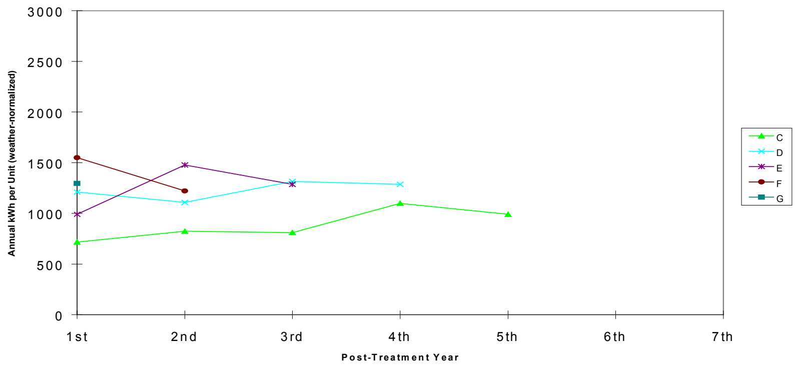


Figure 4-XVI: Low-Income Tenant Meters

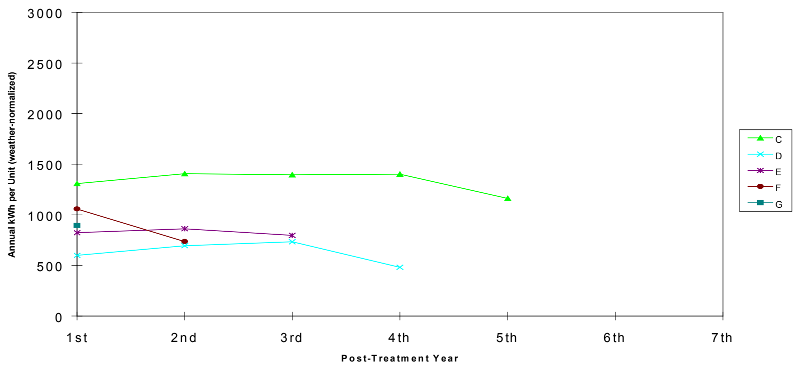


Figure 4-XVII: Standard-Income House Meters

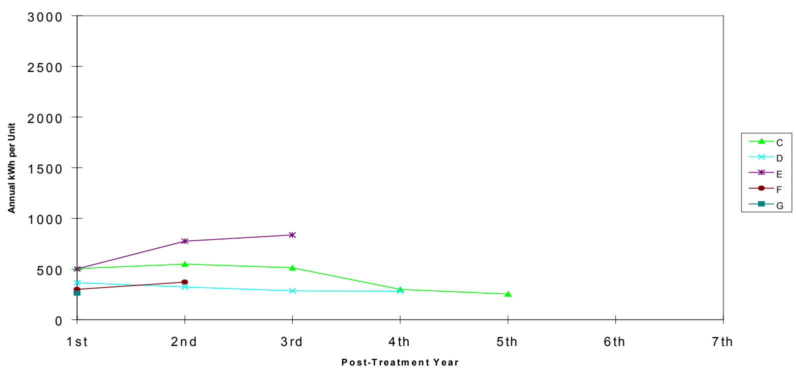
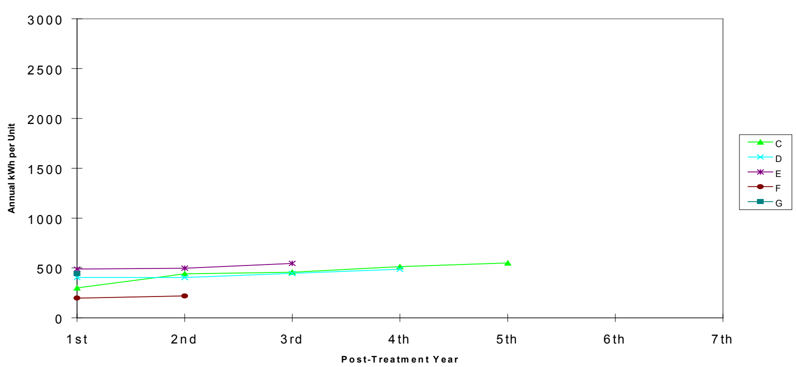


Figure 4-XVIII: Low-Income House Meters



This page contains four graphic figures to allow comparisons among Standard-Income and Low-Income buildings on Tenant-Meter and House-Meter net energy savings (Method I). Cohorts A and B are dropped from this analysis because Nonparticipant data were not developed for their pre-periods. These figures are greatly reduced; larger versions appear in Appendix C of this report.

One observes that Tenant Meter savings cluster in a range between 500 kWh and 1,500 kWh per unit, lower than in Net Method I. No cohort lies below the 500 kWh level. Yearly scores have smoothed out over the five post-periods, while cohorts are still seen to vary.

Results on House Meters are also more consistent than in Net Method I. In both programs, results range between 200 kWh and 500 kWh per unit, with one Standard-Income cohort projecting above this bound. The trends for House Meters still seem fairly flat over the post-installation years.

In this analysis, the Non-participant control groups represent and adjust for effects driven by underlying changes in appliances, behaviors, and economic factors. The pre-period covariate adjusts for effects attributable to unique building profiles in energy consumption.

Figure 4-XIX: Annual Energy Savings by Period, Net Method II, Weighted Average for Cohorts A to G

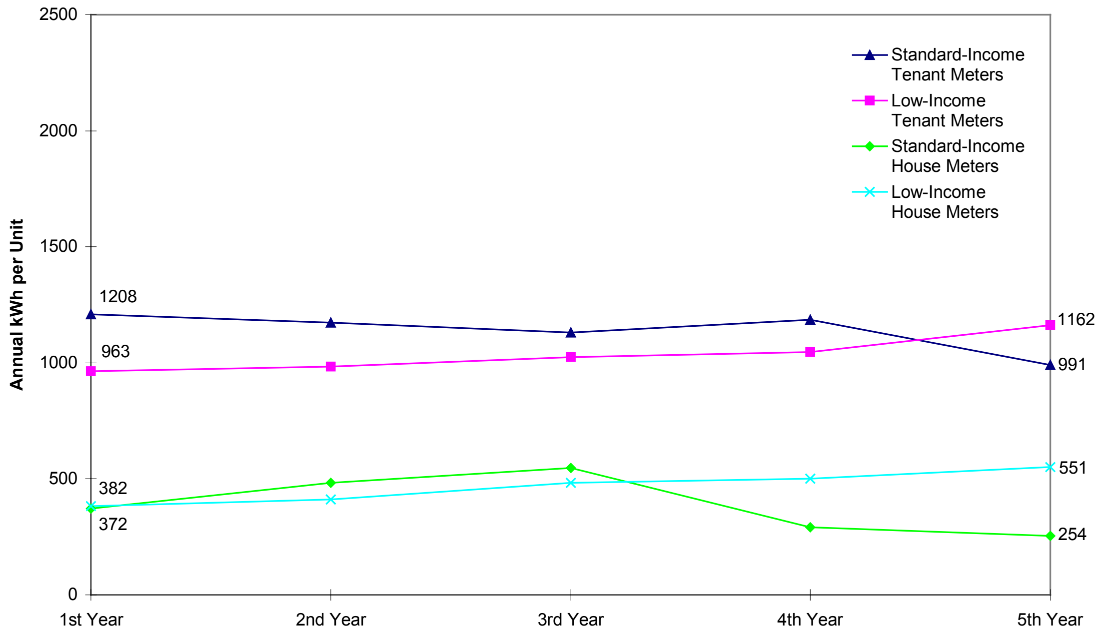


Table 4-E: Net Method II First Year Savings by Program and Meter Type

Measured kWh/Unit Energy Savings (First Year Post-Retrofit)	Cohort C 1988 Participants	Cohort D 1989 Participants	Cohort E 1990 Participants	Cohort F 1991 Participants	Cohort G 1992 Participants
Standard-Income					
House Meter Savings	507	368	503	301	264
in Pct. of Units	*93%*	*99%*	*84%*	*94%*	*95%*
Adjusted House-Meters	472	364	423	283	251
Tenant Meter Savings	717	1,210	992	1,550	1,295
Building Average Savings	1,189	1,574	1,415	1,833	1,546
Low-Income					
House Meter Savings	301	404	490	197	444
in Pct. of Units	*67%*	*89%*	*76%*	*67%*	*83%*
Adjusted House-Meters	202	360	372	132	369
Tenant Meter Savings	1,308	601	824	1,059	896
Building Average Savings	1,510	961	1,196	1,191	1,265

4.4 Comparison of Savings Score Methods

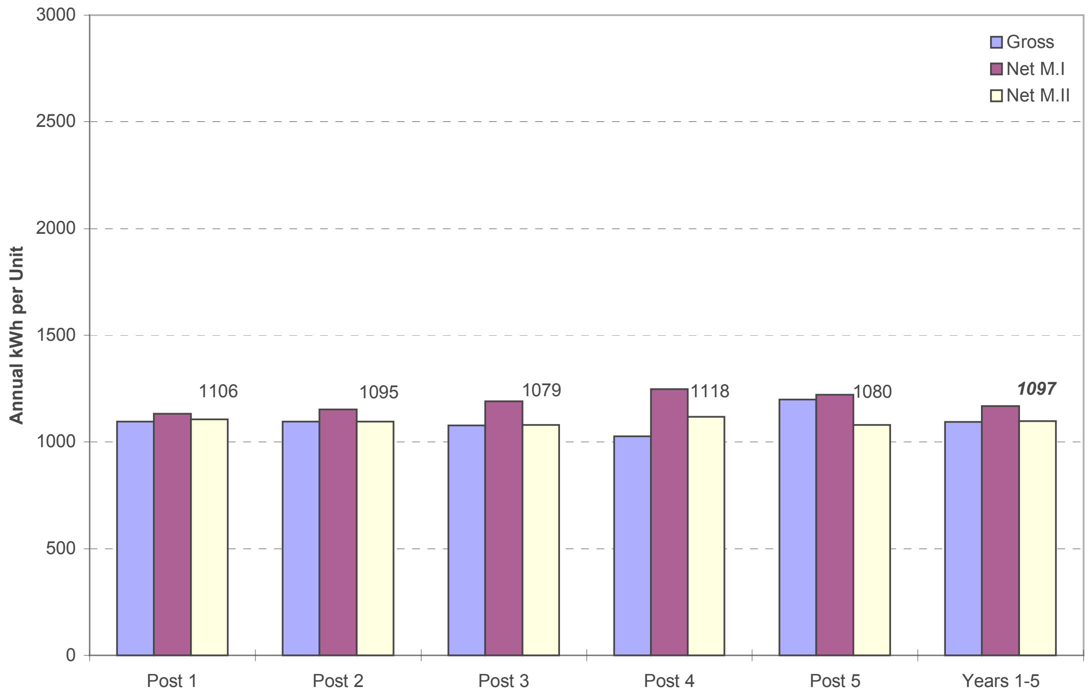
The preceding sections of this chapter presented in graphical form the results of three savings score methods. These methods present a picture that progressively decreases known sources of error variance in electricity use change over time for the study groups. The Gross Scores method calculated the change in use, from pre-period to each post-period for participating buildings, to estimate program impacts. This method introduced an adjustment for annual variations in weather conditions across the study period, in the examination of Tenant Meter scores. The Net Method I Scores introduced a control group to adjust for changes due to economic, social, and behavioral effects. The Net Method II analysis introduced an additional correction for the correlation of pre- to post-period energy use in individual buildings. This method adjusted for unique, pre-existing building profiles that varied independently of subsequent program or external impacts.

The following three figures bring together the results of these three change-score methods. The Standard-Income and Low-Income programs are combined to yield a generalized estimate of impacts from the Multifamily Conservation Programs. As in the larger graphic figures presented earlier, observations are weighted by the number of units per cohort to create a single result for each post-treatment year. To the right in each figure is a set of columns that represent the five-year average result by method. In each graph, the values yielded by Net Method II are labeled. These represent the result that most accurately states the programmatic impact on energy consumption in participating buildings.

Across the first five years after program participation, all three methods yielded remarkably stable results on Tenant Meter data, as shown in Figure 4-XX. When an adjustment for nonparticipant change was introduced via Net Method I, energy savings were estimated at a higher level. However, Net Method II, by introducing another adjustment for non-equivalent energy use patterns in the pre-period, provided results very close to those of the Gross Score approach. This suggests that no real change occurred among Nonparticipants over the years to influence energy use in tenant spaces. Hence one may conclude that there are no “free riders” taking advantage of this program to install measures who might have done so on their own.

Of the methods presented so far, Net Method II best reflects the programmatic influence on tenant-meter energy use. As the five-year average shows, participating buildings saved 1,097 kWh per residential unit in a normal meteorological year. Examination of the year-to-year results shows this level to be completely stable across a five-year span, evidencing excellent persistence of savings from the building shell and showerheads measures. The year-to-year Tenant-Meter results are stable across the five-years, beginning the time span at 1,106 kWh per unit and ending it at 1,080 kWh per unit.

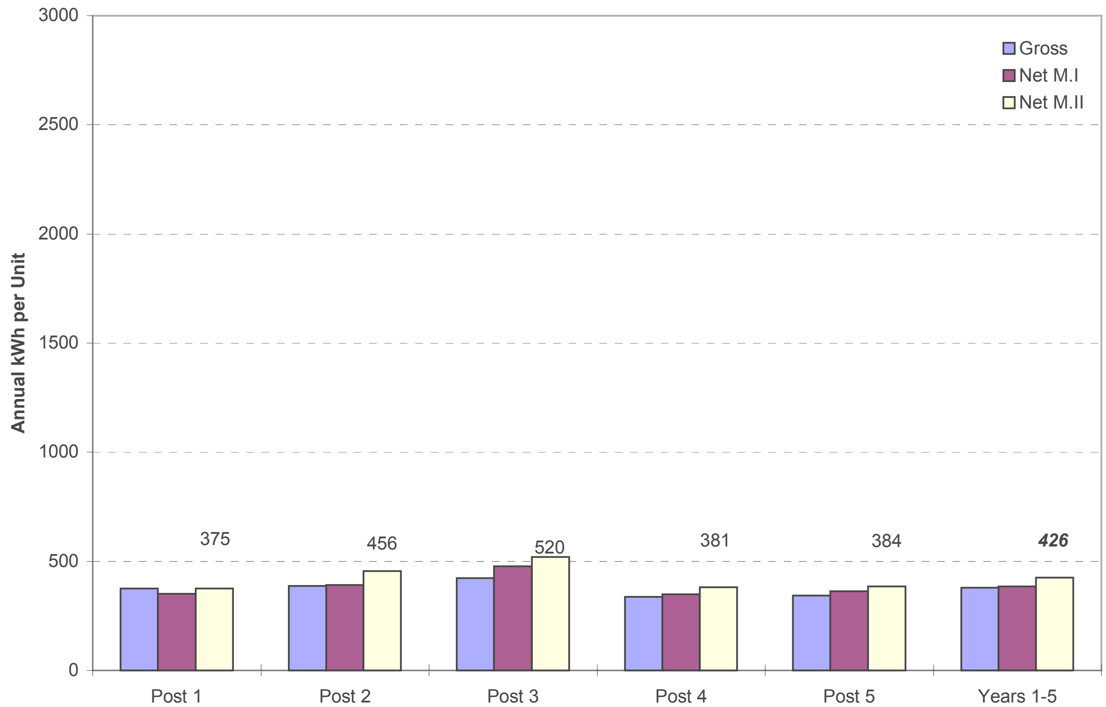
Figure 4-XX: Annual Tenant-Meter Energy Savings by Period, Weighted Average of Cohorts C to G, Standard-Income and Low-income Combined



Turning to the House Meter results shown in Figure 4-XXI, the same pattern among the methods emerges. Net Method I, which adjusts for nonparticipant change, yields results slightly below those of Net Method II, which introduced another adjustment for non-equivalent energy use patterns in the pre-period.

Net Method II best reflects the programmatic influence on house-meter energy use. As the five-year average shows, participating buildings having house meters saved 426 kWh per residential unit in a normal meteorological year. Examination of the year-to-year results shows this level to be fairly stable across a five-year span, beginning and ending the time span at a level around 380 kWh per unit. This pattern evidences excellent persistence of savings from the common-area lighting measures. Keeping in mind that not all studied buildings had house meters, these data can be adjusted to the common denominator of total units in Cohorts C through G buildings. When this is done, the Net Method II results show five-year average savings of 361 kWh per residential unit. The year-to-year House-Meter results are stable across the five-years, beginning the time span at 322 kWh per unit and ending it at 305 kWh per unit.

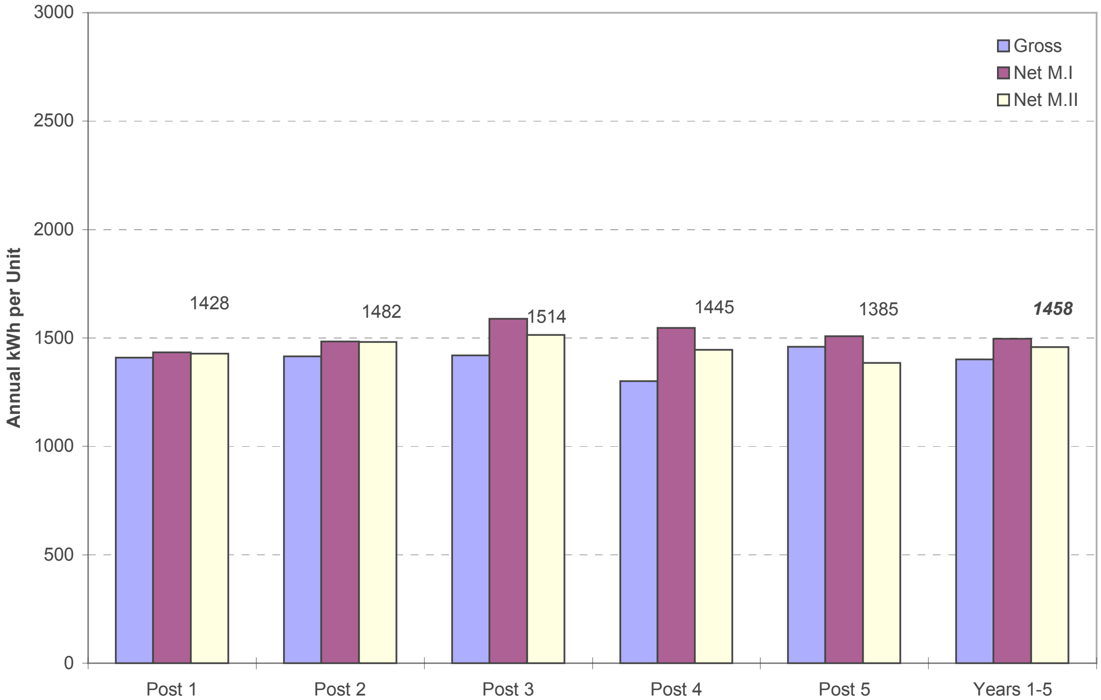
Figure 4-XXI: Annual House-Meter Energy Savings by Period, Weighted Average of Cohorts C to G, Standard-Income and Low-income Combined



The final of these bar graphics combines the results of Tenant-Meter and House-Meters analyses. Before summing results from the two meter types, House-Meter data are adjusted by the ratio of units these buildings to the total number of units in the study groups. Figure 4-XXII establishes the total building electricity savings observed from Cohorts C through G in the five-year Post-period from 1989 through 1993 (combining the Standard-Income and Low-Income programs)..

The Gross Score approach states savings very near those of Net Method II. Net Method I, which adjusts for nonparticipant change, slightly exceeds the results of Net Method II, which adjusts for non-equivalent patterns in the pre-period. The Net Method II five-year average shows participating buildings saving a total of 1,458 kWh per residential unit in a normal meteorological year from all measures combined. Examination of the year-to-year results shows this level to be stable across a five-year span, beginning and ending the time span at a level around 1,428 kWh to 1,385 kWh per unit. This pattern evidences excellent persistence of savings from the all program measures, and no discernable “free ridership” on the program (from Participants who might have installed measures on their own).

Figure 4-XXII: Annual Total-Building Energy Savings by Period, Weighted Average of Cohorts C to G, Standard-Income and Low-income Combined



Of the three approaches, Net Method II provides the best available adjustment for external factors and for natural variability within groups. The final results from Net Method II are presented in the table below for Cohorts C through G. The savings results reported here average all post-periods for a given cohort, thus reflecting one post-year for Cohort G but five post-years for Cohort C.

The House-Meter findings for the two programs are very similar in buildings with this type of meter. The five-year average savings across cohorts were 393 kWh per unit from Standard-Income buildings and 428 kWh per unit from Low-Income buildings. However, because fewer Low-Income buildings have these meters, adjusted to total building units the five-year average results were 365 kWh per unit from Standard-Income buildings and 326 kWh per unit from Low-Income buildings.

By contrast, the Tenant-Meter findings for the two programs were farther apart, by about 300 kWh per unit. The five-year average savings across cohorts were 1,236 kWh per unit from Standard-Income buildings and 952 kWh per unit from Low-Income buildings. When combined to the building level, five-year average savings across Cohorts C through G were 1,601 kWh per unit from Standard-Income buildings and 1,278 kWh per unit from Low-Income buildings.

