Manufactured Home Acquisition Program

Analysis of Program Impacts

Final Report

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TABLE OF CONTENTS

TABLE OF TABLES

Executive Summary

Introduction

This report summarizes the performance of a sample of manufactured homes built to energy-efficiency standards in the Pacific Northwest. The Manufactured Homes Acquisition Program (MAP) extended Model Conservation Standards (MCS) to electrically-heated manufactured homes in the Northwest. Bonneville Power Administration (BPA) paid incentive payments to all Northwest manufacturers (there was unanimous participation) and was reimbursed by electric utilities serving the homes. The program paid out incentives to about 50,000 homes between April, 1992 and July, 1995. This report studies homes sited during the first year of the program.

Ecotope, Inc. wrote sampling and field audit protocols which were used by State Energy Office personnel in Idaho, Montana, Oregon and Washington to characterize the regional performance of the MAP. The field audit included a homeowner survey, home set-up review, and measurement of house and duct tightness. Auditors visited 178 homes in BPA's primary service territory.

The study also evaluated energy savings from the program. Utility bills were obtained for 162 of these homes. A variable-base degree-day analysis and an additional billing analysis were used to evaluate utility bills. Total bills were compared with earlier studies of submetered use in similarly constructed homes in order to assist in the analysis.

In earlier predictions of MAP home performance, a prototype manufactured home with an appropriate heat loss rate was modeled with an accepted simulation program to predict annual heating energy. Field audit data were used to tune the earlier simulations. The heating energy requirements of a prototype built to 1994 HUD thermal specifications and a MAP home were modeled in order to estimate program energy savings.

Findings From Homeowner Survey and Set-up Review

- MAP homeowners were overwhelmingly satisfied with their homes. They reported limited problems with comfort and/or high bills.

- Homeowners displayed uneven knowledge of mechanical ventilation systems. Many homeowners did not understand the purpose of whole-house ventilation and did not know how the system in their home worked.

- Average set-up compliance rate was about 75%. Crossover duct installation shortcomings and belly penetrations were the most common set-up deficiencies.

House/Duct Tightness Findings

- Blower door tests found an average air change rate at 50 Pascals (ACH_{50}) of 5.50 ACH. This tightness measurement, converted to an estimated natural infiltration rate, found that 94% of MAP homes fail ASHRAE air quality standard 62 of 0.35 ACH for natural infiltration/exfiltration.

- As operated, whole-house ventilation systems supplied, on average, just less than 0.05 ACH additional ventilation to homes. This level of added ventilation decreases the ASHRAE Standard 62 failure rate slightly, to 87%.

- Duct Blaster measurements found an average leakage rate of heated supply air to the crawlspace of about 104 ft^3/min at 25 Pa duct system pressure.

Energy Savings/Cost-Effectiveness Findings

The impact of MAP specifications on manufactured homes in the Pacific Northwest was ascertained using the SUNDAY engineering simulation. This simulation was calibrated to the results of a utility billing analysis with field audit data so that predictions of MAP space heating electricity use were consistent with field observations.

Using the assumptions generated from the calibration, the performance of homes built to 1994 HUD thermal specifications (which allow about 30% more building shell heat loss than MAP specifications) was estimated. Energy savings from the MAP were calculated using the new HUD specifications in a "base case" prototype home.

The average cost of MAP energy conservation in Zone 1 is approximately 29 mills ($0.029) per kWh saved, with the most expensive conservation measure costing about 34 mills. The regional average cost, weighted by the distribution of sitings among the various climate zones, is approximately 25 mills per kWh saved.

					Levelized Costs	
Climate Zone (weather site used)	1994 HUD space heat (kWh/yr)	MAP space heat (kWh/yr)	Savings (kWh/yr)	MAP Package Retail Cost ($)	Cumulative mills/kWh	Incremental* mills/kWh
1 (Portland)	8364	4737	3627	1915	28.8	33.8
2 (Spokane)	13888	8574	5314	1915	19.7	22.8
3 (Missoula)	16299	10129	6170	1915	17.0	19.6
TOTAL			4293		25.4	29.6

Changes from earlier MAP cost-effectiveness analyses which affected the results in this report are as follows:

- The long-term discount rate was increased from 3% to 4.8%.
- The distribution efficiency of the forced-air heating system was lowered from 99% to 86%, based on direct research.
- The thermostat setpoint was increased from 65° F to 67° F.
- The size of the prototype home was decreased from 1568 ft^2 to 1400 ft^2.
- Unintentional air leakage rates ("natural" infiltration/exfiltration) were changed from a uniform rate of 0.35 ACH to 0.24 ACH in Climate Zone 1, 0.29 ACH in Climate Zone 2, and 0.31 ACH in Climate Zone 3.
- The HUD base case home was reset to the 1994 thermal specifications (U_o=0.079 Btu/hr °F ft^2) as a result of changes in federal regulations.

