First-Year Load Impacts of Southern California Gas Company's 1994 Energy Advantage Home Program

Study No. 709

Submitted to:

The Gas Company
555 West Fifth Street
Los Angeles, California 90013

Submitted by:

Regional Economic Research, Inc.
12520 High Bluff Drive, Suite 220
San Diego, California 92130
(619) 481-0081

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Executive Summary

Overview

This is an Executive Summary of an evaluation of the impacts of Southern California Gas Company's (The Gas Company's) 1994 Energy Advantage Home Program (EAHP). Regional Economic Research, Inc. (RER) conducted this study under contract to The Gas Company. Four subcontractors supported RER: Mr. Ken Parris provided data development support, VIEWtech, Inc. conducted an on-site survey to support the analysis, Taylor Research completed a telephone survey of builders, and Mr. Robert Mowris, P.E., provided engineering support. Ms. Melissa Cuaycong acted as project manager for The Gas Company. In addition, Mr. Ken Parris acted as a liaison between Ms. Cuaycong and RER project staff for all data requests dealing with EAH Program records, Gas Company billing files and collection of weather data.

The remainder of this Executive Summary presents the results of the evaluation, describes the program, outlines the study objectives, discusses a set of evaluation issues, describes the data, and summarizes the overall methodology.

Preview of Results

Table ES-1 summarizes the results of our analysis by measure and end use. The table presents per unit ex ante and ex post estimated gross savings, net-to-gross ratios, the proportion of ex post to ex ante gross savings estimates, confidence intervals for estimated gross savings, the ex post measure count, and the ex post net savings estimated in this analysis. Note that our estimates are based on a total of 8,525 participants. This estimate is somewhat lower than the estimate underlying The Gas Company's ex ante estimates, primarily because of the use of a more stringent means of allocating participants to the 1994 program year. Note also that the impacts of low-saturation measures not covered by our realization rate analysis have been set equal to the values reported in The Gas Company's first-year earnings claim. This simplification has little bearing on the overall estimate of savings, insofar as these measures account for a very low fraction of savings. Four major conclusions arise from this summary:

Table ES-1: Net Program Savings

Measure	Per Unit Savings: Ex Ante Gross	Per Unit Savings: Ex Post Gross Realized	Per Unit Savings: Ex Post Net Realized	Net-to-Gross Ratio	Ex Post Gross % of Ex Ante Gross	90% Conf. Interval (Ex Post Gross)	80% Conf. Interval (Ex Post Gross)	Ex Post Measure Count	Total Gross Program Savings[a]	Ex Post Net Program Impacts
Non-Fuel Substitution Measures										
Duct Testing	22.0	11.80	11.80	1.0	53.0	10.4 - 13.2	10.7 - 12.9	6,146[b]	72,523	72,523
Furnace (88% AFUE)	29.0	41.07	41.07	1.0	141.6	36.2 - 45.9	37.3 - 44.9	1,472	60,456	60,456
Water Heater (.60 - .69 EF)	14.0	20.90	7.52	0.36	149.3	9.4- 52.4	14.1 - 47.7	1,568	210	11,798
Water Heater (.70 EF)	30.0	30.00[a]	10.80	0.36	100.0	9.1 - 50.9	13.7 - 46.3	7[b]	32,771	76
Combination System (.58 EF)	23.0	25.65	25.65	1.0	102.8	22.6 - 28.7	23.3 - 28.0	1,173	30,088	30,088
Duct Insulation	5.0	1.13	1.13	1.0	22.6	1.0 - 1.3	1.0 - 1.2	2	2	2
Heat Traps	10.0	1.40	0.50	0.36	11.4	1.2 - 1.6	1.3 - 1.5	146	204	73
Recirculating Controls	405.0	405.00[a]	405.00	1.0	100.0	122.7 - 687.3	185.0 - 625.0	1[b]	414	414
MH Water Heaters (.60 EF)	21.0	21.00[a]	21.00	1.0	100.0	6.4 - 35.6	19.1 - 22.3	0[b]	0	0
MH Furnace (80 - 87% AFUE)	14.0	14.00[a]	14.00	1.0	100.0	12.3 - 15.7	12.7 - 15.3	34[b]	476	476
MH Furnace (88%+ AFUE)	37.0	37.00[a]	37.00	1.0	100.0	23.6 - 41.4	33.6 - 40.4	0[b]	0	0
Non-Fuel Substitution Measures Subtotal								1,356	197,45	175,906
Fuel Substitution Measures										
Furnaces	-147.0	-133.68[a]	-133.68	1.0	90.9	-117.8 - 149.5	-121.3 - 146.0	68[b]	-9,094	-9,094
Gas Ovens	-19.0	-15.57	-7.79	0.50	81.9	-13.7 - 17.4	-14.1 - 17.0	1,534	-23,884	-11,942
Fuel Substitution Measures Subtotal									-32,978	-21,036
All Measures	-	-	-	0.94	-	123,256 - 205,077	132,355 - 195,999	12,151	164,167	154,870

a The Gas Company ex ante estimates of gross realized savings per measure. Realized savings could not be estimated ex post because the no sample sites installed this measure.
b Measure counts based on program records.

- First, according to our analysis, total gross program savings for the 1994 program amount to over 164,000 therms. Gross savings from non-fuel substitution measures are over 197,000 therms, while fuel substitution is estimated to increase gas usage by almost 33,000 therms. This compares with The Gas Company's *ex ante* estimate of 212,597 therms overall, 251,644 therms for non-fuel substitution and 39,047 therms for fuel substitution.
- Net program savings are almost 155,000 therms. Net savings associated with non-fuel substitution measures are estimated to be just under 176,000. The net increase in gas consumption stimulated by fuel substitution is slightly over 21,000 therms.
- In order to construct confidence intervals for gross savings, the efficiency model was re-estimated combining all savings terms weighted by their respective coefficient into a single composite term. The *t-value* on this term was used to construct confidence intervals for gross savings. This results in a 90% confidence interval of 132,256 to 205,077 Therms and an 80% confidence interval of 132,335 to 195,999 Therms.
- Insofar as net-to-gross ratios are estimated by end-use, confidence intervals were constructed for water heating and space heating measures and then summed. This results in a 90% confidence interval on net savings of 126,871 to 182,869 Therms and an 80% confidence interval of 133,050 to 176,690 Therms for all DSM measures.

Program Description

The EAHP is designed to induce builders to increase energy efficiency in new homes beyond the levels required by Titles 20 and 24. The program offers informational and training workshops for builders, and provides incentives for the following efficiency actions:

- Installation of high-efficiency gas space heating and water heating equipment, heat traps and duct insulation,
- Builder duct testing, and
- Installation of gas space heating and ovens as alternative to electric options.

The evaluation of EAHP recognizes the relative importance of these general program offerings and their specific elements. Table ES-2 presents an overview of the expected savings from specific measures based on installation records and The Gas Company's initial *ex ante* estimates of natural gas savings.

Table ES-2: Overview of Program Ex Ante Savings

Program Measure	Number Installed	Per Unit Savings	Total Annual Savings (therms)
Installation Measures			
Duct Testing	7,159	22	157,498
Furnace (88% AFUE)	1,512	29	43,848
Water Heater (.60-.69 EF)	1,608	14	22,512
Water Heater (.70 EF)	7	30	210
Combination System (.58 EF)	1,095	23	25,185
Duct Insulation	10	5	50
Heat Traps	146	10	1,460
Recirculating Controls	1	405	405
MH Water Heaters (.60 EF)	0	21	0
MH Furnace (80-87% AFUE)	34	14	476
MH Furnace (88+% AFUE)	0	37	0
All Installation Measures	**11,572**	-	**251,644**
Fuel Substitution Measures			
Furnaces	68	-147	9,996
Gas Ovens	1,529	-19	29,051
All Fuel Substitution Measures	**1,597**		**39,047**
All Measures	**13,169**		**212,597**

As shown in Table ES-2, The Gas Company's ex ante estimate of savings from DSM measures exceeds 250,000 therms annually. The largest single impact from DSM measures is expected to come from the results of duct testing. High-efficiency gas furnaces, water heaters and combined systems are also projected to yield significant savings. Other DSM measures are expected to generate relatively small savings. All three manufactured home measures, taken together, are expected to account for less than 0.2% of total program savings.

As shown by the *ex ante* estimates in Table ES-2, the direct impact of fuel substitution is projected to amount to just over 39,000 therms. Gas ovens are expected to account for most of the impacts of fuel substitution. Fuel substitution measures cause a direct increase in the consumption of natural gas, but also cause electricity savings. This study focused on the analysis of the direct gas impacts.

The program structure had several implications for the evaluation:

- First, this analysis focused considerable attention on duct testing, given that this measure accounts for over half of the total expected program direct gas savings.
- Second, relatively little emphasis was placed on the manufactured home measures. No estimates of high-efficiency water heaters or 88+% AFUE furnaces were possible due to the lack of installations of these measures.
- Third, recirculating controls, which affect central systems, merited modest attention insofar as only one such control was installed during 1994.
- Fourth, the sample design ensured an adequate number of homes with each of the major DSM measures.

Study Objectives

The primary purpose of the project was to estimate the gross and net *ex post* savings associated with the 1994 EAHP. The associated specific objectives included the following:

- To develop a comprehensive database reflecting the role of the program in the new construction market,
- To analyze the gross impacts of program and non-program measures on participants' natural gas consumption,
- To assess the net impact of the program on participants' installations of both program and non-program measures, and
- To estimate the overall gross and net impacts of the program on gas consumption.

General Evaluation Issues

Any new construction impact evaluation method must deal with a variety of conceptual and practical issues, including the breadth and interdependence of DSM options, the definition of energy efficiency, the meanings of gross *ex ante*, gross *ex post*, and net program impacts, the difficulties of estimating gross realized savings, and problems complicating the definition and estimation of net savings. These issues are discussed below.

Breadth and Interdependence of DSM Options

New construction programs are multidimensional, covering multiple end uses and a variety of DSM equipment options and measures. Choices may also be interdependent, in the sense that the choices of some measures may affect the evaluation of others. This interdependence can be linked to budgetary or design issues; however, it can also stem from performance-based paths of code compliance (e.g., energy budgets), which permit substitution of efficiency within and across end uses. One implication of this interdependence is that it is necessary to take a comprehensive view of efficiency choices, rather than focusing exclusively on the most directly affected measures or end uses. Our realized savings and net-to-gross analyses are designed to recognize this need. Specifically, it was deemed necessary to direct the analysis to both program and non-program measures. Thus, the analysis covered shell measures (insulation and window treatments) and water heater blankets, even though they were not incented by the program.

Defining Energy Efficiency

A portion of the evaluation of any DSM program focuses on the different choices of energy efficiency made by participants and nonparticipants. Defining energy efficiency for participants and nonparticipants requires reference points. In this study, energy efficiency was measured relative to compliance with building and appliance efficiency. This does not mean that standards comprise the overall baseline for the evaluation; they merely comprise convenient intermediate baselines for the gross savings analysis. However, even the definition of code compliance becomes ambiguous when performance-based compliance paths can be utilized. For the purposes of this evaluation, we used the prescriptive standards imposed by Titles 20 and 24 as reference points, defining DSM activity as the extent to which builders exceeded these standards.

Defining Gross Ex Ante, Gross Ex Post, and Net Program Impacts

The CPUC Protocols refer to gross and net impacts and comment on *ex ante* and *ex post* estimates of savings. We suggest that some confusion can be avoided if we adopt clear definitions of three concepts: gross *ex ante* impacts, gross *ex post* impacts, and net impacts. In the remainder of this proposal, we use these terms in the following ways:

- ***Gross ex ante impacts*** are those expected on the basis of prior assumptions on the behavior of direct program participants. The gross *ex ante* savings estimates referenced in this study are those submitted by The Gas Company in its first-year earnings claim. These program *ex ante* estimates are restricted to measures adopted through the program.
- ***Gross ex post impacts*** are those estimated after the fact on the basis of actual observations on the behavior of direct program participants. They are *ex post* in the sense that they have somehow been "verified" after the fact. We will sometimes refer to them as *gross realized* savings. As will be seen, we develop estimates of gross realized savings through the use of a realization rate analysis, which involves both engineering and statistical analyses. For measures covered by the program, these realized savings estimates may differ from the gross *ex ante* estimates because of the violation of assumptions underlying the *ex ante* estimates. One form of violation could be characterized as rebound, or snapback, which may

be significant in the residential sector. Like *ex ante* estimates, gross *ex post* program impacts can be derived explicitly for measures adopted through the program. However, we also need to estimate realized savings stemming from other DSM activities conducted by both participants and nonparticipants, because these estimates are necessary for the net-to-gross analysis.

- ***Net impacts*** are those actually attributable to the program. They can differ from gross realized (*ex post*) savings because of free ridership and free drivership. In this context, free ridership indicates that some of the measures adopted through the program would have been adopted in the absence of the program. Free drivership can take two forms. Participant free drivership would be conveyed through the adoption of measures by participants (in participating buildings) outside the program. Nonparticipant free drivership is evident through the program's influence on measure adoptions for nonparticipating homes. Participant free drivership can be positive or negative. On one hand, participating in a program raises awareness of efficiency options in general, and could induce adoptions of non-incentivized measures. However, there could be a perverse form of participant free drivership operating through the trade-offs available through performance-based code compliance. For instance, a builder receiving incentives for enhanced furnace efficiency may choose to reduce shell efficiencies below what would have been chosen otherwise. Nonparticipant free drivership may be significant for new construction programs because developers participating in the program for one development may install some or all of the measures in other nonparticipating developments. Throughout the remainder of this report, net impacts will be defined to include the effects of both free ridership and both types of free drivership.

Difficulties in Estimating Gross Ex Post (Realized) Savings

In evaluating new construction programs, we cannot rely on pre- and post-installation comparisons of energy bills. Instead, we focus on differences in consumption across homes with different stocks of DSM measures (different levels of energy efficiency). This enables us to control for a wide range of factors affecting differences in energy use levels *across* buildings. If estimates of impacts are to be derived at the measure level, it also requires the use of a model that is capable of disentangling the individual effects of these measures. This demands a very highly structured estimation approach. For this evaluation, we used a form of statistically adjusted engineering approach called a realization rate model. RER has tailored the model precisely to the analysis of new construction programs, and has applied it successfully to programs operated by several utilities.

Difficulties in Operationalizing and Estimating Net Savings

Defining the baseline against which *net* program impacts are measured is conceptually straightforward but operationally difficult. There are two major issues in doing so:

- First, it is necessary to focus on the decision-maker. While the gross savings analysis relates to the behavior of occupants of participating and nonparticipating homes, the net-to-gross analysis should focus on the behavior of builders to the extent possible. Except in the case of custom building, builders determine whether or not participation will occur, as well as which specific DSM measures will be installed and which fuel choices will be made. In light of this, we found it necessary to gather information from participating and nonparticipating builders through a telephone survey.
- Second, it is necessary to establish a baseline for net impacts. The true baseline is the measures that participants (participating builders) would have implemented in the absence of the program. However, this is not directly observable. As a result, evaluators sometimes use nonparticipant behavior as a proxy. The use of nonparticipants as a comparison group, however, can result in significant bias in the estimation of net program effects. Some means of mitigating self-selection bias—as well as controlling for other differences between participants and nonparticipants—must be developed if net program savings are to be estimated. This entails the specification of a model of behavior covering both adoption decisions and participation decisions.

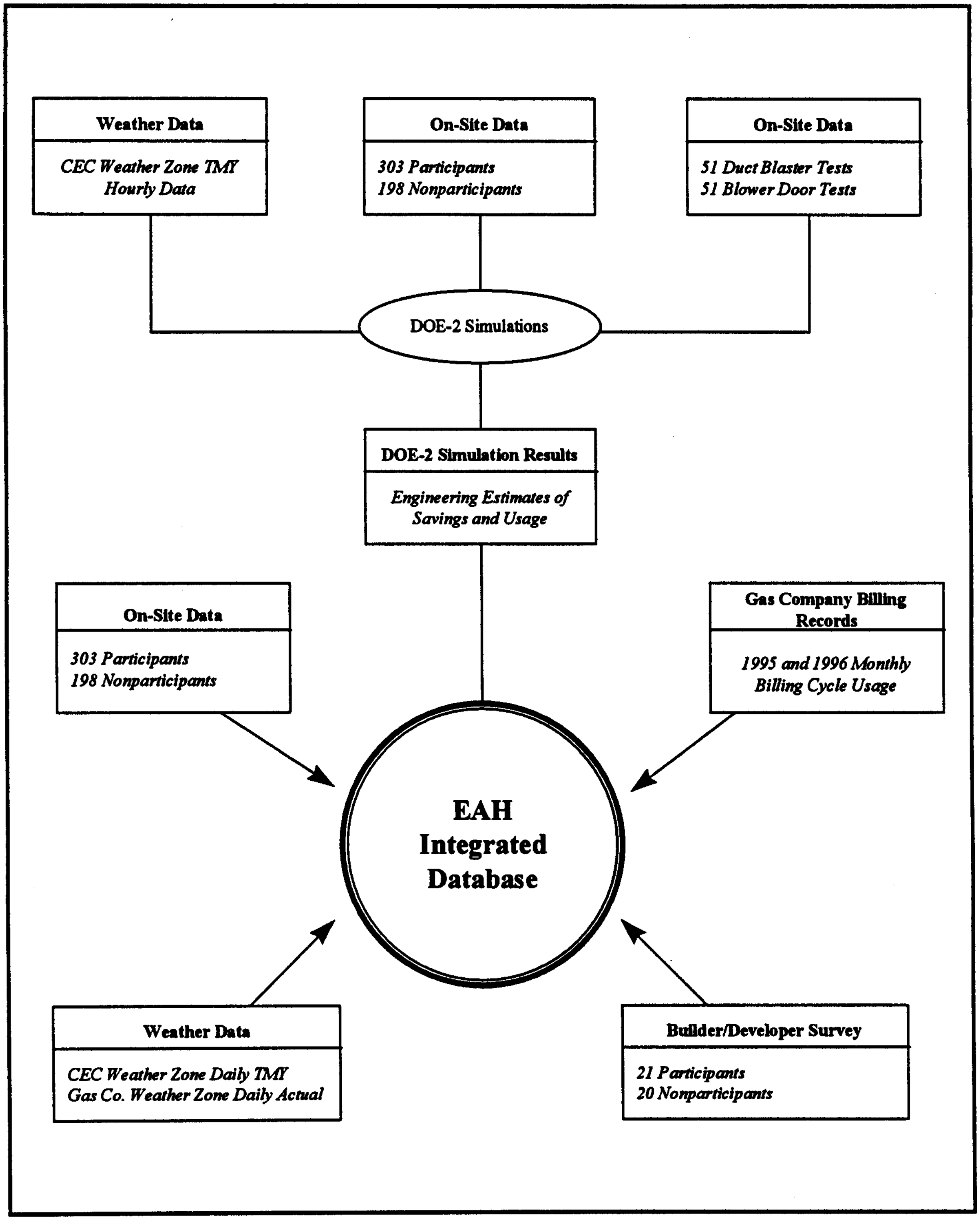
Data

RER constructed an integrated database for use in the evaluation. An overview of the database is presented in Figure ES-1. The database contains seven major components:

- On-site survey of participating and nonparticipating homes,
- Duct blaster and blower door tests,
- DOE-2 building simulations,
- Hourly weather information by California Energy Commission (CEC) weather zone,
- Daily weather information by Gas Company weather zone,
- Household gas consumption records, and
- Telephone survey data of participating and nonparticipating builders and developers.

It should be noted that the data collected from the on-site survey and CEC weather data are used to construct the database for the DOE-2 simulations and for the final integrated database used in the billing analysis.

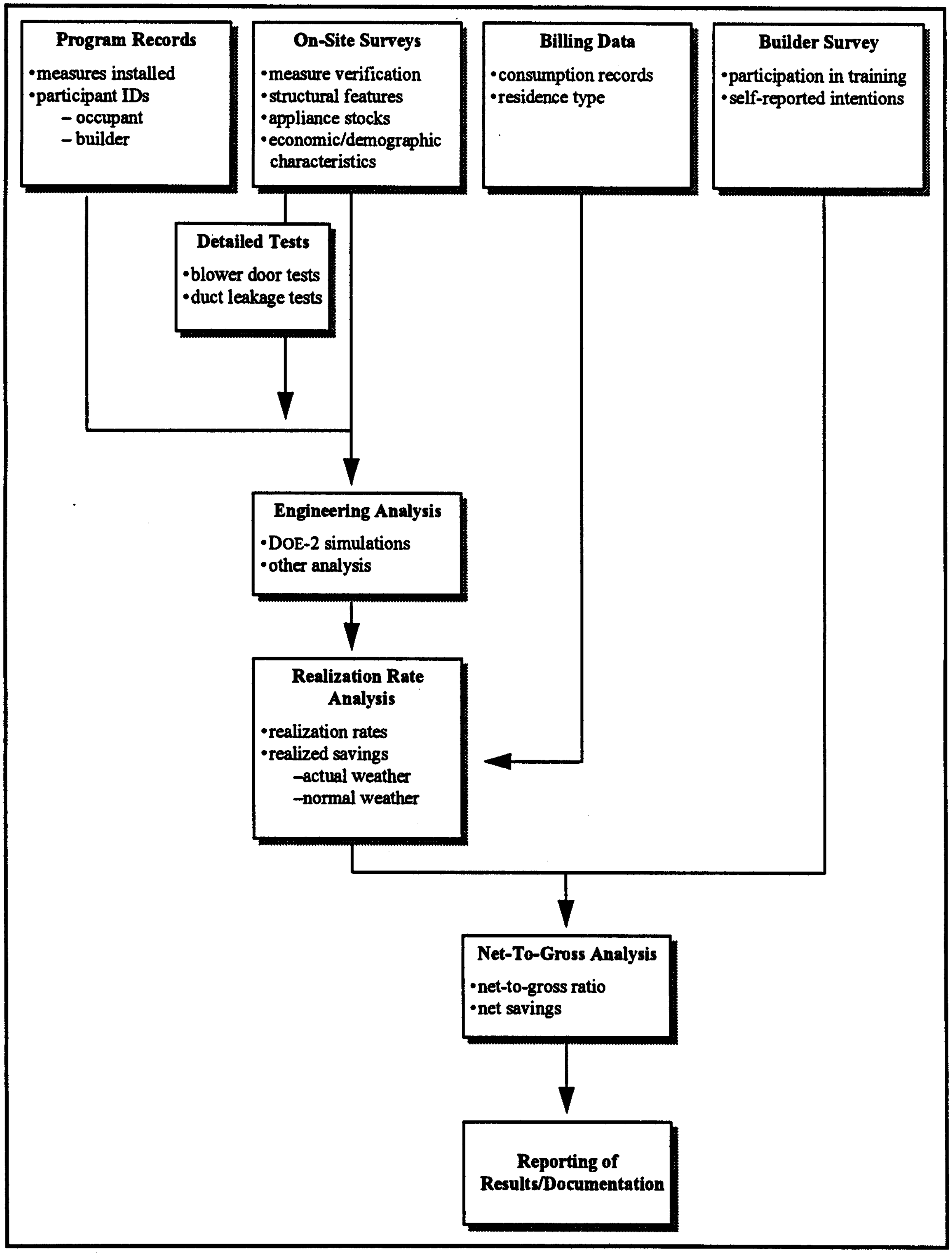
Figure ES-1: Overview of The Gas Company EAHP Evaluation Integrated Database



Overview of Approach

Figure ES-2 provides an overview of the evaluation approach. As shown, the analysis utilized four types of data: program records, on-site survey data, billing and weather records, and builder survey data. The first two data elements were used in the course of the engineering analysis, which entailed DOE-2 simulation analysis of space heating measure impacts, as well as engineering analysis of impacts on non-weather sensitive end-uses (ovens and water heating). The results of the engineering analysis were used, along with billing records, in the realization rate analysis. This analysis yielded estimates of realization rates for each measure, as well as estimates of gross realized savings at the measure level. The net-to-gross analysis utilized the results of the builder survey and the realization rate analysis. The net-to-gross analysis took two forms: a statistical analysis of differential efficiency levels in homes built by participating and nonparticipating builders, and the development of self-reported free ridership and free drivership, as derived from the builder survey.

Figure ES-2: Overview of Approach



1

Introduction

1.1 Overview

This report presents an evaluation of the impacts of Southern California Gas Company's (The Gas Company's) 1994 Energy Advantage Home Program (EAHP). Regional Economic Research, Inc. (RER) conducted this study under contract to The Gas Company. Four subcontractors supported RER: Mr. Ken Parris provided data development support, VIEWtech, Inc. conducted an on-site survey to support the analysis, Taylor Research completed a telephone survey of builders, and Mr. Robert Mowris, P.E., provided engineering support. Ms. Melissa Cuaycong acted as project manager for The Gas Company. In addition, Mr. Ken Parris acted as a liaison between Ms. Cuaycong and RER project staff for all data requests dealing with EAH Program records, Gas Company billing files and collection of weather data.

The remainder of this section describes the program, defines study objectives, discusses a set of evaluation issues, discusses data, summarizes the overall methodology and the results of the evaluation, and previews the remainder of the report.