Table 4-F: Net Method II Five-Year Average Savings by Program and Meter Type

Measured kWh/Unit Energy Savings (Post Years 1-5 Average)	Cohort C 1988 Participants	Cohort D 1989 Participants	Cohort E 1990 Participants	Cohort F 1991 Participants	Cohort G 1992 Participants
Standard-Income					
House Meter Savings	424	316	705	337	264
in Pct. of Units	*93%*	*99%*	*84%*	*94%*	*95%*
Adjusted House-Meters	394	311	589	317	250
Tenant Meter Savings	889	1,231	1,252	1,386	1,295
Building Total Savings	1,282	1,542	1,842	1,703	1,545
Low-Income					
House Meter Savings	453	435	511	209	444
in Pct. of Units	*67%*	*89%*	*76%*	*67%*	*83%*
Adjusted House-Meters	303	387	390	140	369
Tenant Meter Savings	1,335	628	829	898	896
Building Total Savings	1,637	1,015	1,219	1,038	1,265

The next natural question is, how do these findings compare to expectations? Figure 4-XXIII summarizes the longitudinal study engineering projections for Standard-Income Participants in the Multifamily Conservation Programs.

From 1986 to 1992, the engineering estimates show a clear upward trend beginning at about 1,293 kWh per unit in 1986 and incrementing by about 99 kWh per unit each year (the r-square implying that 84% of the variance is due to the time trend). Relative to this trend, the projections published in the annual ENERGY CONSERVATION ACCOMPLISHMENTS report also trend upwards; however, they start about 80 kWh lower in 1986 and incline upward at a rate about 85% of the engineering projection rate (1,211 kWh per unit in 1986 plus about 85 kWh per program year).

Figure 4-XXIII: Prior Projections of Annual Energy Savings

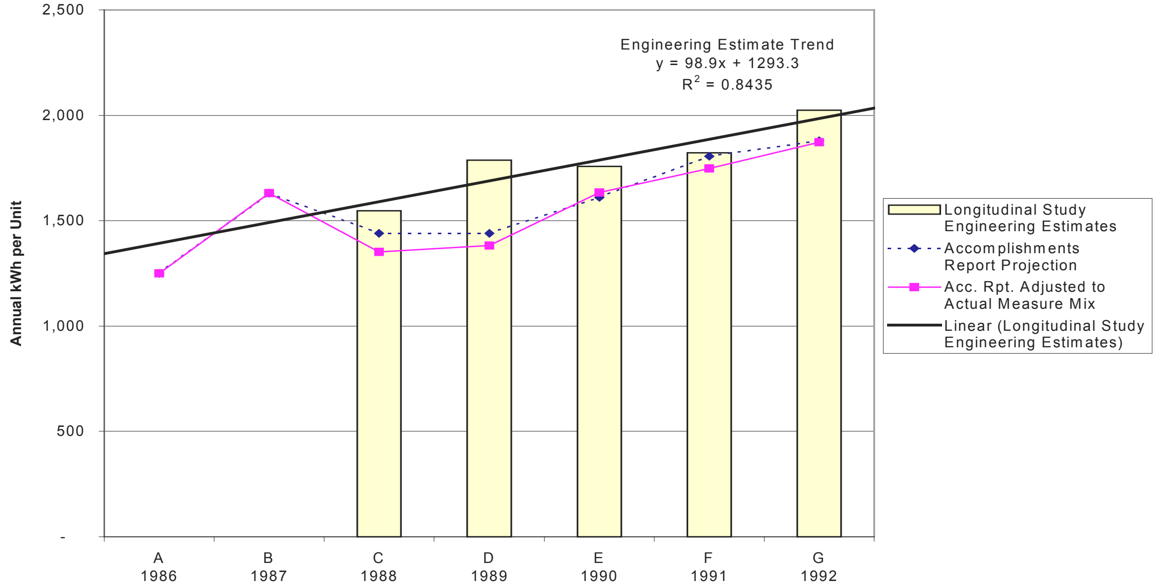


Table 4-G depicts the Net Method II results for Cohorts C through G (Standard-Income Participants only) as a percentage of prior estimates established for program years 1988-1992. The savings results reported here average all post-periods for a given cohort, thus reflecting one post-year for Cohort G but five post-years for Cohort C.

The first comparison is to values estimated in the annual ENERGY CONSERVATION ACCOMPLISHMENTS report. The second series, developed in Chapter 3 of the present longitudinal study, adjusts the ACCOMPLISHMENTS report estimates to reflect the actual mix of measure types installed in each Standard-Income program year 1988 through 1992. The third series, developed in Chapter 2 of the present study, estimates expected savings based on engineering data about the Standard-Income buildings and measures installed. These three series are illustrated in Figure 4-XXIII, above.

Table 4-G: Total Building Savings from Net Method II Compared to Prior Estimates for Standard-Income Participants

Measured kWh/Unit as Percentage of Prior Estimates	Cohort C 1988 Participants	Cohort D 1989 Participants	Cohort E 1990 Participants	Cohort F 1991 Participants	Cohort G 1992 Participants
Energy Conservation Accomplishments Report Prior Estimation	1,440 *89%*	1,440 *107%*	1,610 *114%*	1,805 *94%*	1,880 *82%*
ECAR Adjusted to Actual Measure Mix	1,351 *95%*	1,382 *112%*	1,634 *113%*	1,747 *98%*	1,873 *83%*
Longitudinal Study Engineering Estimates	1,547 *83%*	1,788 *86%*	1,757 *105%*	1,823 *93%*	2,024 *76%*
Net Method II, Combined Meters	1,282	1,542	1,842	1,703	1,545

In Table 4-G, the first two series of prior estimates projected an upward trend in savings beginning in 1990, when higher-efficiency window measures became prevalent and then mandatory. Since actual net savings increased and then declined over the five program groups from Cohort C to Cohort G, the percentage of adjusted prior estimates seen in measured savings varied between 95% and 113% in 1988-1991 participants, dropping to just above 83% in 1992 participants. The proportion of engineering estimates actualized in measured savings varied between 83% and 105% in 1988-1991 participants, dropping to about 76% in 1992 participants. The three series of prior projections by year varied within ±24% of actual savings (ranging from 76% to 114%), as measured by Net Scores Method II. By studying virtually all buildings in these cohorts, the sampling error in stating annual energy savings has thus been reduced from ±24% to nearly zero.

4.5 Net Savings Score Method III

The final element of this examination of net energy savings is to judge whether expected increases in energy savings in fact occurred among the 1991 and 1992 participants (represented here by Cohort F and Cohort G). The final graphical figures (Figure 4-XXV and Figure 4-XXV) report First Post-year energy savings separately for the Standard-Income and Low-Income programs. The cohorts have been clustered into two groups, Cohorts A through E representing the program with early-technology windows, and Cohorts F plus G representing the program after Class 40 windows became the norm (Uα0.40). The sub-sample mean values are bracketed by a range representing the minimum and maximum of a 95% confidence interval about the population mean.

Figure 4-XXIV: Net Method III, First Post-Year Energy Savings, Standard-Income Pooled Cohort Clusters A–E and F–G

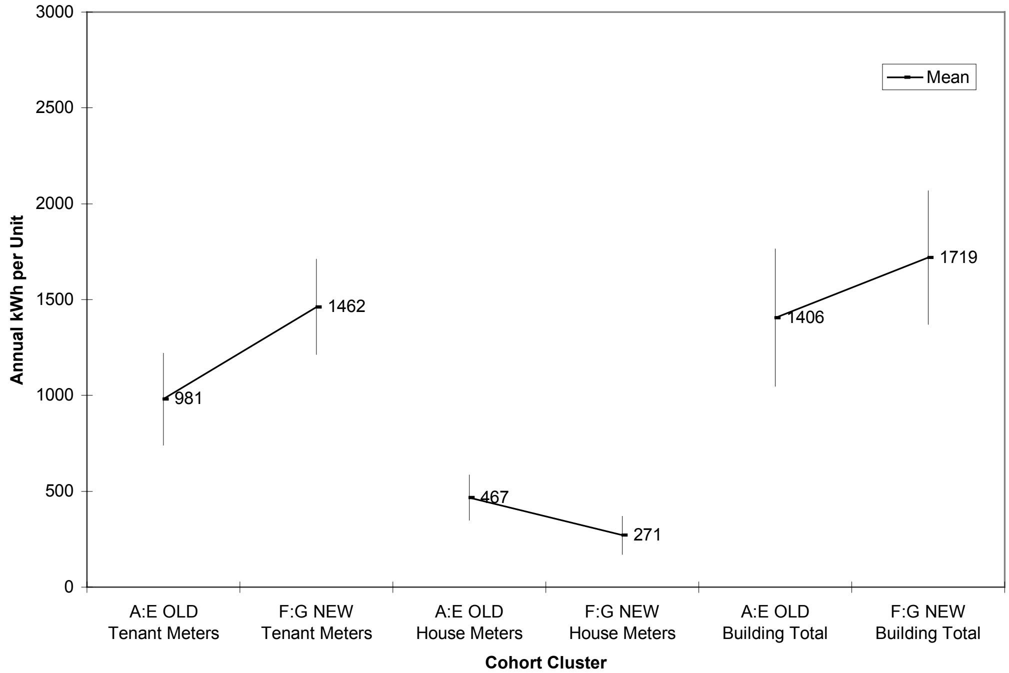


Figure 4-XXV: Net Method III, First Post-Year Energy Savings, Low-Income Pooled Cohort Clusters A–E and F–G

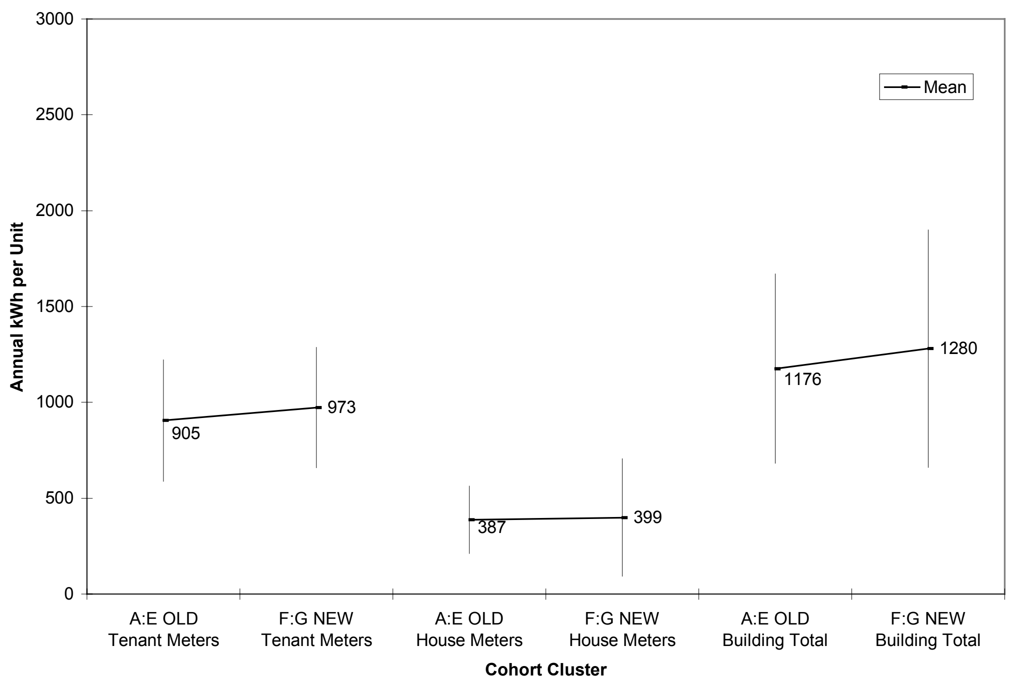


Figure 4-XXIV provides the building total profile for the two cohort clusters among Standard-Income participants. This profile is preceded by a breakout on Tenant Meters and on House Meters. Dwelling area space-heat and water-heat savings rose from 981 kWh to 1,462 kWh per unit on average with the new window technology, for a *net increment* of 481 kWh per unit. However, common-area lighting savings dropped from 467 kWh to 271 kWh per unit on average during that transition. Before summing to the building level, these findings were adjusted by the proportion of study buildings with house-meter data (91% in Cohorts A-E and 95% in Cohorts F-G). The overall effect was to mute the expected increase in building savings such that they rose from 1,406 kWh per unit in the early cohorts to only 1,719 kWh in later cohorts.

Figure 4-XXV likewise provides a building total profile for the two cohort clusters among Low-Income participants, is preceded by a breakout on Tenant Meters and on House Meters. Dwelling area space-heat and water-heat savings rose only slightly from 905 kWh to 973 kWh per unit, on average. This demonstrates little *net effect* from the new window technology (only 68 kWh per unit). Meanwhile, common-area lighting savings moved from 387 kWh to 399 kWh per unit on average during that transition. These findings were also adjusted by the proportion of study buildings with house-meter data (70% in Cohorts A-E and 77% in Cohorts F-G). The overall effect was that total building savings only rose slightly from 1,1176 kWh per unit in the early cohorts to just 1,280 kWh in later cohorts.

These results show that the Standard-Income program came close to fulfilling expectations for annual energy savings. The expected values started at 1,440 kWh (prior) to 1,351 kWh (adjusted) per unit for 1988 participants and rose to 1,880 kWh (prior) to 1,873 kWh (adjusted) for 1992 participants. The expected increment of 440 kWh (prior) to 522 kWh (adjusted) was satisfied by the actual overall increment of 481 kWh per unit (1462-981).

The Low-Income program started at a lower level among 1988 participants and did not evidence the strong net gains that were anticipated from the newer window technology. Savings were incremented by only 68 kWh per unit (973-905). Unfortunately, an adjustment to the actual measure mix was not possible for the Low-Income cases (due to lack of detailed building-file data), so it is not possible to judge whether 'targets' of 1,351 kWh (1988) to 1,873 kWh (1992) were appropriate for this group.

5. Regression Models: Impact Results

Statistical regression methods were used to refine estimates of energy savings impacts for the Standard-Income 1988-1992 program. This was possible because field-work files for this program contained numerous details about building construction and program-installed measures. It was possible from these files to construct engineering projections of impacts on energy usage. The Low-Income Multifamily Program kept abbreviated field-files that did not lend themselves to this type of detailed analysis.

5.1 Analysis of Covariance

The multivariate linear regression analyses presented in this chapter all incorporate pre-period energy consumption as a covariate. This variable provides a correction for the correlation between post- and pre-period levels and the contribution of this correlation to the error variance. The covariate correction is performed because the treatment (Participant) cohorts and control (Nonparticipant) groups are not precisely equivalent. They were not randomly selected, are not homogeneous, and cases were not explicitly matched. Buildings have intrinsic weather sensitivities (cf. reference temperatures) which are reflected in the pre-period energy use level. The impact of program measures is expected to reduce this intrinsic sensitivity in Participant buildings. Because post-period energy consumption is highly correlated with pre-period consumption (more so than with any other building characteristic), the analysis of covariance approach provides a better estimate of programmatic energy savings than either the Gross Score or Net Score Methods.

The multiple linear regression models used in this research design extend analysis of covariance across multiple observations per building, one for each post-installation year. The Participation Model incorporates a nominal dummy variable (taking the value zero or one), to represent impacts in observations that occur after program participation. The Engineering Model substitutes an interval scaled variable in its place (taking values from zero to the maximum), to represent the quantity of energy use change expected as the result of reductions in building heat-loss, lighting wattage, and hot-water flows. This variable is calculated using engineering equations that represent physical properties of the buildings and of program measures. The Measure Detail Model substitutes several interval scaled variables decomposing the engineering variable into its constituent parts (windows, insulation by surface type, showerheads, and lighting).

5.2 Tenant Meter Regressions

The three model types were applied to Tenant-Meter data with Nonparticipants and three samples of Participants. The full sample (Cohorts A through G) was examined with the Participant Model. A sub-sample having sufficient data for engineering projections was examined with all three models. A smaller sub-sample also participated in the follow-up Measures Survey. From that survey a few additional variables were developed to represent impacts due to unusual actions in Nonparticipant buildings and by Participants subsequent to installation of program measures. This group of cases was also examined under all three models, with the addition of a few nominal dummy variables from the survey data.

The following set of graphical figures represents the results of the Participant and Engineering Models as applied to Tenant-Meter data for each participant Cohort C through G. A final figure in the set represents a pooled result obtained in one common regression incorporating all the cohorts.

Detailed tables in Appendix B provide regression results for each cohort by meter type. Each table contains relevant statistics such as model intercept (I), variable coefficients (ϑ_j), associated *t*-statistics, degrees of freedom, model F-value, and adjusted R^2 (percent variance "explained"). For the sub-samples analyzed under Engineering Model, the tables also specify the mean values of engineering projections and number of cases. In a separate set of tables by Model type, the outcome of each model has been translated into estimates of net energy savings per unit in each post-year, accompanied the standard error of each mean and a 95% confidence interval. The latter statistic is invoked mainly to represent the uncertainty about Nonparticipant means (Participant means being known with better certainty due to the near-census of data points). A few highlights are given below in Table 5-A.

Table 5-A: Tenant-Meter Savings by Regression Method and Cohort

Measured kWh/Unit Energy Savings (First Year Post-Retrofit)	Cohort C 1988 Participants	Cohort D 1989 Participants	Cohort E 1990 Participants	Cohort F 1991 Participants	Cohort G 1992 Participants
Standard-Income					
Model I	554	1,118	983	1,391	1,229
Model II	562	1,118	1,023	1,403	1,225
Model III	659	872	618	708	1,019
Model V	604	990	1,015	1,448	1,249
Model VI	647	658	669	764	1,112

Annual Energy Savings by Period: Regressions

Figure 5-I: Cohort C Tenant Meters

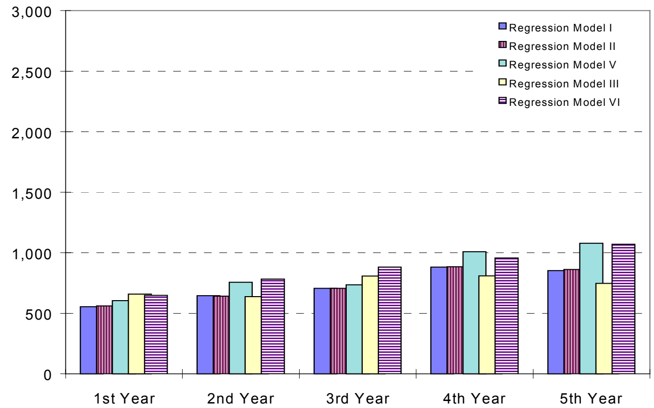


Figure 5-II: Cohort D Tenant Meters

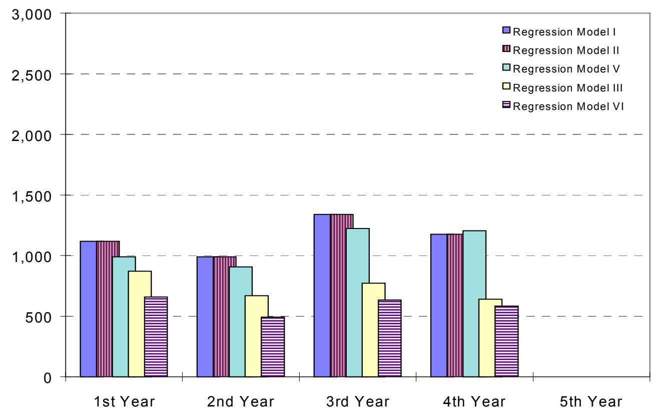
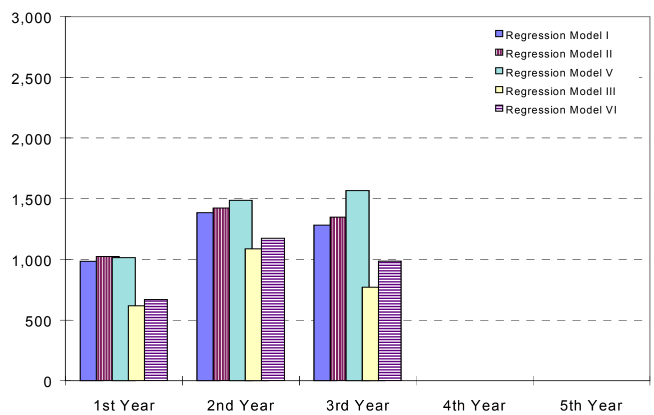


Figure 5-III Cohort E Tenant Meters



Five regression models were applied to Tenant Meter data from the Standard-Income program. Full-sized versions of each graphic figure appear in Appendix C.

The first five graphic figures show the resulting estimates of electricity savings for Cohort C through Cohort G, in each year after measure installation. The sixth graph represents a pooled analysis where all cohorts were combined to make a generalized estimate of net savings in five post-years.

In each cluster of columns, the ***participation*** models (I, II, and V) precede the ***engineering*** models (III and VI). Model V (the central column in each cluster) is preferred because it contains the greatest amount of information about intervening factors, and in many analyses Model V maximized the proportion of variance explained (R-squared).