Conclusion

The report finds that the MAP specifications and in-plant quality control have delivered a cost-effective resource to the region and a greatly improved, affordable home to the consumer.

1. Introduction

The purpose of this report is to document several reviews of the energy efficiency and building characteristics associated with the Manufactured Housing Acquisition Program's (MAP's) first year of operation (1992 - 1993).

In the mid-1980s, Bonneville Power Administration (BPA) began to investigate including manufactured housing in its growing portfolio of electrical energy conservation activities in the residential sector. Electrically-heated manufactured homes at that time accounted for about 10% of the new housing stock. Over the next several years, some manufacturers participated in various marketing Super Good Cents (SGC) and research (Residential Conservation Demonstration Program (RCDP) projects offered by the BPA through the State Energy Offices (SEOs) in the region.

In 1992, as a result of negotiations between the manufacturers and the BPA, the MAP was established. This program required that all of electrically-heated manufactured homes meet a set of uniform energy efficiency standards. The BPA and local utilities agreed to pay incentives directly to the manufacturer for each home produced.

The MAP contains a uniform set of specifications for individual manufactured homes. The program applies to all manufactured homes sold in the Pacific Northwest region (Washington, Oregon, Idaho and western Montana). During MAP's first year of operation, each manufacturer was given $2,500 per home built to MAP specifications, with the stipulation that every home heated with electricity would be built to this standard. The standard had some variation, depending upon the amount of glazing and other physical characteristics of home designs. Quality control ensured that manufactured homes maintained a performance level equivalent to the prescriptive specifications, even if some variations were allowed for individual manufacturers. These variations were applied for and approved by the SEOs, acting on behalf of the BPA and participating utilities. Inspections of each manufacturing plant were made through these agencies, ensuring that homes produced maintained the specifications.

Once the homes were built, they were sold through the existing manufactured homes dealer network. The program did not provide additional incentives to dealers or homebuyers, except as rebated by the manufacturers. Manufactured homes were set up on their sites using set-up manuals from the manufacturers. Some of the set-up crews were trained in and aware of factory standards; others were not. Home set-up included the air sealing of marriage lines, crossover duct installation, bearing point installation, and the bracing of doors and other components.

Thermal standards specified by MAP were about 60% more efficient than the 1976 HUD standards. Homes were to be built with a normalized overall heat loss rate (U_o) of 0.053 Btu/hr °F ft^2(not including heat loss rate due to air infiltration). Homes were equipped with whole-house ventilation systems, consisting almost exclusively of bathroom fans controlled by programmable timers.

The goal of this study is to determine whether the overall performance of manufactured homes built under the MAP is consistent with the assumptions made in the cost-benefit analysis at the outset of the program. Several important assumptions were made, including duct efficiency, home infiltration, and internal gains. It is important to determine whether the space heating requirements of these buildings were accurately predicted by the simulation and cost-benefit analysis [Baylon and Davis 1993], and whether any modifications should be made in the performance analysis to more accurately characterize MAP homes.

1.1 Objectives

The objectives of this study are as follows:

1. To draw and study a random sample of houses built to MAP specifications throughout the Pacific Northwest that are representative of set-up, infiltration, ductwork and overall building characteristics.

2. To evaluate the overall heating requirements of MAP homes using billing analysis techniques.

3. To provide revised savings and cost-benefit estimates using the SUNDAY simulation and the findings from the field review and billing analysis.

1.2 Field Study

The field protocol (Appendix A) included a physical review of the home, methods for determining house and duct air leakage (blower door and Duct Blaster™ tests), and homeowner interviews. The field reviews were conducted mostly by representatives of the individual states, usually through the SEOs, with supplemental work provided by Ecotope and Delta T of Eugene, Oregon. All homes were reviewed using the same protocol, and all homeowners were asked to sign a billing release allowing the State Energy Offices or Ecotope to access their energy bills for the period of their occupancy. Each state was given a target for this recruitment, a random list from which to recruit participants, and accompanying instructions. Targets were set for each state. The minimum number of homes to be studied was 160 homes. The recruitment done by the states actually produced a total of 178 homes, broken down as shown in Table 1.1.