1.2 Preview of Results

Table 1-1 summarizes the results of our analysis by measure and end use. The table presents realized savings per measure, the proportion of participants incented to install the measure, total gross realized savings, percentage of incented measures, total gross program savings, net-to-gross ratios, and estimated net program savings. Note that our estimates are based on a total of 8,525 participants. This estimate is somewhat lower than the estimate underlying The Gas Company's ex ante estimates, primarily because of the use of a more stringent means of allocating participants to the 1994 program year. Note also that the impacts of low-saturation measures not covered by our realization rate analysis have been set equal to the values reported in The Gas Company's first-year earnings claim. This simplification has little bearing on the overall estimate of savings, insofar as these measures account for a very low fraction of savings. Two major conclusions arise from this summary:

- First, according to our analysis, total gross program savings for the 1994 program amount to over 164,000 therms. Gross savings from non-fuel substitution measures are over 197,000 therms, while fuel substitution is estimated to increase gas usage by almost 33,000 therms. This compares with The Gas Company's *ex ante* estimate of 212,597 therms overall, 251,644 therms for non-fuel substitution and 39,047 therms for fuel substitution.
- Net program savings are almost 155,000 therms. Net savings associated with non-fuel substitution measures are estimated to be just under 176,000. The net increase in gas consumption stimulated by fuel substitution is slightly over 21,000 therms.
- In order to construct confidence intervals for gross savings, the model was re-estimated combining all savings terms weighted by their respective coefficient into a single composite term. The *t-value* on this term was used to construct confidence intervals for gross savings. This results in a 90% confidence interval of 132,256 to 205,077 Therms and an 80% confidence interval of 132,335 to 195,999 Therms.
- Confidence intervals for net savings were based on Version 1 for space heating and Version 1 for water heating of the efficiency choice model presented in Table 5-4. Insofar as net-to-gross ratios are estimated by end-use, confidence intervals were constructed for water heating and space heating measures and then summed. This results in a 90% confidence interval on net savings of 126,871 to 182,869 Therms and an 80% confidence interval of 133,050 to 176,690 Therms for all DSM measures.

Table 1-1: Summary of Estimated Net Program Savings

Program Measures	Gross Realized Savings per Measure	Percent Incented	Total Gross Program Savings[c]	Net-to-Gross Ratio	Total Net Program Savings
Installation Measures					
HE Furnaces (88+% AFUE)	41.07	0.17267	60,456	1.00	60,456
Duct Testing	11.80	0.72094[a]	72,523	1.00	72,523
Duct Insulation	1.13	0.00023	2	1.00	2
Combined Hydronic Systems	25.65	0.13760	30,088	1.00	30,088
HE Water Heaters(.70+ EF)	30.00[b]	0.00082[a]	210	0.36	76
HE Water Heaters(.60-.69 EF)	20.90	0.18393	32,771	0.36	11,798
Heat Traps	1.40	0.01713	204	0.36	73
Recirculation Controls	405.00[b]	0.00012[a]	414	1.00	414
MH Water Heaters (.60 EF)	21.00[b]	0.00000[a]	0	1.00	0
MH Furnace (80-87% AFUE)	14.00[b]	0.00399[a]	476	1.00	476
MH Furnace (88+% AFUE)	37.00[b]	0.00000[a]	0	1.00	0
All Installation Measures			**197,145**		**175,906**
Fuel Substitution Measures					
MF Gas Furnaces (78% AFUE)	-133.68	0.00798[a]	-9,094	1.00	-9,094
Gas Ovens	-15.57	0.17994[a]	-23,884	0.50	-11,942
All Fuel Substitution Measures			**-32,978**		**-21,036**
All Measures			**164,167**		**154,870**

a Installation rates are based upon program records. Installation rate equals the number of measures installed from program records divided by the total number of participating homes (8,525).
b The Gas Company ex ante estimates of gross realized savings per measure. Realized savings could not be estimated ex post because the no sample sites installed this measure.
c Total gross program impacts = the product of gross realized savings per measure and ex post measure count.

1.3 Program Description

The EAHP is designed to induce builders to increase energy efficiency in new homes beyond the levels required by Titles 20 and 24. The program offers informational and training workshops for builders, and provides incentives for the following efficiency actions:

- Installation of high-efficiency gas space heating and water heating equipment, heat traps and duct insulation,
- Builder duct testing, and

- Installation of gas space heating and ovens as alternative to electric options.

The evaluation of EAHP recognizes the relative importance of these general program offerings and their specific elements. Table 1-2 presents an overview of expected savings from specific measures based on installation records and The Gas Company's initial *ex ante* estimates of natural gas savings.

Table 1-2: Overview of Program Ex Ante Gross Savings

Program Measure	Number Installed	Per Unit Savings	Total Annual Savings (therms)
Installation Measures			
Duct Testing	7,159	22	157,498
Furnace (88% AFUE)	1,512	29	43,848
Water Heater (.60-.69 EF)	1,608	14	22,512
Water Heater (.70 EF)	7	30	210
Combination System (.58 EF)	1,095	23	25,185
Duct Insulation	10	5	50
Heat Traps	146	10	1,460
Recirculating Controls	1	405	405
MH Water Heaters (.60 EF)	0	21	0
MH Furnace (80-87% AFUE)	34	14	476
MH Furnace (88+% AFUE)	0	37	0
All Installation Measures	**11,572**	-	**251,644**
Fuel Substitution Measures			
Furnaces	68	-147	9,996
Gas Ovens	1,529	-19	29,051
All Fuel Substitution Measures	**1,597**		**39,047**
All Measures	**13,169**		**212,597**

As shown in Table 1-2, The Gas Company's ex ante estimate of savings from DSM measures exceeds 250,000 therms annually. The largest single impact from DSM measures is expected to come from the results of duct testing. High efficiency gas furnaces, water heaters and combined systems are also projected to yield significant savings. Other DSM measures are expected to generate relatively small savings. All three manufactured home measures, taken together, are expected to account for less than 0.2% of total program savings.

As shown by the *ex ante* estimates in Table 1-2, the direct impact of fuel substitution is projected to amount to just over 39,000 therms. Gas ovens are expected to account for most of the impacts of fuel substitution. Fuel substitution measures cause a direct increase in the consumption of natural gas, but also cause electricity savings. This study focused on the analysis of the direct gas impacts.

The program structure had several implications for the evaluation:

- First, this analysis focused considerably on duct testing, given that this measure accounts for over half of the total expected program direct gas savings.
- Second, relatively little emphasis was placed on the manufactured home measures. No estimates of high-efficiency water heaters or 88+% AFUE furnaces were possible due to the lack of installations of these measures.
- Third, recirculating controls, which affect central systems, merited modest attention insofar as only one such control was installed during 1994.
- Fourth, the sample design ensured an adequate number of homes with each of the major DSM measures.

1.4 Study Objectives

The primary purpose of the project was to estimate the gross and net *ex post* savings associated with the 1994 EAHP. The associated specific objectives included the following:

- To develop a comprehensive database reflecting the role of the program in the new construction market,
- To analyze the gross impacts of program and non-program measures on participants' natural gas consumption,
- To assess the net impact of the program on participants' installations of both program and non-program measures, and
- To estimate the overall gross and net impacts of the program on gas consumption.

1.5 General Evaluation Issues

Any new construction impact evaluation method must deal with a variety of conceptual and practical issues, including the breadth and interdependence of DSM options, the definition of energy efficiency, the meanings of gross *ex ante*, gross *ex post*, and net program impacts, the difficulties of estimating gross realized savings, and problems complicating the definition and estimation of net savings. These issues are discussed below.

Breadth and Interdependence of DSM Options

New construction programs are multidimensional, covering multiple end uses and a variety of DSM equipment options and measures. Choices may also be interdependent, in the sense that the choices of some measures may affect the evaluation of others. This interdependence can be linked to budgetary or design issues; however, it can also stem from performance-based paths of code compliance (e.g., energy budgets), which permit substitution of efficiency within and across end uses. One implication of this interdependence is that it is necessary to take a comprehensive view of efficiency choices, rather than focusing exclusively on the most directly affected measures or end uses. Our realized savings and net-to-gross analyses are designed to recognize this need. Specifically, it was deemed necessary to direct the analysis to both program and non-program measures. Thus, the analysis covered shell measures (insulation and window treatments) and water heater blankets, even though they were not incented by the program.

Defining Energy Efficiency

A portion of the evaluation of any DSM program focuses on the different choices of energy efficiency made by participants and nonparticipants. Defining energy efficiency for participants and nonparticipants requires reference points. In this study, energy efficiency was measured relative to compliance with building and appliance efficiency. This does not mean that standards comprise the overall baseline for the evaluation; they merely comprise convenient intermediate baselines for the gross savings analysis. However, even the definition of code compliance becomes ambiguous when performance-based compliance paths can be utilized. For the purposes of this evaluation, we used the prescriptive standards imposed by Titles 20 and 24 as reference points, defining DSM activity as the extent to which builders exceeded these standards.

Defining Gross Ex Ante, Gross Ex Post, and Net Program Impacts

The CPUC Protocols refer to gross and net impacts and comment on *ex ante* and *ex post* estimates of savings. We suggest that some confusion can be avoided if we adopt clear definitions of three concepts: gross *ex ante* impacts, gross *ex post* impacts, and net impacts. In the remainder of this proposal, we use these terms in the following ways:

- ***Gross ex ante impacts*** are those expected on the basis of prior assumptions on the behavior of direct program participants. The gross *ex ante* savings estimates referenced in this study are those submitted by The Gas Company in its first-year earnings claim. These program *ex ante* estimates are restricted to measures adopted through the program.
- ***Gross ex post impacts*** are those estimated after the fact on the basis of actual observations on the behavior of direct program participants. They are *ex post* in

the sense that they have somehow been "verified" after the fact. We will sometimes refer to them as *gross realized* savings. As will be seen, we develop estimates of gross realized savings through the use of a realization rate analysis, which involves both engineering and statistical analyses. For measures covered by the program, these realized savings estimates may differ from the gross *ex ante* estimates because of the violation of assumptions underlying the *ex ante* estimates. One form of violation could be characterized as rebound, or snapback, which may be significant in the residential sector. Like *ex ante* estimates, gross *ex post* program impacts can be derived explicitly for measures adopted through the program. However, we also need to estimate realized savings stemming from other DSM activities conducted by both participants and nonparticipants, because these estimates are necessary for the net-to-gross analysis.

- ***Net impacts*** are those actually attributable to the program. They can differ from gross realized (*ex post*) savings because of free ridership and free drivership. In this context, free ridership indicates that some of the measures adopted through the program would have been adopted in the absence of the program. Free drivership can take two forms. Participant free drivership would be conveyed through the adoption of measures by participants (in participating buildings) outside the program. Nonparticipant free drivership is evident through the program's influence on measure adoptions for nonparticipating homes. Participant free drivership can be positive or negative. On one hand, participating in a program raises awareness of efficiency options in general, and could induce adoptions of non-incentivized measures. However, there could be a perverse form of participant free drivership operating through the trade-offs available through performance-based code compliance. For instance, a builder receiving incentives for enhanced furnace efficiency may choose to reduce shell efficiencies below what would have been chosen otherwise. Nonparticipant free drivership may be significant for new construction programs because developers participating in the program for one development may install some or all of the measures in other nonparticipating developments. Throughout the remainder of this report, net impacts will be defined to include the effects of both free ridership and both types of free drivership.

Difficulties in Estimating Gross Ex Post (Realized) Savings

In evaluating new construction programs, we cannot rely on pre- and post-installation comparisons of energy bills. Instead, we focus on differences in consumption across homes with different stocks of DSM measures (different levels of energy efficiency). This enables us to control for a wide range of factors affecting differences in energy use levels *across* buildings. If estimates of impacts are to be derived at the measure level, it also requires the use of a model that is capable of disentangling the individual effects of these measures. This demands a very highly structured estimation approach. For this evaluation, we used a form of statistically adjusted engineering approach called a realization rate model. RER has tailored the model precisely to the analysis of new construction programs, and has applied it successfully to programs operated by several utilities.

Difficulties in Operationalizing and Estimating Net Savings

Defining the baseline against which *net* program impacts are measured is conceptually straightforward but operationally difficult. There are two major issues in doing so:

- First, it is necessary to focus on the decision-maker. While the gross savings analysis relates to the behavior of occupants of participating and nonparticipating homes, the net-to-gross analysis should focus on the behavior of builders to the extent possible. Except in the case of custom building, builders determine whether or not participation will occur, as well as which specific DSM measures will be installed and which fuel choices will be made. In light of this, we found it necessary to gather information from participating and nonparticipating builders through a telephone survey.
- Second, it is necessary to establish a baseline for net impacts. The true baseline is the measures that participants (participating builders) would have implemented in the absence of the program, but this is not directly observable. As a result, evaluators sometimes use nonparticipant behavior as a proxy. The use of nonparticipants as a comparison group, however, can result in significant bias in the estimation of net program effects. Some means of mitigating self-selection bias—as well as controlling for other differences between participants and nonparticipants—must be developed if net program savings are to be estimated. This entails the specification of a model of behavior covering both adoption decisions and participation decisions.

1.6 Data

RER constructed an integrated database for use in the evaluation. The database contains seven major components:

- On-site survey of 303 participating and 198 nonparticipating homes,
- Duct blaster and blower door tests for 20 participating and 31 nonparticipating homes,
- DOE-2 building simulations for 501 homes,
- Hourly weather information by California Energy Commission (CEC) weather zone,
- Daily weather information by Gas Company weather zone,
- Household gas consumption records, and

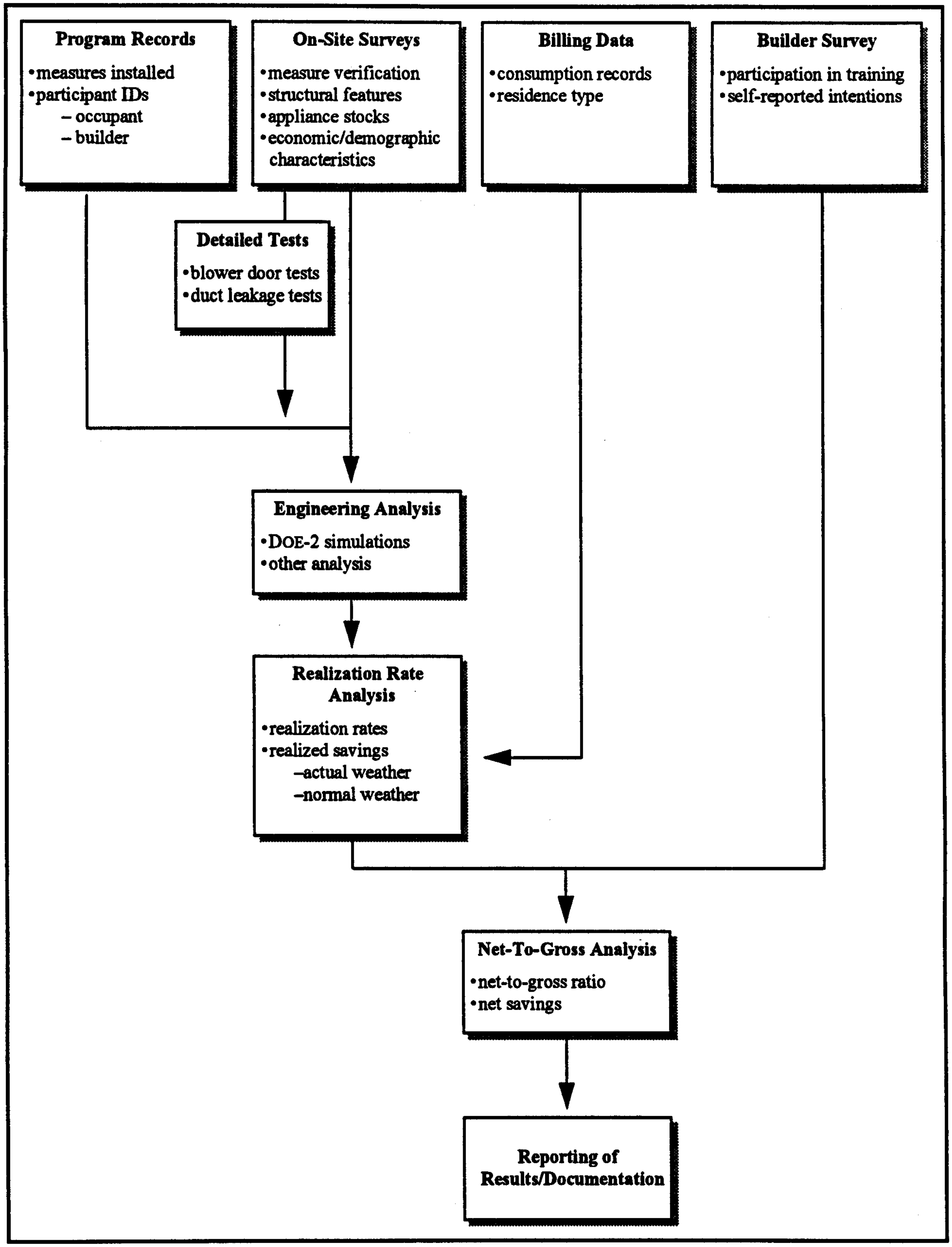
- Telephone survey data from 21 participating and 21 nonparticipating builders and developers.

It should be noted that the data collected from the on-site survey and CEC weather data are used to construct the database for the DOE-2 simulations and for the final integrated database used in the billing analysis.

1.7 Overview of Approach

Figure 1-1 provides an overview of the evaluation approach. As shown, the analysis utilized four kinds of data: program records, on-site survey data, billing and weather records, and builder survey data. The first two data elements were used in the course of the engineering analysis, which entailed DOE-2 simulation analysis of space heating measure impacts, as well as engineering analysis of impacts on non-weather sensitive end-uses (ovens and water heating). The results of the engineering analysis were used, along with billing records, in the realization rate analysis. This analysis yielded estimates of realization rates for each measure, as well as estimates of gross realized savings at the measure level. The net-to-gross analysis utilized the results of the builder survey and the realization rate analysis. The net-to-gross analysis took two forms: a statistical analysis of differential efficiency levels in homes built by participating and nonparticipating builders, and the development of self-reported free ridership and free drivership, as derived from the builder survey.

Figure 1-1: Overview of Approach



1.8 Organization of Report

The remainder of this proposal is organized as follows:

- Section 2 summarizes the development of the databases used in the building simulations and billing analysis,
- Section 3 discusses the use of building simulations and other engineering algorithms to develop engineering estimates of savings for program and non-program measures installed in participating and nonparticipating homes,
- Section 4 explains the use of a realization rate approach to estimate the gross realized savings associated with program and non-program measures,
- Section 5 discusses the estimation of net program impacts, and
- Appendix A presents the On-Site Survey Questionnaire.
- Appendix B contains copies of the pre- and post-survey letters.
- Appendix C presents the Blower Door/Duct Blaster Survey Instrument.
- Appendix D contains Blower Door/Duct Blaster Survey protocol.
- Appendix E contains the builder and developer survey instruments.
- Appendix F contains CPUC Protocols Table 6 and Table 7.

2

Data

2.1 Overview

This section discusses the development of the databases used in the evaluation of the 1994 Southern California Gas Company's (The Gas Company's) Energy Advantage Home Program (EAHP). An overview of the database is presented in Figure 2-1. The database contains seven major components:

- On-site survey of participating and nonparticipating homes,
- Duct blaster and blower door tests,
- DOE-2 building simulations,
- Hourly weather information by California Energy Commission (CEC) weather zone,
- Daily weather information by Gas Company weather zone,
- Household gas consumption records, and
- Telephone survey data of participating and nonparticipating builders and developers.

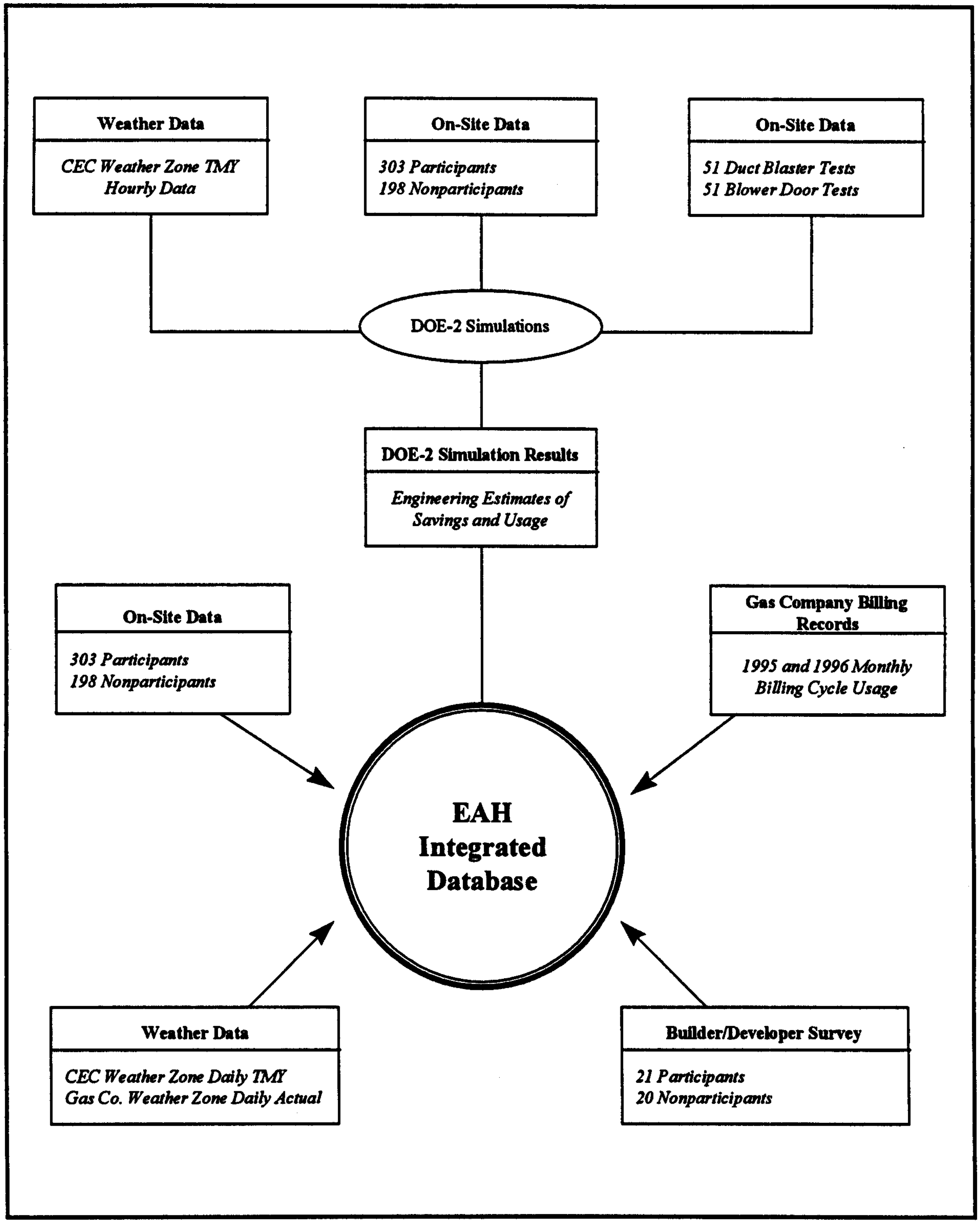
It should be noted that the data collected from the on-site survey and CEC weather data are used to construct the database for the DOE-2 simulations and for the final integrated database used in the billing analysis. Further, the DOE-2 simulations are a key portion of the analysis and as such are described in detail in Section 3 of this report. A detailed discussion of the seven database components is provided in the following subsections. Subsections 2-7 and 2-8 summarize final data preparation and the structure of the database.

2.2 On-Site Survey of Participating and Nonparticipating Homes

The on-site survey serves two major objectives: to support the building simulation analysis discussed in Section 3, and to accommodate the billing analysis described in Section 4. The on-site survey focused on collecting the following pieces of information:

- Structural features of the unit, including size, geometry, thermal integrity, exposure, and orientation,
- Appliance characteristics, including size, efficiency, and fuel,
- Appliance utilization data, including thermostat settings and frequency of use,
- Current economic and demographic characteristics of the household, and
- Changes at the site since initial occupancy.

Figure 2-1: Overview of SCGEHA Evaluation Integrated Database



To complete the on-site surveys, five major subtasks were identified:

- Sample design,
- Survey instrument design,
- Survey protocol and fieldwork,
- Survey pre-test,
- Blower door and duct blaster tests, and
- Compilation of survey results.

Each of these survey subtasks are discussed below.

Sample Design

The first element of the overall sample design relates to the on-site survey which collected detailed information on participating and nonparticipating dwellings. The Gas Company's evaluation design specified a desired *combined completed sample size* of 500 participants and nonparticipants. This combined sample was split into *300 participants and 200 nonparticipants*. While an even split would have been more traditional, a larger participant sample size was specified to increase the precision with which impacts of individual classes of measures could be estimated. This 300/200 split satisfies the Protocols, which call for 150 participant on-sites for each affected end use and "a comparable sample" of nonparticipants.

Participant Group Sampling Plan

The *frame* for the residential participant sample consisted of a screened list of all 1994 participants. This list was derived from a broader list of program participants provided by The Gas Company. For the purposes of the sample design, the following screens developed the participant frame:

- First, participants must have payment dates in either 1994 or the first quarter of 1995. The extension of the period to cover the first quarter of 1995 was justified by the time lag between completion of construction and delivery of payments.
- Second, participants had to be covered by contracts that were fully paid in this time period. Without this screen there was no way to ascertain which of the listed lots were constructed during the 1994 program year for cases with only partial payment.
- Third, it had to be possible to trace the home to the billing frame (i.e., to match billing records to the site). This was not always possible, given that participating sites are identified only by job IDs, parcel numbers, and lots, while the billing frame identifier is an account number or a premise number. We were able to track roughly 75% of all participating sites to the billing file. Links to billing records were required for inclusion in the participant frame because consumption records

were needed for the realization rate analysis. One of the implications of this screen was that manufactured homes were omitted from the frame.

This unfortunate omission was the result of the inability to trace participating manufactured homes to billing records without the manufacturer agreeing to divulge the names and addresses of individuals purchasing these homes. Incidentally, the only measures actually installed in manufactured homes in 1994 were gas furnaces with AFUEs between 80% and 87%.

A residence type indicator was defined for each participant to support the sample design. The participant files included a designator with five values: single family detached homes, town homes, condominiums, multi-family dwellings, and manufactured homes. For the purposes of the sample design, town homes were grouped with detached single family homes, and condominiums were consolidated with multi-family dwellings. This practice was consistent with the operation of the program, in the sense that single family measures (e.g., furnaces with 88+% AFUEs) were offered for townhomes, but not to condominiums.