In several figures, the ***participation*** models estimate higher levels of savings than the ***engineering*** models. This is possible because the engineering estimates may contain error due to inadequate data inputs, but also because not all program interventions are expressed in the engineering equations.

Annual Energy Savings by Period: Regressions

Figure 5-IV Cohort F Tenant Meters

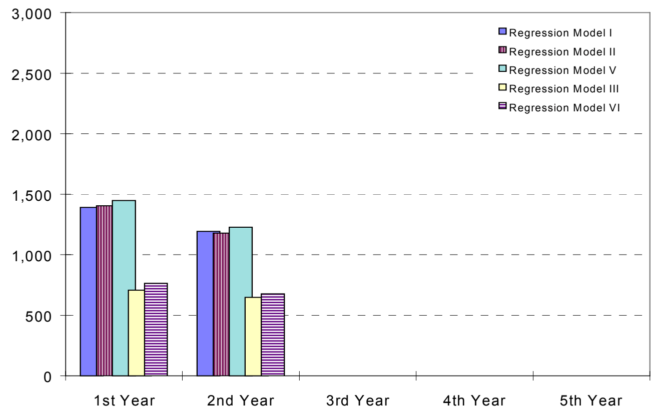


Figure 5-V Cohort G Tenant Meters

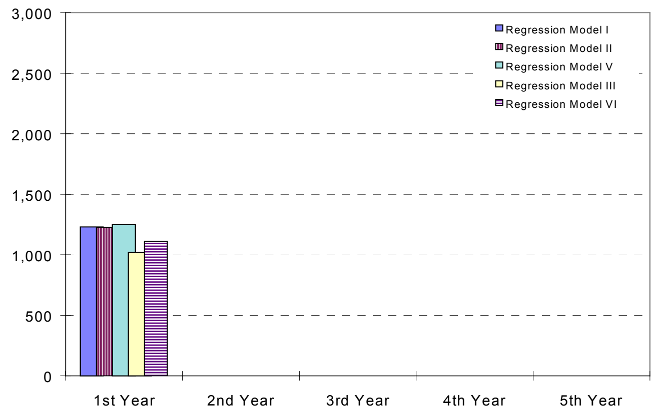
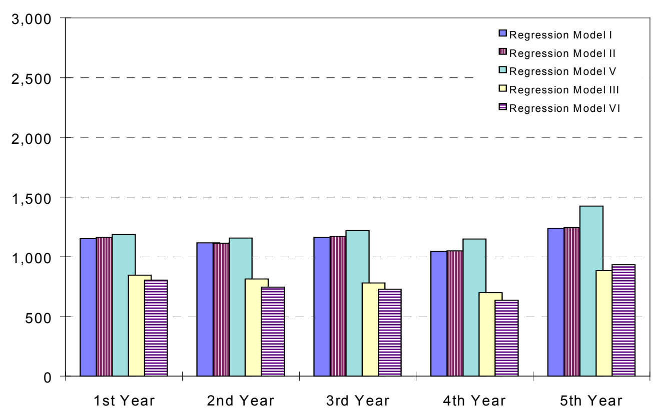


Figure 5-VI Pooled Cohorts C–G Tenant Meters



Model V estimates first year electricity savings per unit as follow:

Cohort C	604 kWh,
Cohort D	990 kWh,
Cohort E	1,015 kWh,
Cohort F	1,448 kWh, and
Cohort G	1,249 kWh.

These estimates take account of pre-period non-equivalence, changes in control group use patterns, and changes at each site to appliances and lighting during the post-period.

The pooled analysis combining all Standard-Income cohorts finds that the average first-year savings from Tenant Meters Model V) have been 1,186 kWh per unit. Year-by-year, these savings were:

Year 1	1,186 kWh,
Year 2	1,157 kWh,
Year 3	1,219 kWh,
Year 4	1,150 kWh, and
Year 5	1,425 kWh.

These estimates clearly show persistence of dwelling-area energy savings on space heat and water heat, in the region of 1,200 kWh per year over four years, rising in the fifth.

It is not known whether any cohorts installed new showerheads in 1992-1993 through the Home Water Savers Program, which might have contributed to a rise then in savings.

The Model II and Model V results specify total energy savings per unit measured on Tenant Meters. The Model III and Model VI results represent that proportion of energy savings associated with the engineering projections. The difference between each pair of results (II-III, V-VI) indicates that portion of energy savings per unit not correlated with the engineering projections.

5.3 House Meter Regressions

The three model types were also applied to House-Meter data with Nonparticipants and three samples of Participants. The full sample (Cohorts A through G) was examined with the Participant Model. A sub-sample having sufficient data for engineering projections was examined with all the Participant and Engineering models. A smaller sub-sample also participated in the follow-up Measures Survey. From that survey a few additional variables were developed to represent impacts due to unusual actions in Nonparticipant buildings and by Participants subsequent to installation of program measures. This group of cases was also examined under both models, with the addition of a few nominal dummy variables from the survey data.

The following set of graphical figures represents the results of the Participant and Engineering Models as applied to House-Meter data for each participant Cohort C through G. A final figure in the set represents a pooled result obtained in one common regression incorporating all the cohorts. Detailed tables in Appendix B provide regression results for each cohort by meter type. A few highlights are given below in Table 5-B.

Table 5-B: House-Meter Savings by Regression Method and Cohort

Measured kWh/Unit Energy Savings (First Year Post-Retrofit)	**Cohort C 1988 Participants**	**Cohort D 1989 Participants**	**Cohort E 1990 Participants**	**Cohort F 1991 Participants**	**Cohort G 1992 Participants**
Standard-Income					
Model I	493	391	573	351	274
Model II	539	474	610	321	330
Model III	335	466	425	247	342
Model V	531	515	682	358	194
Model VI	351	503	446	260	214

The Model II and Model V results specify total energy savings per unit measured on House Meters. The Model III and Model VI results represent that proportion of energy savings associated with the engineering projections. The difference between each pair of results (II-III, V-VI) indicates that portion of energy savings per unit not correlated with the engineering projections.

Annual Energy Savings by Period: Regressions

Figure 5-VII: Cohort C House Meters

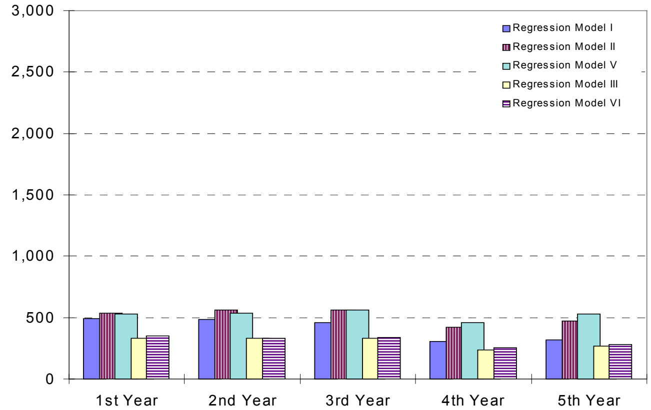


Figure 5-VIII: Cohort D House Meters

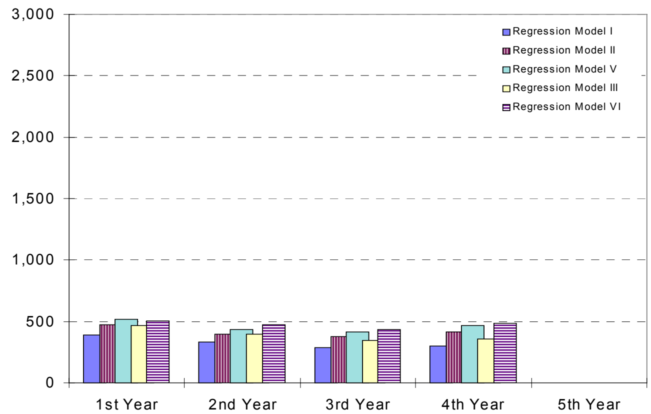
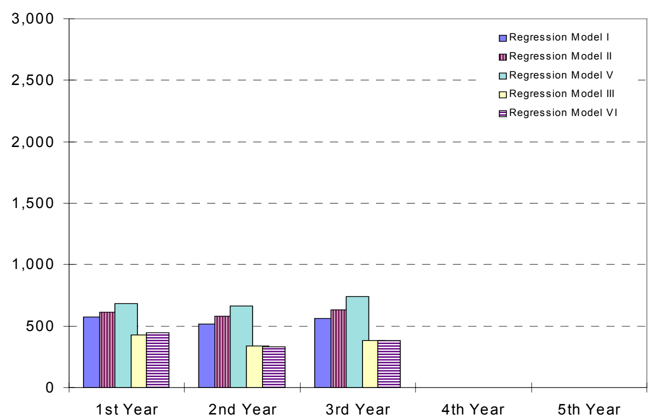


Figure 5-IX: Cohort E House Meters



Five regression models were applied to Tenant Meter data from the Standard-Income program. Full-sized versions of each graphic figure appear in Appendix C.

The first five graphic figures show the resulting estimates of electricity savings for Cohort C through Cohort G, in each year after measure installation. The sixth graph represents a pooled analysis where all cohorts were combined to make a generalized estimate of net savings in five post-years.

In each cluster of columns, the ***participation*** models (I, II, and V) precede the ***engineering*** models (III and VI). Model V (the central column in each cluster) is preferred because it contains the greatest amount of information about intervening factors, and in many analyses Model V maximized the proportion of variance explained (R-squared).

In several figures, the ***participation*** models estimate higher levels of savings than the ***engineering*** models. This is possible because the engineering estimates may contain error due to inadequate data inputs, but also because not all program interventions are expressed in the engineering equations.

Annual Energy Savings by Period: Regressions

Figure 5-X: Cohort F House Meters

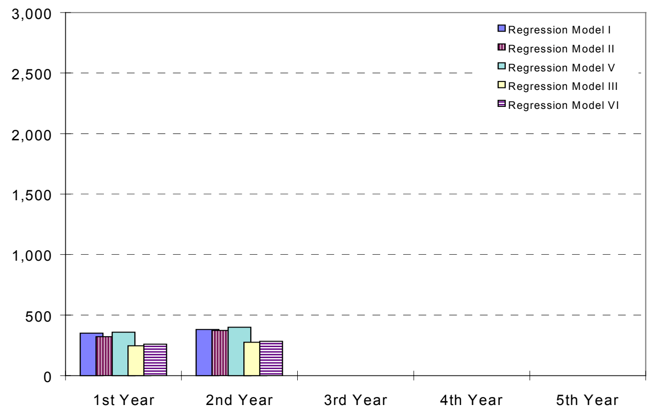


Figure 5-XI: Cohort G House Meters

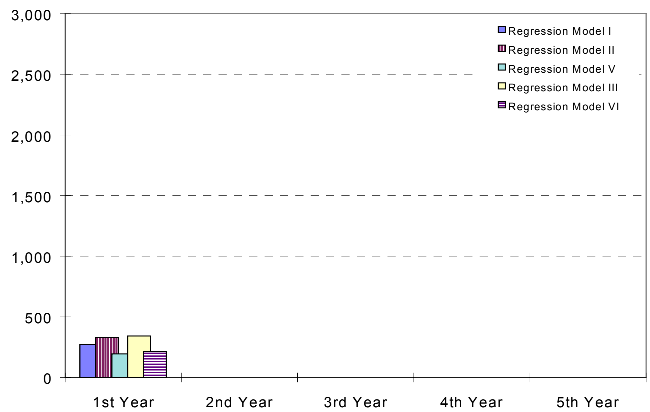
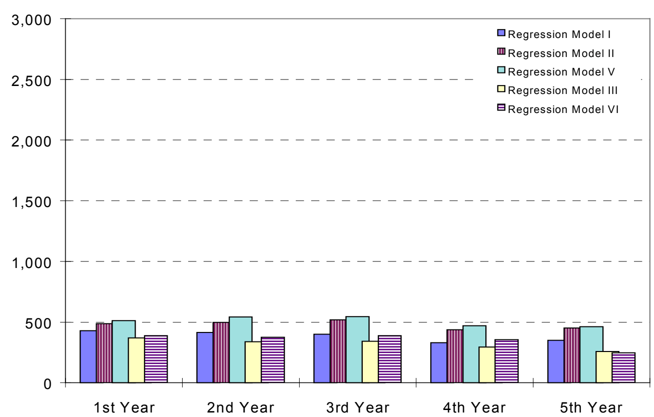


Figure 5-XII: Pooled Cohorts C–G House Meters



Model V estimates first year electricity savings per unit as:

Cohort C	531 kWh,
Cohort D	515 kWh,
Cohort E	682 kWh,
Cohort F	358 kWh, and
Cohort G	194 kWh.

These estimates take account of pre-period non-equivalence, changes in control group use patterns, and changes at each site to laundry appliances and lighting during the post-period.

From these results it is apparent that common-area measures generated lower energy savings from Cohorts F and G (the 1991-1992 program years). This was certainly not expected from prior estimates of lighting savings, which did not trend downward either on engineering estimates or on measure penetration.

The pooled analysis combining all Standard-Income cohorts finds that the average first-year savings from House Meters (Model V) have been 511 kWh per unit. Year-by-year, these savings were:

Year 1	511 kWh,
Year 2	543 kWh,
Year 3	545 kWh,
Year 4	470 kWh, and
Year 5	461 kWh.

These estimates clearly show persistence of common-area lighting energy savings, in the region of 500 kWh per year over a span of five years.

This chapter concludes with two tables that indicate the degree to which energy savings have persisted from the first to fifth year after installation of program measures. In the case of Tenant Meters, Table 5-C, energy savings from all Standard-Income cohorts pooled were higher in the fifth year than initially, growing by about 8% (Model I) since the first year. All models demonstrated similar growth ranging from 4% to 20% over initial savings. However, taking into account the scores in *each year* after measure installation, the average rate of change from first to fifth post-year was only -1% per year. This is indistinguishable from no change at all.

Table 5-C: Tenant-Meter Savings by Regression Method, All Cohorts Pooled

Measured kWh/Unit Energy Savings (by Post-Retrofit Year)	First Year Savings	Second Year Savings	Third Year Savings	Fourth Year Savings	Fifth Year Savings	*Persis-tence ($5^{th}/1^{st}$)*
Standard-Income						
Model I	1,152	1,115	1,161	1,046	1,239	*108%*
Model II	1,162	1,113	1,169	1,050	1,245	*107%*
Model III	847	814	781	700	884	*104%*
Model V	1,186	1,157	1,219	1,150	1,425	*120%*
Model VI	806	746	728	635	934	*116%*

Meanwhile on House Meters, Table 5-D, energy savings from all Standard-Income cohorts pooled were lower in the fifth year than initially, dropping by about 19% (Model I) since the first year. All models demonstrated a similar decline, although estimated shrinkage ranged widely from 7% to 36% of initial savings. The decline is less marked in the portion of buildings (roughly more than half) that had house meters and engineering data. The presence of some decline indicates that the impact of common-area lighting measures does persist but not in full force over time. The average rate of change is about -5% per year.

Table 5-D: House-Meter Savings by Regression Method, All Cohorts Pooled

Measured kWh/Unit Energy Savings (by Post-Retrofit Year)	First Year Savings	Second Year Savings	Third Year Savings	Fourth Year Savings	Fifth Year Savings	*Persis-tence ($5^{th}/1^{st}$)*
Standard-Income						
Model I	429	414	399	329	349	*81%*
Model II	486	497	517	436	452	*93%*
Model III	369	337	341	295	256	*70%*
Model V	511	543	585	470	461	*90%*
Model VI	388	374	387	355	247	*64%*

The overall impact of these two trends in persistence may be obtained by adjusting the House-Meter results for number of units affected and summing with the Tenant-Meter results (Table 5-E). Net building energy savings from all cohorts pooled were the same in the fifth year as in the first, being within 1% (Model I) of the initial value. The various models demonstrated similar findings lying within 3% to 14% of initial savings. The average rate of change was –2% per year, taking into account the scores in *each year* after measure installation. This degree of change is not distinguishable from a flat trend line. The data demonstrate that, at the building level, programmatic energy savings persist over time in standard-income buildings.

Table 5-E: Total-Building Savings by Regression Method, All Cohorts Pooled

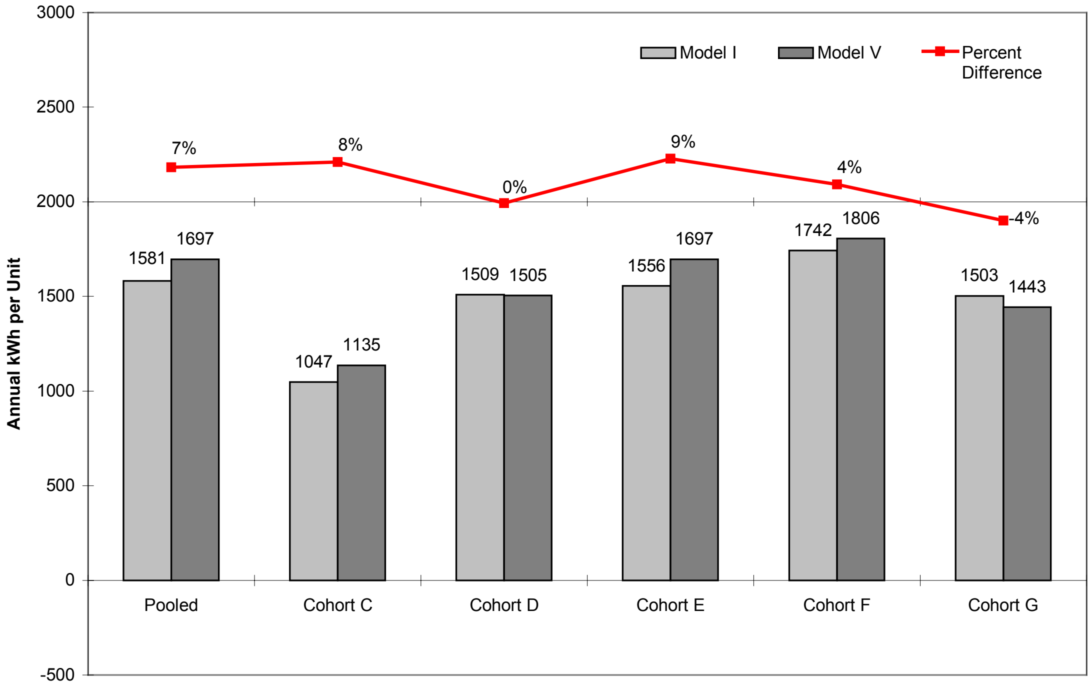
Measured kWh/Unit Energy Savings (by Post-Retrofit Year)	First Year Savings	Second Year Savings	Third Year Savings	Fourth Year Savings	Fifth Year Savings	*Persis-tence ($5^{th}/1^{st}$)*
Standard-Income						
Model I	1,525	1,475	1,508	1,332	1,543	*101%*
Model II	1,439	1,396	1,464	1,299	1,503	*104%*
Model III	1,057	1,006	975	868	1,030	*97%*
Model V	1,477	1,467	1,552	1,418	1,688	*114%*
Model VI	1,027	959	949	837	1,075	*105%*

5.4 Effect of Survey Data Adjustments in First Post Year

The Measures Survey searched for independent effects that might confound estimates of net programmatic energy savings. Building owners and managers were queried about changes in building occupancy pattern, appliance features, structural characteristics, and efficiency practices or actions that might affect energy usage over the period after program participation. This information was collected from both program Participants and Nonparticipants. Statistical correlations were examined between each survey item and Gross Savings scores. A handful of significant items was retained for further examination. Several of these variables were introduced into Regression Models V, VI, and VII. They include replacement of water heaters, addition of clothes washing machines or clothes dryers, and installation of high-efficiency windows or lighting.

The following figure demonstrates the effect on the net savings estimate from introducing information about post-period changes in specific buildings. The paired columns represent results estimated by Model I (without survey data) and Model V (with survey data). Both models are based on a binary participation variable, and both include pre-participation annual usage as an independent covariate. The models were estimated simultaneously for all post-periods, but only the results for the First Post-year are presented. The first set of columns represents a pooled analysis of Cohorts C through G; the following sets represent separate analyses for each cohort. As Figure 5-XIII shows, the effect of including the survey information is to raise the estimate of programmatic savings by 7% over the basic participation model results. This amounted to 116 kWh per unit of savings missed by the simple participation model. The proportionate effect varies across cohorts from -4% (Cohort G) to +9% (Cohort E).

Figure 5-XIII: Effect of Survey Data Adjustment in First Post-Year on Estimate of Total-Building Energy Savings



The next two figures break out the impacts of the survey data for Tenant Meters and House Meters. Overall, very little effect (+3%, or 34 kWh) is seen in Figure 5-XIV for Tenant Meters. However, the proportionate effect was notable (+19%, or 82 kWh) for House Meters, as Figure 5-XV shows.

When individual cohorts are examined, one sees that House-Meter savings dropped between Cohort E and Cohort F by about 324 kWh per unit. At the same time, Tenant-Meter savings between these two cohorts rose by 433 kWh. One might speculate that some energy loads normally expected on House Meters were perhaps actually wired to Tenant Meters in some Cohort F buildings, and were possibly were influenced by the program‘s common-area lighting measures. This possibility does not help explain why Cohort G savings on House Meters dropped so significantly, as no corresponding rise is observed in Tenant-Meter savings.