TABLE 1.1
DISTRIBUTION OF MAP HOMES AND SAMPLE

STATE	# OF HOMES*	%	TARGET	%	AUDITED	%
ID	1,368	14.1	40	25.0	40	22.5
MT	212	2.2	20	12.5	18	10.1
OR	3,605	37.2	50	31.2	50	28.1
WA	4,343	44.8	50	31.2	70	39.3
OTHER	170	1.7	0	0	0	0
TOTAL	9,698	100.0	160	100.0	178	100.0

* Shipped and sited before June, 1993

1.3 Report Organization

The report is organized into seven sections. Section 1 is the introduction. Section 2 describes the sampling and field work procedures used to collect the data. This includes the stratification design, the field protocol, and the billing analysis data collection methods. Section 3 presents the characteristics of the sampled homes, summarizes the results of the home review, blower door and Duct Blaster™ tests, set-up and quality control review, and the results of the occupant interviews. Section 4 presents the billing analyses conducted for those homes for which bills could be obtained. Section 4 also details the billing analysis procedure used for estimating space heat usage in each home, and compares the results of regression analysis with other billing analysis methods. Characteristics associated with the reviewed homes (such as climate and temperature characteristics) are also presented in this section. Section 5 uses the results of the billing analysis and the field review to calibrate the SUNDAY simulation used to develop the cost-benefit and optimization evaluation for the MAP program. Section 6 uses the recalibrated SUNDAY model to evaluate the cost-effectiveness of the MAP specifications as compared to the 1994 HUD standards for the thermal performance of manufactured homes. Overall heating energy requirements for MAP homes are also presented. Section 6 provides conclusions and revised cost-benefit analyses for MAP homes, based on simulations, optimizations and billing analyses conducted on the field sample. These results are then compared to other evaluations of the MAP. Section 7 summarizes the results of the analysis and briefly addresses other recent impact evaluations of MAP.

2. Sample Selection

2.1 Introduction

After the first 14 months of MAP, the BPA MAP database contained information on 9,698 homes. These homes were sited in Washington, Oregon, Idaho, Montana and other states (mostly in Wyoming and Utah.) Only 170 of the total homes sited were sited in states other than Oregon, Washington, Idaho and Montana. Due to the jurisdiction of the primary SEOs involved in the program, the sample was drawn from the four primary states in the program.

TABLE 2.1
REVISED POPULATION SUMMARY
(MAP Homes Sited in First Year)

State	# of Homes in BPA Database	% of Homes in Main BPA Service Territory
Washington	4343	45.6
Oregon	3605	37.8
Idaho	1368	14.4
Montana	212	2.2
Total	**9528**	**100.0**

2.2 Sampling Methodology

In an effort to resolve several issues involving MAP home performance and quality of field installations, a field review for a representative sample of homes was proposed. Because sufficient resources for this work were available, and because the results were of considerable importance, Ecotope encouraged the BPA and the state energy offices (SEOs) to examine a large number of homes (100 to 200 homes in the four-state region.)

Sample selection relied on a combination of approaches. The general approach involved drawing a random sample from the population and stratifying it by state only. It was first necessary to determine sample sizes. To do this, the variables of most interest had to be identified and the range of expected variation of these variables had to be described. During the initial phases of planning the field work, the main point of interest was set-up compliance. Set-up compliance can be crucial to home performance; however, direct quantification of energy savings from set-up compliance is not straightforward.

As the goals of the field evaluation evolved, much more interest was expressed in measuring the homes' heating energy use. It became apparent that a billing analysis would be necessary. Thus, MAP homes' kWh usage per year became an important consideration in the sample selection process.

Thermal specifications for MAP homes (U_o = 0.053 BTU/hr-°F) were similar to those for a group of manufactured homes built to Super Good Cents (SGC) specifications (U_o = 0.060 BTU/hr-°F) submetered to determine heating energy use under the Residential Conservation Demonstration Program (RCDP). The results of this analysis can be found in Baylon et al [1991] and are summarized in Section 5.4 of this report. Because of the similarities between MAP and RCDP manufactured homes, the submetered RCDP space heating data offered a logical starting point for determining a MAP sample size.

Ecotope decided to use the expected coefficient of variation of normalized space heating (kWh/ft^2-yr) to determine the size of the MAP field study sample. The coefficient of variation is defined as the standard deviation of the sample variable in question, divided by the mean value of this variable: $(s/\bar{x})$. The sample size is proportional to the square root of the coefficient of variation. As the coefficient of variation of a sampling distribution increases, a larger sample size is required to ensure a distribution of results within a desired confidence interval. In the RCDP sample, the coefficient of variation for kWh/ft^2-yr was 0.27. The RCDP sample was considered representative of the RCDP population. Standard formulas were used to find a MAP sample size given the desired 95% confidence interval.