Participants were sampled with a modified stratified sample design. The development of the sample design entailed four steps:

- First, the initial sample size equaled 600. This reflected the target of 300 completed on-sites for participants, coupled with assumption of an approximate response rate of 50%.
- Second, given the diversity of the program as it applies to individual dwelling types, the sample was stratified by residence type (single family non-manufactured homes, multi-family units and manufactured homes). Proportional stratification across dwelling types was employed.[1]
- Third, the sample was also stratified by weather zone, in light of the importance of space heating in the context of the program, coupled with the substantial variation in heating requirements across The Gas Company's service area. Neyman allocation determined initial sample allocations across weather strata within residence types. The Neyman allocation essentially minimizes the total variance of gas consumption with respect to the distribution of sites across weather zones, based on variability of total gas usage within and across these strata.
- Fourth, the initial sample developed from the first two steps was modified to ensure sufficient coverage of all measures. This was deemed necessary because the first sample list included too few homes with low incidence measures (e.g., multi-family furnaces with 78% AFUEs) to permit the estimation of savings from these measures. This was accomplished by replacing some homes with high

[1] Neyman allocation could have also been used to determine initial sample sizes by dwelling type. However, this would have resulted in too small a sample of multi-family dwellings to permit sufficient precision in estimating the impacts of some multi-family measures.

saturation measures with homes having low saturation measures in the same dwelling type and weather zone.

Table 2-1 summarizes the completed sample design. For reference, we also present the population distribution, the completed sample distribution that would have resulted from proportional sampling across weather zones as well as dwelling types, the completed sample distribution implied by "pure" Neyman allocation across weather zones *and* dwelling types, and the completed sample distribution implied by "pure" Neyman allocation across weather zones *within* dwelling types. Also shown for each sample design is the associated relative precision (the proportional error in estimating participants' average whole-house consumption at the 90% confidence level). As shown, the Neyman allocation across residence types and weather zones offers the most overall precision. However, it offers relative low precision for multi-family dwellings. The loss in precision implied by using Neyman allocation only within residence types is minimal.

Table 2-2 summarizes the coverage of specific measures by the final sample design. In order to indicate the limited degree to which the initial Neyman allocation had to be overridden in order to achieve this measure distribution, we also present the measure distribution that would have resulted from the "pure" Neyman allocation within residence types. Note that these measure counts are for the initial sample, which is twice as large as the targeted completed sample. The actual numbers of measures in the completed sample can be expected to be roughly half of the numbers listed in Table 2-2.

As shown, sample design was refined to increase the coverage of heat traps, multi-family water heaters (.60-.69 EF), and multi-family furnaces (78+% AFUE). Note that it was not possible to develop samples containing duct insulation, water heaters (.70+ EF), manufactured home furnaces, or recirculation controls; the participant frame (which had already been screened as described above) contained no homes that had received these measures.

An important aspect of the sample design is to develop expansion factors used to expand the sample to the population. The expansion factors reflect the sample design stratification by weather zone and residence type and the oversampling of certain program measures. A full description of expansion factors is forthcoming.

Table 2-1: Completed Sample Design: Participants

Dwelling Type/ Weather Zone	Participant Frame		Target Completed Sample under Alternative Sample Designs					
			Proportional Allocation		Neyman Allocation across Dwelling Types		Neyman Allocation within Dwelling Types	
	N	%	N	%	N	%	N	%
Single Family								
Mountain	5	0.1	1	0.3	1	0.3	1	0.3
Low Desert	197	3.9	12	4.0	7	2.3	6	2.0
Coastal	592	11.7	35	11.7	37	12.3	33	11.0
High Desert	879	17.4	52	17.3	46	15.3	41	13.7
Inland Valley	1,161	23.0	69	23.0	86	28.7	76	25.3
LA Basin	1,185	23.5	69	23.0	90	30.0	81	27.0
All Zones	***4,019***	***79.6***	***238***	***79.3***	***267***	***89.0***	***238***	***79.3***
Multi-family								
Mountain	0	0.0	0	0.0	0	0.0	0	0.0
Low Desert	0	0.0	0	0.0	0	0.0	0	0.0
Coastal	257	5.1	15	5.0	7	2.3	14	4.7
High Desert	97	1.9	6	2.0	3	1.0	5	1.7
Inland Valley	6	0.1	1	0.3	1	0.3	1	0.3
LA Basin	672	13.3	40	13.3	22	7.3	42	14.0
All Zones	***1,032***	***20.4***	***62***	***20.7***	***33***	***11.0***	***62***	***20.7***
Grand Total	***5,051***	***100.0***	***300***	***100.0***	***300***	***100.0***	***300***	***100.0***
Relative Precision			***.0504***		***.0481***		***.0496***	

Table 2-2: Distribution of Covered Measures (Initial Sample)

Measure	Number of Homes with Measure (Initial Sample)			
	Before Replacements		After Replacements	
	SF	MF	SF	MF
Duct Testing	404	5	402	4
Duct Insulation	0	0	0	0
Furnace 88+% AFUE	125	0	125	0
Water Heater 60-69 EF	53	13	53	28
Water Heater 70+ EF	0	0	0	0
Ovens	78	74	80	72
Manufactured Home Furnace	0	0	0	0
Heat Traps	14	6	20	15
Furnace 78+ AFUE	0	3	0	13
Combination Furnace/Water Heating	5	99	7	80
Recirculation Controls	0	0	0	0
Totals	***679***	***200***	***687***	***212***

Nonparticipant Group Sampling Plan

The residential nonparticipant sample design was similar to the participant sample design. The nonparticipant frame consisted of all homes completed in 1994 that did not participate in the program. Homes completed in 1994 or the first quarter of 1995 were identified from billing records on the basis of initial meter set date. This group of 50,000 customers was screened for participants by deleting the following accounts:

- All 1994 participants (paid or partially paid) who could be matched to billing records, and
- All customers in the initial frame who had the same ZIP+4 as any other participant.

The second screen was necessary because of the difficulty of matching all participants to billing records. This severe screen ensures the elimination of all participants, even if this meant also eliminating some nonparticipants. The imposition of the two screens resulted in a nonparticipant frame of 34,177 customers.

As noted above, the targeted completed sample size for nonparticipants consisted of 200 homes. Therefore, initial sample of nonparticipants consisted of 400 homes, on the assumption that a 50% response rate could be achieved. The nonparticipant sample was stratified on the basis of both residence type and weather zone. Billing data helped to identify single family and multi-family homes. Similar to the participant sample design, strata targets were determined by using proportional stratification across residence types and by using Neyman allocation across weather zones within dwelling types. Table 2-3 presents the design of the targeted completed nonparticipant sample. For reference, Table 2-3 also depicts the nonparticipant frame distribution, the completed sample distribution that would have prevailed with proportional sampling, the completed sample structure that would have been chosen with pure Neyman allocation across residence types *and* weather zones, and the final design, which entails Neyman allocation across zones within residence types. Overall relative precision levels for estimating nonparticipant whole-house gas usage are also presented for the alternative nonparticipant sample designs. As shown, the final design yields precision almost as high as the pure Neyman allocation, while still providing a large enough sample of multi-family nonparticipants to support the estimation of impacts of multi-family measures.

Table 2-3: Completed Sample Design: Nonparticipants

Dwelling Type/ Weather Zone	Non-participant Frame		Target Completed Sample under Alternative Sample Designs					
			Proportional Allocation		Neyman Allocation across Dwelling Types		Neyman Allocation within Dwelling Types	
	N	%	N	%	N	%	N	%
Single Family								
Mountain	357	1.0	2	1.0	6	3.0	5	2.5
Low Desert	2,667	7.8	16	8.0	17	8.5	16	8.0
Coastal	2,960	8.8	17	8.5	21	10.5	20	10.0
High Desert	5,991	17.5	35	17.5	33	16.5	30	15.0
Inland Valley	9,606	28.3	57	28.5	59	29.5	55	27.5
LA Basin	5,420	15.8	32	16.0	34	17.0	32	16.0
All Zones	***27,001***	***79.0***	***159***	***79.5***	***170***	***85.0***	***158***	***79.0***
Multi-family								
Mountain	7	0.0	0	0.0	0	0.0	0	0.0
Low Desert	405	1.3	0	0.0	0	0.0	0	0.0
Coastal	1,368	4.0	8	4.0	7	3.5	9	4.5
High Desert	666	2.0	4	2.0	3	1.5	4	2.0
Inland Valley	1,885	5.5	11	5.5	9	4.5	13	6.5
LA Basin	2,845	8.3	18	9.0	11	5.5	16	8.0
All Zones	***7,176***	***21.0***	***41***	***20.5***	***30***	***15.0***	***42***	***21.0***
Grand Total	***34,177***	***100.0***	***200***	***100.0***	***200***	***100.0***	***200***	***100.0***
Relative Precision			***.0622***		***.0605***		***.0612***	

On-Site Survey Instrument

Obtaining accurate data is critical to correctly model the building with DOE-2. The on-site survey elicited data on building geometry, appliance operating schedules, connected loads generating internal gains, shell characteristics, and HVAC equipment features.

RER and VIEWtech staff developed a draft survey instrument and The Gas Company staff reviewed the draft instrument. Final edits and logic changes were made to the instrument based on comments received from The Gas Company. A copy of the survey instrument is provided in Appendix A.

Survey Protocols and Fieldwork

The project team developed a set of survey protocols in advance of the survey implementation. These protocols covered the following issues:

- Procedures for contacting customers,
- Survey personnel training procedures,
- Field work, and
- Quality control.

A description of each of these issues is provided below.

Customer Contact. RER provided VIEWtech with a list of customers within each stratum, along with a stratum-specific quota. In anticipation of a response rate of 50% the initial samples for participants were roughly twice the size of each stratum target. Given that response rates for nonparticipants tend to be somewhat lower, the initial sample of nonparticipants was approximately three times the targeted completed sample size of 200.

Prior to any customer contact by the project team, The Gas Company sent an introductory letter to the initial sample of homes by The Gas Company. The letter encouraged cooperation and provided legitimacy to the survey effort. RER drafted the letter text while The Gas Company staff reviewed the letter; RER made final edits. RER was responsible for mailing the 1,200 pre-letters to the initial sample. A copy of the pre-letter is provided in Appendix B.

VIEWtech was responsible for making the initial telephone contacts with the 300 EAHP participant customers and the 200 nonparticipating customers. The telephone contact solicited participation in the on-site survey. All recruiting calls were made from VIEWtech's telephone facility in Carson and were conducted from 8:00 a.m. to 5:00 p.m. on weekdays. Callbacks were arranged at a convenient time when necessary. Due to an initial relatively large number of answering machines and no answers received by VIEWtech, the initial scheduling hours were extended to 7:00 p.m. This action increased the contact rate and accommodated working families not home during the day.

On-site surveys were scheduled at the convenience of the customer. Initially, survey appointments were restricted to weekdays. However, this was expanded to include Saturdays to accommodate customers unable to schedule appointments during normal business hours.

A protocol of three call backs was instituted during the scheduling process. This procedure required that VIEWtech randomly selected an initial active list of 300 participants and 200 from the sample provided by RER. Each valid phone number was attempted up to three separate occasions at differing times of the day before it was dropped from the active list.

Recognizing the need for a reasonable response rate, RER offered an incentive of $50 for each household agreeing to the on-site survey. These payments were disbursed at the end of each week based on reports from VIEWtech on completed surveys. Payments were made in the form of money orders and were accompanied by a thank-you letter.

Training of Survey Personnel. VIEWtech personnel performed all field data collection. Prior to the conducting field data collection, all surveyors were provided with two full days of orientation designed to acquaint personnel with the program and service delivery requirements. A comprehensive On-site Survey Manual was also provided to each surveyor[2]. Training workshops included the following topics:

- Program goals and objectives,
- Performance processes - work flow,
- Thorough review of survey instrument, and
- Interviewing techniques and form completion.

In addition, the training workshops included topics to reinforce VIEWtech's emphasis on customer satisfaction and service on behalf of The Gas Company including:

- Customer relations, communication, and professional appearance VIEWtech's role in providing service to The Gas Company,
- Employee's role as an extension of The Gas Company,
- Professional etiquette, and
- Role of each position, how it relates to servicing customers, and achieving program goals.

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[2] *SoCal Gas Demand-Side Management Program Load Impact Evaluation: On-Site Survey Manual*, prepared by VIEWtech, Carson CA, 1996

Survey Field Work. The field data collection is summarized below. For identification purposes, The Gas Company provided photo id badges for all field staff.

- All appointments were scheduled at the customer's convenience. Field representatives arrived within 15 minutes of the scheduled appointment.
- Field representatives presented identification to the customer, and explained both the purpose of the survey and the data collection process.
- Data were collected in a courteous manner. Some data were collected through an interview lasting roughly 15-minutes with a member of the household, while other data were identified through inspection.
- Field representatives thanked each customer for participation, and answered any final questions.
- Following data collection, all survey forms were reviewed by a VIEWtech field supervisor.
- Complete data collection forms were then passed to RER for data entry.

On-site surveyors were responsible for the following activities while on site:

- Visual confirmation of equipment installed as a result of program (or similar equipment for nonparticipants),
- Plan view of residence including roof, wall and window information,
- Observation of the measure/equipment in operation—to the degree permitted by season and other operating constraints,
- Duct leakage and building envelope leakage tests (for a subsample of sites as described in a later section),
- Collection and confirmation of equipment operating parameters for both program measures and other "as-built" measures (included by builder or added by homeowner that are not part of the program). These include but are not limited to:
  - Manufacturer and model number or specification of equipment,
  - Manufacturer's rated operating output, power requirements, including volts, amps, rated efficiency, observed load factor, other factors related to actual energy use,
  - For non-energized equipment—performance ratings from manufacturers (e.g. R-value and shading coefficient for windows, thickness and R-value for insulation, etc.), and
  - Performance factors for equipment control, operating schedules, temperature control setpoints and operating parameters (to permit assessment of impact).

Gas Appliance Manufacturer Association (GAMA) publications[3] were provided to help field staff to identify energy factors (EFs) and AFUEs of specific water heating and space heating equipment.

Quality Control. Field survey work required a number of quality control measures:

- The assigned Field Supervisor inspected all paperwork for legibility and completeness prior to delivery to RER for data entry and further inspection.
- All field personnel carried beepers to facilitate communication between field staff and project management. Whenever possible, questions were handled at the time of the on-site survey, eliminating repeat site visits.
- After survey forms were submitted to RER, results were entered into a database and subjected to a series of data quality checks, including verification of completeness, internal logic checks, and range checks.
- Periodic project staff briefings were held to communicate pertinent information to field staff, and to obtain feedback and provide clarification on any issues that arose during the on-site surveys.

Conduct Pretest

A pre-test of 10 participating and 10 nonparticipating homes was completed in order to check the implementation of the survey protocol and the quality of the survey instrument. RER and VIEWtech staff reviewed the results of the pretest and reported to The Gas Company. Included in the report were some recommended changes to the survey instrument and survey protocol.

The major results of the pre-test resulted in (1) a change in the order of questions on the survey to better facilitate the completion of the interview portion of the survey, (2) clarification on the content of the drawing of the plan of the residence, (3) an extension of the scheduling time for VIEWtech staff to the early evening hours to accommodate working families, and (4) scheduling surveys for Saturdays to increase the likelihood of participation of homes unable to completed surveys during normal business hours.

Blower Door and Duct Blaster Tests

Because program savings estimates from duct inspections represent roughly 50% of total program savings, obtaining information on building shell air changes represents a key element of the analysis. In particular, DOE-2 requires data on air changes in cubic feet per minute at a reference pressure (50 Pascal). To obtain this data, standardized Duct Blaster

[3] Consumer Directory of Certified Efficiency Ratings for Residential Heating and Water Heating Equipment, program sponsor GAMA, Arlington Virginia, 1995

and Blower Tests were conducted at 25, 50, 75 and 100 Pascal of pressure for a sub sample of 20 participant and 31 nonparticipant homes.

Appendix C contains a copy of the testing results form used for the two tests and Appendix D provides the protocol followed when completing these tests.

Compilation of On-Site Survey Results

RER compiled data from the on-site survey, weekly reports and a final project summary provided by VIEWtech, such as response rates and dispositions. Key findings are discussed below.

Additional Sample. The initial sample design specified 600 participants and 400 nonparticipants in order to complete the 500 on-site surveys. This sample was further augmented with 450 participants and 300 nonparticipants due to the substantial number of invalid samples (disconnected, moved wrong number etc.) in the participant program database and Gas Company billing files. However, for some strata, not all sample additions were needed, and VIEWtech continued to use a three-callback protocol.

Survey Response Rates. Table 2-4 presents a summary of the completed on-site surveys. Included in the tables are survey goals, completed surveys, completed blower door and duct blaster tests, and the number of homes contacted for participants and nonparticipants by weather zone and residence type. As indicated by Table 2-4, the overall response rate for participants was 33.3% and 28.7% for nonparticipants.

Table 2-4: Summary of Completed On-Site Surveys

	Single Family									
	Participants					Nonparticipants				
	Survey Only		BD/DB			Survey Only		BD/DB		
Zone	Goal	Complete	Goal	Complete	Contacted	Goal	Complete	Goal	Complete	Contacted
Mountain	1	1			4	4	4	1	1	15
Low Desert	5	5	1	0	15	14	15	2	2	48
Coastal	31	35	2	2	73	17	16	3	4	62
High Desert	38	38	3	2	97	25	24	5	5	103
Inland Valley	71	73	5	8	218	47	47	8	8	172
LA Basin	76	80	5	6	259	27	25	5	6	134
Total	**222**	**232**	**16**	**18**	**666**	**134**	**131**	**24**	**26**	**534**
	Multi-Family									
	Participants					Nonparticipants				
	Survey Only		BD/DB			Survey Only		BD/DB		
Zone	Goal	Complete	Goal	Complete	Contacted	Goal	Complete	Goal	Complete	Contacted
Mountain										
Low Desert						1	1			3
Coastal	13	9	1	1	46	8	8	1	1	30
High Desert	4	4	1	0	16	3	3	1	0	21
Inland Valley	1	0			4	11	11	2	2	47
LA Basin	40	38	2	1	178	13	13	2	2	54
Total	**58**	**51**	**4**	**2**	**244**	**36**	**36**	**6**	**5**	**155**

Total Completed Surveys Only			450
by	Participants	283	
	Nonparticipants	167	
by	Single Family	363	
	Multifamily	87	
Total Completed Blower Door/Duct Blower Surveys			51
by	Participants	20	
	Nonparticipants	31	
by	Single Family	44	
	Multifamily	7	

Total Completed Surveys:			501
by	Participant	303	
	Nonparticipant	198	
by	Single Family	407	
	Multifamily	94	

Survey Disposition. Summaries of survey dispositions for participating and nonparticipating homes are presented in Table 2-5 and Table 2-6, respectively. As indicated in these tables, wrong, disconnected and unlisted numbers represented a significant portion of the phone numbers supplied to VIEWtech. In particular, invalid numbers represented roughly 20% of all first calls for participants and 23% for nonparticipants. VIEWtech also experienced a number of canceled appointments during the on-site survey fieldwork. There were 30 cases of canceled appointments for participants and 44 for nonparticipants. This caused scheduling problems and accounted for some delays in the completion of the on-site survey work.

Table 2-5: Participant Disposition

Call Status	1st Call	2nd Call	3rd Call
Completed Survey	188	49	66
Scheduled Appointment	17	10	16
Customer Will Call Back	19	17	15
Left Message/Call Back	360	192	100
No Answer/Busy Signal	76	39	32
Language Barrier	-	-	-
Canceled Appointment	13	7	10
Not Interested	57	14	11
Disconnected/Customer Moved	12	2	-
Wrong Number	31	14	5
No Phone Listing Available	137	8	4

Table 2-6: Nonparticipant Disposition

Call Status	1st Call	2nd Call	3rd Call
Completed Survey	81	51	66
Scheduled Appointment	54	53	26
Customer Will Call Back	7	12	2
Left Message/Call Back	244	132	84
No Answer/Busy Signal	79	32	31
Language Barrier	4	-	-
Canceled Appointment	4	18	22
Not Interested	58	33	35
Disconnected/Customer Moved	11	2	1
Wrong Number	19	6	3
No Phone Listing Available	128	4	8

Coverage of program Measures. A summary of the number of survey respondents with each measure covered by the EAH Program is presented in Table 2-7. Included in the table are the expected number of measures based on the sample design and the number from the completed sample. As shown in this table, there are considerably more measures that qualify for incentives for water heating, ovens, and duct testing in the final database.

Table 2-7: Summary of Covered Measures in Completed On-Site Sample

Measure	SF targets	SF on-site	MF target	MF on-site
Duct Testing	202	240	3	23
Duct Insulation	0	3	0	-
Furnace 88+% AFUE	63	71	0	1
Water Heater (.60-.69 EF)	27	344	7	67
Water Heater (.70+ EF)	0	1	0	-
Ovens	39	283	37	65
Manufactured Home Furnace	0	-	0	-
Heat Traps	7	53	3	13
Furnace (.78+ AFUE)	0	-	2	-
Combination Furnace/Water Heating	3	4	50	20
Recirculation Controls	0	-	0	-
Totals	***341***	***999***	***102***	***189***

Summary of Survey Results. The data collected from the on-site survey were merged into the EAH integrated database for use in the billing analysis. In addition, DOE-2 simulations utilized household information on household characteristics, building shell data, and equipment efficiencies. Table 2-8 presents a summary of some of the key demographic data from the on-site survey for participants and nonparticipants by residence type.

Table 2-8: Summary of Demographics by Participant and Nonparticipant by Residence Type

	Single Family		Multi-Family	
	Parts	Nonparts	Parts	Nonparts
Home Square Footage (SF)	1,949	1,881	1,046	1,413
Income ($)	68,876	66,507	55,829	58,421
Number in Household	3.3	3.1	1.8	2.5
Gas Space Heating (%)	0.998	1.000	0.958	0.682
Gas Water Heating (%)	0.987	0.980	1.000	0.745
Gas Ovens (%)	0.693	0.633	0.934	0.748
Gas Ranges (%)	0.991	0.935	1.000	0.974
Gas Dryers (%)	0.884	0.807	0.711	0.680
Gas Pool Heat (%)	0.015	0.051	0.000	0.000
Spa Pool Heat (%)	0.027	0.053	0.000	0.000
Gas Fireplaces (%)	0.683	0.613	0.552	0.388
Average Annual Bill (Therms)	397	383	205	210

Blower Door/Duct Blaster Tests. Results of the blower door and duct blaster tests were entered into the database for the 31 nonparticipating and 20 participating sites. In particular, the following tests were completed and the results recorded.

- Single point blower door test at 50 Pascal,
- Single point blower door test with house pressurized to 50 Pascal, and
- Multi-point duct blaster tests at 25, 50, 75 and 100 Pascal.

2.3 Weather Data

This analysis utilized weather data from the CEC and The Gas Company. The CEC weather data was used for the DOE-2 simulations and in the billing analysis to calibrate engineering estimates of usage to actual billing data. The Gas Company weather data was used in the billing analysis.

CEC Weather Zone TMY Data

DOE-2 simulations required hourly CEC weather typical meteorological year (TMY) by weather zone data. CEC weather data was opted over The Gas Company's weather data because of its greater level of detail of temperature, wind speed, solar radiation dew point necessary to run DOE-2. The reason for using the CEC weather data was the unavailability of this level of detail in The Gas Company's weather files.

A standard TMY weather data is constructed by reviewing individual months of weather data from each weather station over a 23-year period. A typical month for each of the 12 calendar months from the long term period of record is chosen and combined to form the TMY. The basis of the selection for a typical month consists of 13 daily indices calculated from the hourly values of dry-bulb and wet-bulb temperature, wind velocity, and solar radiation. Month/year combinations that have statistics "close" to the long term statistics are candidates for typical months. Final selection of a typical month includes consideration of persistence of the weather patterns.

Daily high and low temperatures by weather zone were used to construct the hourly TMY data. These values daily values were then used to used to construct monthly heating degree days (HDDs)[4] base 65 by weather zone. These data were added to the EAH integrated database and normalized to 30.4 days per month. Figure 2-2 presents the annual heating degree days by CEC weather zone.

The Gas Company Weather Data

Actual daily high and low temperatures by weather zone were obtained from Gas Company weather files. The data covered the period January of 1995 to October of 1996 for each of the six weather zones. These data were used to construct HDD base 65 and were then added to the EAH integrated database. Figure 2-3 a summary of annual HDD for the period November 1995 to the end of October 1996.

[4] Heating degree days are computed as follows:

HDD base 60 = max{0, (60 - (Daily High + Daily Low/2) }.