Figure 5-XIV: Effect of Survey Data Adjustment in First Post-Year on Estimate of Tenant-Meter Energy Savings

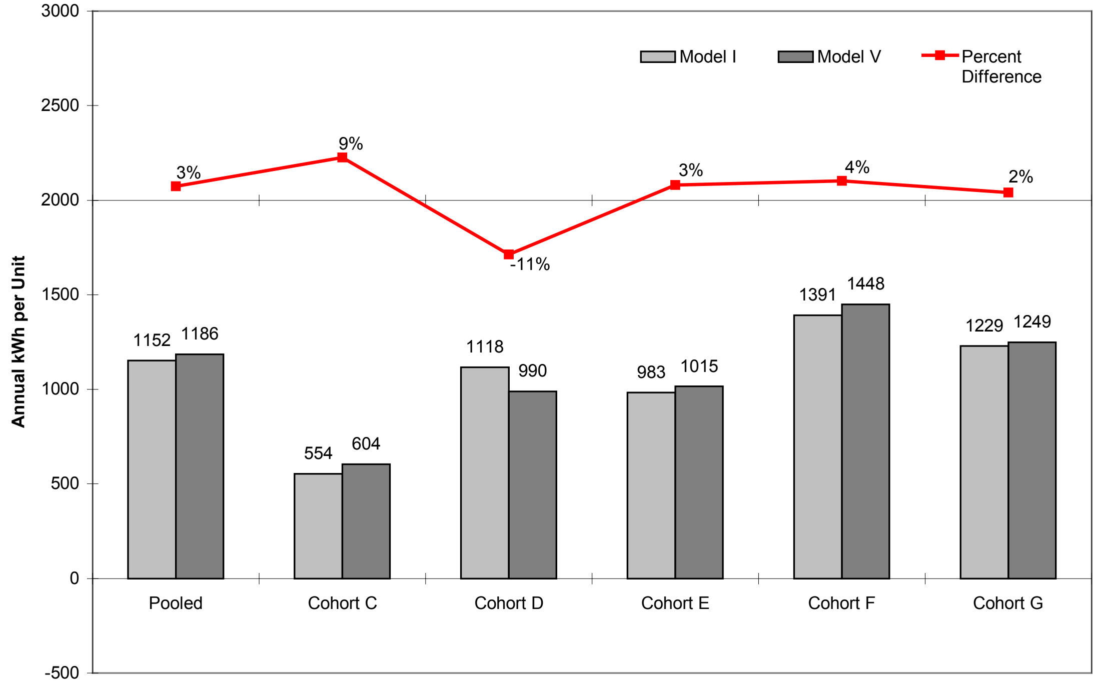
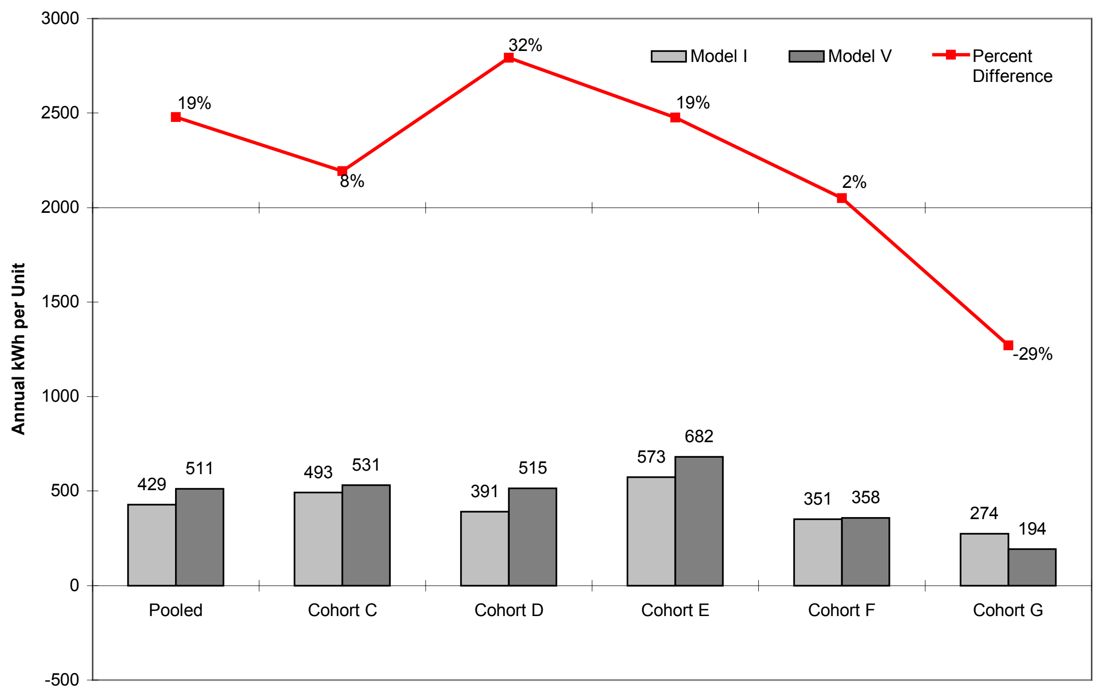
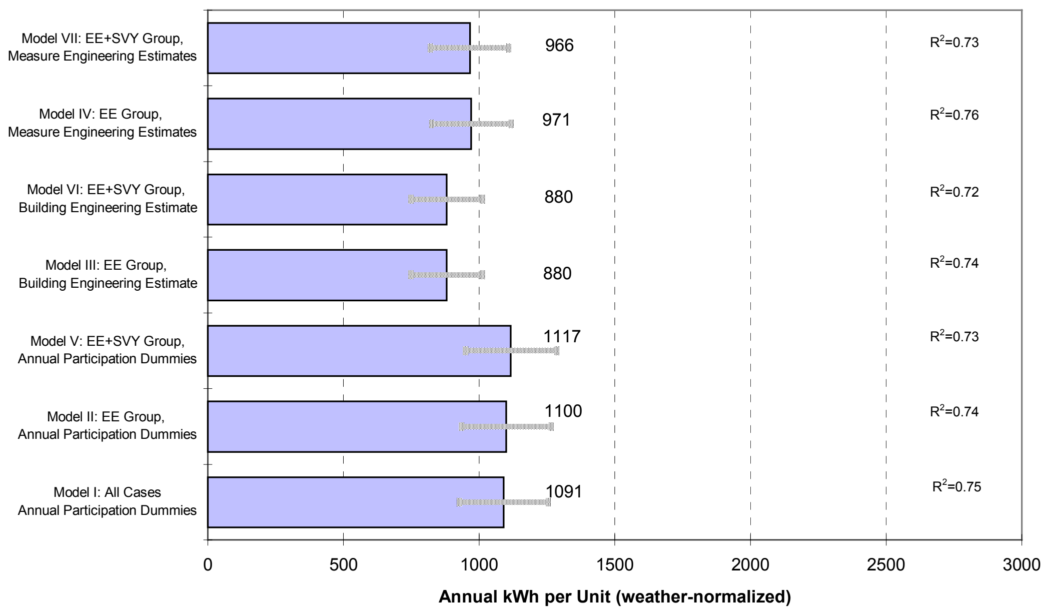


Figure 5-XV: Effect of Survey Data Adjustment in First Post-Year on Estimate of House-Meter Energy Savings



The final figure in this section summarizes the regression results on net savings from Standard-Income Tenant Meters, pooling all cohorts into one summary analysis per model. This version was estimated using only First Post-year inputs; for this reason the Model I and Model V results vary slightly from those presented above in Figure 5-XIV. The annual energy savings per unit are labeled next to each horizontal bar. To the far right appears the diagnostic statistic for each model, the squared correlation coefficient (R^2). This number represents the proportion of variance in post-period energy use explained by factors such as pre-period energy use, program participation, measures installed, and subsequent changes in buildings.

Figure 5-XVI: Regression Models I–VII, First Post-Year Energy Savings, Standard-Income Tenant-Meter Pooled Cohorts



The R^2 proportion is highest in Model IV (76%). However, as explained earlier, Model V is preferred because it incorporates more known factors and a larger number of cases (and degrees of freedom). Model V is also preferred because not all program effects are associated with engineering estimate data. As Figure 5-XVI clearly shows, moving from a *participation model* (I, II, V) to a *building-level engineering estimate model* (III, VI) drops estimated savings by about 200 kWh per unit. Breaking out the engineering estimate by category in the *measure-level models* (IV, VII) restores about half of this amount. This indicates that the building-level model masks the effects of factors influencing realization rates for separate measures.

Model V states that the Standard-Income program acquired 1,117 kWh per unit Tenant-Meter net energy savings from participants in the first year after measures were installed. Most of these savings, 966 kWh (86%) can be associated purely with the engineering estimates for individual measure categories, as Model VII demonstrates. The remaining 151 kWh (14%) of net energy savings are attributable (a) to the effects of program actions not documented in engineering-estimate data, (b) to inaccuracies in the parameters used to calculated engineering projections, (c) to confounding effects from loads normally expected on House Meters but actually wired to Tenant Meters, or (d) to other missing unknown variables.

5.5 Realization of Engineering Estimates

Energy savings predicted by engineering equations are not always observed in conservation program participant sites. Sometimes evaluated savings exceed expectations; more often they fall short. Such outcomes are not necessarily to be interpreted as measure or program failures. Reasons for falling short are varied. Inputs to engineering equations for lighting or window glazing, for example, are derived from laboratory testing data. In a laboratory, the fixture may be suspended in mid-air; in construction, it may be fitted into a ceiling cavity (e.g., canister lamp) or wall framing. The thermal transfer characteristics of these two environments can affect evaluated performance. However, the most important reason for lower performance on Tenant-Meter results is derived from some basic factors about how conservation measures affect building performance, and the specification of equations for weather-normalizing energy use data and generating engineering estimates.

In order to weather-normalize the Tenant-Meter data, an equation indexed to heating degree-days was applied to all meter readings, both before and after program participation. The usual algorithm adds to a building's observed meter reading (in kilowatt-hours) an amount equal to the product of number of dwelling units, deviation from normal heating degree-days, innate temperature sensitivity of the structure, and a factor that estimates the reduction in sensitivity rendered by program participation.

The *temperature sensitivity coefficient* is an *a priori* performance factor; it reflects the building's response to cold weather, in kWh per unit per heating degree-day of deviation from normal weather conditions. In the past evaluation of the Multifamily Conservation Programs (Okumo 1991 appendix), a fixed value was used for this performance factor, derived from separate analysis of individual unit data. The value was set at 0.57 kWh/HDD for Standard-Income buildings and 0.53 kWh/HDD for Low-Income buildings. The same value was used for participants and nonparticipants. These values indicate that, for every degree that outdoor temperatures drop below 65°F, indoor temperatures drop by half in the typical Seattle multifamily building. This sluggish pattern of response to outdoor temperature, by comparison to single-family homes, reflects the larger thermal mass of multifamily buildings and slower internal conduction of heat.

Realization of Engineering Estimates

Figure 5-XVII: Standard-Income Tenant Meters, Model III

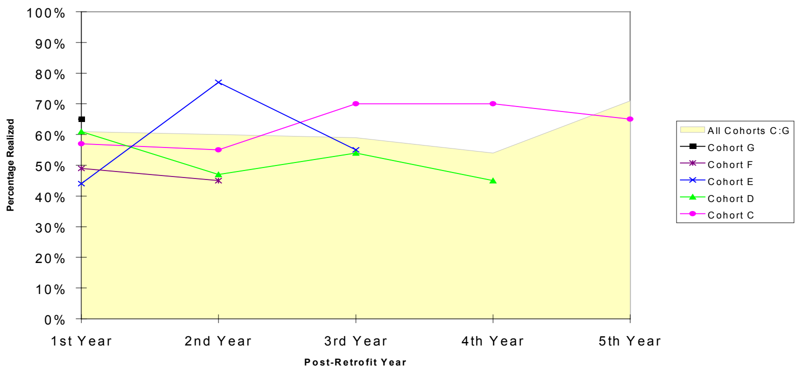


Figure 5-XVIII: Standard-Income Tenant Meters, Model VI

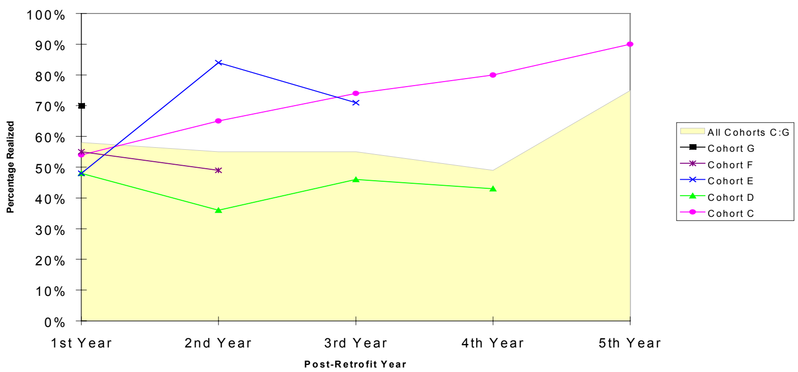


Figure 5-XIX Standard-Income House Meters, Model III

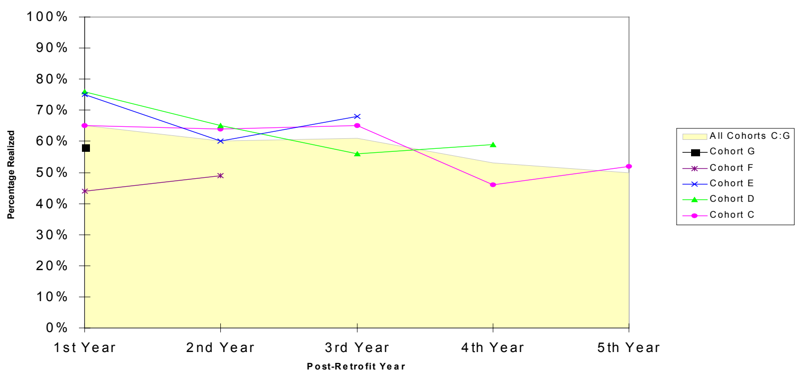
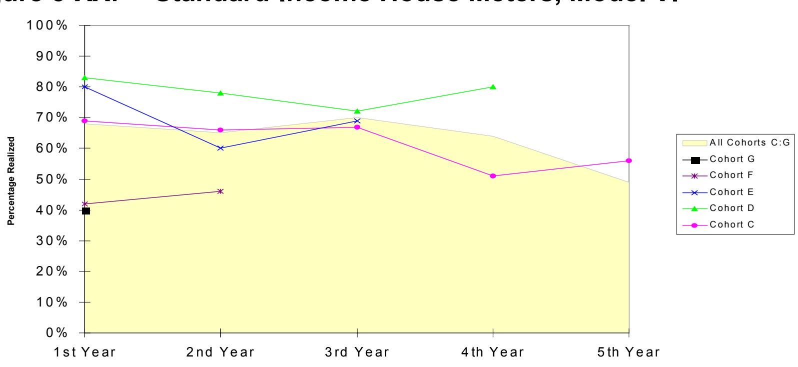


Figure 5-XX: Standard-Income House Meters, Model VI



This page contains four graphic figures to allow comparisons among Standard-Income and Low-Income buildings on Tenant-Meter and House-Meter realization rates. These figures are greatly reduced; larger versions appear in Appendix C of this report.

Regression Models III and VI replaced a binary participation variable with a variable representing the total engineering estimate of savings expected across all end-uses and measure types. The coefficients on these engineering terms may be interpreted as ***realization rates*** in each year.

The lines in these figures show the percentage of engineering estimates realized in five post-periods for each cohort. The shaded area represents a pooled analysis across all five cohorts, around which the individual cohorts vary. Model VI incorporates additional terms for post-participation building changes (from the Measures Survey) that do not appear in Model III. Shifting values in the Fifth Post-year are likely due to extraneous factors not captured by Measures Survey questions.

Another way of thinking about this term is in relation to the empirical correction factor for the heating effect versus 65° F days ($CFAC_{DD}$), as described in Appendix A. This factor was left unit-less (=1.0) in the weather-normalization procedure. It could not be retrieved from the billing analysis, but is embedded in the realization rate coefficients estimated for the regression models. $CFAC_{DD}$ is a weather sensitivity correction factor that is equivalent to the product of temperature sensitivity and the retrofit reduction in sensitivity. According to ASHRAE documentation, $CFAC_{DD}$ tends to range around 0.6 when annual heating degree-days are near 5,000, as in Seattle (bracketed by a standard deviation ranging from about 0.4 to 0.9).

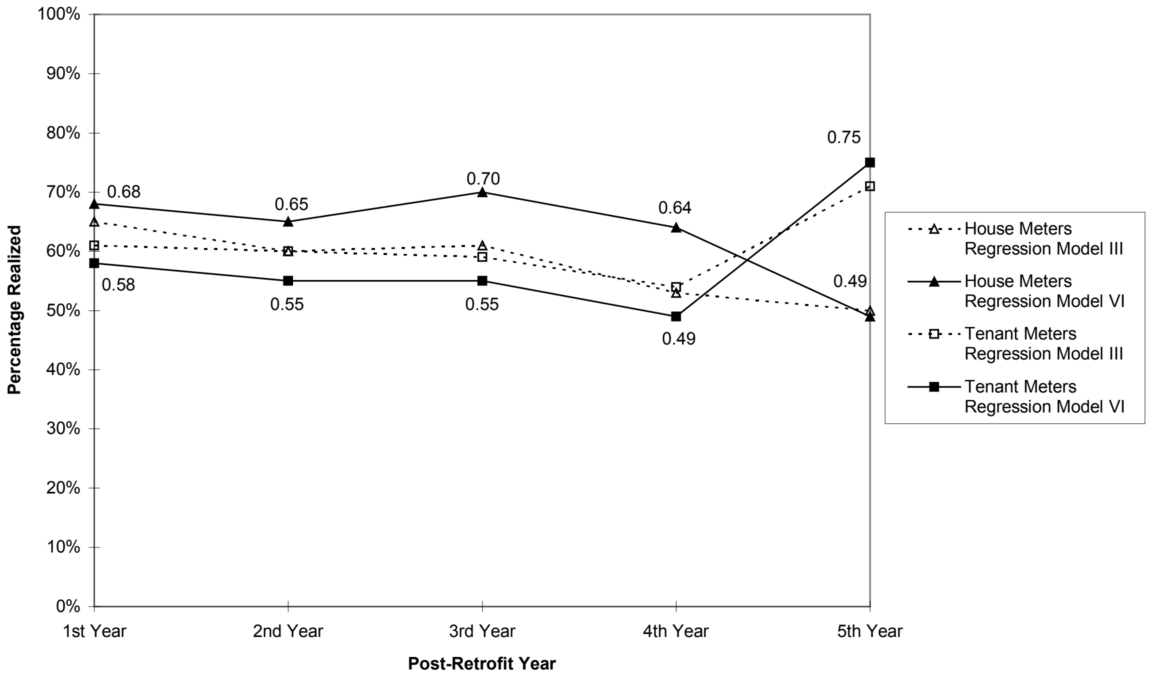
The *retrofit sensitivity coefficient* is a term expressing the reduction in temperature sensitivity that occurs when a building shell is weatherized with insulation and high-efficiency replacement windows. In the prior evaluation (Okumo 1991, ibid.), this term was set *a priori* at 0.46 for Standard-Income Participants (-54%) and 0.77 for Low-Income Participants (-23%). This term reflects the greater efficiency of the weatherized building structure in retaining internal heat.

In the present longitudinal study, no explicit value was established *a priori* for the retrofit sensitivity coefficient. What is more, when the engineering equations were specified, no factor was established *a priori* to represent air infiltration rates. These two terms represent major areas of uncertainty when estimating changes in building heat-loss. Rather than assume standard values, the research design determines these values *a posteriori*; they are embedded in the engineering estimate realization rate.

A value for *air infiltration rate* for multifamily buildings might lie in the range of 0.34 to 0.67 (for 0.3 to 0.5 air exchanges per hour), with an intermediate value of 0.50. The cross-product of retrofit sensitivity and air infiltration rate may be calculated, for example, as 0.46 x 0.50 = 0.23. This is the proportion by which engineering estimates of savings should be reduced. In the regression models, therefore, the expected value of coefficients on the engineering estimate terms would be close to 77% (1.00-0.23). If retrofit sensitivity were set to 0.77, the cross-product would be 0.77 x 0.50 = 0.39, and expected coefficients would be more like 62%.

Figure 5-XXI, below, provides the realization rates specified by Models III and VI for Tenant Meters and House Meters. Model VI is represented by solid lines. One observes that in the First Post-year program participants realized 58% of savings projected from engineering estimates on Tenant Meters and 68% on House Meters (Models VI). By the Fourth Post-year these values declined to 49% on Tenant Meters, while the realization rate remained stable at 64% for House Meters.