The minimum sample size of 112 homes for the four-state region was judged adequate to measure regional MAP annual heating energy per square foot with a significance of 5%. That is, the possibility of making a Type I error using data is less than 5% (about two standard deviations). The actual number of homes audited in the study (178) is considerably greater than the minimum sample required to describe normalized space heat, based on the sampling distribution found in RCDP. Since the actual performance of the MAP homes might be different from RCDP, and since the measurement technique used was a billing analysis rather than the direct measurement used in RCDP, it was desirable to over-sample when possible.

It was important that each state be represented, especially in evaluating home set-up. Therefore, new targets were determined using a more relaxed confidence interval. Audit targets for each state were approximately 35 homes (assuming a coefficient of variation of about 0.3) if confidence intervals were reduced to 0.90. Montana and Idaho were asked to obtain at least 40 homes in order to produce reasonable statewide results. Washington and Oregon were asked to obtain 50 homes in order to ensure that they would be adequately represented in any regional sample. In this way, individual states could learn more about their MAP housing stock, and more robust comparisons of summary statistics by state could be made.

TABLE 2.2
SAMPLE COMPOSITION BY STATE

State	Minimum Regional Sample	Minimum State Sample	Target By State	Homes Audited
Idaho	16	34	40	40
Montana	3	32	40	18
Oregon	41	35	50	50
Washington	50	35	50	70
Other	2	--	--	--
Total	**112**	**136**	**180**	**178**

The state sample sizes allow summaries and comparisons with confidence intervals of 0.90 and significance levels of 0.05 in all states except Montana. Summaries from Montana may be unreliable, and we have noted this when appropriate in this report. The regional sample allows the sampling criteria to be met for variables with coefficients of variation of about 0.34 or less. Once normalized, all of the building measurements meet or exceed the criteria, except the summaries by climate zone. Climate zone summaries do not meet or exceed the criteria unless the confidence interval is reduced to 0.90. For blower door and other set-up reviews, it appears that the original sampling criteria were adequate; these confidence intervals are comparable to those used to produce the original sample.

2.3 State-by-State Population Weights and Fan Test Weights

The field review was conducted by staff at the state energy offices in Oregon, Washington, Idaho and Montana. Energy office personnel audited 178 homes. The audit was more complete at some sites than others. In several cases in Washington, blower door, Duct Blaster™, and parts of the walk-through audit were not completed. This necessitated recruiting additional homes so that more complete audits could be done. An additional contractor was also hired to assist Washington; this contractor revisited about ten of the sites and conducted blower door and Duct Blaster™ tests.

Weights were calculated to adjust the field results for state-by-state sitings (see Table 2.3). That is, since some states did not perform the desired number of audits relative to the number of MAP homes sited within their borders, a multiplier larger than 1 was used to weight basic descriptive statistics such as home size and number of occupants. Multipliers less than one were applied to descriptive statistics for "oversampled" states.

Different weights were calculated for the blower door tests because auditors did not perform blower door tests at some sites, or the blower door data were ruled out-of-bounds because of unacceptable flow exponents. A flow exponent, *n*, is generally expected to have a value of $0.45 < n < 0.75$. If the value falls outside this range, the field technician may have made a mistake, or the data may have been corrupted by windy conditions during the test. The results from these homes are not included in data summaries.

TABLE 2.3
STATE-BY-STATE WEIGHTING FACTORS

State	Target Audit Population (Column A)	Homes Audited (Column B)	Population Weight Multiplier (Col. A/Col. B)	Target Blower Door Tests* (Col. D)	Acceptable** Blower Door Tests (Col. E)	Blower Door Weight (Col. D/Col. E)
Washington	81	70	1.16	72	62	1.16
Oregon	67	50	1.34	59	48	1.23
Idaho	26	40	0.65	23	32	0.72
Montana	4	18	0.22	4	15	0.27
Total	**178**	**178**		**158**	**157**	

* Population weight multiplied by homes audited, rounded to the nearest unit.
** After cases with out-of bound flow exponents excluded.