Figure 2-2: Heating Degree Days by CEC Weather Zone: TMY

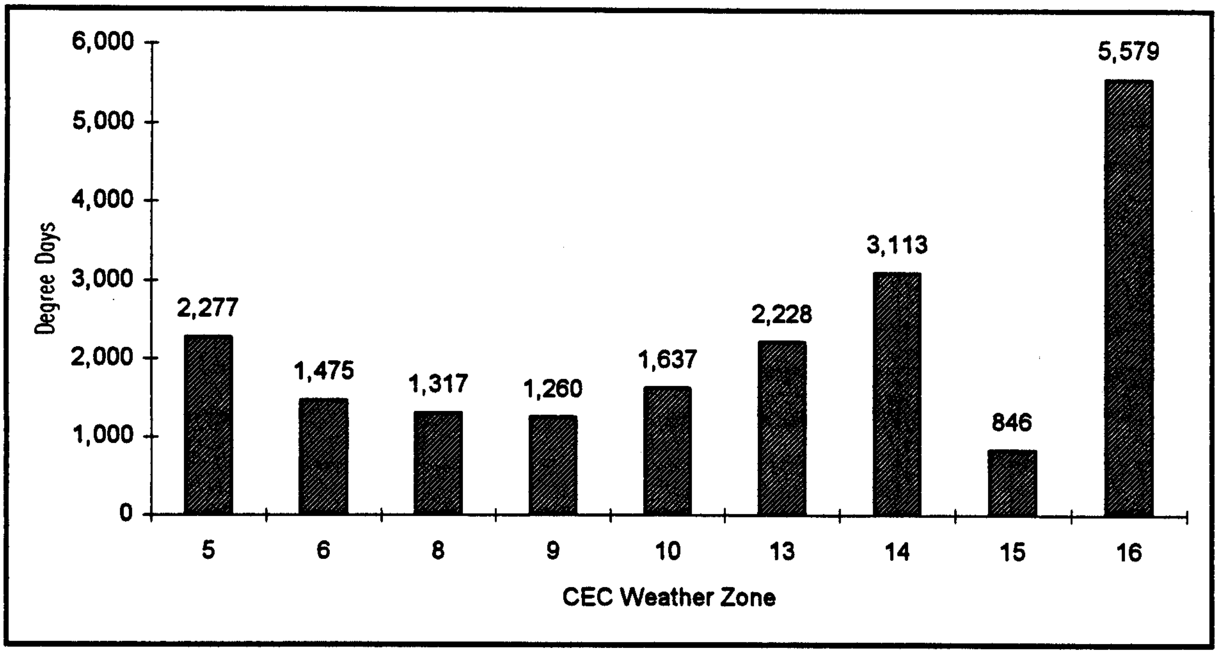
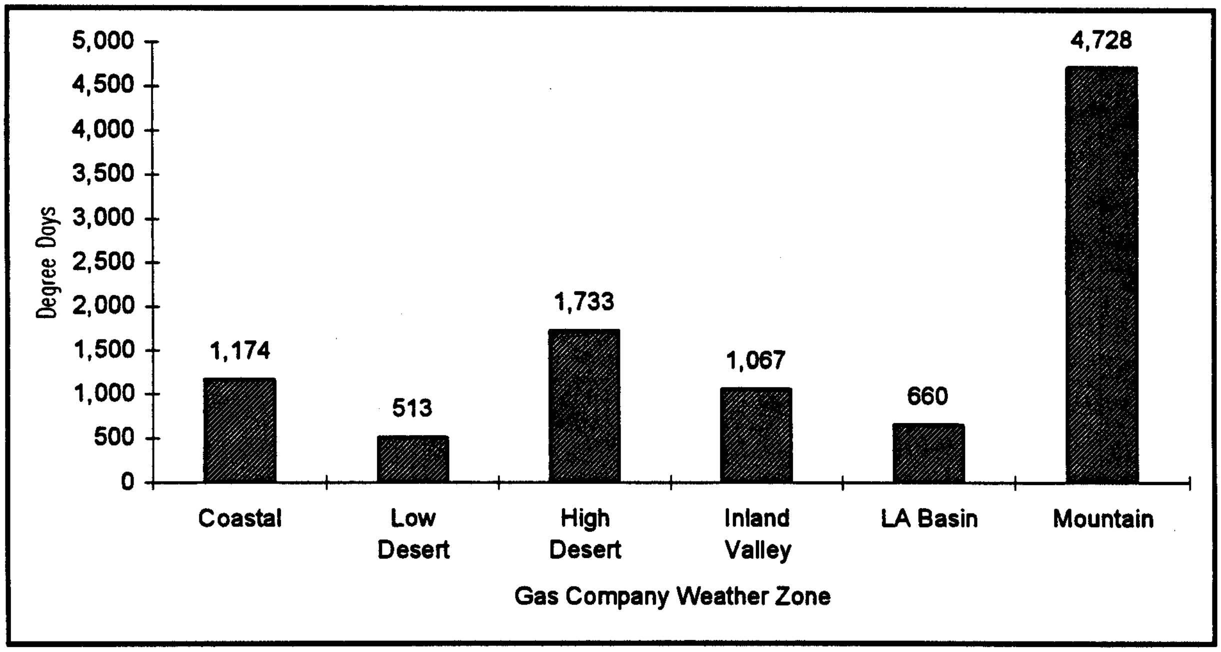


Figure 2-3: Heating Degree Days by Gas Company Weather Zone: 1995:10 - 1996:9



2.4 Consumption Data

The Gas Company provided consumption data for the participants and nonparticipants. This included billing cycle data for usage (therms), read dates and number of billing days by premise ID for the period from January 1995 to October 1996. The EAH integrated database is a normalized calendar month database. This was done to be consistent with the monthly engineering estimates of usage and savings from DOE-2. As such, the consumption data was normalized to calendar month data using read dates and number of billing days.

Insofar as this is a new construction program, some of the consumption series may begin in January of 1995 while others begin later in the year. As will be discussed in Section 4, the database was ultimately limited to cover the period September 1995 through the end of October 1996.

2.5 Builder and Developer Survey

Taylor Research conducted a telephone survey of builders whose projects include the homes in the sample. The survey provided data useful for modeling efficiency choices of new equipment for each home in our analysis. The results of the efficiency choice modeling developed estimates of net-to-gross ratios used to net out free-rider effects in the estimates of program savings.

The initial work plan specified a sample of 80 to 100 builders, which was thought to be sufficient to cover the majority of participant and nonparticipant homes in our completed sample. This proposed number of completes was based on the availability of a list of builders from The Gas Company records. This was particularly true for nonparticipants since builder information was available from program records.

Four major elements of the survey design are described below including:

- Sample frame,
- Sample size,
- Survey instrument design,
- Fieldwork, and
- Survey results.

Sample Frame

Individual builders and developers were in some cases responsible for the construction of many homes in our sample. Further, certain builders and developers were responsible for multiple homes across different developments. Given the assumption that a particular builder may use different decision criteria across developments, it was decided to use a single development as the lowest common denominator for the sample frame. To accommodate this approach, the participant and nonparticipant samples were disaggregated by building development. Builders/developers where then identified for each of these developments.

In the case of participants this was relatively straight forward given the availability of program data on builders, contract numbers and customer addresses. Table 2-9 presents the number of unique developments and builders and developers for the participant sample.

For nonparticipants, Gas Company records helped to identify builders and developers for 124 of the 200 nonparticipants. This sample was aggregated into developments by matching builders and customer city and street addresses. Table 2-9 also disaggregates nonparticipant developments and builders and developers.

Table 2-9 : Developments and Builders/Developers

	Total Sites	Developments	Builder/Developers
Participants	303	149	72
Nonparticipants	124	165	91

Sample Size

Ideally, we would like to have interviewed the builders of all of the homes in our on-site sample. However, the resulting sample frame indicated that we did not have sufficient information to contact all builders. More specifically, the review of the sample frame indicates a survey of 72 participating and 91 nonparticipating builders/developers would cover all participant sites and just over 60% of nonparticipating sites in the sample. It was anticipated that not all of these builders/developers would respond to the telephone survey. Given these factors, we attempted to contact every builder/developer.

Survey Instrument Design

RER and Taylor Research designed the telephone survey instrument. The survey collected several kinds of information, including:

- Participation in The Gas Company's education/training workshops,
- Information on general decision-making criteria relating to fuel choices and energy efficiency choices,

- Self-reported estimates of free ridership,
- Information on possible participant free drivership in the form of installation of non-program measures in participating homes,
- Information on possible nonparticipant free drivership in the form of participating builder installation of covered measures in nonparticipating homes,
- Reasons for participating or not participating in the program, and
- General company features (size, organization, etc.).

The Gas Company reviewed a draft of the survey instrument. A copy of the final survey instruments are provided in Appendix A.

Fieldwork

Taylor Research conducted the telephone survey. Given that we were attempting to contact all builders and developers on the sample list, Taylor attempted up to five call backs before eliminating a site from the list. A more traditional approach uses a three call back protocol.

Taylor spent considerable time ensuring they were interviewing the decision maker for the development in question. This was accomplished through a series of pre-screening questions. In some cases, this required additional calls in order to complete a survey.

A notable consideration was that certain builders were responsible for multiple developments. To encourage response and mitigate the time need to respond to the survey, Taylor scheduled call back interviews at the convenience of the interviewee.

Survey Results.

Table 2-10 presents a summary of completed surveys by participant and nonparticipant builders/developers.

Table 2-10: Summary of Completed Builder/Developers Surveys

	Builders/Developers	Developments	Sample Sites
Participants	21	54	121
Nonparticipants	24	31	40

The majority of the information collected in the survey aided in the efficiency choice modeling used to determine net-to-gross ratios in the impact evaluation. Other questions were also included that provide information on other program related issues.

Source of information on the Existence of the Program. Table 2-11 and Table 2-12 indicate that the vast majority of builders and developers become aware of the program through direct contact with Gas Company representatives and through Gas Company marketing materials. This is evident for participants and nonparticipants

Participation on The Gas Company's Education and Training Workshops. Table 2-13 indicates that just under 40% of participants have attended Gas Company sponsored education and training workshops. This number may be understated due to the relatively high "Don't Know" responses.

Most Important Reason for Influencing Measure Installation. As shown in Table 2-14, just under 50% of participants indicated that the rebates from measure installation was the main reason influencing measure installation. Interestingly, just under 10% responded that they were influenced by past experience with energy efficient equipment.

Reason for Not Participating in the Program. As presented in Table 2-15, nonparticipants were roughly split between too much paper work, insufficient rebates and tight project schedules, and other unidentified issues as reasons for not participating in the program.

Table 2-11: Knowledge Source of the EAH Program (Nonparticipants)

Source	Percentage
Approached Directly by The Gas Company	48.6
The Gas Company Information Brochure	2.5
Other Builders or Developers	4.2
Architect or Designer	-
Other	-

Table 2-12: Knowledge Source of the EAH Program (Participants)

Source	Percentage
Approached Directly by The Gas Company	84.7
The Gas Company Information Brochure	14.2
Other Builders or Developers	1.1
Architect or Designer	-
Other	-

Table 2-13: Participation in The Gas Company's Education and Training Workshops (Participants)

Response	Percentage
Yes	29.3
No	28.8
Don't Know	41.9

Table 2-14: Most Important Reasons Influencing Measure Installation (Participants)

Reason	Percentage
Program Rebates	47.6
The Gas Company's Advice/Recommendations	28.2
Equipment Literature or Advertisements	9.7
Past Experience with Energy Efficient Equipment	9.3
Information From a Vendor	3.8
Other	1.3

Table 2-15: Reason for not participating (Nonparticipants)

Reason	Percentage
The rebates didn't cover enough of the cost.	20.2
Energy efficient equipment doesn't add enough value.	10.8
The program required too much paperwork.	23.7
The construction schedule was too tight.	21.4
Other	25.5

2.6 Data Preparation

The data are generally viewed as providing an accurate picture of respondents' gas usage patterns, appliance ownership, and demographic and household characteristics. Nevertheless, a number of cross-checks were performed to identify errors in reported data and to fill missing values. The following subsections describe the methods utilized to identify anomalous data.

Inspection of Consumption Data

The consumption data in the EAHP database is derived directly from customer billing files. These billing records, while reasonably accurate, contain some anomalies that can be troublesome in the analysis. The billing records of the sample were inspected closely for the following problems:

- Erroneous billing days and/or read dates,
- Abnormal monthly consumption,
- Missing or zero gas usage (the latter may indicate an inactive account),
- Special billing flags (estimated bills, correction billing, etc.), and

Consumption data was inspected for anomalies such as high reads, inconsistencies due to new accounts and transfers of accounts from builder developers to tenants. At the discretion of RER staff, the consumption of suspect observations were set to missing or accounts being excluded from the analysis. This resulted in four sites being completely omitted and roughly 50 observations being set to missing for the billing analysis.

Inspection of End-Use Responses

End-use variables are inspected carefully to identify anomalous responses. Misreporting is a chronic problem in survey-based analysis and careful inspection of responses is one of the most important aspects of data preparation. In most cases, comparing gas consumption patterns and end-use responses helped to identify erroneous responses. For example, a customer may report not having gas space heating, but an investigation of their consumption patterns may indicate clearly that gas space heating is present. In cases where evidence of misreporting is clear, end-use designations in the database are overridden. End use responses for total of 66 accounts were overridden after inspection of consumption patterns.

2.7 Final Database Structure

The final EAHP database consists of seven primary elements:

- On-site survey of participating and nonparticipating homes,
- Duct blaster and blower door tests,
- DOE-2 building simulations,
- Hourly weather information by California Energy Commission (CEC) weather zone,
- Daily weather information by Gas Company weather zone,
- Household gas consumption records, and
- Telephone survey data of participating and nonparticipating builders and developers.

This time-series cross-sectional database contains unique (constant) household characteristics that have been "fanned out" with monthly consumption and weather data, thereby creating monthly observations for each household.

With the integrated database in place, the following data transformations were conducted to ensure consistency across customer accounts with different read dates.

- Historical consumption data and weather data were normalized to a 30.4-day billing period with the use of billing days and read dates.
- With the use billing days and meter read dates, weather data was converted to billing cycle degree-day measures. In order to make these values consistent with the usage levels contained in billing records, degree days were also normalized to a 30.4 day billing period.

The final integrated database consists of 6,513 observations for the sample of 501 sites.

3

Building Simulation Analysis

3.1 Introduction

The key elements of the realization rate billing analysis are engineering estimates of baseline whole-house usage and savings for each measure covered by the Energy Advantage Home Program (EAHP). This section describes the modeling approach used to develop these estimates and summarizes the results of the engineering simulations.

An overview of the building simulation framework is shown in Figure 3-1. Information from the on-site survey was used to evaluate space heating and non-space heating measures. DOE-2 simulations helped to derive engineering estimates of savings associated with all measures with weather-sensitive impacts for the 501 surveyed sites. These measures include:

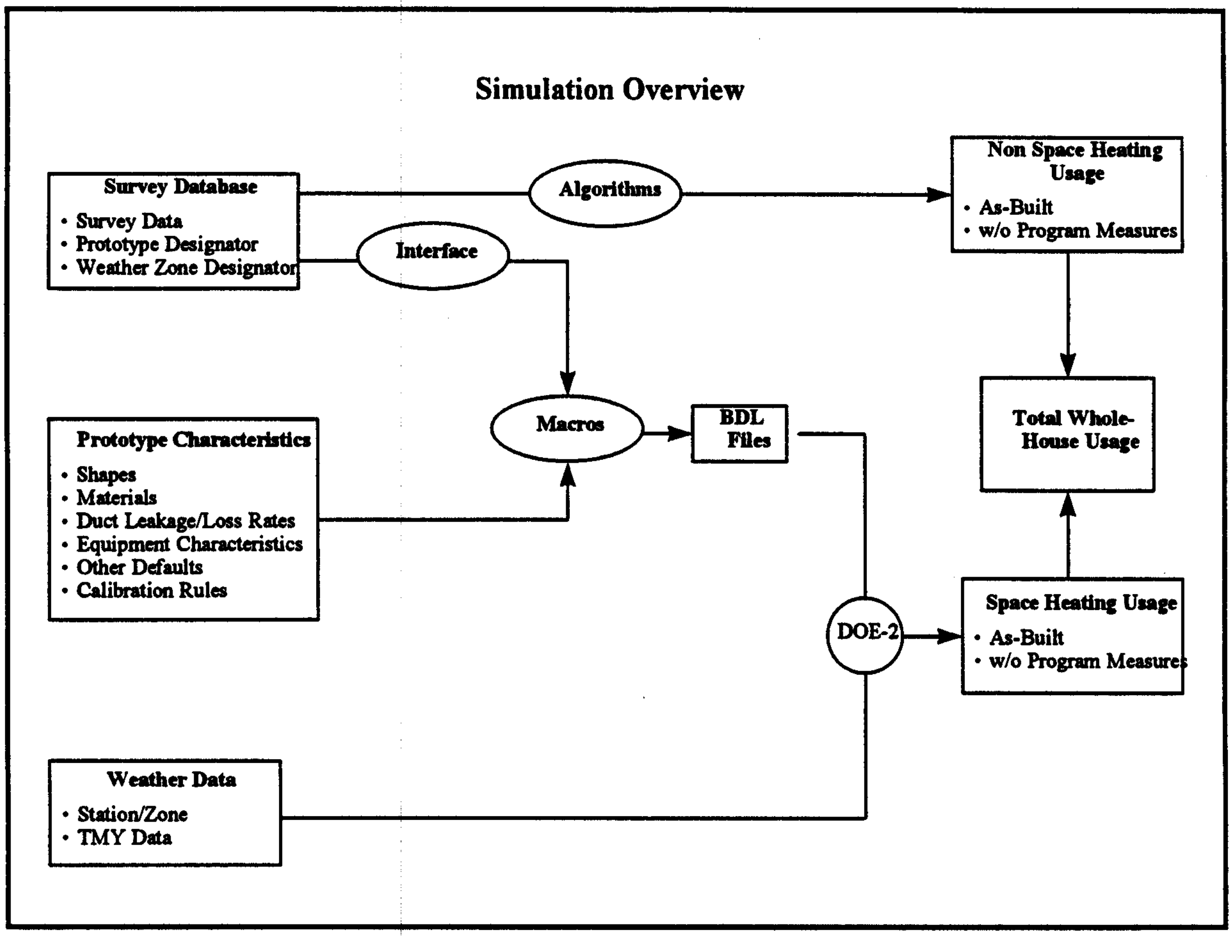
- Duct Testing,
- High-Efficiency Furnaces (88%+ AFUE),
- High-Efficiency Combined Hydronic Systems (high-efficiency system EF .58),
- Multi-Family Space Heating (fuel substitution),
- Duct Insulation (R-4.2 to R-8), and
- Manufactured Housing Furnace (80-87% AFUE).

Non-space heating measures were evaluated using engineering algorithms and/or conditional demand analysis. Important parameters include equipment efficiency, normalized energy usage data, summer-time monthly billing data, number of occupants and behavioral data obtained from the on-site surveys. Non-weather-sensitive measures include:

- Water heaters (.60-.69 EF and .70+ EF),
- Heat traps,
- Water heater recirculation controls. and
- New construction gas oven.

The following sections explain the approach used to estimate weather and non-weather-sensitive end-use savings.

Figure 3-1: Overview of Building Simulation Framework



3.2 Building Simulation Analysis

Overall Strategy

Building simulation modeling provided estimates of space heating usage under various assumptions concerning the presence/absence of both covered and non-covered DSM measures. These simulations were conducted using the DOE-2 building energy simulation program under the guidelines set forth in the Protocols. Simulations were performed for all 501 sites using the following multi-step procedure.

- ***Define Prototypes.*** The first step of the simulation process defined a set of building prototypes. The initial thinking was to develop a set of approximately 30 prototypes in terms of residence type and general geometry (number of stories, configuration, etc.). However, after examining the project, program files and basic Title 24 information and in consultation with Robert Mowris, P.E., , only two prototypes (single family detached, multi-family, townhouse and apartment) were necessary to complete the analysis.

- ***Define Weather Variables for Use in DOE-2.*** Detailed hourly weather data from California Energy Commission (CEC) weather zone files were used in the analysis. In particular, the data are TMY weather based on historical weather from 1952 to 1975 and are constructed from individual months rather than entire years.
- ***Develop BDL Files.*** Mr. Mowris developed BDL files for each of these prototypes, using assumed characteristics provided by RER. These features included shell characteristics, equipment features, estimates of internal gains from electric equipment (derived from RER's in-house library of electric UECs and heat gain conversion factors), infiltration rates derived from blower door tests conducted on a subsample of homes, and results of duct tests conducted for a sample of homes. BDL files for each prototype were designed with a series of analog and digital switches relating to specific site features (square footage, window area, glass type, insulation level, etc., as well as the measures covered by the program).
- ***Calibrate DOE-2.*** RER collected billing information and survey information on a subsample of 72 homes fitting into the defined prototype classes. These were homes were surveyed early in the on-site survey process. Mr. Mowris conducted a preliminary calibration of these prototype simulations, using actual features, TMY weather data, and billing data.
- ***Simulate Space Heating Usage for the 501 Sites.*** Using these prototypes, Mr. Mowris developed the logic to simulate space heating usage under various assumptions with respect to the presence of the space heating measures covered by the program. At the conclusion of the on-site survey, a database of these measures and relevant site features were developed for all 500 sample members. Each site was assigned to a prototype category. Using its Protoman software, RER batch processed DOE-2 simulations for all sites under various assumptions including:
  - A *reference case (or Title 24 baseline)*, which sets all relevant site features equal to the levels that would minimally comply with Ttile20/24 code,
  - An *intermediate case*, in which all non-program measures in excess of code are set equal to the value actually found at the site but program measures are assumed to be absent, and
  - A *program case*, which is identical to the intermediate case except that the program measures found at the site are set equal to their actual values.

  The differences among these scenarios can be interpreted as follows:
  - The difference between the reference case and the intermediate case is the estimated impact of *non-program DSM* at the site;
  - The difference between the intermediate case and the program case is the estimated effect of the *program measures* found at the site;
  - The difference between the program case and the reference case is an estimate of the impact of *all DSM* at the site.

- ***Final Calibration of DOE-2.*** Mr. Mowris conducted a preliminary calibration of simulations using actual features, actual weather, and billing data for 72 sites. After the completion of the simulation of all 501 sites, DOE-2 results were reevaluated and changes to calibration rules were made. These were almost exclusively limited to changes in ranges to thermostat setpoints.

Each of these steps are described in detail following a brief overview of DOE-2, implementation of DOE-2, and a description of input macros.

Description and Use of DOE-2.1E

DOE-2 Building Description Language (BDL) files were developed from building characteristics obtained from the surveys, Title 24 specifications and/or program default values. Development of DOE-2 BDL input for each building generally involved the following steps.

- ***Geometry and Characteristics.*** A simple polyhedron was used to model each building. The building geometry had the correct wall, roof, and window areas as well as the correct interior volume. Building characteristics for opaque surfaces and windows were obtained from the on-site surveys and/or building plans.
- ***Shading.*** Exterior shading was modeled using site survey drawings and survey data showing distance and height of landscape and/or other buildings close to the site. Interior window shading was modeled by assuming a 0.4 multiplier on the shading coefficient if the solar radiation exceeded 50 Btu/hr-ft^2 and the use of interior drapes or blinds were indicated in the site survey.
- ***Internal Loads.*** Loads from lighting, equipment, and people were taken from the site surveys and modeled as average loads per square foot (kBtu/ft^2, W/ft^2, etc.).
- ***Schedules.*** Schedules were obtained from site survey data and modified as necessary to calibrate to monthly billing data (see above). Minimum and maximum thermostat settings for the 500 sites were established based on simulation results from the 72 calibration sites.
- ***Equipment Performance Parameters.*** Packaged heating equipment performance data was derived from the site surveys. Model numbers obtained during the site survey were mapped to manufacturers' catalogs to obtain rated performance data (i.e., AFUE for heating equipment). Supply air flow rates (cfm) were estimated from survey data assuming 100 cfm per kBtu.

DOE-2 Input Macros

The conventional method of creating a single "stand alone" BDL file for each site is very inefficient and inflexible. Making simple changes to single BDL files and doing analysis for DSM measures can be difficult and tedious. The "input macros" feature available with DOE-2 allows a modular approach to creating BDL files and provides much more flexibility in evaluating DSM measures. DOE-2 input macros were used to develop a fast and accurate methodology to create DOE-2 BDL files for each of the 501 simulation sites. The input macros add the following capabilities to DOE-2:

- Allows external files containing separate pieces of the BDL (schedules, loads, systems, and plant) to be incorporated into the main BDL input stream. This feature eliminates redundancy and allows flexibility in making modifications to individual parts of each prototype (e.g., changing shell characteristics, system types, or equipment efficiencies). The input macros also provide flexibility in designing and modifying output files.
- Selectively accepts or skips portions of the input. This feature allows conditional *IF* and *ELSEIF* statements to be used to accept or skip lines. Further, it is very efficient in setting up parametric runs that use desired lines of code depending on specific conditional variables that need to be changed only once in a general parametric input file.
- Performs arithmetic operations. Arithmetic operations can be used to set the values of certain parameters (zone areas, window areas, R-values) that can be modified throughout the entire BDL input stream with only one change to an input macro variable.
- Macro debugging and input control. The debugging feature makes it easier to quickly find and correct errors in the BDL input stream. Input control allows separate files containing variable parametric data to be accepted and included into the main BDL input stream. Input control provides an efficient way to create multiple parametric runs for evaluating the impacts of individual measures.

Prototype Definition

Two basic building prototypes were used in the DOE-2 simulations. These included a single family detached prototype and a multi-family apartment or townhouse prototype. The macro-driven DOE-2 model was designed to handle multiple story single and multi-family buildings including detached or attached apartments, townhouses and condominiums Examples of the various types of prototypes that were modeled with the macro-driven DOE-2 model are shown in Figure 3-2.

- ***Single Family Detached Prototype.*** This prototype had options for more than one floor and a crawl space, basement, or slab foundation. Duct locations could be in the attic or crawl space. Space heating options included natural gas forced-air furnace or natural gas combined hydronic systems.

- ***Multi-Family, Apartment, and Townhouse.*** These prototypes were modeled using one or more floors with crawl space, basement, or slab foundation. These prototypes might also include an adiabatic wall or floor (i.e., common walls, ceiling, or floor with essentially zero heat transfer). Space heating options included natural gas forced-air furnace or natural gas combined hydronic systems.

Weather Data

Typical meteorological year (TMY) weather data files were used for the DOE-2 simulation modeling. TMY weather are based on historical weather from 1952 to 1975 and are constructed from individual months rather than entire years.[1] TMY data contain actual measured solar insolation, and are a good representation of historical weather data (Huang 1996). TMY weather data for the simulations were obtained from the California Energy Commission (CEC 1992, CEC 1995) and are based on weather data from the National Climatic Data Center in Asheville, North Carolina (NCDC 1995).

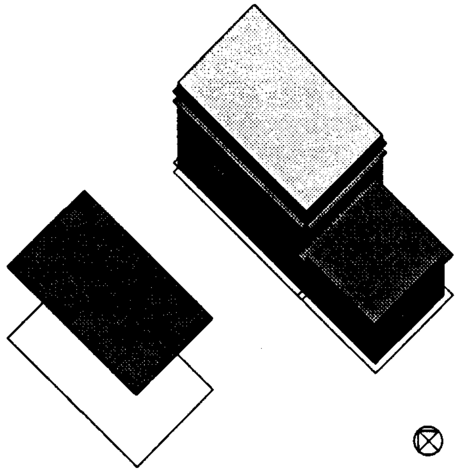
Calibrating DOE-2

Calibrated DOE-2 simulations were performed using typical meteorological year (TMY) weather data and monthly utility billing data[2] for a subset of 72 sites. These sites were randomly selected from the target 500 survey sites. The sites were then grouped into single and multi-family prototypes and then further grouped by climate zones. Each of the sites were calibrated to utility billing data in order to develop a set of climate zone specific calibration "rules" that were applied to the 501 survey sites.