Figure 5-XXI: Regression Model III vs. Model VI, Post-Years 1 to 5 Realization of Engineering Estimates by Period, Standard-Income Meters Pooled



For Tenant Meters, the value 0.58 is lower than the 0.77 expected, indicating that either the air infiltration or the reduction in temperature sensitivity, or both, were greater than previously observed. If the sensitivity reduction is held constant close to the values observed in the 1991 evaluation (say, at 50% to 70%), then the range of infiltration values may be estimated at 0.60 to 0.80, equivalent to 0.5 to 0.8 air exchanges per hour. This statement depends entirely upon the assumption that no other factors operate to reduce observed savings levels below those specified by engineering equations. It is likely, therefore, that the speculated values (above) represent upper limits on retrofit sensitivity, air exchanges, and measure performance.

The final two figures in this section represent the findings of Models IV and VII, which were specified only for Tenant Meter data. In these models, the engineering estimates were specified separately for each measure category, that is, windows, showerheads, and three insulation surfaces (ceilings, walls, and under-floors). Figure 5-XXII finds that that wall insulation and efficient windows garnered savings at rates close to those originally expected (that is, 77%). The engineering estimate for wall insulation was realized at the rate of 73% in Model VII (89% in Model IV), and windows at 67% (74%). Based on actual measure penetrations, these rates result in very little wall insulation savings, around 22-23 kWh per unit, but significant impacts from window retrofits, as much as 627-679 kWh per unit (see the next figure).

Figure 5-XXII: Regression Model IV vs. Model VII, First Post-Year Realization of Engineering Estimates by Measure Type, Standard-Income Tenant Meter Pooled Cohorts

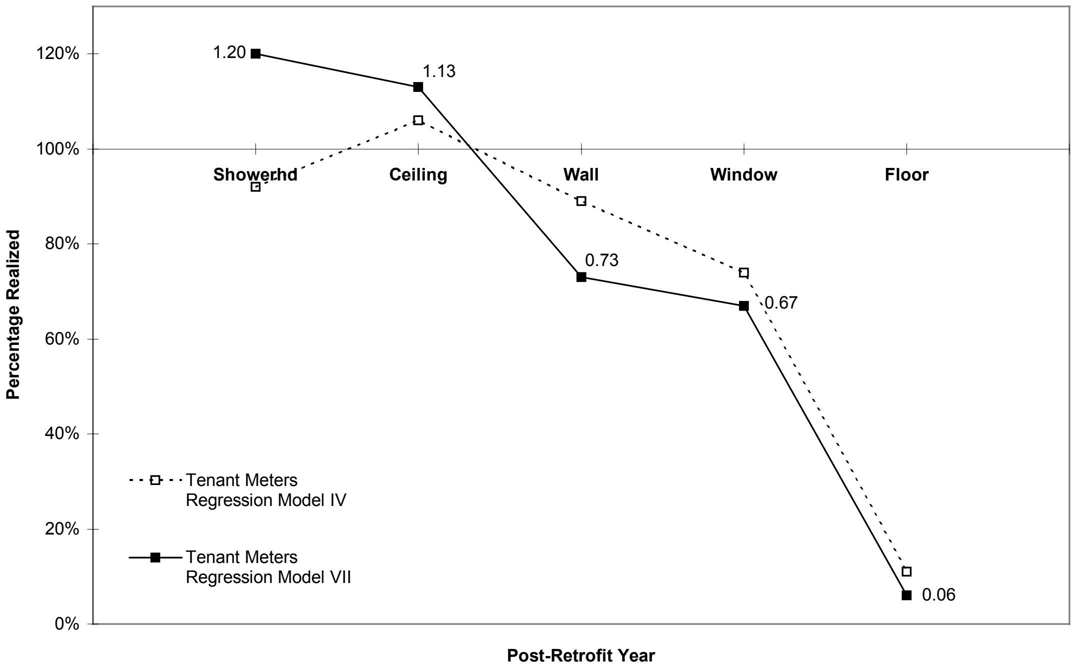
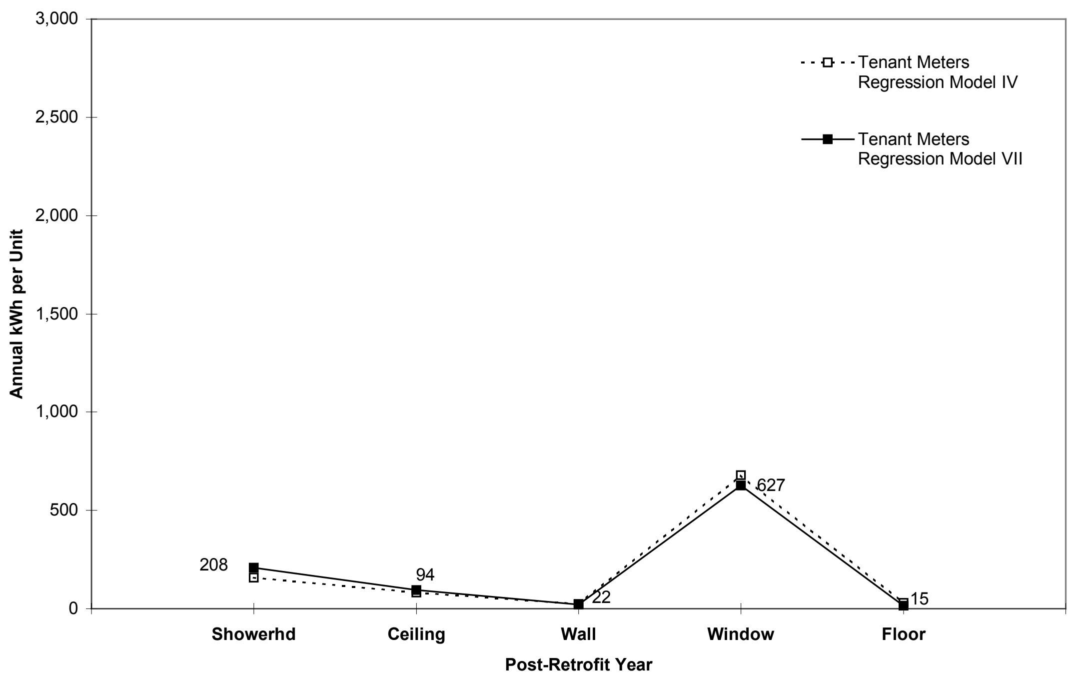


Figure 5-XXIII: Regression Model IV vs. Model VII, First Post-Year Energy Savings by Measure Type, Standard-Income Tenant Meter Pooled Cohorts



By contrast, ceiling insulation produced 106-113% (82-94 kWh per unit) of savings estimated in engineering equations, and under-floor insulation a mere 6-11% (15-30 kWh per unit). This last finding recapitulates that of Okumo (1991), which also found very little evidence for electricity savings from under-floor insulation. However, the regression method used here has likely confounded ceiling impacts with under-floor impacts, due to the high degree of correlation between the two measures. What is more, while a design temperature differential of 60°F may apply to ceilings, as with windows and walls, the floor temperature differential is probably more in the neighborhood of 20°F (due to buffered spaces). Keeping these facts in mind, if the ceiling realization term were set to an average value of 0.75 rather than 1.13, then an *adjusted* floor term might have a coefficient closer to 0.56 rather than 0.06 (Floor EE_{adj} = Floor EE x 60/20). The combined savings from ceilings and floors remain the same at 109 kWh per unit anually.

The showerhead measure also exceeds expectations (although an adjustment for reduced temperature sensitivity and air exchanges should not apply to this measure). Showerheads were specified in the engineering equations as saving 200 kWh per residential unit. In fact, the study on which that value was based claims two values, ranging from 200 to 250 kWh/year depending upon flow rate reduction characteristics of the equipment. Model IV associates savings of 157 kWh with each showerhead, while Model VII derives a coefficient equivalent to 208 kWh (see Figure 5-XXIII).

The clear drivers of Tenant Meter energy savings are thus revealed to be efficient window and showerhead retrofits. With the market saturation of showerhead measures, window measures remain the mainstay of dwelling area energy savings for the Multifamily Conservation Programs.

6. Discussion, Conclusions and Recommendations

6.1 Summary of Program Impacts

The table below summarizes the results of three analytical methods applied to billing data from in the Multifamily Conservation Programs. The longitudinal study did not estimate net scores for Cohort A and Cohort B, as suitable Nonparticipant data were not developed for their pre-periods. However, a prior study (Okumo 1991) did estimate net savings using different control groups but the same statistical approach as Net Method II. The gross scores estimated in that study bear a reasonable relationship to gross scores reported in the current study; the net values are presented below to round out the longitudinal study findings.

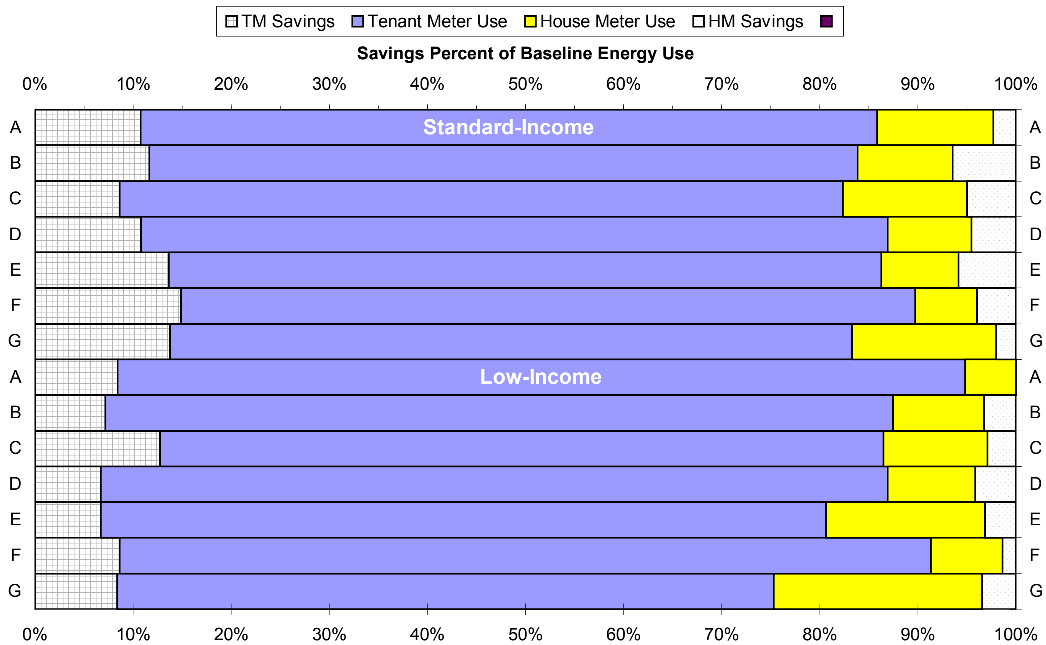
Table 6-A: Energy Savings Impacts of the Multifamily Conservation Programs

	Standard-Income			Low-income	
Program Year	Gross Score	Net Method II	Regression Model V	Gross Score	Net Method II
Cohort A (1986)	1,184	1,213 *	—	1,806	1,025 *
Cohort B (1987)	1,602	1,628 *	—	1,844	1,089 *
Cohort C (1988)	748	1,283	1,322	1,353	1,638
Cohort D (1989)	1,351	1,543	1,534	854	1,015
Cohort E (1990)	1,806	1,844	1,937	1,535	1,219
Cohort F (1991)	1,805	1,703	1,696	1,544	1,038
Cohort G (1992)	1,580	1,546	1,433	1,695	1,265

* Cohorts A & B: Equivalent of Net Method II scores drawn from prior evaluation (Okumo 1991).

The following figure represents the net savings results, broken out by program meter type, as a percentage of total baseline energy usage per unit in the average building. Standard-Income Cohorts C through G are represented by the results of Regression Model V. The baseline for Figure 6-I was established for each Participant cohort as the year immediately preceding the retrofit year.

Figure 6-I: Net Program Savings as Percent of Pre-period Energy Use, Cohorts A to G by Program and Meter Type



Among Standard-Income participant buildings, net energy savings were about 17% of baseline for the average unit over all cohorts from 1986-1992. Among cohorts, this value ranged from 13% to 19%. On Tenant Meters, program measures saved about 15% of pre-period energy use (range: 10%-17%). Program actions saved about 31% of baseline consumption on House Meters (range: 12%-43%).

Among Low-Income participant buildings, net energy savings were about 12% of baseline for the average unit over all cohorts from 1986-1992. Among cohorts, this value ranged from 8% to 16%. On Tenant Meters, program measures saved about 10% of pre-period energy use (range: 8%-15%). Program actions saved about 19% of baseline consumption on House Meters (range: 14%-32%; not applicable to Cohort A).

The following two graphics summarize three sources of prior projections of annual energy savings, compared to the results of three analytical methods shown in Table 1. As Figure 6-II shows among Standard-Income Participants, gross scores lie quite close to net scores except in Cohort C, where Participants and Nonparticipants alike had unusually low consumption during the pre-period year 1987 (this depressed the Participant gross scores, but not the net results). The reason for this fluctuation is unknown, but average annual temperatures in both 1987 and 1992 were significantly below normal (with heating degree-day deviations twice those of other study years). It is possible that weather normalization procedures distorted the gross data for Cohort C.

Among Low-Income Participants Figure 6-III, gross scores diverge more widely from net scores, due to the greater variability and skewed distribution of scores across Participant buildings, and to the Nonparticipant energy use patterns discussed in the previous chapter. Net scores are consistently lower than gross scores except in Cohort C and Cohort D. The pre-to-post periods for these two cohorts correspond to the time span when Nonparticipant energy use increased at an accelerated rate. This result is quite different than found in the impact evaluation of the 1986-1987 low-income pilot program. The longitudinal study control group is drawn from the remaining unserved market pool, while the pilot program control group was drawn from program waiting list *pre-participants*. It is possible for this program segment that a more suitable baseline would have been *prior participants*, as in the Bonneville Power Administration's retrospective evaluation of the Residential Weatherization Program (Oates 1993).

The same information has been expressed in a different way in the next set of graphics (Figure 6-IV and Figure 6-V), to clarify the relationship of engineering estimates and actual energy savings to the prior projections stated in the ENERGY CONSERVATION ACCOMPLISHMENTS report published each year by Seattle City Light. All values from Figure 6-II and Figure 6-III have been re-stated as difference scores relative to the pre-study projections from that the ACCOMPLISHMENTS report.

As may readily be seen, most Standard-Income engineering estimates per unit lie within ±200 kWh of the prior projections (except for Cohort D). Gross savings scores per unit lie within ±300 kWh of the prior projections (except for Cohort C). Net Method II savings per unit all lie within ±300 kWh; while Regression Model V savings per unit are within ±200 kWh of prior projections(with the exception of Cohort G, representing the 1992 program).

Most Low-Income gross savings scores per unit lie within ±200 kWh of the prior projections (except for the singular Cohort A, and Cohort D). Net Method II savings per unit in the Low-Income program all lie farther from prior projections, by ±300-700 kWh. In general, Low-Income program measures affecting Tenant-Meter usage seem to be performing about 300 kWh per unit lower than program measures in the Standard-Income program. The reasons for this lower performance are not known and should be investigated. Likely candidates for examination would be measure penetrations for window retrofits, high-efficiency showerheads, and ceiling insulation.

The Regression Model V results for Standard-Income buildings, labeled on the two graphical figures, came remarkably close to projections for the 1989-1991 program years (Cohort D to Cohort F). The reason for lower performance from the 1992 program year is not known, but as Cohort G was represented by only one post-retrofit year of data, judgment should be deferred on expected savings in subsequent years for this group. Future evaluation follow-up on Cohort G and subsequent program years would be in order to interpret this apparent lower performance.

In the following sections of this chapter, the impact analysis results are used to make projections of energy savings to program years subsequent to the 1986-1992 study years.

Figure 6-II: Actual Savings Compared to Prior Projections, Standard-Income Building Totals

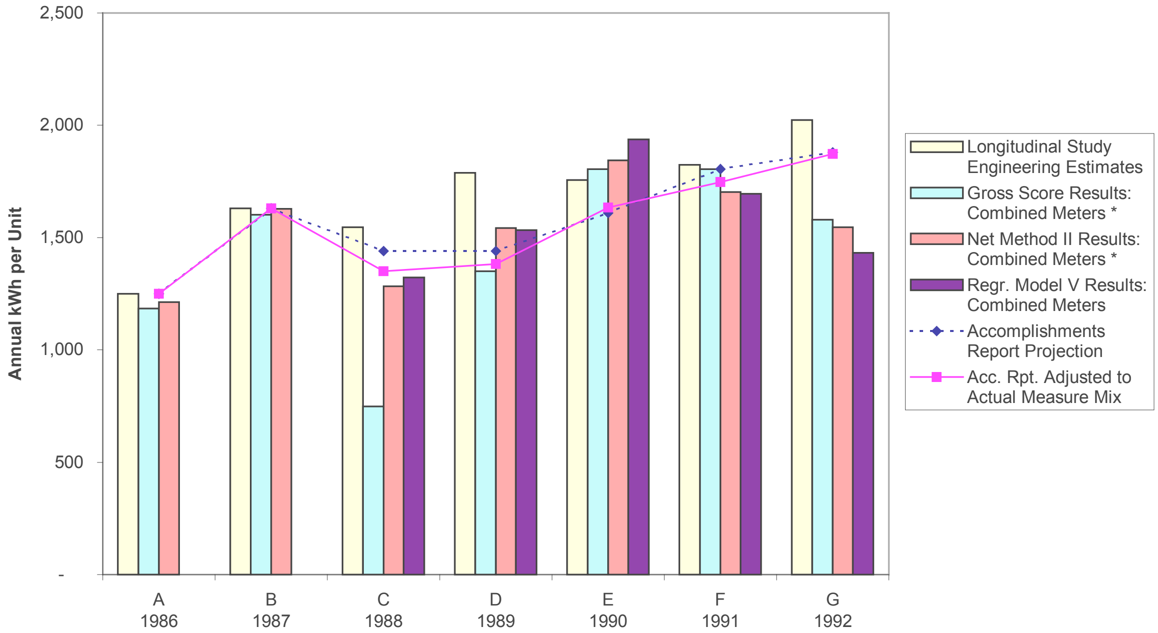


Figure 6-III: Actual Savings Compared to Prior Projections, Low-Income Building Totals

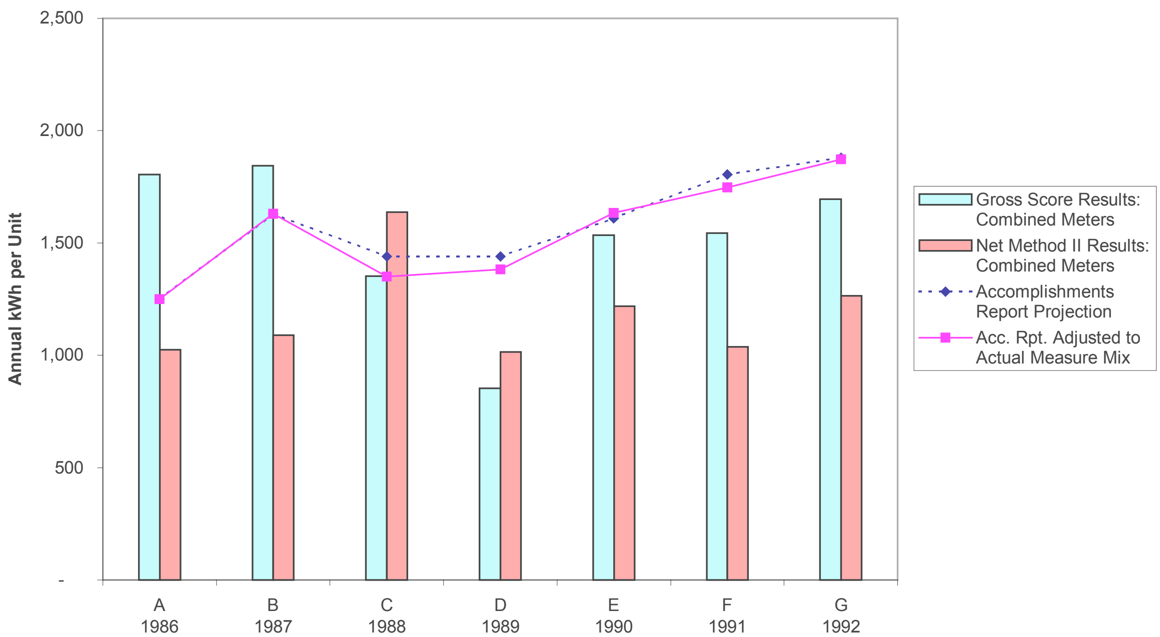


Figure 6-IV: Difference in Savings from Prior Projections, Standard-Income Building Totals