3. Field Audit Results

The goals of the field review of MAP homes were:

1. To assess homeowner acceptance of MAP specification features
2. To assess the successes and failures of MAP specifications, especially those associated with home set-up
3. To develop operating characteristics of MAP homes for assessing overall performance, and for developing simulation inputs to reassess the program's cost-effectiveness
4. To collect detailed information on envelope and duct sealing practices and provide input to potential specification changes
5. To develop a sample of MAP homes for energy performance review using billing analysis and field review results

The field audit consisted of four main parts. An occupant survey was conducted first. The survey documented and catalogued basic demographic information, homeowner perceptions, and homeowner behavior (primarily thermostat setpoint and setback temperature and duration). Following the survey, a walk-through audit was conducted. The field technician surveyed heating, ventilation, and combustion appliances, checked the hot water system, and measured the relative humidity inside the home. These data were used primarily to inform the billing analysis. The third phase of the field audit was a set-up review. Because a manufactured home is only partly "finished" when it reaches the site, the quality of the set-up is crucial to ensuring long-term energy efficiency and homeowner comfort. The set-up review assessed marriage line sealing, the condition of the crossover duct and belly board, and the support of the home (footings, piers, and point loads). The final portion of the field audit measured house and duct tightness with calibrated pressurization fans (blower door and Duct Blaster™). These measurements were used as inputs into the revised simulations found in Section 5 of this report.

3.1 Occupant Survey

Field auditors talked to MAP home occupants as part of their protocol. Of particular interest in the occupant survey were the occupant's reasons for buying a MAP home, whether the occupant believed the home was performing as expected, the occupant's knowledge of the ventilation system (very important), and the occupant's description of any problem areas in the home. At the time of the field audit, 140 out of the 178 homes had been occupied for at least three heating season months.

When asked whether they thought their home was as energy-efficient as they expected when at time of purchase, 74% of these homeowners responded affirmatively. Homeowners were asked a series of questions about their purchasing decisions, their home's energy performance, and their comfort in their homes. Not all homeowners responded to all questions; the number of responses to each question is indicated, and in some unknown number of cases, the auditor did not ask one or more questions.

When asked what was the most important factor influencing their decision to purchase a MAP home, 100 out of 133 (75%) of those responding to this question indicated that lower energy bills were the reason. This response is probably misleading, since no questions we asked were designed to elicit responses related to other factors associated with new home purchases (e.g., low initial cost, availability, kitchen design, bathroom amenities, etc.). The response to this question does suggest that the MAP conservation package is an effective incentive to prospective homebuyers.

An important input in a performance analysis is the ventilation rate of each home. This determines the amount of heat loss and energy use associated with the ventilation system. Part of effective ventilation is homeowner understanding of the issue. Since "tight" houses are a relatively recent occurrence in the United States, it is interesting to assess homeowner knowledge of ventilation and how this affects ventilation rates in new manufactured housing. Earlier studies of new manufactured housing, combined with improved air sealing techniques in MAP homes, have raised concerns that MAP homes would be much tighter than current standards recommend.

When asked whether their home had a ventilation system, 71% of respondents (126/178) answered affirmatively. Because all of these homes relied on one type of whole-house ventilation system (two 50 CFM bathroom fans on 24-hour timers for exhaust and operable fresh air inlet vents), the auditor judged the homeowner's knowledge based on the homeowner's understanding of how the timeclocks controlled the fans and the (intended) function of window vents. Detailed auditor comments suggested that about 35% (50/146) had a good understanding of the ventilation system.

Nearly 20% of homeowners had disabled their timeclocks. For 261 fans with reported bathroom run times, the median fan run-time was four hours. This was the run-time set at the factory. The median exhaust fan flow rate (for 261 fans measured) was 56 CFM. This combination of fan run time and flow rate does not provide adequate effective ventilation in many MAP homes. Section 3.5 of this report discusses ventilation in more detail.

During the 1970s and early 1980s, the manufactured housing industry was damaged by lawsuits involving formaldehyde emissions. The industry responded with bound- and low-formaldehyde adhesives and other products, and indoor formaldehyde levels are now almost always well below the EPA's recommendations. Indoor air quality and humidity are still of great concern, however, especially since manufactured housing has followed the trend of site-built housing in becoming increasingly airtight.

Occupants of all 178 MAP homes were asked about indoor air quality in their home, and Table 3.1 presents their responses. Homeowners could answer affirmatively in more than one category.

TABLE 3.1
OCCUPANT-IDENTIFIED INDOOR AIR QUALITY PROBLEMS
(178 Homeowners Interviewed)

Air Quality Complaint	Yes	%
Mold/Mildew/Condensation	42	23.6
Stuffy/Too Humid/Too Dry	43	24.2
Drafty	52	29.2

Field auditors did not note as many air quality problems as did homeowners. Whereas the homeowner could be expected to remember any occurrence of a problem, the auditor was only in the house for part of one day. Also, some of the audits were conducted during parts of the year (fall and spring) when certain air quality problems might not be very apparent due to better dilution of interior air (from opened windows, etc.).