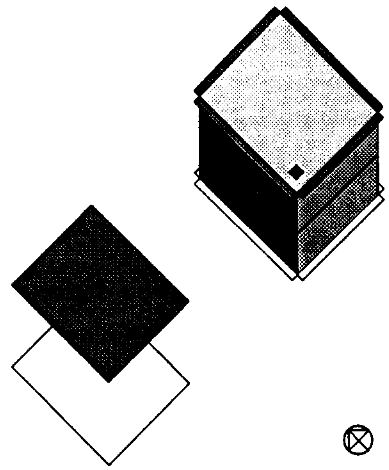
[1] Standard TMY weather data is constructed by reviewing individual months of weather data from each weather station over a 23 year period. A typical month for each of the 12 calendar months from the long term period of record is chosen and used to form the TMY. The basis of the selection for a typical month consists of 13 daily indices calculated from the hourly values of dry bulb and wet bulb temperature, wind velocity, and solar radiation. Month/year combinations that have statistics "close" to the long term statistics are candidates for typical months. Final selection of a typical month includes consideration of persistence of the weather patterns.

[2] See *Integration of Billing and Metering Data*, prepared for the California Demand Side Management Advisory Committee: The Subcommittee on Modeling Standards for End Use Consumption and Load Impact Models, prepared by Pacific Consulting Services, 1320 Solano Avenue, Suite 203, Albany, CA 94706, December 1994.

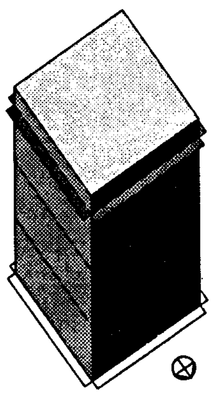
Figure 3-2: Examples of Prototypes Modeled with Macro-Driven Doe-2 Model



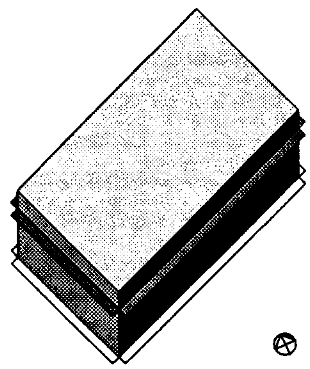
2-Story Single Family Residence
with attached garage and shading from neighbor
Site#: 031psfsa (participant)



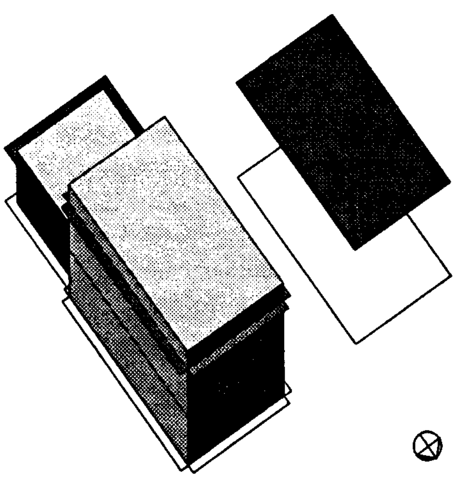
2-Story Multi-family Apartment (>5 units)
with adiabatic walls and shading from neighbor
Site#: 218nmfia (non participant)



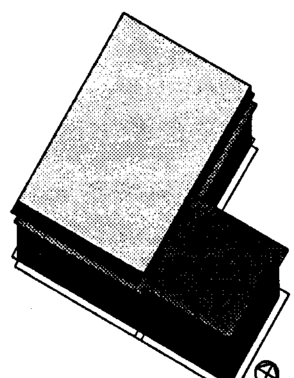
3-Story Townhouse
with adiabatic common walls
Site#: 043nmfia (non participant)



1-Story Multi-family Apartment
with adiabatic common walls
Site#: 247pmsfa (participant)



2-Story Condominium with attached garage,
adiabatic common walls and shading
Site#: 247pmsfa (participant)



1-Story Single Family Residence
with attached garage
Site#: 311pmfca (participant)

The calibration rules established minimum and maximum thermostat settings that were applied to the raw survey data. DOE-2 simulation assumptions were taken from the detailed on-site surveys, program defaults, and manufacturers' data. Duct loss and infiltration characteristics were developed from duct leakage and blower door test data obtained from 51 survey sites representing 20 participants and 31 nonparticipants. The calibration procedure involved the following steps.

- Create "as-built" DOE-2 BDL input file based on survey information,
- *Calibrate* "as-built" DOE-2 BDL input file to monthly billing data,
- Perform annual simulation for the "as-built" and Title 24 "base case,"
- Evaluate results, and
- Recalibrate.

The result of this procedure is a set of "calibration rules." These rules provided guidelines for the other 429 simulation sites. The calibration rules were developed by evaluating the following DOE-2 inputs.

- ***Thermostat Setpoints.*** Reported thermostat setpoints might not reflect actual setpoints. For example, the reported "on" setpoint might be 74°F, but the calibration procedure might find that a maximum value of 72°F is more representative or typical for the prototype and climate zone in question. In addition, the reported "off" setback might be 50°F, but the calibration procedure might find that a setback of 55°F is more representative or typical for the prototype and climate zone in question. Data from the 72 calibration sites was evaluated in order to determine appropriate adjustment factors for the thermostat setpoints.
- ***Thermostat Schedules.*** Reported thermostat schedules might not reflect actual schedules for periods of non-use (i.e., vacations, weekends, holidays). For example, the reported schedule might be the same for all days of the week, but the calibration might require a different weekend or holiday schedule with different setback periods. Data from the 72 calibration sites was evaluated in order to determine appropriate adjustment factors for thermostat schedules.
- ***Internal Gains.*** Estimated internal gains from people, non-space heating usage, and miscellaneous equipment loads was developed for the 72 calibration sites. The magnitude of internal loads was adjusted for calibration. In addition, internal loads reported in the surveys do not have specific schedules. Therefore, a set of "generic" load shape schedules was developed. Data from the 72 calibration sites was evaluated in order to determine appropriate adjustment factors and schedules for internal gains.

Modeling EAH Weather-Sensitive Program Measures

Duct Testing and Duct Insulation

Duct testing was modeled in DOE-2 using the DUCT-AIR-LOSS keyword. The DUCT-AIR-LOSS keyword defines duct air losses from the air supply ducts to the unconditioned attic or crawl spaces where the ducts are located. Input values are based on average air loss measurements taken from duct leakage measurements at 50 sites using the same methodology employed by participants in the program. Participants were assigned an average DUCT-AIR-LOSS of 16.9% based on measurements at 20 participant sites, and nonparticipants were assigned an average DUCT-AIR-LOSS of 22.5% based on measurements at 31 nonparticipant sites.

Duct insulation was modeled using the DUCT-DT keyword. The DUCT-DT keyword defines duct conduction losses from the air supply ducts to the unconditioned attic or crawl spaces where the ducts are located . DUCT-DT includes losses through the duct insulation, as well as any bypass effects due to the duct hangars, crushed insulation, etc. Participants having duct insulation greater than R-4.2 were assigned an average DUCT-DT of 1°F and nonparticipants with R-4.2 or less were assigned an average DUCT-DT of 2°F.

High-Efficiency Gas Furnaces

The SYSTEM module in DOE-2 requires three BDL input commands to model a gas furnace: (1) FURNACE-HIR, (2) FURNACE-AUX, and (3) FURNACE-HIR-FPLR. These inputs were redefined to properly model new gas furnaces. This is illustrated for a *PAYNE* model *#376CAV036070* furnace with 69,000 Btu/hr input and 56,000 Btu/hr output having a steady-state efficiency of 81.2% and an AFUE of 80.5 (GAMA 1994[3]).

The FURNACE-HIR default is 1.35 corresponding to a steady-state efficiency value of 0.74. For the *PAYNE* model noted above, the FURNACE-HIR was changed to 1.23 (i.e., 1/0.812 = 1.23).

The FURNACE-AUX default is 800 Btu/hr corresponding to an annual pilot light auxiliary heating load of 70.08 Therms (at 8,760 hr/yr). All new furnaces sold in California are required to have electronic ignitions, and this eliminates the pilot. FURNACE-AUX was set to zero to model new gas furnaces.

The FURNACE-HIR-FPLR is used to model the furnace part-load performance. The defaults for this curve are $a = 0.018610$, $b = 1.094209$, and $c = -0.112819$. The *a, b,* and *c* coefficients are used by DOE-2 in the following quadratic equation.

[3] *Consumer's Directory of Certified Efficiency Ratings for Residential Heating and Water Heating Equipment,* Gas Appliance Manufacturers Association, April 1994.

$$FURNACE - HIR - FPLR = a + b \times (PLR) + c \times (PLR^2)$$

where

PLR = the part-load ratio for the hour and is defined as the ratio of the load divided by the peak output.

The ANSI/ASHRAE test procedure for gas furnaces measures "the ratio of annual output energy to annual input energy" and includes "cyclic and part-load performance" effects (ASHRAE 103-1982 and 103-1988[4], ASHRAE 103-1993[5]). According to the test procedure, the average burner cycle time for the non-steady-state test is 3.87 minutes "on-time" followed by 13.3 minutes "off time". During an hour, this cycle time yields a total "on-time" of 13.52 minutes. This "on-time" represents a part-load ratio of 22.5% (i.e., 13.52 min./60 min.) at the AFUE rating. The ANSI/ASHRAE test procedure for gas furnaces captures part-load performance at low part-load conditions (ASHRAE Special Project 43[6]). The current generation of efficient gas furnaces have almost constant part-load performance with AFUEs that are only one or two percentage points less than the steady-state efficiency.

The default gas furnace equipment performance curve in DOE-2 produces erroneous results for new furnaces especially at low part-load values. For the *PAYNE* model *#376CAV036070*, the default DOE-2 curve yields an AFUE efficiency of 70% at 22.5% part-load rather than 80.5% (see Table 3-1). A closer match to the manufacturer's performance data is obtained with revised coefficients a = 0.000 010 00, b = 1.011 165 75, and c =-0.011 175 75. The revised curve is essentially flat indicating that AFUE remains relatively constant even at low part-load conditions. The revised curve was used to model new furnaces in DOE-2.

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[4] *Method of Testing for Heating Seasonal Efficiency of Central Furnaces and Boilers*, American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc., 1791 Tullie Circle, Atlanta, GA 30329, ASHRAE 103-1982, and ASHRAE 103-1988.

[5] *Method of Testing for Annual Fuel Utilization Efficiency of Residential Central Furnaces and Boilers* (pending adoption), ASHRAE 103-1993.

[6] *Supplemental Information From SP43 Evaluation of System Options for Residential Forced-Air Heating*, D.W. Locklin, K. Herold, R. Fischer, F. Jakob, R. Cudnik, ASHRAE Paper NT-87-20-4, 1987.

Table 3-1: Default HIR-FPLR Efficiency Versus Revised HIR-FPLR Efficiency and ANSI/ASHRAE Tested Efficiency for a Payne Model #376CAV036070 Gas Furnace

Part-Load Value	Default *HIR-FPLR* Efficiency[7]	Revised *HIR-FPLR* Efficiency	ANSI/ASHRAE Tested Efficiency
10%	0.634	0.8038	
20%	0.691	0.8048	
22.5%	0.700	0.8050	0.805 (derived)
30%	0.717	0.8057	
40%	0.735	0.8066	
50%	0.749	0.8075	
60%	0.761	0.8084	
70%	0.773	0.8093	
80%	0.784	0.8010	
90%	0.794	0.8111	
100%	0.805	0.8120	0.812 (measured)

High-Efficiency Combined Hydronic Systems

Combined hydronic space heating systems were modeled using the combined hydronic heating option in DOE-2.1E. A custom DOE-2 curve fitting algorithm was used to translate water heater energy factors (obtained from survey data) into DHW heating input ratios (H-I-R) and DHW part-load performance (P-L-R) curves. The DOE-2 curve fitting algorithm was developed using manufacturers' performance data and then calibrated using unit energy consumption (UEC) data from The Gas Company.

Energy savings for combined hydronic systems were based on nonparticipants having high-efficiency equipment (61% energy factor and 80% recovery efficiency) and nonparticipants having standard equipment (54% energy factor and 76% recovery efficiency). Survey data verified participant equipment efficiencies.

[7] DOE-2 Efficiency = (1/HIR) X (FURNACE-HIR-FPLR).

Modeling Non-Weather-Sensitive EAH Program Measures

Non-weather-sensitive measures were modeled using engineering algorithms or a conditional demand approach. In particular, gas ovens were modeled using a conditional demand approach, and the water heating measures using engineering algorithms incorporated in DOE-2.

High-Efficiency Water Heating

Energy usage associated with high-efficiency domestic hot water (DHW) heaters (.60-.69 EF and .70 EF) were evaluated using a DOE-2 curve fitting algorithm (mentioned above) that translates DHW heater energy factors (obtained from survey data) into DHW heating input ratios (H-I-R) and DHW part-load performance (P-L-R) curves. The DOE-2 curve fitting algorithm was developed using manufacturers' performance data and then calibrated using unit energy consumption (UEC) data from The Gas Company. In addition, the engineering algorithms were specified to account for the number of people in the household. Table 3-7 presents the engineering estimates of water heating usage for participants and nonparticipants by number in household.

Table 3-2: Engineering Estimates of Water Heating Use by Number in Household

Number in Household	Participants		Nonparticipants	
	Estimated Annual Use (Therms)	Saturation	Estimated Annual Use (Therms)	Saturation
1	109	.093	122	.081
2	162	.305	156	.357
3	183	.221	181	.162
4	209	.222	201	.229
5	227	.079	225	.086
6	257	.046	254	.010
7+	245	.023	240	.006

Heat Traps

Heat traps were modeled using the water heating algorithms incorporated in DOE-2 for water heating usage. In particular, heat traps were considered an add-on measure which improved the water heaters energy factor by .02[8]. For example a standard .544 water heater with heat trap was modeled as a water heater with EF of .564.

Modeling Other "As-Built" Non-Program Measures

Some buildings included non-program measures beyond Title 24 standards. These non-program measures were accounted for in the reference case DOE-2 runs for program energy savings. These included window upgrades, passive solar design, thermal mass, improved insulation levels, water heater blankets, or other non-program measures.

Final DOE-2 Model Calibration

After completion of the 501 DOE-2 simulations using the initial model calibration rules, engineering estimates of heating were compared to billing data estimates of space heating use. This was done to check the performance of the initial calibration rules. Further, four alternative versions of the simulations were run to evaluate the calibration rules for thermostat setpoints.

- ***Version A.*** Engineering estimates use heating schedules derived from thermostat settings by daytype (weekdays and weekends) reported from on-site survey.
- ***Version B.*** Engineering estimates use heating schedules reported from on-site survey by daytype with an upper bound of 70° and lower of 50° F.
- ***Version C.*** Engineering estimates use default heating schedule by daytype, by residence type and by weather zone.
- ***Version D.*** Engineering estimates use default heating schedule by daytype and residence type.

The estimation results of these models are presented in Table 3-3. The mean absolute difference between the engineering estimate and the billing estimate divided by the mean of the billing estimate (Mad/Mean) helped to evaluate the performance of the thermostat setting assumptions. A lower Mad/Mean (i.e, a lower percentage in Table 3-3) indicates a better fit of the simulations. Engineering estimates in this analysis were derived from Version D results. The default schedules presented in Table 3-4 and Table 3-5 were used for thermostat setting for weekends and weekdays, based upon these comparisons. Note that the default schedules are based upon lower and upper limits rather than point estimates.

[8] Gas Appliance Manufacturers Association

Table 3-3: Comparison of Engineering to Billing Estimates of Space Heating Use (MeanAbsoluteDifference/Mean[Mad/Mean])

Residence Type	CEC Weather Zone *	Frequency	Version A (%)	Version B (%)	Version C (%)	Version D (%)
All	*All*	501	99	77	66	59
Single Family		118	176	140	120	95
Multi-Family		383	88	68	59	54
	04	1	150	150	94	94
	05	22	118	109	77	85
	06	102	79	63	63	58
	08	110	118	88	79	60
	09	30	146	122	131	75
	10	129	69	44	45	41
	13	39	175	142	91	93
	14	41	82	68	42	47
	15	23	73	48	46	43
	16	4	207	204	169	170

* California Climate Zone Descriptions for New Buildings, California Energy Commission, July 1995.

Table 3-4: Default Heating Schedule (low (l) and high (h)) - Weekday

1-5		6-8		9-14		15-17		18-20		21-24	
l	h	l	h	l	h	l	h	l	h	l	h
55	65	65	72	60	68	60	68	68	72	55	65

Table 3-5: Default Heating Schedule (low (l) and high (h)) - Weekend

1-5		6-8		9-14		15-17		18-20		21-24	
l	h	l	h	l	h	l	h	l	h	l	h
55	65	65	72	60	68	60	68	68	72	55	65

Modeling Baseline Usage Under Title 20/24

The DOE-2 baseline simulations were run using assumptions for Title 20/24[9] standards (*Package D*) by CEC weather zone for shell measures, space heating equipment, and water heaters. Table 3-6 presents a summary of the assumptions by CEC weather zone and element.

Table 3-6: Summary of Assumptions Used for Title 20/24 Baseline Simulation

	CEC Weather Zone			
Element	4-10	13	14-15	16
Shell Measure				
Windows[1]	2,000	2,000	2,000	2,000
Wall (R-Value)	13	13	19	21
Ceilling (R-Value)	30	38	38	38
Floor (R-Value)	19	19	19	19
Foundation (R-Value)	1	1	1	7
Equipment				
Central Furnace (AFUE)	78%	78%	78%	78%
Water Heating (EF)	.544	.544	.544	.544
Tank insulation (int or ext)	None	None	None	None
Pipe Insulation	None	None	None	None
1 Values pertain to DOE-2 window definitions (2000= double pane clear)				

[9] Energy Efficiency Standards for Residential and Nonresidential Buildings, California Energy Commission, July 1992

3.3 Simulation Results

Engineering estimates of savings by measures are presented in Table 3-7 and Table 3-8 for participants and nonparticipants respectively.

Table 3-7: Engineering Estimates of Savings for Participants

Measure	Annual Savings	Saturation	Savings per Participant
Duct Testing			
All	16.97	0.80	13.58
Incentivized	16.97	0.80	13.58
Not incentivized	-	-	-
Homes incentivized - measure not found	0.00	0.00	0.00
High-Efficiency Furnace (88%+AFUE)			
All	44.13	0.21	9.27
Incentivized	43.36	0.20	8.67
Not incentivized	53.70	0.02	1.07
Homes incentivized - measure not found	5.33	0.03	0.16
Duct Insulation			
All	1.62	0.01	0.02
Incentivized	-	0.00	0.00
Not incentivized	1.62	0.01	0.02
Homes incentivized - measure not found	0.00	0.00	0.00
High-Efficiency Hydronic Combo System - Space Heating			
All	2.83	0.18	0.51
Incentivized	2.83	0.18	0.51
Not incentivized	-	0.00	0.00
Homes incentivized - measure not found	0.00	0.00	0.00
High-Efficiency Hydronic Combo System - Water Heating			
All	23.76	0.18	4.28
Incentivized	23.76	0.18	4.28
Not incentivized	-	0.00	-
Homes incentivized - measure not found	0.00	0.00	0.00
Water Heater (.60-.69 EF)			
All	18.92	0.83	15.70
Incentivized	22.15	0.23	5.09
Not incentivized	17.90	0.60	10.74
Homes incentivized - measure not found	8.36	0.39	3.26
Water Heater (.70+ EF)			
All	-	-	-
Incentivized	-	-	-
Not incentivized	-	-	-
Homes incentivized - measure not found	0.00	0.00	0.00
Heat Traps			
All	3.58	0.11	0.39
Incentivized	4.41	0.03	0.13
Not incentivized	3.47	0.10	0.35
Homes incentivized - measure not found	0.00	0.57	0.00

Table 3-8: Summary of Preliminary Engineering Estimates of Savings for Nonparticipants

Measure	Annual Savings	Saturation	Savings per Participant
Duct Testing			
All	-	-	-
High-Efficiency Furnace (88%+AFUE)			
All	110.38	0.01	4.48
Duct Insulation			
All	-	-	-
High-Efficiency Hydronic Combo System			
All	5.69	0.03	0.17
Water Heater (.60-.69 EF)			
All	21.57	0.73	15.75
Water Heater (.70+ EF)			
All	73.00	0.01	.73
Heat Traps			
All	4.43	0.14	0.62

4

Realization Rate Analysis

4.1 Introduction

Billing analysis is generally used to develop estimates of program savings on the basis of observed differences in energy usage associated with different levels of energy efficiency. As noted earlier, billing analysis in new construction evaluations focuses on differences in consumption across buildings with different stocks of DSM measures (different levels of energy efficiency). A variety of statistical approaches are available that use consumption data to estimate new construction savings directly or to calibrate engineering estimates of savings. These include pure statistical approaches as well as a variety of hybrid statistical/engineering approaches.

The realization rate approach, a specific type of mixed engineering/statistical method, was used in this evaluation. In the taxonomy used in the protocols, the realization rate model can be considered a conditional demand model with engineering priors, so the proposed approach is consistent with the methodological requirements of the Protocols. This approach, which was initially developed by RER for the evaluation of retrofit programs, has been tailored in four recent studies for application to new construction programs. It focuses explicitly on differences in consumption associated with differences in efficiency levels across sites. As such, it is tailored to the needs of the evaluation of new construction programs. The general new construction realization rate model is described in the Section 4.2. Section 4.3 discusses the specific realization rate model developed for this evaluation and discusses the estimates of realized savings yielded by the model.

4.2 The General New Construction Realization Rate Model

General Logic

The general logic of the new construction realization rate approach is illustrated in Figure 4-1. As shown, the model relies on engineering estimates developed under three scenarios for both participants and nonparticipants: the reference scenario (e.g., minimal compliance with building and appliance energy efficiency standards); a set of intermediate scenarios representing the introduction of individual program and non-program measures in sequence; and an as-built scenario (with all program and non-program measures in place). The development of these estimates was discussed in Section 4. The model also makes use of information on factors that might affect the realization of the engineering estimates of usage under these scenarios and the associated DSM-related savings. The model produces a set of adjustment coefficients (or adjustment functions) that translate these engineering estimates into estimates consistent with observed energy usage and savings. These coefficients are sometimes called realization rates; however, they should not be confused with the realization rates reported in Table 6 of the CPUC reporting protocols. While the realization rates reported in Table 6 have the utility's ex ante estimates as their bases, the realization rates estimated in the realization rate model have project engineering estimates of savings as bases. As explained below, the realization rates on savings reflect the proportion of these engineering-based savings estimates actually realized in the form of reduced site usage.

Model Specification

To develop the general realization rate model, we begin with the standard specification of a statistically adjusted engineering approach:

$$(1)\quad G_{it} = \sum_{e} \alpha_e EEACTUAL_{iet} + \varepsilon_{it}$$

where G_{it} is whole-house gas consumption at home i in time t, and $EEACTUAL_{iet}$ is an engineering estimate of consumption through end use e based on assumptions reflecting the actual characteristics of the building, including its stock of DSM measures. The presence of the adjustment coefficient (α_e) reflects the possibility of general engineering bias. The model can be expanded by decomposing the engineering estimates into three elements:

$$(2)\quad EEACTUAL_{iet} = EEREF_{iet} - \sum_{j} EEPSAV_{ijet} - \sum_{k} EEOSAV_{iket}$$

where $EEREF_{iet}$ represents an engineering estimate of usage under a reference assumption with respect to the presence of energy conservation measures (minimal code compliance); $EEPSAV_{ijet}$ represents a set of engineering estimate of savings from program-covered measure j (whether or not installed through the program); and $EEOSAV_{iket}$ represents an engineering estimate of savings associated with DSM measure k not covered by the program, but exceeding code requirements. The specification shown in (2) simply splits the engineering estimate of as-built usage into a baseline estimate and estimates of the savings associated with the program and non-program energy conservation beyond baseline levels. Substituting (2) into (1), we obtain:

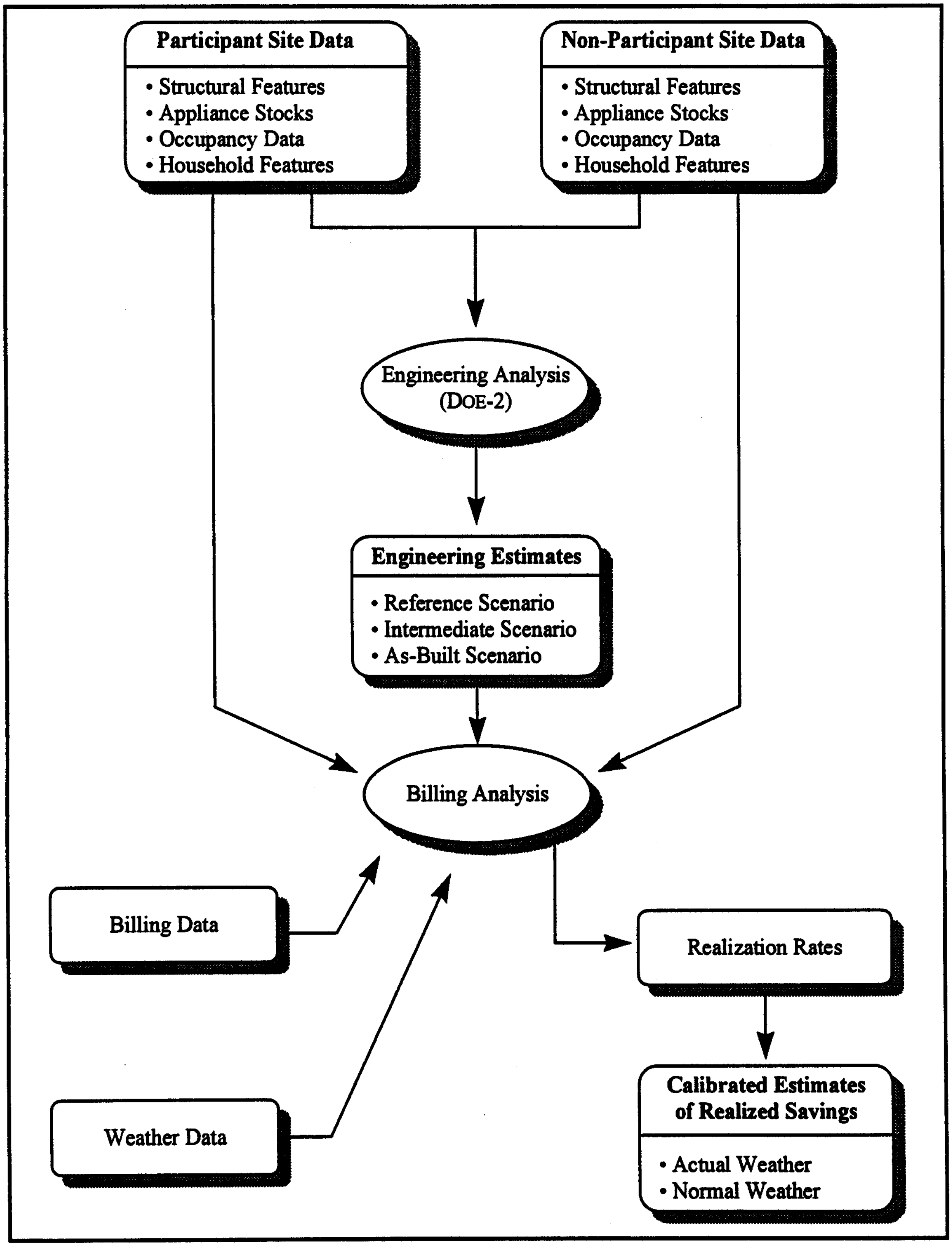
$$(3)\quad G_{it} = \sum_{e} \alpha_e \left[EEREF_{iet} - \sum_{j} EEPSAV_{ijet} - \sum_{k} EEOSAV_{iket} \right] + \varepsilon_{it}$$

This specification enables further modification. First, the basic adjustment coefficients on the estimated energy savings terms could be allowed to differ from the adjustment coefficient of the reference engineering estimate, thereby allowing the degree of engineering bias to vary across efficiency levels. Second, these adjustment coefficients should be permitted to vary across sites as conditions vary. One possible version of the revised model is as follows:

$$(4)\quad G_{it} = \sum_{e} \alpha_e (X_{it}) \left[EEREF_{iet} - \sum_{j} \beta_{je} EEPSAV_{ijet} - \sum_{k} \beta_{ke} EEOSAV_{iket} \right] + \varepsilon_{it}$$

where β_{je} and β_{ke} are adjustment coefficients encompassing two phenomena: (a) the bias in engineering savings estimates *relative* to the bias in the baseline energy usage estimates, and (b) the presence of behavioral rebound. Note also that the overall adjustment coefficient (α_e) is assumed to be a function of relevant factors (X_{it}) including site characteristics, weather, or other variables thought to affect the overall accuracy of baseline engineering calculations.