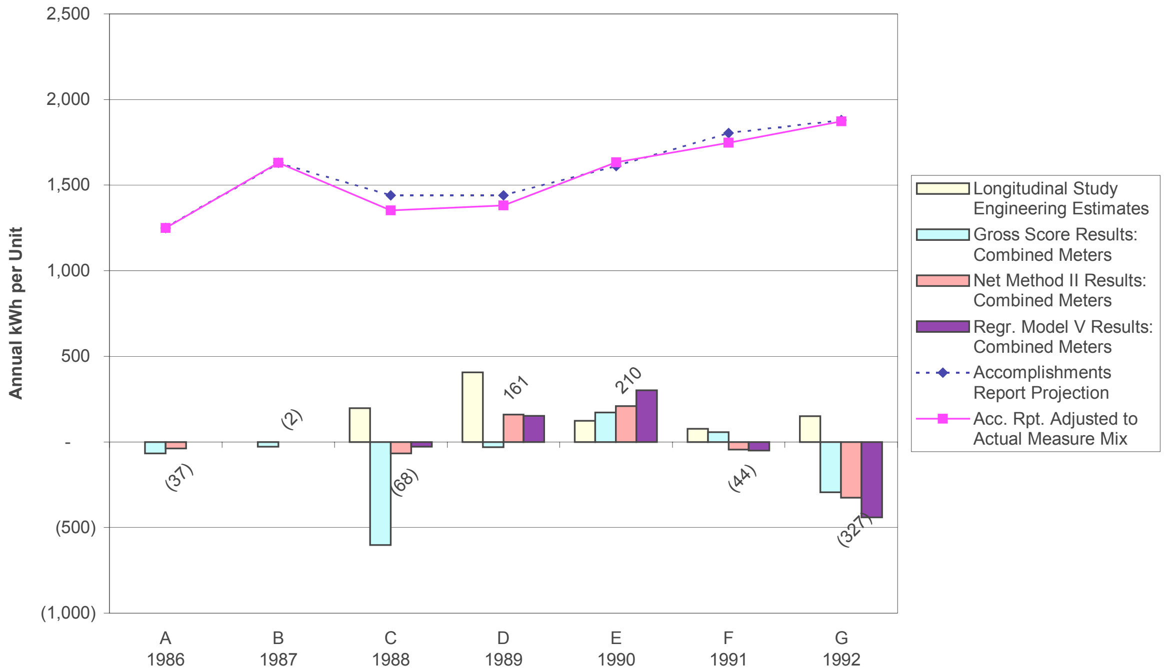
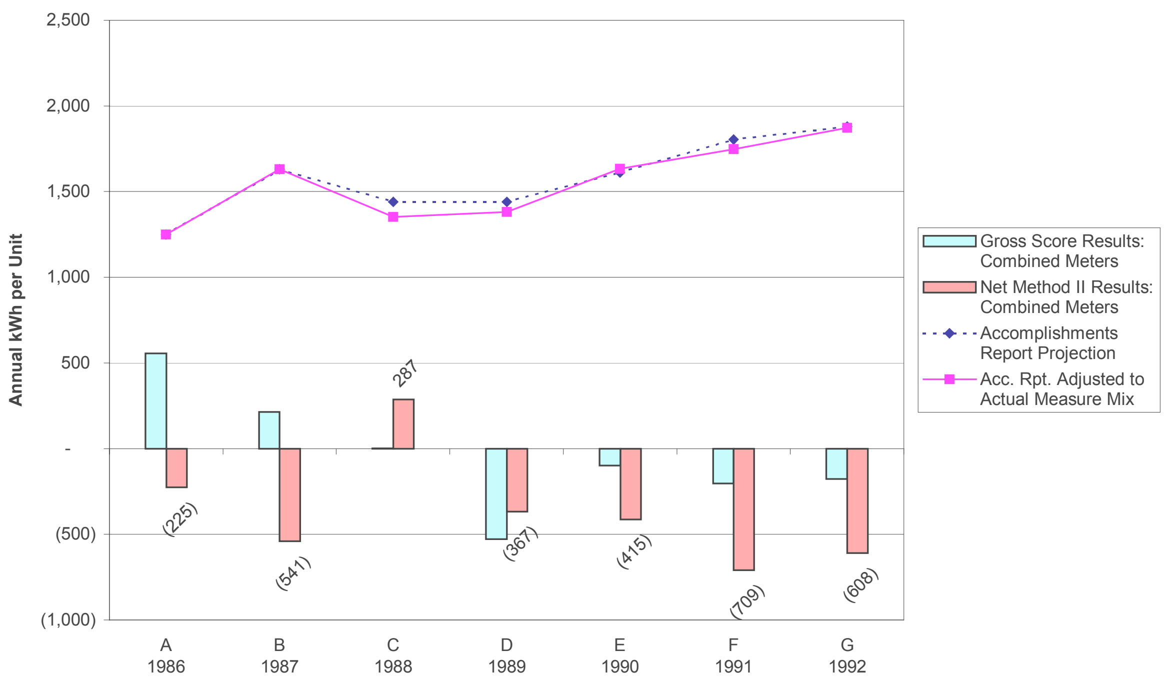


Figure 6-V: Difference in Savings from Prior Projections, Low-Income Building Totals



6.2 Implications for the Current Program: 1997-2000

In February 1998, an analysis was prepared to help in planning for the 1998-1999 Multifamily Conservation Programs. The memorandum resulting from that analysis addressed common-area lighting issues (engineering estimates, realization rates, estimated lighting savings for 1998-1999) and tenant-area weatherization issues (showerhead measure penetration, building shell measure mix). The analysis concluded that first-year energy savings from 1998-1999 participants in the standard-income program were likely to be in the range of 1,650 to 1,750 kWh per residential unit. This range was about 88%-93% of prior estimates published in the annual ENERGY CONSERVATION ACCOMPLISHMENTS report.

The purpose of the analysis presented below is to update that earlier analysis. The major question addressed below is the level of energy savings to report for 1998 participants and to project for 1999-2000 participants. Here is the bottom line:

Our conclusion for the standard-income program is that currently in 1998 the average building saves about 1,800 kWh per residential unit from tenant-area and common-area measures combined.

In the low-income program, the average building now saves about 1,300 kWh per residential unit from tenant-area and common-area measures combined. In low-income buildings not installing common-area measures (lighting), the average building savings are about 900 kWh per unit.

6.3 Analysis of the Standard-Income Program

6.3.1 COMMON-AREA LIGHTING ISSUES

In projecting energy savings from lighting measures in the 1998-2000 Multifamily Program, three factors must be examined: the proportion of customers receiving program measures (penetration rate), engineering estimates of energy savings from program measures, and expected realization rates from engineering estimates to actual net on-site performance.

6.3.1.1 Measure Penetration

According to survey research[9], 100% of standard-income participant buildings have exterior lighting, while 92% have interior common-area lighting on commercial house meters. Among low-income program

[9] Tachibana, Debra-L. O., MULTIFAMILY RETROFIT CONSERVATION PROGRAMS: CUSTOMER SERVICE MEASURES, July 1998.

participants, 96% have exterior and 80% have interior common-area lighting on house meters. In the longitudinal impact evaluation, similar proportions of units were found in buildings with house-meter data: 92% among standard-income buildings and 76% among low-income buildings (including Participants and Nonparticipants).

In the longitudinal study cohorts, the proportion of served buildings having commercial house meters seems to have trended slightly upward over the 1987-1992 period. This suggests that the average proportion of units in buildings with house meters may be expected to be 92% in 1993 and to exceed 99% in 1998 (time trend R^2=0.18).

In the meantime, there has been a weak trend downward over the 1987-1998 period in the proportion of served buildings receiving common-area lighting measures. During the period 1988-1992, 66% of participant buildings (containing 66% of the studied units) installed program lighting measures. The trend line suggests that the average proportion of retrofitted units may be expected at about 66% in 1993 and about 63% in 1998 (time trend R^2=0.08). In fact, in 1997 fewer customers in the Multifamily Conservation Program received lighting retrofits than in the previous year (Table 6-B). The proportion installing program lighting dropped from two-thirds in 1996 to just one-half in 1997. The average 1997 building receiving a lighting retrofit was somewhat smaller as well, in terms of units per building. In 1998 the proportion installing program lighting measures rose to a level were similar to the 1996 program.

Table 6-B: Jobs Currently Receiving Lighting Retrofits in Standard-Income Program

	Authorized Jobs			Received Lighting Retrofits		
Program Year	Bldgs.	Units	Avg. U/B	Bldg.	Units	Avg. U/B
1996 Contracts	67	1,223	18.3	45	835	18.6
Percent Retrofit				*67%*	*68%*	
1997 Contracts	77	1,337	17.4	43	645	15.0
Percent Retrofit				*56%*	*48%*	
1998 Contracts	69	1,364	19.8	53	946	17.8
Percent Retrofit				*78%*	*69%*	
1999 Waiting*	46	560	12.2			

* Remainder from the 1998-1999 wait-list observed in February 1998.

Overall over the period 1987-1992, about 28% of buildings with house meters did not receive program common-area lighting measures. If lighting measures were installed only in buildings with house meters, in 1993 it may be assumed that 72% of units in buildings with house meters received lighting measures (0.66/0.92). If the same relationship holds in 1998, this proportion is likely to drop to 63% of units (in house-metered buildings) that received lighting measures (0.63/0.99), and 37% of units in buildings with house meters will not have received program lighting measures.

Table 6-C: Penetration of Lighting Measures in Standard-Income Program

MF-Std. Program Penetration Rates	Bldgs. Installing C.-A. Lighting
1986 (A)	9%
1987 (B)	71%
1988 (C)	68%
1989 (D)	57%
1990 (E)	70%
1991 (F)	64%
1992 (G)	70%
1993	66%
1994	53%
1995	61%
1996	68%
1997	56%
1998	69%

6.3.1.2 Engineering Estimates

Engineering estimates for savings from installing high-efficiency lighting measures were developed from 1988-1992 program records by the evaluator and a consulting engineer (BRACO). A lighting survey sheet was adapted from the Multifamily Common-Area Lighting (MF-CAL) Program tool in MS-Excel, called AutoCAL. A workbook was created with one survey sheet for each standard-income building receiving a lighting retrofit. Existing fixtures (quantity, wattage, operating hours) were entered from the winning contractor's bid sheet, along with the proposed retrofit fixtures. The consulting engineer reviewed each proposed lighting specification to make corrections that incorporate fluorescent ballast wattage. Three columns were added to the worksheet template to calculate kWh energy use: before retrofit, after retrofit, and gross savings per year. The engineering projections of common-area energy savings were calculated for standard-income participants in the Multifamily Conservation Program and *normalized to the average unit having house-meter data* (see below).

Table 6-D: Projected Lighting Savings of Standard-Income Study Cohorts

MF-Std. Program Engineering Projections	kWh per Average Unit
1988 (C)	515
1989 (D)	613
1990 (E)	566
1991 (F)	561
1992 (G)	589
Average (Cohorts C-G)	567
Receiving Measures	*66%*
Expected Gross Savings	374

The longitudinal impact evaluation found *gross energy savings* of 365 kWh in the first post-retrofit year. Over a five-year span after measure installation, the annual house-meter savings varied within a range from 344 to 479 kWh per unit, averaging 390 kWh. This amount is 104% of the common-area lighting savings predicted by engineering estimates.

Another method was used to calculate energy savings while adjusting for pre-retrofit differences between the participant and nonparticipant (control group) buildings. This comparison found *net energy savings* of 372 kWh in the first post-year. Over a five-year span after measure installation, the annual house-meter savings varied within a range from 254 to 547 kWh per unit, averaging 389 kWh per unit. This amount is 104% of the common-area lighting savings predicted by engineering estimates. Because gross savings and net savings are identical, we can infer that few or no nonparticipants installed similar measures. As a result, we can be assured that there is no ‘free ridership’ in this program for lighting measures. We also are assured that 100% of the expected impact from lighting has been observed.

The engineering equations are most vulnerable to error when it comes to assumptions about operating hours. Interior lights in hallways and rooms without windows have been assumed to be on 24 hours per day, and exterior lights for 12 hours per day. Program energy service representatives designated half of all standard-income program lighting in 1986-1992 as being ‘exterior’ (the proportion is based on building averages of kWh installed). Engineering equations for lighting are also vulnerable to incomplete knowledge about actual pre-existing lamp wattages, which may have been reported based on a limited sampling, and missing information about the percentage of burned-out lamps during the pre-retrofit period. Apparently the effects of all these factors cancel out sufficiently to allow for reasonable accurate engineering projections to be made using the AutoCAL worksheet method and simple operating hour assumptions.

Turning to a more recent year, all standard-income buildings authorized in 1997 for program lighting measures were examined by the program evaluator to develop engineering estimates of (gross) energy savings. Program staff had generated a preliminary estimate, at the time of the building audit, of energy consumption from the existing lighting; this was recorded in each building's field file-folder. No estimates had been made of energy savings, however. For this exercise, again a lighting survey sheet was adapted from the Multifamily Common-Area Lighting Program's AutoCAL worksheet. Estimated energy savings were then transcribed into a list of the 43 buildings to generate the summary statistics presented below. As this table shows, the average 1997 project is expected to save about one-fourth more than the average project in 1988-1992 (695/567 = 123%). However, since only 56% of buildings received common-area lighting measures in 1997, expected annual average savings remain constant at 389 kWh per unit in the average program participant building. [10]

Table 6-E: Projected Lighting Savings of Current Standard-Income Program

1997 Participants Annual kWh Usage	All Buildings (n=43)	Average Unit (n=645)
Pre-existing Lighting	650,147	1,008
Proposed Retrofit	– 201,942	– 313
Estimated Savings	448,205	695
Receiving Measures		56%
Expected Gross Savings		389

The Multifamily Conservation Program (standard-income) savings estimates may be compared with findings for the Multifamily Common-Area Lighting Program. In recent years, program staff prepared engineering estimates of common-area energy savings. Normalized to the average unit in this program, savings for 1993-1996 were projected at an average of 1,040 kWh (see the middle column below). Excluding the 1993 start-up year, the average engineering estimate was 981 kWh per unit. The level of MF-CAL savings is higher by half than the estimate for 1997 standard-income buildings in the weatherization program (which itself was higher by one-fourth compared to earlier years). Since 100% of MF-CAL buildings receive lighting measures, there is no further adjustment for measure penetration.

[10] For comparison, in the annual ENERGY CONSERVATION ACCOMPLISHMENTS report, for 1993-1997 we used the projection of 520 kWh per unit in buildings receiving the measure, or 390 kWh from the average unit served in the program year (520 kWh realized net savings*0.75 expected penetration).

Table 6-F: Projected Savings of Common-Area Lighting Program Participants

MF-CAL Program Annual kWh Usage	Average Unit	* 62% Realization
1993	1,379	855
1994	995	617
1995	973	603
1996	982	609
Average to Date	1,040	645

6.3.1.3 Realization Rates

Energy savings predicted by engineering equations are not always observed in conservation programs. Sometimes evaluated savings exceed expectations; more often they fall short. Such outcomes should not necessarily be interpreted as measure or program failures. Reasons for falling short are varied. Take lighting for example: commercial house meters carry *other loads*, which may have been affected by the program intervention. Then there is the way engineering equations are calculated. Sometimes real program effects occur with *control systems*, even in buildings not receiving fixture retrofits; the analysis may not contain a variable to express this induced action, but certainly the engineering projection does not account for it. Then there is the adjustment from *gross* to *net* savings outcomes, based on usage patterns among nonparticipants. Finally and most importantly, there is the matter of assumptions, discussed above, regarding operating hours, pre-existing wattages, and missing information about burned-out lamps or non-operational fixtures during the pre-period.

Other factors come into play with engineering equations for shell insulation measures, which may force the ‘realization rate’ to also embed the effects of *unknowns* like infiltration, innate sensitivity of each building to outdoor temperatures, reduced sensitivity after the retrofit, set-point or reference temperature, performance factors for the heating system, and interactions with other end uses that produce waste heat. The engineering equations are often over-simplified, and the source of measurements (bimonthly utility meter readings) not specific to the calculated load change. All of these factors force the ‘realization rate’ away from 100% of engineering predictions.

There are two sources for estimating the realization rate of energy savings projected from engineering data on common-area lighting retrofits. One is the pilot program evaluation completed in 1993, which showed that actual savings in common-area lighting projects were 38% lower than engineering projections in a sample of eleven buildings receiving only lighting measures.[11] Based on that study, a *62% realization rate* has been used to adjust MF-CAL Program energy savings in the ACCOMPLISHMENTS report for the 1993-1997 program years.

Applying the 62% realization rate to engineering estimates cited for the Multifamily Common-Area Lighting Program, in recent years the average unit in this program has likely saved the amounts shown in the right-hand column of the table above. The realized savings range from 855 kWh per unit in 1993 to 609 kWh per unit in 1996. These savings average to 645 kWh per unit across the four program years; the 1994-1996 average was 608 kWh. The penetration rate for this program is 100%, since this is the only measure delivered. In the absence of a more formal evaluation analysis, the ACCOMPLISHMENTS report has continued to use the prior estimate of 700 kWh per unit per year. This position may be adjusted in future, keeping in mind the shift downward from 1993 and the flat trend in 1994-1996.

A second source for estimating a realization rate more specific to the Multifamily Conservation Program itself is the longitudinal evaluation that has been underway since 1994. This study has examined standard-income buildings retrofit with lighting measures during 1988-1992. This program presents a special case for interpreting the realization rate results, because not all buildings in this program install common-area measures. For this reason, the *realization rate* encompasses the *measure penetration rate* as well.

Weighted across program years and post-retrofit years, regression analyses from the longitudinal study of standard-income buildings found a *68% realization rate* in the first year post-retrofit. The rate went to 65% in the second year, 70% in the third, and 64% in the fourth year post-retrofit. The regression analysis calculates net savings pooled across various participation cohorts (program years) and post-periods, and also adjusts for unique events in particular participant and nonparticipant buildings. These findings provide evidence that common-area lighting savings are durable and persist over at least four years after program participation. The level of savings is well predicted by engineering equations (0.68/0.66 = 103%).

In the longitudinal study, buildings with lighting retrofits had an average engineering estimate of 567 kWh saved per unit. When multiplied by the realization rate, the longitudinal study yields realized savings of 388 kWh per unit in the first post-retrofit year (567 kWh*0.68). This result reflects the level of savings in all program buildings that had house meters (which comprised 92% of all buildings in the standard-income participant group). Extrapolated to all buildings in the 1988-1992 standard-income program, the

---

[11] Humburgs, Christina, EVALUATION OF MULTIFAMILY CONSERVATION LIGHTING IN THE ENERGY SMART DESIGN PROGRAM, February 1993.

average common-area lighting savings per unit would be calculated at ***357 kWh per year*** (567 kWh*0.68 realization*0.92 house-metered). This presumes that the remaining 8% of buildings did not receive any program lighting measures.

6.3.1.4 House Meter Savings Not Associated with Engineering Estimates

An interesting factor disclosed by the longitudinal evaluation is that some energy savings are unrelated to engineering projections. One component of savings, the 388 kWh per year associated with engineering projections, expresses only 76% of the measured house-meter savings. Another 123 kWh per unit of first-year savings are found in buildings without physical lighting retrofits, or in addition to the lighting measures. Over five post-installation years, the added savings average 164 kWh per unit annually. This compares to a similar finding of about 200 kWh per unit added savings in the earlier study of 1986-1987 participants.[12] The total house-meter savings, and savings associated with engineering projections, are as follows:

Table 6-G: Total House-Meter Net Savings of Standard-Income Study Cohorts

kWh Savings in Post-Installation Period	Associated with Engineering Projections	From Program Participation	Total House-meter Savings
1st Year	388	123	511
2nd Year	374	169	543
3rd Year	387	198	585
4th Year	355	115	470
5th Year	247	214	461
Average per Unit	350	164	514

These additional savings may flow from four sources: changes in usage of pre-existing lighting controls; systematic, non-random error in the engineering estimates for retrofit lighting; effects of temperature setbacks on house-metered water heaters; and/or interaction effects of tenant-area measures on house-meter loads. The longitudinal evaluation design did not allow any of these possibilities to be tested.

Returning briefly, then, to the question of realization rates, the total estimate of house-meter savings, including this 123 kWh adder, appears to be 90% of engineering estimates for the lighting measure component (511 kWh measured/567 projected). For comparison, in the prior study of the 1986-87 program, about 80% of projected savings were observed in overall house-meter changes. It is unknown,

---

[12] Okumo, Debra L., THE MULTIFAMILY CONSERVATION PROGRAM: EVALUATION OF ELECTRICITY SAVINGS AND COSTS, July 1991.

however, whether inherent errors related specifically to engineering inputs for lighting are responsible for the added component of savings. With these additional savings in mind, extrapolating to all buildings in the 1988-1992 standard-income program, the ***average house-meter savings per unit*** would be calculated at ***521 kWh per year*** (567 kWh*0.68 realization*0.92 house-metered + 164 kWh). In the average Standard-Income building, this amounts to ***29% of pre-program*** House Meter energy usage.

6.3.1.5 Estimating Lighting Savings for 1998-2000

As stated above, not all longitudinal-study buildings received lighting retrofits. During the period 1988-1992, the buildings installing program lighting had 2,616 tenant units out of 3,969 units in the study samples; thus 66% of units were in buildings retrofit with lighting. (This compares to the 75% expected when the 1986-1987 program was examined in the earlier evaluation.[13]) The measure penetration in 1999-2000 is expected to range from 64% to 66%. This is sufficiently close to the average level in the longitudinal study period to render further adjustment unnecessary, if all factors were held constant to their 1988-1992 state. All factors have not held constant since 1992, however. The projected savings are higher in 1997 and the penetration rate is considerably lower.