TABLE 3.2
AUDITOR-REPORTED INDOOR AIR QUALITY PROBLEMS
(n = 178)

Air Quality Complaint	Yes	%
Mold/Mildew	1	<1
Condensation	6	3.4
Stuffy	8	4.5
Drafty	0	0
Odors	26	14.6

In addition to inspecting for moisture and air quality problems, field auditors solicited detailed homeowner comments on air quality. Less than half of the homeowners had comments on this issue. In detailed comments , interior condensation of varying degrees was reported by 18% of homeowners (16/87). In detailed comments, 8 out of 87 respondents (9%) reported mold or mildew formation. Detailed comments revealed that 18 out of 87 respondents (21%) thought indoor air was too dry.

Indoor relative humidity was measured in 148 homes. The average relative humidity was 52%. If the relative humidity measurements are broken into four equal groups (quartiles), the driest quartile tops out at a relative humidity of 38%. (The lowest measured value is 21%.) The third quartile tops out at a relative humidity of 63%. This means 75% of the cases in which relative humidity was measured had a relative humidity of less than 63%. No systematic connection was found between homes in which homeowners identified moisture-related complaints and the auditors measured an elevated relative humidity.

A summary of blower door results showed slightly higher (but not statistically significant) leakage in homes identified as having drafts (52 cases, average ACH_{50} = 5.60) versus those not described as drafty (126 cases, average ACH_{50} = 5.51). In tight houses such as those built under MAP, drafts are more noticeable, especially if they are in areas such as the bathroom. Some MAP homeowners expect there to be no drafts in their new home; any occurrence of moving air is considered a "draft" by these homeowners.

Different households have different needs for fresh air. If occupants smoke, more ventilation is needed. If occupants are not home very often, less ventilation will do. Given the low natural average infiltration rate of MAP homes (about 0.22 ACH) and limited run-times of ventilation systems, the occupant-reported findings on indoor air quality are not at all surprising. Moreover, during the shoulder months of the year (late spring and early fall), when the stack effect is reduced and homeowners are less likely to open their windows, air quality problems are worsened.

Recent changes in HUD ventilation regulations [HUD 1994] have led some manufacturers to use whole-house ventilation systems that may be more effective. Some of these systems rely on a very quiet, very efficient dedicated whole-house fan; others rely on balanced-flow heat recovery systems. If homeowners are educated properly in the operation of these systems (including being provided with information on the modest costs associated with ventilation), MAP homes should be better ventilated in the future.

3.2 Walk-Through Audit

The auditor collected basic information on the home and occupants and inventoried primary heating equipment, combustion appliances, and outbuildings in order to better inform the billing analysis. Information on occupant behavior, such as thermostat setting, thermostat setback and duration of setback (Tables 3.3 and 3.4), was also recorded in order to assist in the prototype analysis (Section 5).

TABLE 3.3
WALK-THROUGH AUDIT SUMMARY
(Averages weighted by state sitings*)

	Number reported	Average	Std Dev	Range
Home size (ft^2)	178	1433	360	670-2722
# of occupants	176	2.64	1.35	1-11
		% of homes		
Has heat pump**	23	14.6%		
Has room air conditioning	11	6.2%		
Has central air conditioning**	23	14.6%		
Primary wood heat (used more than 100 days/year)	17	9.6%		
Has well pump	21	11.8%		
Has outbuilding (with likely heat or major other electrical use)	22	12.4%		
Single section homes	21	11.8%		
Double section homes	145	81.5%		
Triple section homes***	12	6.7%		

* Population weights from Table 2.3
** Coincidental agreement between these two categories
*** Mostly "2.5" section homes with partial-length "pod" unit

Some of these data, especially on central air conditioning and heat pumps, were revised based on subsequent review of the audit booklets. In a few cases, heat pumps were incorrectly identified as central air conditioners and vice versa. During the billing analysis, anomalous summer bills also prompted us to call about a dozen sample homes to ask whether cooling equipment had been installed since the audit. This was true in several cases.

TABLE 3.4
FURNACE AND DHW OPERATING CHARACTERISTICS

	n	Average	Std Dev	Range
Thermostat setpoint (°F)	151	69.4	3.4	55-78
Thermostat setback (°F)	101	61.6	6.2	40-70
Setback duration (hrs)	54	9.4	3.5	0-20
Furnace size (kW)*	152	15.5		10.4-22.0
DHW tap temperature	146	125.5	9.4	102-158

* Furnace size is a discrete variable. Most common furnace size is 15.5 kW (74 cases), followed next by 11.2 kW (30 cases).