Figure 4-1: Realization Rate



One further modification needs to be made to the standard realization rate model for use in this evaluation. Engineering estimates of savings were developed only for only end uses covered by the program: space heating and water heating. For other end uses, (dryers, pools, spas and other miscellaneous gas appliances), a more traditional conditional demand specification was used. The revised model thus takes the form:

$$(5)\quad G_{it} = \sum_{e-1}^{2} \alpha_e(X_{it}) \left[EEREF_{iet} - \sum_{j} \beta_{je} EEPSAV_{ijet} - \sum_{k} \beta_{ke} EEOSAV_{iket} \right]$$

$$+ \sum_{e-3}^{k} f_e(X_{it}) S_e + \varepsilon_{it}$$

where the summation of the terms representing engineering priors of baseline usage and savings is limited to space heating (end use 1) and water heating (end use 2), S_e is a binary variable representing the presence of gas end use e, $f_e(X_{it})$ is a function representing the UEC through that end use, and where the second summation is over all other end uses.

Applications of the Realization Rate Model

As dictated by The Gas Company's evaluation objectives, the realization rate model was used in two applications: the estimation of incremental impacts of specific measures, and the assessment of the impacts of program-induced fuel switching. These applications are described briefly below.

Estimating Incremental Impacts of Specific Measures. The realization rate model first estimated the incremental impacts of DSM measures promoted through the Program. Given the simple yet flexible realization rate framework, the realization rate for each month and program measure can be defined as:

$$(6)\quad REALIZATION\,RATE_{iet} = \hat{\alpha}_e(X_{it})\hat{\beta}_{je}$$

The annualized end-use-specific realized savings associated with program measures applied to end use e would be:

$$(7)\quad REALIZATION\,SAVINGS_{ie} = \sum \hat{\alpha}_e(X_{it})\hat{\beta}_{je} EEPSAV_{ijet}$$

where $\hat{\alpha}_e$ is the estimated overall adjustment function for the site and end use in question, $\hat{\beta}_{je}$ is the estimated value of β_{je} summed over 12 months.

There are several points to note about this approach:

- It makes full use of engineering estimates under reference and high-efficiency scenarios. By doing so, it allows for at least some level of rebound.
- It can be used to *weather-normalize realized savings*. The approach used for this purpose was very straightforward. Engineering estimates of reference usage and DSM savings were developed through DOE-2 simulations using normal weather conditions (typical meteorological year data). Then, the general realization rate function ($\alpha_e(X_{it})$) was specified to contain terms representing the ratio of actual degree-days to normal degree-days in the billing period in question. This step accommodates the fact that billing data reflect actual weather conditions, whereas engineering estimates reflect normal weather. One the realization rate function is estimated, the weather ratio is set to one and the model is solved for the realization rate and the associated weather-normalized value of realized savings.
- Realization rates derived for a representative sample of participants are applicable to other participants for whom engineering estimates are similarly derived. Thus, these rates can be used to transform engineering estimates of overall gross program savings (adjusted for differences between evaluation engineering estimates and program estimates) into calibrated estimates of realized savings.
- It allocates end-use realized savings to individual DSM measures.

Estimation of Impacts of Program-Induced Fuel Switching. As noted in Section 1, our primary focus in this study was the Program-induced substitution of gas ovens for electric ovens and gas space heating for electric heat pumps. The gross energy impacts of Program-induced installation of gas oven and furnaces were derived from the realization rate model. For ovens, this was accomplished by solving the model for gas oven usage for participants with this end use. For space heating, the model was solved for average space heating usage for participants with 78% AFUE systems, ignoring the presence of other measures.

4.3 The Gas Company Realization Rate Model

Model Specification

The specific realization rate model used in this study was designed to cover all gas end uses. However, savings terms were developed for only two end uses for which DSM measures were offered through the program: space heating and water heating. The specific program measures covered by the analysis were:

- High-efficiency gas furnaces (88+% AFUE),
- Duct testing,

- Duct insulation,
- High-efficiency combined hydronic systems,
- High-efficiency water heating (.60-.69 EF), and
- Heat traps.

Taken together, these measures account for virtually all of the DSM savings from the program. Additionally, the following non-program measures were considered:

- Roof/ceiling insulation,
- Wall insulation,
- Floor insulation,
- Window u values, and
- Water heater blankets.

For convenience, the space heating non-program measures were combined into a single savings term.

The specific EAH realization rate model is given by:

$$(8)\quad G_{it} = \alpha_1 HDDRat_{it}\left[SHFREF_{it} - \beta_{1e} DTISAV_{iet} - \beta_{2e} HEFSAV_{iet} - \beta_{3e} HOTHSAV_{iet}\right]$$

$$+\alpha_2 HDDRat_{it}\left[SHHYDREF_{it} - \beta_{4e} SHHYDSAV_{it}\right]$$

$$+\alpha_3\left[WHHYDREF_{it} - \beta_{5e} WHHYDSAV_{it}\right]$$

$$+\alpha_4\left[WHREF_{it} - \beta_{6e} WHEFSAV_{it} - \beta_{7e} WHTRPSAV_{it} - \beta_{8e} WHOSAV_{it}\right]$$

$$+\alpha_5 EEGCOOK_{it} + \alpha_6 DUSE_{it} GDRY_{it} + \alpha_7 WIN_{it} GSPA_{it}$$

$$+\alpha_8 SUM_{it} GSPA_{it} + \alpha_9 WC_{it} GFPLC_{it} + \alpha_{10} GBBQ_{it} + \varepsilon_{it}$$

where:

G_{it}	=	monthly therms
$HDDRat_{it}$	=	ratio of actual heating degree-days to TMY heating degree-days
$SHFREF_{it}$	=	DOE-2 estimate of space heating furnace usage under baseline scenario
$DTISAV_{iet}$	=	DOE-2 estimate of duct testing and insulation savings

$HEFSAV_{iet}$	=	DOE-2 estimate of high-efficiency space furnace savings
$HOTHSAV_{iet}$	=	DOE-2 estimate of savings from other space heating measures (ceiling insulation, wall insulation, floor insulation and window treatments)
$SHHYDREF_{it}$	=	DOE-2 estimate of combined hydronic space heating usage under baseline scenario
$SHHYDSAV_{it}$	=	DOE-2 estimate of high-efficiency combined hydronic space heating savings
$WHHYDREF_{it}$	=	DOE-2 estimate of combined hydronic water heating usage under baseline scenario
$WHHYDSAV_{it}$	=	DOE-2 estimate of high-efficiency combined hydronic water heating savings
$WHREF_{it}$	=	engineering estimate of water heating usage under baseline scenario
$WHEFSAV_{it}$	=	engineering estimate of high-efficiency water heating savings
$WHTRPSAV_{it}$	=	engineering estimate of high-efficiency water heating savings
$WHOSAV_{it}$	=	engineering estimate of savings from other measures (water heater blanket and pipe wrap)
$EEGCOOK_{it}$	=	engineering estimate of gas usage for cooking
$GDRY_{it}$	=	binary variable reflecting the presence of a gas dryer
$DUSE_{it}$	=	self-reported weekly clothes drying loads
WIN_{it}	=	self-reported weekly spa frequency of use during summer
SUM_{it}	=	self-reported weekly spa frequency of use during summer
$GSPA_{it}$	=	binary variable reflecting the presence of a gas spa
$GFPLC_{it}$	=	binary variable reflecting the presence of a gas fireplace
WC_{it}	=	binary variable representing winter month
$GBBQ_{it}$	=	binary variable representing presence of gas barbecue
ε_{it}	=	random error term

It is important to note here that the savings estimates listed above for equipment efficiencies take into account any improvement relative to the code baseline. For instance, the high-efficiency space heating savings variable encompasses the savings from all space heating systems with efficiencies in excess of code, whether or not they satisfy the program requirement of an 88% AFUE or better. This broad definition is necessary in this context, because efficiencies better than code affect gas usage, even if they do not qualify for the program. Later, we will isolate the savings from measures that satisfy program requirements.

Correction for Autocorrelation. Autocorrelation, which is the correlation of the error term over time for individual sites, is typical in analyses of energy usage over time. This problem was mitigated with generalized least squares, a standard remedy. Each of the models discussed below were corrected for autocorrelation.

Estimated Model

Table 4-1 presents the results of the three model variants discussed below. These versions differ with respect to restrictions placed on the coefficients of the savings terms.

- ***Version 1*** restricts the value of β_{je} to 1 for each savings variable. This essentially assumes that there is no differential bias between engineering estimates of baseline usage and measure savings. Version 1 also combines the baseline space heating and water heating usage and savings for combined hydronic systems.
- ***Version 2*** maintains allows β_{je} to be estimated freely for every savings variable and end use. As shown, the results are reasonably robust, except for other space heating savings, combined hydronic savings and water heater trap savings.
- ***Version 3*** is a combination of Versions 1 and 2. First, it restricts the value of to 1 for high-efficiency space heating and high-efficiency water heating. This is justified on the grounds that improvements in equipment efficiency should have proportional impacts on usage. Additionally, the value of for high-efficiency combined hydronic systems is also set equal to 1. Again, this is reasonable given the fact that the major savings from these hydronic systems is traceable to the efficiency of the water heating unit. The coefficients of other savings variables are estimated without restrictions.

Because it makes use of the most reasonable set of assumptions with respect to relative engineering bias, results from Version 3 are used in all subsequent calculations. Using either of the other versions would have affected the relative savings across measures, but would not have had a material effect on the overall estimate of program savings.

Table 4-1: Estimated Realization Rate Models (t values in parentheses)

End Use/Explanatory Variable	Version 1	Version 2	Version 3
$HDDRat_{it} SHFREF_{it}$	0.89196 (66.52)	0.92771 (47.95)	0.93067 (49.24)
$HDDRat_{it} DTISAV_{iet}$	-0.89196 (66.52)	-0.72998 (3.22)	-0.69560 (3.23)
$HDDRat_{it} HEFSAV_{iet}$	-0.89196 (66.52)	-0.80653 (4.17)	-0.93067 (49.24)
$HDDRat_{it} HOTHSAV_{iet}$	-0.89196 (66.52)	-0.26274 (2.33)	-0.27157 (2.44)
$HDDRat_{it} SHHYDREF_{it}$	0.94900 (9.94)	0.84725 (6.00)	0.96458 (10.07)
$HDDRat_{it} SHHYDSAV_{it}$	-0.94900 (9.94)	0.04605 (0.05)	-0.96458 (10.07)
$WHHYDREF_{it}$	0.94900 (9.94)	0.84725 (6.00)	0.96458 (10.07)
$WHHYDSAV_{it}$	-0.94900 (9.94)	.04605 (0.05)	-0.96458 (10.07)
$WHREF_{it}$	1.11030 (25.58)	1.08493 (23.41)	1.10508 (25.47)
$WHEFSAV_{it}$	1.11030 (25.58)	-0.75019 (2.91)	-1.10508 (25.47)
$WHTRPSAV_{it}$	1.11030 (25.58)	-0.28273 (0.54)	-0.39144 (0.75)
$WHOSAV_{it}$	-1.11030 (25.58)	-0.86923 (3.37)	-1.06454 (4.81)
$EEGCOOK_{it}$	0.75063 (3.67)	0.70331 (3.34)	0.79126 (3.86)
$GDRY_{it} DUSE_{it}$	0.73125 (11.07)	0.71461 (10.85)	0.71850 (10.88)
$WIN_{it} GSPA_{it}$	9.06805 (3.57)	8.81381 (3.48)	8.87420 (3.50)
$SUM_{it} GSPA_{it}$	11.16503 (5.32)	11.43858 (5.47)	11.45935 (5.47)
$WC_{it} GFPLC_{it}$	5.42593 (14.41)	5.32359 (14.13)	5.30073 (14.08)
$GBBQ_{it}$	2.93141 (3.94)	2.75911 (3.71)	2.83563 (3.81)
Adjusted R^2	0.6243	0.6264	0.6262

Gross Realized Savings by Measure

As explained above, the realization rate model can be used to generate estimates of average realized savings from each of the measures. First, realized savings estimates are developed for each of household in the sample. Then, these household-level savings estimates can be averaged across homes. Caution must be exercised, however, in executing these calculations. As noted earlier, the engineering savings estimates included in the model reflect *all* savings relative to code. In the case of equipment efficiencies (high-efficiency furnaces and high-efficiency water heaters), these estimates encompass savings from equipment that exceeded code but fell short of program requirements. Thus, the household-level estimates of realized savings are also defined accordingly. To focus on the realized savings from measures that qualify for the program, the average of these savings estimates must be taken only for homes with qualifying measures. Of course, some insights can also be obtained by looking at realized savings for non-qualifying measures.

Realized savings estimates are included in Table 4-2 for specific program measures. For reference, we have also shown the *ex ante* gross savings estimates filed by The Gas Company in support of its first-year earnings claim. Our results are reasonably consistent with The Gas Company's ex ante estimates except for a few cases. Realized savings on high-efficiency furnaces and high-efficiency water heaters are both considerably higher than the ex ante estimates, while realized savings from duct testing, duct insulation and heat traps are significantly lower. The results for duct insulation are unimportant, given the exceptionally low installation rate for this measure. The results for water heater traps may be partly attributable to the inability of the model to pick up the small savings expected from these measures. Given that the program focuses heavily on duct testing, it is of some concern that realized savings estimated for duct testing are just over half The Gas Company's *ex ante* estimate. This difference reflects two factors: the lower engineering estimate of this impact, which was based on the actual duct leakage found in the field for both participants and nonparticipants; and the results of the realization rate analysis.

Table 4-2: Comparison of ex ante Savings and Gross Realized Savings

Measure	*ex ante* Estimate	Engineering Estimate	Realization Rate	Realized Savings
DSM Measures				
High Effic Furnace (88%+ AFUE)	29	44.13	.93067	41.07
Duct Testing	22	16.97	.69560	11.80
Duct Insulation	5	1.62	.69560	1.13
Combined Hydronic Systems	23	26.59	.96458	25.65
High Effic Water Heaters(.70+ EF)	30	-	-	-
High Effic Water Heaters (.60-.69 EF)	14	18.92	1.10508	20.91
Heat Traps	10	3.58	.39144	1.40
Fuel Substitution Measures				
gas ovens	-19	-19.68	.79126	15.57
gas furnaces	-147	-143.64	.93067	133.68

Table 4-3 provides a comparison of realized savings for participants and nonparticipants. Since nonparticipants may have some measures that qualify for the program, this comparison is useful as a prelude to the net-to-gross analysis presented in Section 5. It is important to note that these estimates differ because of differences in household size, square footage, weather conditions, and a variety of other factors. Several key points should be made with regard to the comparison:

- For high-efficiency furnaces, we show two savings estimates. The first is for units that satisfy program requirements (88% AFUE or better). The second is the average savings level for all other units. Positive savings are included for units that beat code, but fall short of the program standard; while negative savings are included for units that fall short of code. As shown, participants in the first category save over 41 therms per year. All *other* participants with gas furnaces save on average 2.7 therms. The third entry listed for participants, the overall average savings, is a weighted average of the two savings estimates. As such, it takes into account the percentages of participants falling into the two categories.
- Interestingly, nonparticipants show larger savings for both 88+% AFUE units as well as for units falling below this efficiency level. The large savings for 88+% AFUE furnaces is somewhat misleading, in the sense that it reflects only three homes, all in relatively severe climate areas. The most important thing to note from this comparison is that nonparticipants' overall *average* savings from high-efficiency furnaces (4.23 therms) is considerably *below* the average efficiency savings for participants (10.88) as a result of nonparticipants' relatively low incidence of 88+% AFUE units.

- Both participants and nonparticipants have negative savings from "other" space heating measures. This implies that insulation and window treatments, taken by themselves, fall short of code. For participants, this suggests that some of the gains from incented measures may be counteracted by tradeoffs relating to insulation and glazing. Interestingly, though, nonparticipants perform even more poorly than participants on this count. Inspection of the data for individual sites showed fairly clearly that some tradeoffs were being made in participating and nonparticipating sites. The presence of high-efficiency equipment, for instance, was often linked with sub-code insulation levels or the presence of single-pane windows. Since nonparticipating homes perform at least as badly on this count, however, this behavior affects the gross savings but does not necessary affect the net savings.
- The results for high-efficiency water heaters are disconcerting. It is unsurprising that nonparticipants who *have* high-efficiency units save more than participants, since the former tend to be somewhat larger that the latter. The fact that the *overall average* water heating savings of nonparticipants' are higher than those enjoyed by participants, however, is troubling. This result can be partially attributable the fact that nonparticipants have nearly as high a saturation of high-efficiency water heating as participants. We will return to this point in Section 5.

Table 4-3: Realized Savings Estimates for DSM Measures (therms per year)

DSM Measure	Evaluation Estimate of Gross Realized Savings	
	Participants	Nonparticipants
High-Efficiency Furnace		
qualifies for program (88%+ AFUE)	41.07	102.73
all other furnaces	2.73	3.31
average system efficiency savings	10.88	4.23
Duct Testing	11.80	-
Duct Insulation	1.128	-
Other Space Heating Measures	-3.50	-4.31
Combined Hydronic Systems	25.65	32.07
High-Efficiency Water Heaters		
qualifies for program (.70+ EF)	-	-
qualifies for program (.60-.69 EF)	20.91	23.83
all other water heaters	7.22	7.92
average water heater efficiency savings	18.69	20.47
Heat Traps	1.40	1.73
Other Water Heating Measures	4.86	3.40

Table 4-4 summarizes the total program results of the realization rate analysis. It combines realized savings estimates with estimates of measure-specific installation rates to develop estimates of average gross realized savings per participant. There are several points to note about the estimates contained in Table 4-4:

- First, the *incented* installation rates listed in Table 4-4 for DSM measures are taken from program records. The *total* installation rates are based on one of two sources. If the measure was covered by the survey, the total installation rate is estimated based upon the survey responses and the appropriate expansion weights. These rates may be higher than those shown by program records due to installations outside the program. If the measure was not covered by the survey, the estimate is taken from program records. There was no method for identifying duct testing during the on-site visit.
- Second, the total installation rates shown for fuel substitution measures are taken from program records. It should be note that all participants, however, had gas ovens. Because of the special nature of fuel substitution portion of the program (which targets special circumstances), we are essentially focusing on incented measures here, rather than all installed measures. This differential treatment of fuel substitution measures will be discussed further in Section 5. In that section, we will apply a net-to-gross measure that focuses on the incented substitution measures.
- Third, the table includes only direct gas effects for the fuel substitution measures. These measures can be expected to reduce electricity consumption, and thus to conserve source fuel (probably gas, given the current generation mix). However, we did not have access to the electric consumption data that would be required to independently estimate the kWh impacts of the switch from electric ovens and space heating to their gas counterparts.
- Fourth, the realization rate did not cover some specific DSM measures (e.g., recirculation controls), so we have no independent estimates of the gas savings from these measures. As a result, we used The Gas Company's *ex ante* estimates for the purposes of calculating total gross program savings. The savings from these measures account for less than 0.4% of The Gas Company's total *ex ante* estimate of DSM savings, however, so this shortcut should have little influence on the overall findings of the study.

Two estimates of gross savings are provided in Table 4-4. The first is based on installation rates from program records, while the second is based on total participant installation rates. As shown, the realized gross savings per participant for incented DSM measures is estimated to be 23.13 therms per year. Fuel substitution savings are -3.87 per participant. Total gross realized program savings for DSM measures are estimated to be 197,000 therms. This compares to the savings estimate made by The Gas Company in its first earnings claim, which amounted to roughly 250,000 therms. Total participant savings, however, is far higher than incented savings, amounting to over 341,000 therms annually. This latter value will be the interpreted gross savings estimate used in the net-to-gross analysis presented in the Section 5. This is the appropriate approach, because the net-to-gross analysis will also make use of nonparticipant savings from all measures. The use of a comprehensive indicator of savings is important because of the potential for free drivership as well as the possibility of tradeoffs across incented and non-incented measures.

Table 4-4: Realized Gross Program Savings

Non-Fuel Substitution Measures	Realized Savings	Installation Rate		Measure Savings per Participant		Measure Savings, All Participants	
		Incented	Total	Incented	Total	Incented	Total
High-Efficiency Furnaces (88+% AFUE)	41.07	0.17267	0.21035	7.09	8.64	60,456	73,648
All other furnaces	2.73	0.00000	0.78049	0.00	2.13	0	18,165
Duct Testing	11.80	0.72094	0.72094[d]	8.51	8.51	72,523	72,523
Duct Insulation	1.13	0.00023	0.00511	0.00	0.01	2	49
Other Space Heating Measures	-3.50	0.00000	0.99084[c]	0.00	-3.47	0	-29,564
Combined Hydronic Systems	25.65	0.13760	0.17725	3.53	4.55	30,088	38,759
High-Efficiency Water Heaters(.70+ EF)	30.00[a]	0.00082	0.00082[d]	0.02	0.02	210	210
High-Efficiency Water Heaters(.60-.69 EF)	20.90	0.18393	0.82885	3.84	17.33	32,771	147,749
All other water heaters	7.22	0.00000	0.16027[b]	0.00	1.16	0	9,865
Heat Traps	1.40	0.01713	0.10717	0.02	0.15	204	1,279
Other Water Heating Measures	4.86	0.00000	0.98912[e]	0.00	4.81	0	40,981
Recirculation Controls	405.00[a]	0.00012	0.00012[d]	0.05	0.05	414	414
MH Water Heaters (.60 EF)	21.00[a]	0.00000	0.00000[d]	0.00	0.00	0	0
MH Furnace (80-87% AFUE)	14.00[a]	0.00399	0.00399[d]	0.06	0.06	476	476
MH Furnace (88+% AFUE)	37.00[a]	0.00000	0.00000[d]	0.00	0.00	0	0
All Non-Fuel Substitution Measures				**23.13**	**43.93**	**197,145**	**374,482**
Fuel Substitution Measures							
MF Gas Furnaces (78% AFUE)	133.68	0.00798	0.00798[d]	-1.07	-1.07	-9,094	-9,094
Gas Ovens	15.57	0.17994	0.17994[d]	-2.80	-2.80	-23,884	-23,884
All Fuel Substitution Measures				**-3.87**	**-3.87**	**-32,978**	**-32,978**
All Measures				**19.26**	**40.96**	**164,167**	**341,503**

a The Gas Company ex ante estimates. No realized savings could be estimated because none of the sampled sites installed this measure.
b These are saturations of gas equipment not meeting the program standards for the end-use efficiency in question.
c This installation rate is actually the saturation of gas space heating. Installation rates for specific measures are embedded in the savings estimate.
d These installation rates are based on program records.
e This is the saturation of gas water heating.

5

Net-to-Gross Analysis

5.1 Introduction

The gross program savings estimates derived from the realization rate model reflect savings obtained from measures adopted by participants, without regard for the influence of the programs on these adoptions. As indicated in the previous section, these estimates may include some free drivership, and this is appropriate. To the extent that these measures would have been adopted in the absence of the program, their savings may also include some *free-rider effects*. These impacts must be netted out of the estimates to derive reasonable estimates of net program impacts. Three alternative means of estimating free ridership were implemented for this evaluation:

- Self-reported estimates based on a telephone survey of participating builders,
- Simple comparisons of efficiency levels chosen by participants and nonparticipants, and
- Efficiency choice modeling.