- As for the future, current information on the 1998 program shows that 69% of the units are in buildings receiving lighting measures. This leads us to expect savings of ***658 kWh*** from the average unit served in 1998 (695 kWh *0.68 realization*0.69/0.66 penetration + 164 kWh).
- If 1999-2000 follow a similar pattern, energy savings may be expected at ***615 kWh*** from the average unit awaiting service (695 kWh *0.68 realization*0.63/0.66 penetration + 164 kWh).

6.3.2 TENANT AREA ISSUES: SHOWERHEADS & BUILDING SHELL

In planning for the 1998-2000 Multifamily Conservation Program, a question has been raised about the appropriate planning projection of energy savings from the showerhead and building-shell measures.

6.3.2.1 Showerheads

Beginning with showerheads, market penetration of this measure has varied by year, starting at 57% in 1986 and rising to nearly 100% in 1988-1991. With the drought year of 1992, and extending through 1995, the highly successful Home Water Savers Program delivered efficient-flow showerheads at no cost to 38% of the multifamily buildings in Seattle City Light's service area. Combined with showerheads supplied by the Multifamily Conservation Program, over 45% of all Seattle multifamily buildings received

[13] See Footnote 4.

showerhead upgrades by the end of 1995. Early in 1994, the Multifamily Conservation Program was able to install showerheads in 63% of participating buildings, but by the end of the year program measure penetration had dropped to 30%, and in 1997 it was below 5%.

In reporting for 1998 and planning for 1999-2000, it is time to drop out of savings projections a factor for efficient-flow showerheads. Going back to assumptions stated in the ACCOMPLISHMENTS report, shell savings for 1992-1997 had been estimated at 1,880 kWh per tenant unit. Of this amount, 390 kWh were attributed to common-area lighting savings and 1,490 kWh per unit to shell and showerhead savings. Further decomposition of tenant-area savings is less reliable and depends on several regression equations found in an evaluation report appendix (Okumo 1991). Tenant-area savings were estimated at approximately 230 kWh per unit from insulation, 580 kWh from windows, 440 kWh from improved window technology since 1986-1987, and about 240 kWh from showerheads. The showerhead measure had a penetration rate of 41% (as reported at the time), so added only about 100 kWh to the overall tenant-area savings estimate. It is apparent that the assumption adopted for the ACCOMPLISHMENTS report and for program reporting perpetuated the original 100 kWh per unit component (240 kWh*0.41), and was never adjusted upward to reflect the higher penetration rates of 1988-1992.

According to an independent source, a Seattle-area metering study of showerheads in multifamily buildings[14], high-efficiency showerheads save 200-250 kWh per unit annually on water heat. The current longitudinal evaluation found 208 kWh of annual energy savings associated with each showerhead installed during the 1988-1992 program period.

The mix of measures installed in 1997 shows that 3% of participants received energy-efficient showerheads. The penetration of showerhead measures averaged 91% in 1988-1992. Thus the adjusted calculation for 1997 would lead us to expect ***showerhead savings of 7 kWh*** from the average unit (208 kWh *0.03/0.91 penetration). The 1998-2000 program is expected to have no savings whatsoever from showerhead measures, due to saturation of the market and near-zero penetration rate in future.

6.3.2.2 Windows

Turning to window measures, in 1986-1987 the average window installed by the program had a U-factor of 0.72, replacing older windows with U-factors around 1.10. Since then replacement window U-factors have decreased considerably with improving measure technology. The ACCOMPLISHMENTS report estimated that this progressive improvement would provide additional savings: an incremental 170 kWh

---

[14] Hickman, Curtis, ENERGY EFFICIENT SHOWERHEAD AND FAUCET AERATOR METERING STUDY: MULTIFAMILY RESIDENCES, by SBW Consulting, Inc., for Bonneville Power Administration, October 1994.

per unit in 1990 (to U=0.58), plus 195 kWh in 1991 (to U=0.46), plus 75 kWh in 1992 (to U=0.40). The cumulative increment in annual energy savings expected from improved window technology from 1989 to 1992 was 440 kWh per residential unit.

The longitudinal evaluation reveals that 67% of window engineering estimates were realized. Projected savings for window measures, and the realized net savings, appear in the table below. The 1988 program savings of 450 kWh per unit are somewhat lower (78%) than the 580 kWh savings attributed by the prior evaluation to windows in the 1986-1987 program. The realized window savings in 1992, 847 kWh, are also clearly lower (83%) than the 1,020 kWh savings expected from engineering projections (580 + 440). However, savings did rise by 397 kWh per unit between 1988 and 1992, which compares favorably with the 440 kWh rise expected (90%). The lower gross savings in all years appear due to baseline savings from 1988-1989 windows that were 130 kWh per unit lower than expected from the evaluation of 1986-1987 participants in the pilot program.

Table 6-H: Projected Window Savings of Standard-Income Study Cohorts

MF-Std. Program kWh per Study Unit	Engineering Projections	* 67% Realization
1988 (C)	672	450
1989 (D)	718	481
1990 (E)	844	565
1991 (F)	1,042	698
1992 (G)	1,264	847
Average (C-G)	936	627

The mix of measures installed in 1997 shows that 100% of participants received window retrofits. The penetration of window measures averaged 96% in 1988-1992. Thus the adjusted calculation for 1997 would lead us to expect ***window savings of 882 kWh*** from the average unit, based on 1992 impacts (847 kWh *1.00/0.96 penetration). Current 1998 windows typically have U-factors closer to 0.35 than to the 0.40 observed in 1992, which may add an increment of up to 40-60 kWh per unit in energy savings. As the regression models have shown, the current realization rate in 1998 is expected to be about 70% of engineering projections for window measures (0.67*1.00/0.96), using the engineering equations and assumptions of the longitudinal impact study.

6.3.2.3 Insulation

Finally, regarding insulation measures, the following table displays the engineering projections and the realized net savings for each insulation category. The most notable finding was that floor insulation generated only a fraction of the expected savings (based on engineering estimates and proportion of measure mix during 1988-1992). This is not entirely surprising, since the engineering estimate was calculated using a design temperature differential of 60°F when a value of 20°F would have been more appropriate for underfloors. The previous evaluation (Okumo 1991) also found very few kilowatt-hour savings associated with floor insulation measures. It is likely that the regression correlation method confounds the impacts of underfloor insulation with those of ceiling insulation. Overall, insulation contributed energy savings of about ***131 kWh*** per average unit to the overall impact of the longitudinal study buildings. This compares to about 230 kWh per unit found in the pilot program evaluation.

Table 6-I: Projected Insulation Savings of Standard-Income Study Cohorts

MF-Std. Program	Engineering Projections			* Realization Rate			Insulation
kWh per Study Unit	Ceilings	Walls	Floors	Ceilings 113%	Walls 73%	Floors 6%	Total
1988 (C)	58	4	295	66	3	18	87
1989 (D)	107	26	404	121	19	24	140
1990 (E)	19	0	299	21	0	18	39
1991 (F)	31	60	141	35	44	8	87
1992 (G)	90	0	96	102	0	6	108
Average (C-G)	57	21	236	94	22	15	131

The mix of measures installed in 1997 shows that 29% of participants received insulation but available information is not specific as to areas of application. The penetration of insulation measures as a whole was 36% in 1988-1992. Thus the adjusted calculation for 1997 would lead us to expect ***insulation savings of 105 kWh*** from the average unit (131 kWh *0.29/0.36 penetration). The contribution of this measure to overall savings has decline steadily since the pilot program years.

6.3.2.4 Tenant Meter Savings Not Associated with Engineering Estimates

As with the house-meter analysis, the longitudinal evaluation disclosed some tenant-meter energy savings unrelated to engineering projections. The regression analyses revealed 966 kWh per year energy savings associated with engineering projections (208 showerheads + 627 windows + 131 kWh insulation). This component of savings expresses only 86% of the measured tenant-meter savings. Another 151 kWh per unit of first-year savings are found in buildings without physical window, insulation, or showerhead retrofits, or in addition to these measures. This compares to a finding of 303 kWh per unit in the earlier study of 1986-1987 participants. The total savings per tenant-meter, and savings associated with engineering projections, are as follows:

Table 6-J: Total Tenant-Meter Net Savings of Standard-Income Study Cohorts

kWh Savings in Post-Installation Period	Associated with Engineering Projections	From Program Participation	Total Tenant-meter Savings
1st Year	966	151	1,117

With these additional savings in mind, among buildings in the 1988-1992 standard-income program, the ***average tenant-meter savings per unit*** would be calculated at ***1,117 kWh per year***. In the average Standard-Income building, this amounts to ***14% of pre-program*** Tenant Meter energy usage.

6.3.3 CONCLUSIONS FOR THE STANDARD-INCOME PROGRAM

Going back to assumptions stated in the ACCOMPLISHMENTS report, shell savings for 1992-1997 had been estimated at 1,880 kWh per tenant unit. Of this amount, 390 kWh were attributed to common-area lighting savings and 1,490 kWh per unit to shell and showerhead savings. For the standard-income Multifamily Conservation Program in 1997, it is more accurate to say that ***estimated energy savings were 1,725 kWh per tenant unit***, including 565 kWh of common-area lighting savings and 1,160 kWh per unit of shell and showerhead savings. The differences are mainly attributable to higher savings from common-area lighting, the discontinuation of showerhead measures, and slightly lower baseline impacts of window retrofits than previously estimated. Declining penetration of several measure categories also played a clear part in reducing observed energy savings. These declines are mitigated by a potential slight upward trend of energy savings from window measures.

Table 6-K: Total-Building Net Energy Savings of Current Standard-Income Participants

Annual kWh Energy Savings per Residential Unit	1997 Program Estimate	1998 Projection	1999-2000 Projection
Lighting Savings from E. E.	401	494	451
House Meter Savings Not Associated with Engineering Estimate	164	164	164
Showerhead Savings from E. E.	7	0	0
Window Savings from E. E.	847	847	847
Insulation Savings from E. E.	105	105	105
Tenant Meter Savings Not Associated with Engineering Estimates	151	151	151
Current Window Technology	+ 50	+ 50	+ 50
Total Electricity Savings	1,725	1,811	1,768

At this time in reporting on standard-income participants in the 1998 Multifamily Conservation Program and planning for 1999-2000, savings may be estimated to fall ***between 1,782 kWh and 1,811 kWh per unit***. This range is about 95% of prior published estimates.

Our conclusion for the standard-income program is that currently the average building saves about 1,800 kWh per residential unit from tenant-area and common-area measures combined.

6.4 Analysis of the Low-Income Program

In reporting on the 1997-1998 and projecting savings for the 1999-2000 Low-Income Multifamily Program, we find both parallels with and differences from the standard-income program findings.

6.4.1 COMMON-AREA LIGHTING ISSUES

The actual proportion of customers receiving common-area lighting measures (penetration rate) is not available from the Low-Income Database. Program field files did not provide sufficient detail to generate engineering estimates of energy savings from program measures (that is, data on pre-existing and replacement fixtures). For that reason, statistical regression methods were not applied to analyze energy use patterns, and realization rates (from engineering estimates to actual net on-site performance) were not calculated. However, one factor is available for examination, that being the proportion of customers likely to receive program measures (approximated penetration rate) due to having internal common areas and commercial house meters.

6.4.1.1 Measure Penetration

It is known from the longitudinal study that about 72% of units in Low-Income Cohorts A through G were located in buildings having house-meter data. This proportion probably represents the upper bound on the proportion of units affected by program (interior) lighting measures in the 1986-1992 program years. The proportion of units in served buildings having commercial house meters seems to have trended slightly upward over the 1987-1992 period, suggesting that it may be expected to exceed 76% in 1993 and 82% in 1998 for low-income participants (time trend R^2=0.06).

Survey research states that, among low-income program participants in 1991-1992, 96% of buildings have exterior and 80% have interior common-area lighting on house meters. This compares to 100% of surveyed standard-income participant buildings in 1986-1992 having exterior lighting and 92% with interior common-area lighting on commercial house meters. In Cohorts C through G of the longitudinal impact study, similar proportions of units (to the survey proportions with interior lighting) were found in buildings with house-meter data: 76% among Low-Income buildings and 92% among Standard-Income buildings (including Participants and Nonparticipants). These data suggest a reasonable bound of about

80% for units in low-income buildings that might be affected on house-meters by programmatic measures.

By contrast, among Low-Income Nonparticipants in the control group, 96% of buildings (containing 99% of studied units) had commercial house meters. This fact reveals one important difference between the sub-populations from which the Low-Income Participant and Nonparticipants were drawn. As the Low-Income Multifamily Program has increasingly saturated the available market pool, the remaining unserved buildings (from which the control group was drawn) have revealed distinctions from those served in past years. Any future participants are more likely to have interior hallways, rather than exteriorized unit entries, requiring higher penetration of common-area lighting measures.

This nonparticipant factor must be taken into consideration in planning future programmatic measure offerings. In fact, increasingly the Multifamily Common-Area Lighting program is serving low-income buildings in advance of participation in the Low-Income weatherization program (specifically in the public housing subsector). Projections of energy savings in 1999-2000 will require further adjustment than provided for in this report, based on program service strategies for common-area lighting and the remaining potential market for multifamily retrofit programs.

Table 6-L: Approximate Penetration of Lighting Measures in Low-Income Program

MF-Low Program Penetration Rates	Bldgs. with House Meters
1986 (A)	10%
1987 (B)	73%
1988 (C)	67%
1989 (D)	89%
1990 (E)	76%
1991 (F)	67%
1992 (G)	83%
Average	72%

6.4.1.2 House-Meter Savings

The longitudinal impact evaluation found *gross energy savings* of 391 kWh in the first post-retrofit year for low-income participants with house meters. Over a five-year span after measure installation, the annual house-meter savings varied within a range from 327 to 391 kWh per unit, averaging 391 kWh across the seven Participant cohorts. These values are very close to gross scores found in the standard-income program for participants with house meters. It is not possible to partition this savings estimate into effects of measures versus effects of program participation, as with the standard-income participants, due to the lack of an engineering estimate basis.

Another method was used to calculate energy savings while adjusting for pre-retrofit differences between the Participant and Nonparticipant (control group) buildings. The Net Method II comparison found *net energy savings* of 382 kWh in the first post-year. Over a five-year span after measure installation, the annual house-meter savings varied within a range from 382 to 551 kWh per unit, averaging 428 kWh per unit. This amount is higher than the gross savings measure in later years, suggesting both differing statistical distributions and some increased house-meter loads among nonparticipants that are not observed in the participant groups. It is very likely that few or no nonparticipants installed similar measures to those sponsored by the Low-income Multifamily Program. As a result, we can be assured that there is no 'free ridership' in this program for lighting measures. As stated above, these savings of 428 kWh per unit in buildings with house-meters represent the combined effects of lighting measures plus any other programmatic actions taken that might affect house-meter usage in participating buildings.

With these additional savings in mind, extrapolating to all buildings in the 1988-1992 standard-income program, the ***average house-meter savings per unit*** would be calculated at ***308 kWh per year*** (428 kWh *0.72 house-metered). In the average Low-Income building, this amounts to ***22% of pre-program*** House Meter energy usage.

6.4.1.3 Estimating Lighting Savings for 1998-2000

As stated above, not all longitudinal-study buildings received lighting retrofits. During the period 1988-1992, 64% of participating buildings had commercial house meters. The Low-Income buildings with house meters had 2,483 tenant units out of 3,441 units in the study samples (72%). In Cohorts C through G, 76% of units were in buildings retrofitted with lighting. (This compares to the 75% expected when the 1986-1987 program was examined in the earlier evaluation.) A long-term trend line fitted to the approximated measure penetration data for 1988-1992 has projected measures affecting house meters in over 80% of participating low-income buildings during 1997-1998. (Meanwhile, the average penetration rate for lighting measures among Standard-Income Participants is expected to be about 66%.) To be conservative based on increased levels of prior service by the Multifamily Common-Area Lighting Program, the Low-Income Multifamily Program measure penetration in 1999-2000 will be projected at 70%.

Meanwhile, engineering estimates for recent participants in the standard-income program have been increasing each annually in proportion to the study years, due to improving lighting technology. Estimated impacts of these incremental increases lead to expected energy savings rising by 8% in 1997, 26% in 1998, and 21% in 1999-2000 over study-year impacts (based on future impacts of 401, 494, and 465 kWh per unit, respectively, plus 164 kWh, over the denominator of 521 kWh observed in 1988-1992). These proportionate increases in lighting technology impacts are reasonable expectations for added effects among low-income participants as well.

- Assuming that the 1997 program has 80% of units in buildings receiving house-meter measures, annual energy savings of ***371 kWh*** may be expected from the average unit served in 1997 (428 kWh *0.80 penetration *1.08). Most if not all of these savings would have come from common-area lighting measures.
- Annual house-meter savings may be expected at ***432 kWh*** from the average unit served in 1998 (428 kWh *0.80 penetration *1.26).
- If the penetration rate drops to 70% in future years, the 1999-2000 program energy savings may be expected at ***362 kWh*** from the average unit awaiting service (428 kWh *0.70 penetration *1.21).

6.4.2 TENANT AREA ISSUES: SHOWERHEADS & BUILDING SHELL

In reporting on the 1997-1998 and planning for the 1999-2000 Multifamily Conservation Program, the question has also been raised about appropriate planning projections of energy savings from the showerhead and building-shell measures. The low-income program records do not allow for disaggregation of tenant-meter savings by measure category. To the extent that inferences can be drawn from data about the standard-income program, however, some adjusted projections from the longitudinal study results are possible.

6.4.2.1 Showerheads

As described earlier in the discussion of showerhead measures for the standard-income program, market penetration of this measure has changed markedly over the period 1986-1998. Drawing upon the experience of the standard-income program, program penetration of showerhead measures may be estimated at less than 5% in 1997 and should be assumed at 0% in 1998-2000. The same Seattle-area metering study of showerheads in multifamily buildings is pertinent to estimating low-income program impacts. As with the standard-income program, the 1998-2000 Low-Income Multifamily Program is expected to have no savings whatsoever from showerhead measures, due to saturation of the market and near-zero penetration rate in future.

6.4.2.2 Windows & Insulation

The analysis of the Standard-Income cohorts provides discussion on issues of improved window technology and changing insulation measure mixes over time. For the purpose of making projections for the Low-Income Multifamily Program, it will be assumed that similar changes have occurred. It will also be assumed that tenant meter savings not associated with engineering estimates occur equally in both programs. Low-income projections made for future years will be set equal to those already determined for Standard-Income participants. The only adjustment made for differences between the two programs takes the form of a generic subtractor, described below.

6.4.2.3 Tenant Meter Savings

In the study period 1988-1992, first-year *gross savings* from Low-Income Cohorts A to G averaged 1,201 kWh per unit, ranging from 1,116 kWh to 1,473 kWh per unit over a five-year span after installation of measures. When only the recent Cohorts D-G were examined, first year gross savings from the Low-Income program were 1,009 kWh per unit. This level of savings is lower by 200 kWh per unit than overall tenant-meter gross scores for Cohorts D-G in the Standard-Income program (1,219-1,009 = 210). In 1988-1992, first-year *net savings* were lower by 300 kWh per unit (Net Method I) to 470 kWh per unit (Net Method II) in the Low-Income than the Standard-Income program. Using past-participants as an alternate, more closely matched comparison group, *net savings* remained lower by about 200 kWh per unit (Past-participant Net Method I).

It is only reasonable to assume that this pattern of lower net savings will continue in subsequent years. Given the range of estimates by method (from 200 to 470 kWh), the projections for the 1993-2000 Low-Income program will contain a subtractive factor in the amount of 300 kWh per year to represent the difference between programs. An additive factor will adjust for ongoing improvements in window technology, as in projections for the Standard-Income program. Current 1998 windows typically have U-factors closer to 0.35 than to the 0.40 observed in 1992, which may add an increment of up to 40-60 kWh per unit in energy savings in future years.

6.4.3 CONCLUSIONS FOR THE LOW-INCOME PROGRAM

Going back to assumptions stated in the ACCOMPLISHMENTS report, shell savings for 1992-1997 had been estimated at 1,880 kWh per tenant unit. Of this amount, 390 kWh were attributed to common-area lighting savings and 1,490 kWh per unit to shell and showerhead savings. For the Low-Income Multifamily Program in 1997, it is more accurate to say that ***actual energy savings were 1,231 kWh per tenant unit***, including 371 kWh of common-area lighting savings and 860 kWh per unit of shell and showerhead savings. The differences are mainly attributable to the discontinuation of showerhead measures, and reductions in net effects due to basic differences between programs, statistical distributions, and nonparticipant actions. The effects in participating buildings are mitigated by a potential slight upward trend of energy savings from window measures.

Table 6-M: Total-Building Net Energy Savings of Current Low-Income Participants

Annual kWh Energy Savings per Residential Unit	1997 Program Estimate	1998 Projection	1999-2000 Projection
House-Meter Savings	371	432	362
Standard-Income Tenant-Meter Savings	1,110	1,103	1,103
Low-Income Tenant-Meter Subtractor	– 300	– 300	– 300
Current Window Technology	+ 50	+ 50	+ 50
Total Electricity Savings	1,231	1,285	1,215

In 1997 ***actual energy savings of 1,231 kWh per tenant unit*** among low-income participants included 371 kWh of house-meter savings and 860 kWh per unit of tenant-meter savings (7+847+105+151+50-300). Projecting to low-income participants in the 1998 Multifamily Conservation Programs and planning for 1999-2000, savings may be estimated to fall ***between 1,215 kWh and 1,285 kWh per unit***. This range is about 66% of prior published estimates. Low-income buildings ***not installing lighting measures*** in 1999-2000 (having previously been served by MF-CAL) can be expected annually have net savings of about ***860 kWh per unit.*** Gross energy savings among low-income participants are likely to continue at a level equivalent to gross impacts among standard-income participants. The reasons for lower net savings impacts have not been discerned by this study, but are likely to relate to the distinct features of low-income buildings in both the served and unserved market pools.