Table 3.5 summarizes the distribution of manufacturers whose homes were included in this study. All manufacturers in BPA's primary service territory were represented in the sample. One supplier (Atlantic Homes) ships large single-wide homes (16' x 70') to Montana from Nebraska. Some MAP manufacturers supplying from California were not included in this sample because they were not involved in MAP during its first year. Oregon builders accounted for 50% of the homes in the sample, which is somewhat less than the 58% share of the 9,000+ homes that were built in the program's first year. The weighting factors used in this report, however, are based on where the homes are sited rather than on where they are manufactured. Homes built for Idaho and Montana are somewhat over-represented in the sample, and so these results are slightly skewed towards Idaho manufacturers that operate in these states.

Because of various sorts of attrition, not all of these homes were used in the billing analysis (Section 4), but data from all homes, when available, were used in preparing the various characteristics summaries.

TABLE 3.5
MANUFACTURER INFORMATION

Manufacturer	State Where Built	# of homes in sample	% of sample
Fleetwood	Idaho	25	14
Golden West	Oregon	16	9
Fleetwood	Oregon	15	8.4
Marlette	Oregon	14	7.9
Fleetwood	Washington	12	6.7
Moduline	Washington	12	6.7
Nashua	Idaho	12	6.7
Skyline	Oregon	11	6.2
Guerdon	Oregon	9	5.1
Liberty	Oregon	8	4.5
Champion	Idaho	7	3.9
Kit	Idaho	7	3.9
Redman	Oregon	7	3.9
Guerdon	Idaho	6	3.4
Silvercrest	Oregon	6	3.4
Valley	Washington	5	2.8
Fuqua	Oregon	3	1.7
Atlantic	Nebraska	2	1.1
Silvercrest	California	1	0.6

3.3 Set-Up Review

The quality of a manufactured home is not the sole responsibility of the manufacturing plant. Set-up crews also determine how well a home will perform. Indeed, set-up has often been the weak link in an otherwise quality manufactured home. Set-up crews have traditionally provided work of uneven quality, they have not been subject to reliable or corrective regulation or training until very recently, and they have the most influence over the most vulnerable part of the heating system: the crossover duct.

3.3.1 Set-Up and Inspection

Both Oregon and Washington have had set-up laws since the late 1970s. In Oregon, manufactured home final set-up inspections are the responsibility of the Building Codes Agency. In Washington, set-up crews must be licensed; however, until recent legislation was passed, there was no direct connection between licensing and demonstrated skill. Idaho regulatory agencies have had no organized influence on set-up quality until the autumn of 1994, and Montana operates under a rather sketchy "self-certification" plan. Set-up crews have traditionally operated in a sort of twilight zone, with (usually) a set of manufacturer's instructions to guide them and limited or nonexistent oversight.

Home structural support, air-sealing of the marriage line, and proper installation of the crossover duct are critical determinants of home thermal integrity and homeowner comfort. Other set-up requirements, such as installation of the vapor barrier and complete perimeter skirting, improve the appearance and longevity of the home.

Table 3.6 summarizes all set-up variables except those concerning the crossover duct. In each case, the component had to be installed to MAP specifications to be judged in compliance (see appendices for the specifications.) These summary statistics are population-weighted.

TABLE 3.6
SET-UP COMPLIANCE
(First Column Population-Weighted)

Variable	% Complying (all states; n=176)	Highest state compliance rate	Lowest state compliance rate
Skirting installed	94%	100% (OR)	61.5% (MT)*
Vapor barrier properly installed	95%	98% (OR)	62.5% (MT)
I-beam properly supported	87%	97% (WA)	55% (ID)
Piers under exterior doors	83%	94% (WA)	71% (ID)
Pier supports installed per mfr's markings	79.5%	94% (WA)	38.5% (MT)**
Piers properly capped & shimmed	87%	98.5% (WA)	58% (ID)
Footings under piers	96.5%	100% (WA)	69% (MT)
Belly penetrations sealed	66%	77% (MT)	61% (OR)
Marriage line sealed	90%	98.5% (WA)	74% (ID)

* Five of these homes were on permanent foundations.
** No markings seen in 7/18 cases.

Compliance with basic home set-up specifications, at least in this sample from the first group of MAP homes, improves as the homebuyer moves westward. At the time these homes were set up (late 1992 through early 1993), only Oregon nominally required on-site final inspections. Note that overall compliance rates, especially when weighted by the states with more sitings, are generally in the range of 85%-95%.