These approaches are discussed in Sections 5.2 to 5.4. Section 5.5 provides an overview of the results of these analyses and identifies the net-to-gross ratios chosen for the evaluation of net impacts. Finally, Section 5.6 presents our estimates of total program net savings.

5.2 Self-Reported Free Ridership

The most direct means of estimating free ridership is to poll participants (i.e., participating builders) on the influence of the program on adoptions of covered and non-covered measures. Participants who report that they would have installed a given covered measure in the absence of the program would be considered free riders in this context. The use of self-reported free-ridership estimates is subject to both hypothetical bias and strategic bias. However, carefully crafted questions regarding decision-making criteria can be used to mitigate these biases. Self-reported estimates of free ridership were developed for the EAHP on the basis of telephone survey information collected from builders. The survey reminded each participating builder which measures he/she had installed in the development(s) under consideration, then asked how likely it was that they would have installed the measure without the program incentives. Possible answers were:

- Definitely would have installed the measure (100%),
- Probably would have installed it (67%),
- Probably would not have installed it (33%),
- Definitely would not have installed it (0%), and
- Don't know.

Specific probabilities of installation in the absence of the program were assigned to these responses. These probabilities are indicated in parentheses by the responses in question. "Don't know" responses were ignored in the analysis. The free-rider fraction for each measure was then defined as the average probability of installation. The implied net-to-gross ratio is just the reciprocal of the free-rider ratio. These ratios are available only for those measures installed by the surveyed builders.

The results are presented in Table 5-1. As shown, the net-to-gross ratios vary fairly sharply across specific measures. The highest estimate is for high efficiency furnaces, while the lowest values are for hydronic systems (allocated to space heating here for convenience) and high efficiency water heaters. These measure-specific values were translated into end-use specific values using total realized program savings from incented measures from section 4 as weights. According to these combined values, the net-to-gross ratio for space heating is roughly 66%, while the net-to-gross ratio for water heating is 43%. The estimated net-to-gross ratio for gas oven installations is just over 52%. Note that no estimates were available for some DSM measures (e.g., duct insulation), or for the multi-family gas furnace fuel substitution measure.

While these self-reported values offer some insights into program influences, they are subject to three problems: first, they are subject to the response biases to which we alluded earlier; second, they ignore the potential for participant free-drivership; and third, they are based on a relatively small sample of responding builders. As a result, we do not attach particularly great confidence in them. In the next two sections, we turn to two alternative means of focusing on free-ridership, each of which considers actual efficiency choices made by participants and nonparticipants.

Table 5-1: Self-Reported Free Ridership Estimates

Program Measure	Number of Homes Represented	Self-Reported Free Ridership	Implied Net-to-Gross Ratio
Non-Fuel Substitution Measures			
High Effic Furnace (88+% AFUE)	27	17.0	83.0
Duct Testing	108	34.0	66.0
Combined Hydronic Systems	1	66.0	34.0
Weighted Average for Space Heating		**33.6**	**66.4**
High Effic Water Heaters (.60-.69 EF)	17	56.4	34.2
Water Heater Heat Traps	4	31.9	68.1
Weighted Average for Water Heating		**57.1**	**42.9**
Fuel Substitution Measures			
Gas Ovens	16	47.6	52.4
MF Gas Furnaces (78+% AFUE)	-	-	-

5.3 Comparisons of Participant and Nonparticipant Efficiency

Participants and nonparticipant efficiency choices can be compared to derive rough estimates of free ridership, and these can be used to develop estimates of net program savings. In this approach, nonparticipant behavior is used as a proxy for the behavior of participants in the absence of the program. This approach can suffer seriously from self-selection bias. It was applied in the course of the analysis, for two reasons. First, it serves as a useful reference point for the results of the efficiency modeling described below; second, it provides some insights about the general process of efficiency choice in new construction.

Development of Efficiency Indices

The first step of the efficiency analysis was the development of a set of efficiency indices. As explained earlier, engineering estimates of savings relative to a reference level of usage were developed for each end use and each site on the basis of program information. These estimates, coupled with the results of the realization rate analysis, were used to define a set of efficiency indices (EFF_{ie}) as:

$$(1)\quad EFF_{ie} = \alpha_e(X_{it})\left[\sum \beta_{je} EEPSAV_{ijet} - \sum \beta_{ke} EEOSAV_{iket}\right] / \hat{\alpha}_e(X_{it}) EEREF_{ie}$$

where all realized savings estimates in the numerator and the reference usage in the denominator have been annualized and weather-normalized. Note that the efficiency measures represented in the numerator include both covered measures and non-program measures. The is important given the potential for the program to affect builders' installation of non-program measures (either because of free drivership or because of efficiency substitution in satisfying energy budgets). While the efficiency measures may seem complex, each one simply represents the proportion by which the site "beats Code" for the end use in question. Two efficiency indices were developed: one for space heating and one for water heating.

Efficiency Comparisons

Figure 5-1 and Figure 5-2 present the results of the efficiency comparisons. Each figure shows overall end-use efficiency levels for participants and nonparticipants, as well as the decomposition of these estimated efficiency levels into program measures, which are defined in this context as those that qualify for incentives *whether or not* they are incented for the sites in question; and other measures. For water heating, the latter category includes water heater blankets, pipe wrap, and water heaters that fall short of the .60 energy factor required by the program. For space heating, they include insulation, window treatments, and equipment efficiency under the program requirement. According to the estimates in Figure 5-1, participants are 11.03% more efficient than code with respect to space heating usage, while nonparticipants are only 0.05% more efficient. Inspection of the data on individual space heating measures suggests that nonparticipants occasionally install program measures, but seem to be doing so to allow lower insulation levels.

Figure 5-2 suggests that water heating efficiencies are nearly indistinguishable between participants and nonparticipants, with both beating code significantly. This stems from the fact that the saturation of high-efficiency water heaters (with energy factors between .60 and .69) is very similar between the two groups. As discussed in Section 2, the survey data suggest that an energy factor of .60 has become the market standard, even though code requires an efficiency of only 0.54 for a typical tank size.

Figure 5-1: Comparison of Space Heating Efficiency Indices

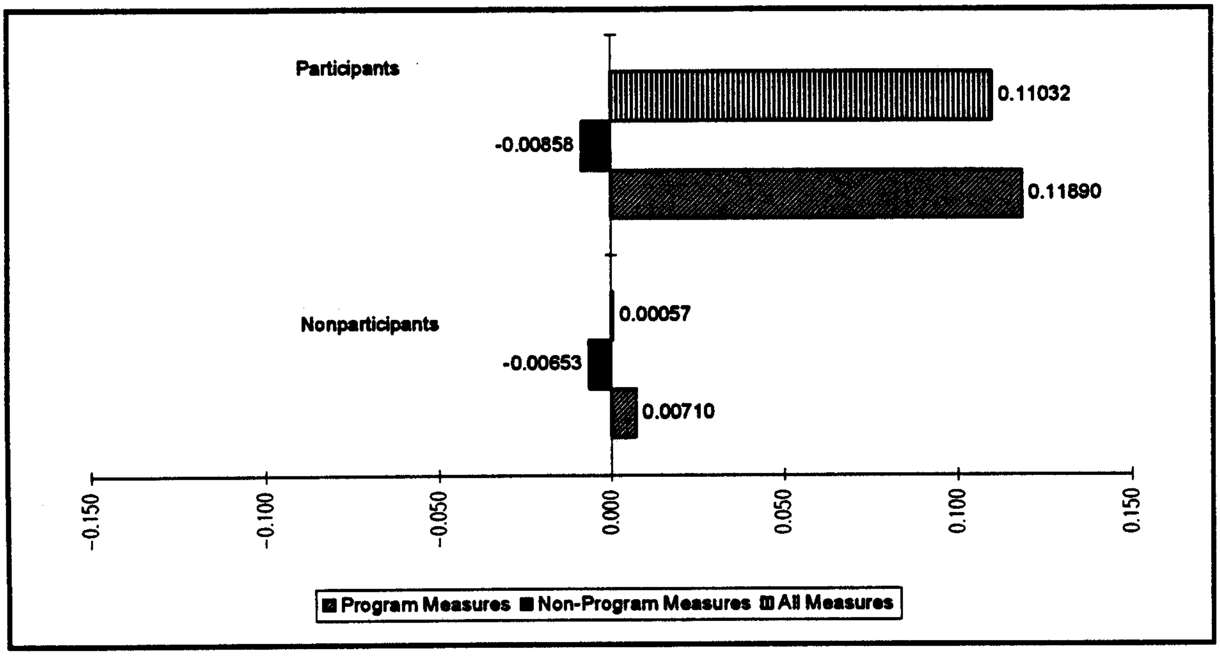
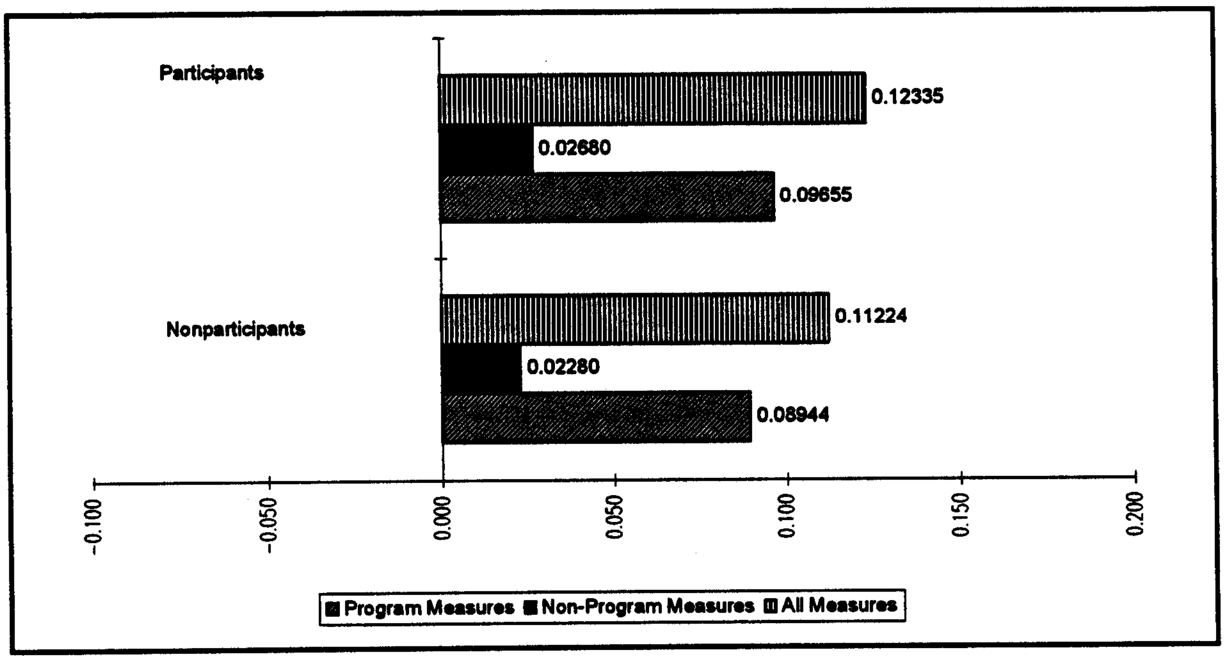


Figure 5-2: Water Heating



Fuel Substitution

For the case of gas ovens, the impacts of fuel substitution can be estimated through the comparison of participant and nonparticipant shares. Our sample suggests that 73.6% of all participants and 65.7% of nonparticipants have a gas oven. This implies a net impact of just under 8%. Unfortunately, comparisons of shares of conventional (78% AFUE) gas furnaces in the multi-family segments do not provide usable evidence of impacts. Indeed, participants had a lower share of conventional units than nonparticipants, leading to the apparently anomalous conclusion that the program had a negative net impact on the installation of these measures. However, the shares simply reflect the fact that participants are much more likely to install high-efficiency units rather than conventional (78% AFUE) equipment. This aspect of the program is targeted specifically at builders who are considering heat pumps as an option, and comparisons of participant and nonparticipant shares of this type of conventional gas furnaces simply does not reveal the impact of this offering.

Implied Net-to-Gross Ratios

The comparison of efficiency levels chosen by participants and nonparticipants can be used to develop a set of net-to-gross ratios for space heating and water heating. The calculation is fairly straightforward. For efficiency measures, we have:

$$\textit{Net-to-Gross Ratio} = \frac{\textit{Participant Efficiency} - \textit{Nonparticipant Efficiency}}{\textit{Incented Participant Efficiency} - \textit{Baseline Efficiency}}$$

For fuel substitution measures, we have:

$$\textit{Net-to-Gross Ratio} = \frac{\textit{Participant Share} - \textit{Nonparticipant Share}}{\textit{Incented Participant Share}}$$

Two points should be noted about these calculations. First, this approach uses a comprehensive view of net efficiency (the numerator), in that it compares both program and non-program measures. This is justified because of the need to recognize tradeoffs across measures. Second, the choice of a denominator depends upon the use of the net-to-gross ratio. If we were to apply it to total participant savings (from incented and non-incented measures), we would have used total participant efficiency in the denominator. Since our intention is to apply it to gross *program* savings from incented measures, however, we must choose this version of gross program savings as the denominator.[1]

[1] Note that this is different from the program efficiency values shown in Figures 5-1 and 5-2. In the context of these figures, savings from program measures cover all measures qualifying for incentives, whether or not they are incented. While this distinction makes little difference for space heating, it is important for water heating. This is because a large number of participants installed qualifying high-efficiency water heaters without incentives.

The net-to-gross ratios arising from this method for efficiency measures are derived in Table 5-2. As indicated, the net-to-gross ratio for space heating is quite high, while the water heating ratio is very low.

Table 5-2: Net-to-Gross Ratios Based on Simple Efficiency Comparison

End Use	Net Efficiency Impact	Participant Program Efficiency (Gross Efficiency Impact of Incented Measures)	Implied Net-to-Gross Ratio
Space Heating	0.10975	0.11380	0.964
Water heating	0.01111	0.04017	0.277

Table 5-3 presents the net-to-gross results for fuel substitution measures, based on comparisons of shares in the relevant populations. As shown, the net-to-gross ratio for gas ovens is 44%. As discussed above, we were unable to develop a sensible estimate of the net-to-gross ratio for conventional gas furnaces.

Table 5-3: Net-to-Gross Ratios for Fuel Substitution Measures

Fuel Substitution Measure	Participant Share	Nonparticipant Share	Incented Share (Participants)	Implied Net-to-Gross Ratio
Gas Ovens	0.73624	0.65728	0.17994	0.439
78 AFUE Gas Furnaces (MF)	0.01815	0.20416	0.00399	na

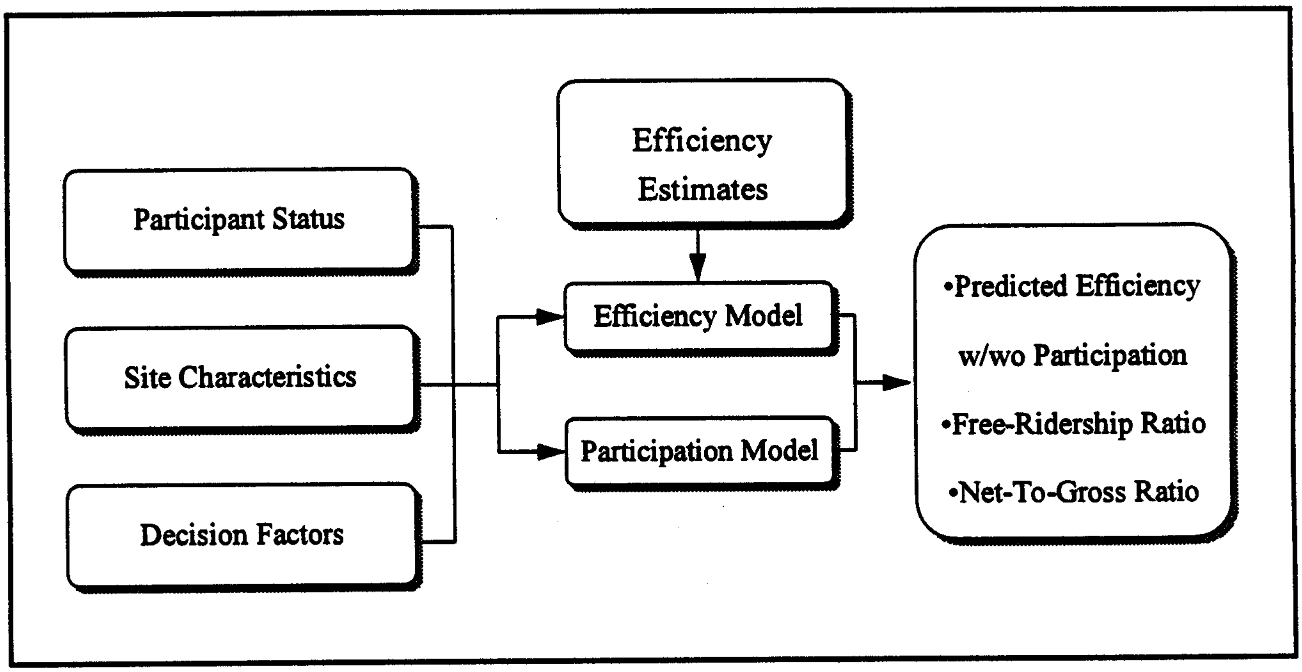
5.4 Efficiency Modeling

Simple efficiency comparisons can be misleading for two reasons: first, efficiencies in participating and nonparticipating homes may differ for a variety of reasons unrelated to the program. For instance, participation homes may be larger, more expensive, or in more severe climate zones than nonparticipating homes. Clearly, there is a need to control for these differences if we are to infer program impacts from comparisons. Second, as noted above, self-selection bias may affect such comparisons, and some means of dealing with this problem needs to be implemented. For these reasons, we developed a set of efficiency choice models to assess net-to-gross issues for the Program. This modeling approach is described briefly below.

Overview of General Efficiency Modeling Approach

The general structure of the efficiency modeling approach is illustrated in Figure 5-3. As shown, the model recognizes that a variety of factors affect both the developer's participation decision and the choice of efficiency levels. Efficiency and participation decisions are also recognized to be interdependent. The model is used to simulate what participants' efficiency choices would have been in the absence of the program, a result that can be translated into a net-to-gross ratio. When applied to new construction programs, the model is generally developed at the individual site end-use level, using information on the sites as well as the decision-makers (developers).

Figure 5-3: Efficiency Choice Model



The models recognize that several factors affect the choice of efficiency. Program participation by the builder at the site in question, of course, is expected to encourage adoptions of high-efficiency equipment as a consequence of better information and (if available) incentives. Builder participation in the educational portion of the program could also influence efficiency decisions. However, it must be noted that adoptions may affect program participation. Participation is endogenous to adoptions (indeed, this is one characterization of self-selection bias). Other factors also influence these decisions. Site characteristics (residence type, normal weather conditions, etc.) can affect the viability or attractiveness of various DSM options. Decision-maker characteristics (attitudes, perceptions, and decision criteria) affect the likelihood of installation of these measures. These characteristics were included in the model to control for differences across sites.

Model Specification

The general algebraic form of the efficiency model for each end use is:

$$(2)\quad PART_i = f(EFF_{ie}, DECISION_i, SITE_i, \varepsilon_{it})$$

$$(3)\quad EFF_{ie} = g_e(PART_i, SITE_i, DECISION_i, \mu_i)$$

where $PART_i$ is a binary indicator of participation in the incentive program, $DECISION_i$ is a set of builder decision variables, $SITE_i$, and is a set of site characteristics, and ε_i and μ_i are random error terms.

The specific model used for this evaluation is presented below. First, the participation model is given by:

$$(4)\quad Part_i = \frac{e^{\beta X_i}}{1 + e^{\beta X_i}}$$

where:

$$(5)\quad \begin{aligned} \beta X_i = {} & \beta_0 + \beta_1 SF_i + \beta_2 SQFT_i + \beta_3 HHSIZE_i + \beta_4 INC_i + \sum_z \alpha_z CZ_i + \beta_5 PAYBACK_i \\ & + \beta_6 NOUNITS_i + \beta_7 PERSF_i + \beta_8 ENEFFR1_i + \beta_9 FCOST_i + \upsilon_i \end{aligned}$$

and where:

SF_i	=	a binary indicator that the home is a single family dwelling
$SQFT_i$	=	square footage
$HHSIZE_i$	=	household size
INC_i	=	income
CZ_i	=	a binary indicator of climate zone
$PAYBACK_i$	=	the required payback of the builder
$NOUNITS_i$	=	the total number of residential units the builder has developed over the past three years
$PERSF_i$	=	the builder's percent of single family homes
$ENEFFR1_i$	=	a binary variable indicating that the builder ranked energy efficiency as the primary determinant of equipment choices

$FCOST_i$	=	a binary variable indicating that the builder cited first cost as the investment criterion used to evaluate energy efficiency
v_i	=	a random error term

The space heating efficiency equation is given by:

$$\begin{aligned} EFFH_i = {} & \gamma_0 + \gamma_1 SF_i + \gamma_2 SQFT_i + \gamma_3 HHSIZE_i + \gamma_4 INC_i + \gamma_5 ONEST_i \\ & + \gamma_6 PAYBACK_i + \gamma_7 ENEFFR1_i + \gamma_8 FCOST_i + \eta_i \end{aligned} \tag{6}$$

where:

$EFFH_i$	=	space heating efficiency (proportion by which as built usage beats code
$ONEST_i$	=	a binary variable reflecting that the home is a single-story dwelling
η_i	=	a random error term

Finally, the water heating efficiency equation is:

$$\begin{aligned} EFFW_i = {} & \rho_0 + \rho_1 SF_i + \rho_2 SQFT_i + \rho_3 HHSIZE_i + \rho_4 INC_i + \rho_5 ONEST_i \\ & + \rho_6 PAYBACK_i + \rho_7 ENEFFR1_i + \rho_8 FCOST_i + m_i \end{aligned} \tag{7}$$

i

where:

$EFFWi$	=	space heating efficiency (proportion by which as built usage beats code
μ_i	=	a random error term

Model Estimation

The participation equation and the two efficiency equations were estimated using data on efficiency choices, site features, decision-maker characteristics, a binary participation variable, and the factors affecting participation. Because of endogeneity of program participation and self-selection of the participants and nonparticipants, the estimation technique had to be designed to resolve self-selection bias. There were three options in this regard:

Self Selection Correction. First, a self-selection correction term (an inverse Mills Ratio) could be included in the efficiency equation. This term is a function of the predicted probability of participation, which is derived from the estimated reduced-form equation for the participation decision. (A reduced form equation is one in which only exogenous variables appear on the right-hand side.) In general, we can expect self-selection bias to be a potential problem for voluntary programs like the EAHP. For this kind of model, mitigating this bias generally involves the incorporation of an inverse Mills Ratio (call this MR_i) into the efficiency model. The Mills Ratio is derived from a participation equation of the form:

$$(8)\quad PART_i = g(SC_i, EDC_i, CLIM_i, BC, PAYBACK, TOTCOST, \mu_i).$$

where, SC_i consists of site characteristics, EDC_i reflects the economic and demographic characteristics of the household, $CLIM_i$ is an indicator of CEC climate zone, *BC* represents characteristics of the builder, *PAYBACK* is the payback rate for a piece fo high efficiency equipment, and *TOTCOST* indicates if the initial cost is of primary importance to the installation of a piece of equipment. The variable μ_i is a random error term. Note that all explanatory variables in expression (8) are constant for each household. The Mills Ratio is a function of the predicted value of participation as derived from the estimated form of expression (8) and differs across participants and nonparticipants. The reduced form of the participation equation could be obtained by solving the above efficiency/participation system for participation in terms of the exogenous variables contained in the system. This method is typically attributed to Heckman. The simple application of the inverse Mills Ratio is a subject of some controversy in the evaluation literature. However, a recent paper by Goldberg and Train (1996) suggest that the ratio should be entered twice in the energy change equation: once as a free-standing term and once interactively with the participation term. The logic of this specification is that the Mills Ratio affects the change in usage as well as the impact of the participation variable in the energy change equation. With this specification, the net impact of participation on the change in energy consumption is a function of the Mills Ratio.

Two-Stage Least Squares. Second, the adoption model could be estimated along with a participation model using two-stage least squares, thus dealing with the simultaneous equation bias inherent in the application of ordinary least squares. In this approach, often attributed to Train, the predicted probability of participation would be used as an instrument for (i.e., substituted for) the participation variable in the efficiency model, and the coefficient of the predicted participation variable would be interpreted as conveying the net program impact on efficiency.

Maximum Likelihood Estimation. Third, the adoption model and the participation model could be estimated simultaneously using full information maximum likelihood estimation. This approach, which can be attributed to Wang, is more efficient that the two-stage approach, but considerably more difficult to implement.

We estimated versions of the first two options: the double Mills Ratio approach and the two-stage least squares approach. The resultant efficiency equations are depicted in Table 5-3. Version 1 refers to the use of two-stage least squares, while Version 2 incorporates the use of the double Mills Ratio approach.

Space Heating Models. As shown in Version 1 in Table 5-4, participation (as represented by predicted participation from the participation model, PART*) is positive and highly significant. In this form of the model, this coefficient represents the net impact on efficiency. Thus, the coefficient suggests that, participation in the program increases space heating efficiency by 0.1296, controlling for other factors. Version 1 also suggests that space heating efficiency in single family homes tends to be somewhat lower than in multifamily dwellings (probably reflecting high efficiency combined systems), that larger homes tend to have more efficient space heating, that one story homes tend to be slightly less efficient, and that homes in severe climates tend to be more efficient. It also suggests that builders with high critical payback periods are less likely to install space heating efficiency, and that builders who use first cost as their primary efficiency choice criterion are less likely to install efficiency. The one anomalous result is that builders who rank efficiency as their primary criterion for designing new homes are less likely to choose efficiency. This latter result may indicate that responses to this question were less than frank, since it would be surprising for any developer to make equipment choices primarily on the basis of energy efficiency.