Our conclusion for the low-income program is that currently the average building saves about 1,300 kWh per residential unit from tenant-area and common-area measures combined. In low-income buildings not installing common-area measures (specifically lighting), the average building savings are about 900 kWh per unit.

6.5 Estimated and Projected Savings, 1986-2000

The longitudinal impact study has evaluated savings from participants in the 1986-1992 Multifamily Conservation Programs. In the preceding two sections, these results have been projected forward to the present program years 1997-1998, and into the future for 1999-2000. During the intervening period program, 1993-1996, annual penetration rates are known for the four major measure categories among Standard-Income participants (but are unknown among Low-income participants). These measure penetration rates have been used to generate adjusted projections for the 1993-1996 program years, both Standard-income and Low-Income (see Table 6-N below).

Table 6-N: Jobs Receiving Measure Retrofits in Standard-Income Program, 1993-1996

	Authorized Jobs			Receiving Measure Retrofits (Units)			
Program Year	Buildings	Units	Avg. U/B	Windows	Insulation	Showerheads	Lighting
1993 Contracts	132	2,056	15.6	2,040	535	*	1,357
Percent Retrofit				*99%*	*26%*	*75%*	*66%*
1994 Contracts	115	2,000	17.4	2,000	476	*	1,060
Percent Retrofit				*100%*	*24%*	*63%*	*53%*
1995 Contracts	109	2,111	19.4	2,111	868	*	1,288
Percent Retrofit				*100%*	*41%*	*30%*	*61%*
1995 Contracts	67	1,223	18.3	1,223	295	*	832
Percent Retrofit				*97%*	*24%*	*10%*	*68%*

* Note: Proportion receiving showerheads is estimated from other sources.

Meanwhile, engineering estimates for recent participants in the standard-income program have been increasing each annually in proportion to the study years, due to improving lighting technology. Estimated impacts of these incremental increases lead to expected energy savings rising by 7% in 1993-1996 over study-year impacts. These are reasonable expectations for added effects among low-income participants as well.

Data on the penetration of showerhead measures among low-income participants were not developed in the study database. Drawing upon the experience of the standard-income program, program penetration of showerhead measures may be estimated at about 75% in 1993, 63% in 1994, 30% in 1995, and 10% in 1996.

Table 6-O describes the energy savings results from Tenant-Meters and House-Meters in terms of annual kilowatt-hours per residential unit. For Cohorts A and B (1986-1987 pilot program), these consist of gross savings scores. For Cohorts C through G (1988-1992 full program), these consist of Regression Model V results for Standard-Income buildings and of Net Method II results for Low-Income buildings. In a sub-analysis it was found that the results of these two methods match exactly for Standard-Income buildings (summarized across cohorts and post-periods), thus validating the use of Net Method II results for the Low-income buildings. For the subsequent program years 1993-1996, values found in Table 6-O and Table 6-P were adjusted to annual measure penetration rates (with no added factor for 'current window technology'). And finally, for 1997-1998 the results are carried forward from that same source tables.

Table 6-O: Estimated and Projected Energy Savings per Unit, 1986-2000

Installation Year	Tenant-Meter Impact kWh per Unit		House-Meter Impact kWh per Unit		Total Building Impact kWh per Unit	
Program	Std-Inc.	Low-Inc.	Std-Inc.	Low-Inc.	Std-Inc.	Low-Inc.
A 1986	989	1,711	195	136	1,213	1,025
B 1987	1,186	1,465	416	379	1,628	1,089
C 1988	837	1,335	485	303	1,322	1,638
D 1989	1,082	628	452	387	1,534	1,015
E 1990	1,356	829	581	390	1,937	1,219
F 1991	1,338	898	358	140	1,696	1,038
G 1992	1,249	896	184	369	1,433	1,265
1993	1,291	991	550	347	1,840	1,338
1994	1,265	965	474	347	1,738	1,312
1995	1,251	951	520	347	1,771	1,298
1996	1,117	817	561	347	1,678	1,164
1997	1,160	860	565	371	1,725	1,231
1998	1,153	853	658	432	1,811	1,285
1999-2000	1,153	853	615	362	1,768	1,215

The values shown in Table 6-O have been applied in Table 6-P to calculate program-wide savings from 1986 through the present date. During the study years, first-year energy savings ramped up about 600 MWh in 1986 to nearly 3,000 MWh each year in 1990-1992. The ramp-up steepened in 1994 to 5,200 MWh, and to 6,000 MWh in 1995. At that time program participation goals were cut and first-year savings dropped back down to the 2,600-3,500 MWh range in 1996-1998.

In 1992, energy savings from cumulative participants in the Standard-Income and Low-Income programs combined totaled nearly 15,800 MWh. This was equivalent to an average load reduction for Seattle City Light in that year of 1.9 aMW (average megawatts, including a 5.2% credit for savings on transmission and distribution).

In 1998, savings from cumulative participants were about 38,600 MWh, yielding an utility load reduction of 4.6 aMW from the two combined programs. These values will be used to revise projections published in the next edition of Seattle City Light's annual ENERGY CONSERVATION ACCOMPLISHMENTS report.

Table 6-P: Program Energy Savings from Completed Projects, 1986-1998

Installation Year	Total Building Impact kWh per Unit		Number of Units in Completed Projects		MWh Savings from Combined Programs	
Program	Std-Inc.	Low-Inc.	Std-Inc.	Low-Inc.	First Year	Cumulative
A 1986	1,213	1,025	254	264	579	579
B 1987	1,628	1,089	399	929	1,661	2,240
C 1988	1,322	1,638	812	894	2,538	4,778
D 1989	1,534	1,015	787	891	2,112	6,889
E 1990	1,937	1,219	1,020	832	2,990	9,879
F 1991	1,696	1,038	1,232	790	2,909	12,789
G 1992	1,433	1,265	1,185	1,021	2,990	15,779
1993	1,840	1,338	981	847	2,938	18,717
1994	1,738	1,312	2,045	1,278	5,231	23,948
1995	1,771	1,298	2,640	1,033	6,016	29,964
1996	1,678	1,164	1,232	469	2,613	32,577
1997	1,725	1,231	1,519	725	3,513	36,090
1998	1,811	1,285	983	626	2,585	38,675

This evaluation has found no evidence of free riders on the Multifamily Conservation Programs for standard-income and low-income buildings. The evidence for this assertion is found in Section 3.3 of this report, where the energy use baselines were examined for program participants, wait-list pre-participants (standard-income), and population nonparticipants (low-income). When seven-year data were fitted with flat trend lines (simple regression) , no significant slopes were observed. When fitted with curvilinear trend lines (polynomial regression), energy use trended slightly upward and downward, ending at levels above initial values. It is very unlikely that nonparticipants in the general population of multifamily building operators on their own are installing significant quantities of measures similar to those sponsored by the Multifamily Conservation Programs. Few or none of the program participants have entered the program to receive financing for measures they would have installed on their own.

This evaluation has also found no evidence of spill-over effects (free drivers) from the Multifamily Conservation Programs for standard-income and low-income buildings. The evidence for this assertion is found in Section 4.2.1 of this report, where the gross and simple net change scores are compared among program participants, wait-list pre-participants (standard-income), population nonparticipants (low-income), and program past-participants (both income levels). It is very unlikely that nonparticipants in the general population of multifamily building operators have been influenced, as a direct spill-over effect of the Utility programs, to install on their own significant quantities of measures similar to those sponsored by the Multifamily Conservation Programs

6.6 Recommendations

This longitudinal impact study of the Multifamily Conservation Programs began with several purposes.

- Produce outcome measures to provide accountability for the Standard-Income and Low-Income programs.
- Track the persistence of savings outcomes from 1986 and 1987 pilot program participants (Cohorts A and B) over a six- to seven-year period after measures were installed.
- Determine the pattern and persistence of savings from the program as it matured in 1988-1990, and as newer technology windows became prevalent in 1991-1992.
- Provide accurate utility load forecast inputs, in the form of energy savings estimates and associated errors for participants, as well as profiles of nonparticipant trends.
- Suggest formative changes in the program delivery or design that may improve on energy savings impacts and persistence.

This chapter has presented and discussed the evidence for energy savings that persist up to seven years after program measure installation. There has been no evidence of participant free-ridership or program spill-over to nonparticipants. As newer vinyl window technology developed in the late 1980s and into the early 1990s, energy savings associated with this measure rose, although more gradually than had been hoped. Meanwhile, programmatic application of insulation measures became less frequent, and efficient showerhead measures reached the saturation point. In the last two years studied for the Standard-Income program (1991-1992), energy savings impacts from common-area lighting measures did not materialize quite as expected from engineering projections. In all post-years studied, Tenant-Meter savings among Low-Income buildings were lower than savings among Standard-Income buildings by a factor of about 200 to 500 kWh per unit annually.

The Control Group selected for comparison with Low-income Participants consisted of buildings drawn from the same neighborhoods where the Low-Income Multifamily Program has penetrated deeply into the available market pool of multifamily buildings. Those buildings available for the Control Group had lower initial energy usage, indicating pre-existing differences between past Participants and Nonparticipants. Virtually all Low-Income Nonparticipants have house meters, compared to only 80% of Participants. Nearly a quarter of the Nonparticipants participated in the immediately following years. Some of the neighborhoods traditionally served by the program have undergone economic revival and a certain amount of "gentrification." It will probably become increasingly difficult to locate buildings optimal for service by the Low-Income Multifamily Program, due to lower initial energy usage levels among the remaining unserved buildings. It is possible that this program will reach the market saturation point in the next few years. Any future participants are more likely to have interior hallways, requiring higher penetration of common-area lighting measures (including LED exit signs).

The following recommendations address issues raised by this impact evaluation. Some of these recommendations expand on actions suggested in the companion process evaluation, "Multifamily Retrofit Conservation Programs: Customer Service Measures." Future evaluation of the Low-Income Multifamily Program would at a minimum address two major issues called out below, those being measure penetrations and market penetration.

6.6.1 DEVELOP OPTIONS FOR RE-DESIGN OF PROGRAM OFFERINGS IN 2001-2004

6.6.1.1 Evaluate Recent Vinyl Window Replacements

Seattle City Light should develop a strategy for following up on specific buildings receiving the current generation of vinyl-framed window products, to determine whether problems observed in 1991-1992 program installations have "shaken out" as high-efficiency (U≤0.40) products matured. Have warranty replacements for vinyl windows been significantly fewer than for the preceding aluminum and early-generation vinyl window products?

6.6.1.2 Offer Vinyl Replacements to Former Aluminum-Window Participants

Seattle City Light should investigate the economics of offering a new generation of vinyl window replacements to customers who participated in the Multifamily Conservation Programs in 1986-1990 and received aluminum window replacements or conversions. The early programs reduced heat transmission U-factors from pre-existing levels around 1.10 to post-retrofit levels around 0.72, a drop of 0.38 points (Btu/hour/°F per square foot). Current window U-factors run closer to 0.35, offering another potential drop of around 0.37 points. Certainly current windows are not twice the cost of earlier retrofits, even though savings per square foot have doubled; in fact, costs have held fairly constant over the years. New building audits for prior participants may not be necessary, since existing program files contain all relevant measurements and prior cost comparisons. Given noneconomic benefits of program measures and economic externalities of competing resources, it may be feasible to replace early aluminum window retrofits with a better-performing product, in a streamlined program format requiring customer payment upon completion of inspections (i.e., no loan financing). Seattle City Light's exposure would be limited to the cost of program administration, and perhaps some percentage of rebate or discount for measures.

6.6.1.3 Offer Spot-Replacements of Failed Window Measures

Seattle City Light should offer a simple, cost-effective rebate program to help single-family homeowners and multifamily building owners to re-fit high-efficiency windows into openings where individual aluminum or other windows have "failed". Windows fail when seals break or glass cracks, rare-gas fills are lost, moisture enters, and sometimes bacterial or mold colonies develop. The lifetimes of windows retrofit by the Multifamily Conservation Programs are ticking away, after 15 years of program operation (20 years for the single-family programs) as of 2001. About 25-35% of windows will naturally have failed by that time, and the new generation of window products offers superior energy efficiency. New audits may not be necessary, since existing program files contain all relevant measurements and prior cost comparisons. The success of this option depends on access to archived field files for the 1986-1998 programs. A rebate format should ensure a streamlined program within minimal overhead costs.

6.6.1.4 Offer Rehabilitation Services

Seattle City Light should consider, where window sills and openings have deteriorated, how rehabilitation could be incorporated into the regular Standard-Income program to increase the quality of window retrofits, the building stock, and ultimately the satisfaction of building owners. Structural deficiencies often lead to later complaints about drafts and water leakage. The Seattle City Light program should investigate installing foam over old aluminum frame perimeters, as done by the Department of Housing and Human Services program. Whenever pre-existing leakage and stains are observed by program auditors, rehabilitation to faulty or degraded wall construction should be initiated to better address owner concerns. Rehabilitation services facilitated by the City would probably require customer payments directly to contractors, due to legal limitations on "lending of credit" by City conservation programs.

6.6.2 EVALUATE THE REMAINING MARKET POOL FOR MULTIFAMILY RETROFIT PROGRAMS

Seattle City Light and the Seattle Office of Housing should embark on a systematic analysis of the market penetration of existing programs and remaining pools available for program services. At Seattle City Light, this investigation of the multifamily housing market should be coordinated with new revisions to the Load Forecast model. Such analysis would include at least three components.

6.6.2.1 Inventory the Multifamily Market Pool (Existing & New Construction)

Inventory the "population pool" of all existing and new-construction multifamily buildings in the City of Seattle and Seattle City Light's service area. Resources and tools include Seattle City Light's Customer Information System (CIS); the SCL Conservation Tracking System (CTS); and the King County tax assessment database (accessible through MetroScan™ software).

6.6.2.2 Identify Served Buildings

Cross-reference the inventory with records on buildings served by the Multifamily Conservation retrofit programs (SCL standard-income, DHHS low-income, SCL common-area lighting) and the Built Smart / Super Good Cents Programs for multifamily new construction. Resources and tools include program databases (such as SCL's older Rbase tracking system, the new Conservation Tracking Sytem, and

DHHS's former Paradox system); and evaluator files for Standard-Income buildings (1986-1998), Low-Income buildings (1986-1992), Common-Area Lighting buildings (1993-1998), and Super Good Cents/Built Smart new construction projects (1992-1998).

6.6.2.3 Analyze Unserved Buildings

Characterize the remaining unserved market by building features, neighborhood demographics, economic development areas, and likelihood of low-income residency. Also characterize previously served buildings that may become markets for new service offerings. Estimate served and remaining market pools for existing and proposed City programs. Identify buildings for targeted marketing by each of the Multifamily Conservation Programs, including the Common-Area Lighting Program.

6.6.3 MODIFY DATA TRACKING FOR THE MULTIFAMILY RETROFIT PROGRAMS

Seattle City Light and the Seattle Office of Housing should collect pertinent data for projecting energy savings from the current and future programs. At the same time, certain data elements tracked in the past are likely to be unnecessary for future evaluations.

6.6.3.1 Streamline Data Elements on Insulation and Windows

Program records on insulation and window measures should continue to track information necessary to conducting program operations and management. However, it is not necessary for future evaluations to track certain data elements used in engineering projections of energy savings from insulation and window measures. These include pre-existing R-values and square footage of cavity areas in ceilings, walls, and floors, as well as similar data on insulation added by the program. U-values of windows should still be tracked in the aggregate for each building (that is, total glass square footage of each rated U-value, if more than one).

6.6.3.2 Track Data Elements on Measure Mix

The programs should continue to track, both in field files and electronic databases, information on the mix of measures installed in the tenant areas of each building. This may consist of simple flags for ceiling insulation, wall insulation, floor insulation; plus counts of showerhead replacements and faucet aerators installed. *Importantly, this should also include counts of water heater thermostat set-backs, an item which in the past has not been recorded in field files or electronic databases.* Where water heaters appear to be wired to house-meter circuits, building auditors should record this information in field files and electronic databases, to help reconcile findings on building house meters. Window retrofits should be recorded by the square footage affected.

6.6.3.3 Collect Appliance Marketing Data

Building auditors should make note of manufacture dates for existing water heaters, where accessible, for use in future marketing of efficient replacement appliances. This information should appear in the Conservation Tracking System or other electronic databases. A barrier for the programs to overcome is the labor-intensive nature of locating this information.

6.6.3.4 Track Details on Common-Area Lighting

Regarding lighting measures, all Multifamily Programs should continue to keep full records on pre-existing and replacement lighting fixtures. This includes line-by-line counts of existing lamps by location and type, accompanied by wattage and annual average hours of operation, along with counts and wattages of replacements by location and type. Tracking engineering projections for lighting continues to be important for the Multifamily Conservation Programs, as energy savings performance on house meters has not always followed expected patterns and future projections are uncertain.

6.6.3.5 Evaluate Measure Penetration in Low-Income Program

It has been suggested that current (1997-1999) differences in house-meter energy savings between the Low-Income and Standard-Income programs may be affected by a slower adoption by DHHS of LED exit sign measures. There may also have been a differential in the rate of water heater thermostat set-backs during past years. Particularly in the Low-Income Multifamily Program, a future impact evaluation would require the following information on measure penetrations (in electronic database format):

- Tracking of measure mix data elements per project (see Rec. 6.6.3.2);
- Tracking of complete lighting details per project (see Rec. 6.6.3.4); and
- Tracking the temperature differential of water heater thermostat set-backs, as well as the quantity.
- Other desirable information includes the types and cost of concurrent building repairs or rehabilitation.
- Associated costs of all measures should also be collected.

7. References

Geist, Arlene, 1990 RESIDENTIAL CUSTOMER CHARACTERISTICS SURVEY, Finance Division, Seattle City Light, Seattle, Washington, March 1992.

Hickman, Curtis, ENERGY EFFICIENT SHOWERHEAD AND FAUCET AERATOR METERING STUDY: MULTIFAMILY RESIDENCES, by SBW Consulting, Inc., for Bonneville Power Administration, Portland, Oregon, October 1994.

Isaac, Stephen and William B. Michael, HANDBOOK IN RESEARCH AND EVALUATION, Second Edition, EdITS Publishers, San Diego, California, 1981 (pp. 191-193); based on Krejcie, R. V. and D. W. Morgan, "Determining Sample Size for Research Activities," EDUCATIONAL AND PSYCHOLOGICAL MEASUREMENT, Vol. 30, 1970 (pp. 607-610).

McNemar, Quinn, PSYCHOLOGICAL STATISTICS, Fourth Edition, John Wiley and Sons, Inc., New York, New York, 1969.

NFRC CERTIFIED PRODUCTS DIRECTORY, Fifth Edition, National Fenestration Rating Council, Inc., Silver Spring, Maryland, November 1995.

Oates, Jean, Ron Moe, Ric Johnston, and Martha Doyle, "Bonneville Power Administration's Residential Weatherization Program: What are the Real Savings and at What Cost?" in PROCEEDINGS OF THE 1993 INTERNATIONAL ENERGY EVALUATION CONFERENCE, Chicago, Illinois, 1993 (pp. 395-398).

Okumo, Debra Laurent, THE MULTIFAMILY CONSERVATION PROGRAM: EVALUATION OF ELECTRICITY SAVINGS AND COSTS, Evaluation Unit, Energy Management Services Division, Seattle City Light, Seattle, Washington, June 1991.

Parsons, Robert A. (ed.), ASHRAE HANDBOOK: FUNDAMENTALS, I-P (INCH-POUND EDITION), American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, Georgia, 1989.

Ridge, Richard, "Errors in Variables: A Close Encounter of the Third Kind," in PROCEEDINGS OF THE 1997 INTERNATIONAL ENERGY EVALUATION CONFERENCE, Chicago, Illinois, 1997 (pp. 479-487).

Riordan, Michael, "Building Heatloss," ENERGY CONSERVATION (pp. 16-17); adapted in part from Anderson, Bruce with Michael Riordan, THE SOLAR HOME BOOK.

Rizzi, Ennio A., DESIGN AND ESTIMATING FOR HEATING, VENTILATING, AND AIR CONDITIONING, Von Nostrand Reinhold, New York, New York, 1980.

Tachibana, Debra-L. O. (Ed.) et al., ENERGY CONSERVATION ACCOMPLISHMENTS: 1977-1997, Evaluation Unit, Energy Management Services Division, Seattle City Light, Seattle, Washington, July 1998 (pp. II:40-41).

Tachibana, Debra-L. O., MULTIFAMILY RETROFIT CONSERVATION PROGRAMS: CUSTOMER SERVICE MEASURES, Evaluation Unit, Energy Management Services Division, Seattle City Light, Seattle, Washington, July 1998.