Version 2 of the space heating model yields similar results. Note that the net impact of participation in this model has to be calculated using both of the participation terms. Given a conditional mean value of the Mills Ratio of -1.233 (derived from the estimated participation model explained above), this net impact is given by:

Net Space Heating Impact = 0.117929 - 0.006976(-1.233) = 0.126530

Note that this is very similar to the net impact yielded by Version 1.

Water Heating Models. Two versions of the water heating model are also presented in Table 5-4. Version 1, which is based on the two-stage least squares approach, yields a net impact of 0.017. Version 2, which makes use of the double Mills Ratio approach, generates the following estimate of the net impact:

Net Water Heating Impact = 0.01829 + 0.004018(-1.233) = 0.013466

Note that the *SQFT* and *HDDN* are absent from the water heating efficiency models. Square footage was excluded because of insignificance of the estimated parameter and water heating is not considered to be a weather sensitive end use.

Like the space heating models, the water heating models reveal other insights into efficiency choice behavior. For instance, they indicate that single family homes tend to have lower water heating efficiency levels, that homes that accommodate large household sizes tend to be less efficient than others, and that reported decision-maker decision factors have little influence on efficiency levels. Note that the relationship between efficiency and household size probably traces at least partly to the definition of the Title 20 baseline for water heater unit efficiency. We used a reference energy factor of .54, which corresponds to the required efficiency at an average tanks size. However the Federal requirement for water heater manufacturers is stated in terms of tank size, with larger tank sizes permitted lower energy factors. Since household size probably acts as a proxy for tank size, our results may simply reflect lower energy factors in larger tank sizes. Nonetheless, it is important to control for this phenomenon in estimating the net impact of participation on the choice of water heater efficiencies.

Table 5-4: Estimated Efficiency Equations

Explanatory Variable	Space Heating		Water Heating	
	Version 1	Version 2	Version 1	Version 2
Intercept	-0.022145 (1.05)	-	0.190237 (12.66)	0.194127 (12.58)
PART	-	0.117919 (14.92)	-	0.01829 (2.69)
*PART**	0.129553 (13.88)	-	0.016996 (2.36)	-
MR	-	0.011724 (2.35)	-	0.000688 (0.17)
*MR*PART*	-	-0.006976 (1.24)	-	0.004018 (0.84)
SF	-0.017725 (2.14)	-0.018884 (2.48)	-0.35304 (6.73)	-0.034986 (6.65)
SQFT	0.000021 (4.73)	0.000022 (5.28)	-	-
HHSIZE	-0.000919 (0.49)	-0.001536 (0.90)	-0.013094 (9.11)	-0.013037 (9.06)
INCOME (in 000)	-0.000020 (0.21)	0.000013 (0.16)	-000077 (1.33)	-0.000079 (1.35)
ONESTORY	-0.011182 (1.86)	-0.009672 (1.75)	-	-
HDDN (in 000)	0.005984 (2.20)	0.007925 (3.17)	-	-
PAYBACK	-0.006144 (2.31)	-0.003736 (1.50)	-0.000399 (0.20)	-0.000797 (0.40)
ENEFFR1	-0.049278 (2.19)	-0.038621 (1.85)	-0.003015 (0.15)	-0.00588 (0.30)
FCOST	-0.004251 (0.23)	0.000979 (0.055)	-0.002719 (0.18)	-0.006704 (0.43)
Adjusted R^2	0.407	0.500	0.245	0.245

Simulation of Net-to-Gross Ratios

Once the efficiency model was estimated, it was used to estimate the impact of program participation on efficiency levels for specific sites. Based on these estimates, a set of net-to-gross ratios was computed. For any individual participant (say, participant *i*), the net-to-gross ratio conservation measures for end-use *k* was defined as:

$$Net\text{-}to\text{-}Gross\ Ratio_{ie} = \left(\partial EFF_{ie} / \partial PART_i\right) / PEFF_{ie}$$

where the net impact in the numerator is derived as the effect of the participation variable on the site's adjusted efficiency, and the denominator ($PEFF_{ie}$) is participant efficiency from incented measures. Weighting and aggregating net savings and gross program savings across all participants, we derive the overall program net-to-gross ratios shown in Table 5-4.

Table 5-4: Net-to-Gross Ratios Based on Model Results

End Use	Net Efficiency Impact	Participant Program Efficiency (Gross Efficiency Impact of Incented Measures)	Implied Net-to-Gross Ratio
Space Heating			
Version 1	0.129553	0.11380	1.138
Version 2	0.126530	0.11380	1.112
Water Heating			
Version 1	0.016996	0.04017	0.423
Version 2	0.013466	0.04017	0.355

5.5 Summary of Net-to-Gross Results

Three approaches have been implemented to estimate net-to-gross ratios for space heating and water heating savings associated with the EAHP: the development of survey-based self-reported values; the simple comparison of participant and nonparticipant efficiency levels; and the use of statistical modeling to compare efficiency levels while controlling for other factors affecting these choices. These approaches yielded generally similar results, as indicated below:

- Both efficiency comparisons and modeling estimates indicate that the net-to-gross estimate for space heating efficiency is close to 100%. The modeling estimates suggest that there may be some participant free-drivership generated by the program. While the self-reported estimate is considerably lower than the other estimates, its vulnerability to various biases cause us to weight it less heavily in the final determination of net impacts. For the purposes of the estimation of overall net program savings, we choose a net-to-gross ratio of 1.0 for space heating.

- All of our estimates indicate that free-ridership is strong for water heating measures. This is particularly true for high-efficiency water heaters. While Title 20 and national manufacturer standards requires an energy factor of .54 for an average sized tank, most of the water heaters covered by the surveys had energy factors around or over .60. Given the evidence shown in Table 5-5, we opt to use a net-to-gross ratio of 36% for water heating efficiency measures.
- No reasonable estimate of the net-to-gross ratio for conventional gas furnace fuel substitution could be developed. The program recorded only 34 homes for which this measure was incented (out of a total participant population of over 8,000), and statistical analysis cannot be expected to reveal much about this kind of targeted measure. For the purposes of this evaluation, we assume a net-to-gross ratio of 1.0 for this measure. While this is arbitrary, it has little influence on the overall results of the evaluation, insofar as impacts stemming from this measure accounted for a very small fraction of gross impacts.
- For gas ovens, only two types of estimates were developed: self-reported estimates and estimates based on comparisons of participant and nonparticipant shares. These estimates are in reasonable agreement. For the remainder of the analysis, we choose a net-to-gross estimate of .50 for this measure.

Table 5-5: Summary of Net-to-Gross Results

End Use/Type	Self-Reported Estimates	Simple Comparisons	Modeling Estimates		Estimates Chosen for Evaluation
			Version 1	Version 2	
Non-Fuel Substitution Measures					
Space Heating	66.4%	96.4%	113.8%	111.2%	100.0%
Water Heating	42.9%	27.7%	42.3%	35.5%	36.0%
Fuel Sub Measures					
MF Gas Furnaces	na	na	na	na	100.0%
Gas Ovens	52.4%	43.9%	na	na	50.0%

5.6 Summary of Net Program Savings

We summarize our analysis by combining the results of Sections 4 and 5. Table 5-6 provides this summary by measure and end use. The table presents realized savings per measure, the proportion of participants incented to install the measure, total realized gross savings, net-to-gross ratios, and estimated net savings. Note that our estimates are based on a total of 8,525 participants. This estimate is somewhat lower than the estimate underlying The Gas Company's ex ante estimates, primarily because of the use of a more stringent means of allocating participants to the 1994 program year. Note also that the impacts of low-saturation measures not covered by our realization rate analysis have been set equal to the values reported in The Gas Company's first-year earnings claim. This simplification has little bearing on the overall estimate of savings, insofar as these measures account for a very low fraction of savings. Four major conclusions arise from this summary:

- First, according to our analysis, total gross program savings for the 1994 program amount to over 164,000 therms. Gross savings from non-fuel substitution measures are over 197,000 therms, while fuel substitution is estimated to increase gas usage by almost 33,000 therms. This compares with The Gas Company's *ex ante* estimate of 212,597 therms overall, 251,644 therms for non-fuel substitution and 39,047 therms for fuel substitution.
- Net program savings are almost 155,000 therms. Net savings associated with non-fuel substitution measures are estimated to be just under 176,000. The net increase in gas consumption stimulated by fuel substitution is slightly over 21,000 therms.
- In order to construct confidence intervals for gross savings, the model was re-estimated combining all savings terms weighted by their respective coefficient into a single composite term. The *t-value* on this term was used to construct confidence intervals for gross savings. This results in a 90% confidence interval of 132,256 to 205,077 Therms and an 80% confidence interval of 132,335 to 195,999 Therms.
- Confidence intervals for net savings were based on Version 1 for space heating and Version 1 for water heating of the efficiency choice model presented in Table 5-4. Insofar as net-to-gross ratios are estimated by end-use, confidence intervals were constructed for water heating and space heating measures and then summed. This results in a 90% confidence interval on net savings of 126,871 to 182,869 Therms and an 80% confidence interval of 133,050 to 176,690 Therms for all DSM measures.

Table 5-6: Summary of Estimated Net Program Savings

Program Measures	Gross Realized Savings per Measure	Percent Incented	Total Gross Program Savings[c]	Net-to-Gross Ratio	Total Net Program Savings
Non-Fuel Substitution Measures					
HE Furnaces (88+% AFUE)	41.07	0.17267	60,456	1.00	60,456
Duct Testing	11.80	0.72094[a]	72,523	1.00	72,523
Duct Insulation	1.13	0.00023	2	1.00	2
Combined Hydronic Systems	25.65	0.13760	30,088	1.00	30,088
HE Water Heaters(.70+ EF)	30.00[b]	0.00082[a]	210	0.36	76
HE Water Heaters(.60-.69 EF)	20.90	0.18393	32,771	0.36	11,798
Heat Traps	1.40	0.01713	204	0.36	73
Recirculation Controls	405.00[b]	0.00012[a]	414	1.00	414
MH Water Heaters (.60 EF)	21.00[b]	0.00000[a]	0	1.00	0
MH Furnace (80-87% AFUE)	14.00[b]	0.00399[a]	476	1.00	476
MH Furnace (88+% AFUE)	37.00[b]	0.00000[a]	0	1.00	0
All Non-Fuel Substitution Measures			**197,145**		**175,906**
Fuel Substitution Measures					
MF Gas Furnaces (78% AFUE)	-133.68	0.00798[a]	-9,094	1.00	-9,094
Gas Ovens	-15.57	0.17994[a]	-23,884	0.50	-11,942
All Fuel Substitution Measures			**-32,978**		**-21,036**
All Measures			**164,167**		**154,870**

a Installation rates are based upon program records.
b The Gas Company ex ante estimates of gross realized savings per measure. Realized savings could not be estimated ex post because the no sample sites installed this measure.
c Total gross program impacts = the product of gross realized savings per measure and ex post measure count.

First-Year Load Impacts of Southern California Gas Company's 1994 Energy Advantage Home Program

Study No. 709

CPUC Protocols: Tables 6 and 7

(Appendix F of Main Report)

February 24, 1997

Table 6: 1994 Energy Advantage Home Program

Item 1: Average Participant Group and Average Comparison Group Usage
A. Pre-Installation Usage, Base Usage, and Base Usage per Designated Unit of Measurement
Not applicable.[1]
B. Impact Year Usage, Impact Year Usage per Designated Unit
Not applicable.[1]

Item 2: Average Net and Gross End Use Load Impacts For the Impact Year				
		Item 5:		
	Point Estimate	90% confid interval	80% confid interval	Reference
A. Load Impacts				
The Gas Company Total Program Gross Impact (Therms) [2]	212,597	na	na	The Gas Company
The Gas Company Total Program Net Impact (Therms) [2]	200,015	na	na	The Gas Company
Estimated Total Program Gross Impacts(Therms) [3]	164,167	123,256 - 205,077	132,335 - 195,999	Gross Load Impact Model
Estimated Total Program Net Load Impacts (Therms)	154,870	126,871 - 182,869	133,050 - 176,690	Net Load Impact Model
B. Load Impacts Per Designated Unit (Per Dwelling Unit)				
The Gas Company Gross Impact (Therms) [2 4]	22.273	na	na	The Gas Company
The Gas Company Net Impact (Therms) [2 4]	20.955	na	na	The Gas Company
Estimated Gross Load Impacts (Therms) [3 5]	19.257	14.45 - 24.1	15.5 - 23.0	Gross Load Impact Model
Estimated Net Load Impacts (Therms) [5]	18.166	14.9 - 21.5	15.6 - 20.7	Net Load Impact Model

[1] Insofar as this is a new construction program, the methodology focuses directly on savings rather than on pre- and post-installation consumption.
[2] The Gas Company Estimates are taken from The Gas Company's earnings claim.
[3] Gross evaluation estimates are weather-normalized.
[4] Assuming 9,545 sites.
[5] Assuming 8,525 sites.

Table 6: 1994 Energy Advantage Home Program (continued)

C. Percent Change in Usage of the Participant Group and Comparison Group
Not applicable.[6]

	Point Estimate	Item 5: 90% confid interval	Item 5: 80% confid interval	Reference
D. Net and Gross Impact Realization Rates[7,8]				
Gross Impact Realization Rate, Total Program Savings	0.7722	na	na	Gross Impact / Filed Gross Savings
Gross Impact Realization Rate, Savings per Household	0.8646	na	na	Gross Impact / Filed Gross Savings
Net Impact Realization Rate, Total Program Savings	0.7743	0.6343 - 0.9143	0.6652 - 0.8834	Net Impact / Filed Net Savings
Net Impact Realization Rate, Savings per Household	0.8669	0.6343 - 0.9143	0.6652 - 0.8834	Net Impact / Filed Net Savings

Item 3: Net-to-Gross Ratios[9]				
A. Net-to-Gross Ratios Based Upon Estimated Program Load Impacts	0.9434	na	na	Net Impact/ Gross Impact
B. Net-to-Gross Ratios Based Upon Estimated Average Load Impacts Per Dwelling Unit	0.9434	na	na	Net Impact/ Gross Impact

Item 4: Designated Unit Intermediate Data
Not applicable.

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[6] This analysis did not estimate UECs.

[7] Gross savings realization rates are defined as the ratios of evaluation estimates of gross savings to the gross savings estimate filed with The Gas Company's earnings claim.

[8] Net savings realization rates are defined as the ratios of evaluation estimates of net savings to the net savings estimate filed with The Gas Company's earnings claim.

[9] Net-to-Gross ratios presented here are defined as evaluation estimates of net savings divided by evaluation savings of gross savings.

Table 6: 1994 Energy Advantage Home Program (continued)

Item 6: Measure Count Data			
A. Number of Measures Installed by Participants in the Participant Group (Refer to Table 2-7)			
End Use	SF On-Site	MF On-Site	All Homes
Duct Testing	240	23	263
Duct Insulation	3	-	3
Furnace 88+% AFUE	71	1	72
Water Heater 60-69 EF	344	67	411
Water Heater 70+ EF	1	-	1
Ovens	283	65	348
Manufactured Home Furnace	-	-	-
Heat Traps	53	13	66
Furnace 78+ AFUE	-	-	
Combination Furnace/Water Heating	4	20	24
Recirculation Controls	-	-	-
Total Installed	*999*	*189*	*1,188*

B. Number of Measures Installed by All Program Participants in the 12 Months of the Program Year	
End Use	Number of Measures Installed
Duct Testing	6,146
Duct Insulation	2,640 L. ft.
Furnace 88+% AFUE	1,472
Water Heater 60-69 EF	1,568
Water Heater 70+ EF	7
Ovens	1,534
Manufactured Home Furnace	34
Heat Traps	146
Furnace 78+ AFUE	68
Combination Furnace/Water Heating	1,173
Recirculation Controls	1

Table 6: 1994 Energy Advantage Home Program (continued)

Item 6 (continued) C. Number of Measures Installed by Comparison Group	
End Use	**Number of Measures Installed**
Duct Testing	0
Duct Insulation	0
Furnace (88+% AFUE)	3
Water Heater (.60-.69 EF)	143
Water Heater (.70+ EF)	1
Ovens	128
Heat Traps	27
Combination Furnace/Water Heating	5
Other Space Heating Measures	183

Item 7: Market Segmentation Data		
Climate Zone	**Participant Group**	**Comparison Group**
Coastal	47	29
LA Basin	125	46
Inland Valley	81	68
High Desert	44	32
Low Desert	5	18
Mountain	1	5
All Zones	303	198

Table 7: 1994 Energy Advantage Home Program Data Quality and Processing

7.A Overview Information
1. 1994 Energy Advantage Home Program, study ID number 709.
2. The program year is 1994. The Energy Advantage Home Program (EAHP) is designed to induce builders to increase energy efficiency in new homes beyond the levels required by Titles 20 and 24. The program offers informational and training workshops for builders, and provides incentives for efficiency actions such as installation of high-efficiency gas space and water heating equipment, heat traps, and duct insulation, builder duct testing, and the installation of gas space heating and oven as alternatives to electric options. See Section 1.2 for a detailed program description.
3. The measures and end uses covered by this analysis include both demand side management (DSM) measures and fuel substitution measures. DSM measures include furnaces (88% AFUE), duct testing, duct insulation, combined hydronic systems, HE water heaters (.60-.69 EF and .70 EF), heat traps, recirculation controls, MH water heaters (.60 EF), and MH furnaces (80% - 87% AFUE and 88%+ AFUE). Fuel substitution measures include MF gas furnaces (78% AFUE) and gas ovens.
4. The realization rate approach, a specific type of mixed engineering/statistical method, was used in this evaluation. This model relies on engineering estimates developed under three scenarios for both participants and nonparticipants: the reference scenario (e.g., minimal compliance with building and appliance energy efficiency standards); a set of intermediate scenarios representing the introduction of individual program and non-program measures in sequence; and an as-built scenario (with all program and non-program measures in place). The development of engineering estimates is detailed in Section 4. The model also makes use of information on factors that might affect the realization of the engineering estimates of usage under these scenarios and the associated DSM-related savings. The model produces a set of adjustment coefficients (or adjustment functions) that translate engineering estimates into estimates consistent with observed energy usage and savings. These coefficients reflect the proportion of the engineering-based savings estimates actually realized in the form of reduced site usage. See Section 4.2 for a summary of the realization rate model specification.
5. In this analysis participants are defined as customers who participated in the 1994 Energy Advantage Home Program. Nonparticipants are considered to be all homes completed in 1994 that did not participate in the program.

Table 7: 1994 Energy Advantage Home Program (continued)

6. The Gas Company's evaluation design specified a desired *combined completed sample size* of 500 homes consisting of 300 participants and 200 nonparticipants. This 300/200 split satisfies the Protocols, which call for 150 participant on-sites for each affected end use and "a comparable sample" of nonparticipants. Refer to Section 2.2 for a detailed summary of participant and nonparticipant analysis samples.

   As summarized in Table 2-7, there were a total of 999 installations in single family units and 189 installations in multifamily units; approximately 65% of all installations were related to space heating.

   The final analysis database consisted of 6,513 observations for 501 unique participating and nonparticipating sites.

7.B Database Management

1. The evaluation of the EAHP required several types of data. The integrated database for the evaluation is comprised of seven components: (1) on-site survey data for participating and nonparticipating homes, (2) duct blaster and blower door tests, (3) DOE-2 building simulations, (4) hourly weather data by CEC weather zone, (5) daily weather data by Gas Company weather zone, (6) household gas consumption records, and (7) telephone survey data of participating and nonparticipating builders and developers. Figure 2-1 provides an overview of the integrated database.
2. The RER project team collected the on-site survey data, the duct blaster and blower door tests, the DOE-2 simulations, and the telephone survey of participating and nonparticipating builders and developers. Hourly weather data by CEC weather zone was provided by the CEC, and the daily weather data was provided by The Gas Company.
3. The participant database consisted of 8525 sites. The nonparticipant sample for the on-site survey consisted of all homes completed in 1994 that did not participate in the Program. The initial sample of 50,000 homes was screened for participation, resulting in the initial sample frame of 34,177 nonparticipating customers. The final sample design specified 300 participants and 200 nonparticipants.
4. The Gas Company staff performed all internal data quality checks and matched customer billing records with Program records, survey data, and weather data.
5. Not applicable.

Table 7: 1994 Energy Advantage Home Program (continued)

7.C Sampling
1. The participants for the on-site survey were sampled based upon a modified stratified sample design. The initial participant sample size equaled 600. This sample was stratified by residence type and proportionally sampled across dwelling type. This sample was also stratified by weather zone with a Neyman allocation strategy, based upon variability of total gas usage within and across these strata. This sample was then modified to ensure sufficient coverage of all measures. Section 2.2 and Table 2-1 summarize the complete participant sample design for the on-site survey. The sampling design and protocols for nonparticipants are identical to those employed for the participant sample design. The sample was stratified by residence type and weather zone. The strata targets were determined by proportional stratification across residence types and by Neyman allocation across weather zones within dwelling types. Refer to page Section 2.2 and Table 2-3 for a detailed summary of the nonparticipant sampling methodology. 2. The On-Site Survey Questionnaire is included as Appendix A, the Blower Door/Duct Blaster Survey Instrument is included as Appendix C, and the Builder and Developer Survey instruments are included as Appendix E. As indicated by Table 2-4, the overall response rate for participants was 33.3% for participants and 28.7% for nonparticipants. Reasons for refusals are detailed in Tables 2-5 and 2-6. Because the survey was conducted on-site item non-response was not a problem. Moreover, the use of stratified sampling largely mitigated problems associated with refusals of on-site candidates. 3. As shown in Table 2-7, and also presented in Item 6A of Table 6 above, there were a total of 1,188 measures installed by the completed on-site sample. Duct testing, water heaters (60 - 69 EF) and ovens account for approximately 86% of all installed measures. Table 2-8 summarizes demographic characteristics for both participants and nonparticipants in the analysis sample by residence type. Tables 3-7 and 3-8 present the engineering estimates of savings for participants and nonparticipants, respectively.

Table 7: 1994 Energy Advantage Home Program (continued)

7.D Data Screening and Analysis
1. In this project, we did not attempt to screen out outliers per se, but large residuals were reviewed to identify data anomalies. The following kinds of anomalies qualified an observation for deletion from the regression: (1) when bills were estimated or subsequently made up, and when these consumption reads were abnormal, they were set equal to missing, (2) consumption values indicated long periods of vacancy for a home, these values were set equal to missing, and (3) when reads simply seemed erroneous, they were also set equal to missing. A total of three sites were completely eliminated and an additional 50 observations were excluded from the analysis data set due to anomalous billing data. 2. Not applicable. 3. In this project, we reviewed large residuals in order to identify data anomalies. The following kinds of anomalies qualified an observation for deletion from the regression: (1) when bills were estimated or subsequently made up, and when these consumption reads were abnormal, they were set equal to missing, (2) when consumption values indicated long periods of vacancy for a home, these values were set equal to missing, and (3) when reads simply seemed erroneous, they were also set equal to missing. A total of three sites were completely eliminated and an additional 50 observations were excluded from the analysis data set due to anomalous billing data. In addition to consumption data, survey data were inspected carefully to identify anomalous responses. Misreporting is a chronic problem in survey-based analysis and careful inspection of responses is one of the most important aspects of data preparation. In most cases, comparing gas consumption patterns and end-use responses helped to identify erroneous responses. In cases where evidence of misreporting is clear, end-use designations in the database are overridden. The most recent 13 months of data for each site were utilized. In addition, screens were used to avoid changes in occupancy and to mitigate problems relating to changes in ownership from builder to home owner. 4. Regression statistics for the realization rate analysis are presented in Table 4-1 and the results of the estimated efficiency equations are presented in Table 5-4 5. Realization rate analysis is presented in Section 4, with the rationale for the model specification detailed in Sections 4-2 and 4-3. The net-to-gross analysis is presented in Section 5. 6. This analysis did not address the issue of measurement error.

Table 7: 1994 Energy Advantage Home Program (continued)

7. Autocorrelation, which is the correlation of the error term over time for individual sites, is typical in analyses of energy usage over time. This problem was mitigated with generalized least squares, a standard remedy. All models presented in the study correct for the presence of autocorrelation. Section 4-3 includes a discussion of methodology employed to mitigate the problem of autocorrelated errors.

8. This analysis did not specifically address the issue of heteroskedasticity. This is seldom a problem in this type of analysis of changes in household-level usage.

9. The issue of collinearity was addressed in this analysis through careful specification of interaction terms and through omission of some variables found to be highly collinear with others. Moreover, individual savings terms were aggregated with prior weights in some specifications in order to mitigate collinearity across program variables

10. The following kinds of influential data points qualified an observation for deletion from the regression: (1) when bills were estimated or subsequently made up, and when these consumption reads were abnormal, they were set equal to missing, (2) when consumption values indicated long periods of vacancy for a home, these values were set equal to missing, and (3) when reads simply seemed erroneous, they were also set equal to missing.

11. Observations considered to be anomalous, for reasons explained above in item 10, were excluded from the analysis data set. A total of three sites were completely eliminated and an additional 50 observations were excluded from the analysis data set due to anomalous billing data.

12. Standard errors on estimated parameters are a standard output of statistical analysis packages. Table 5-4 presents the t-statistics for each estimated parameter in the analysis. Confidence intervals for net savings were based on Version 1 for space heating and Version 1 for water heating of the efficiency choice model presented in Table 5-4. Insofar as net-to-gross ratios are estimated by end-use, confidence intervals were constructed for water heating and space heating measures and then summed.

7.E Data Interpretation And Application

1. Net Program impacts are calculated to be 154,870 therms. Table 5-6 summarizes realized savings per measure, in addition to total gross and net program savings.

2. Sections 4 and 5 detail the rationale for the realization rate model and the net-to gross analysis, respectively. More specifically, Section 4.2 summarizes the rationale for the realization rate model, and Section 4.3 discusses The Gas Company realization rate model in detail. and Section 5.4 discusses efficiency modeling and the simulation of net-to gross ratios.