The lowest-compiler is belly penetration sealing. The floor insulation and belly space must be protected from exterior moisture and animal incursions, and limiting duct air leakage to the crawlspace improves heating system efficiency. Given the square footage of the belly board and the need for periodic plumbing and other repairs (and the deterioration of the belly fabric with age, especially at the perimeter where there is sometimes incident ultraviolet radiation), and also the limited longevity of the most common "sealant" ("duct tape"), there will likely be unsealed belly penetrations in many manufactured homes.

Proper structural support of the home is also necessary for longevity of air sealing measures. If piers and footings are improperly sized and/or spaced, the home can sag and air seals fail. Structural support is now a major focus of set-up training seminars in Idaho and Washington.

Washington [Drazen 1994] and Oregon have recently written or begun reports on MAP manufactured home set-up which examine more closely (than here) the set-up quality of larger groups of homes. Their surveys include many of the items in Ecotope's protocol and add items such as the status of dryer and hot water heater vents, specific fasteners used for the crossover duct, and the type of tape used to seal belly penetrations. Washington and Idaho have new set-up laws, and both states are offering training and certification to set-up crews.

3.3.2 The Crossover Duct

Secure crossover connections (screws, straps), the use of sheet metal elbows, and a crossover of the right length are essential to an effective heating system in manufactured homes, and tend to minimize energy losses and promote even flow of conditioned air to all parts of the home. Only about half of these MAP homes had sheet metal elbows connecting the supply plenum to the crossover duct. If an elbow is not used, air flow can be constricted if the crossover is not cut to the proper length. Even if an elbow is used, inadequate securing of the elbow to the crossover duct can result in failure within a few heating seasons. Compliance with crossover duct specifications is summarized in Table 3.7.

Based on detailed measurements of heating system efficiency in manufactured homes, it is reasonable to assume that the crossover duct is a major contributor to heating system efficiency losses. Trunk ducts in most MAP homes are separated from the outside by three R-11 glass fiber blankets, and duct leakage rates (discussed in the next section) are not extremely high, compared to site-built homes [Olson, et al 1993]. No models of MAP energy performance have explicitly and discreetly expressed the crossover duct's contribution to overall duct leakage and degradation of heating system efficiency. Additional research is underway to better describe duct efficiency and manufactured home floor system thermal performance.

TABLE 3.7
CROSSOVER DUCT SET-UP COMPLIANCE
(Overall Statistics Population-Weighted; Multi-Section Units Only)

Variable	% Complying (all states; n=157)	Highest state compliance rate	Lowest state compliance rate
X-over cut to length	72%	92% (MT)	67% (WA)
X-over connections secure	77%	85% (MT)	74% (WA)
Sheet metal elbow installed*	54.5%	69% (MT)	48% (OR)
X-over to plenum connection insulated	67%	71% (ID)	54% (MT)

* MAP specifications did not require a sheet-metal elbow until 1994.

3.4 House Tightness and Duct Leakage

A major focus of this work was direct measurement of house tightness, duct tightness, and performance of whole-house ventilation systems. Most auditors were experienced with the blower door; direct duct leakage measurement technique (especially measuring "leakage to outside") are much newer, and Ecotope offered training in these methods.

The blower door test was done in depressurization mode, with operable window vents and the make-up air system in their "as-found" condition. All supply registers were open during the test, so some duct leakage is included in the whole-house results shown in Table 3.8. The first row's result represents a regional average weighted as described in Section 2 (Table 2.3).

TABLE 3.8
MAP BLOWER DOOR RESULTS
(Cases with Out-of-Bounds Flow Exponents Excluded)

Group	# of cases	ACH_{50} (averages)	Range (Std. Dev.)	Estimated ACH_{nat} averages*
All (weighted)	157	5.50	1.61-11.69 (1.87)	0.22
Single Wides	18	6.45	3.29-8.85 (1.39)	0.27
Double Wides	127	5.50	1.61-11.69 (1.90)	0.22
Triple Wides	12	4.92	3.61-7.68 (1.22)	0.19
Idaho	32	6.12	3.30-9.84 (1.55)	0.26
Montana	15	5.63	1.61-8.15 (1.70)	0.27
Oregon	48	5.43	2.08-11.69 (2.10)	0.21
Washington	62	5.36	2.37-10.16 (1.77)	0.21

* This estimate takes the ACH_{50} and divides it by a factor appropriate to the climate zone. (The divisor is 21 in Zone 3, 24 in Zone 2, and 27 in Zone 1). The common practice of dividing the ACH_{50} by 20 is not appropriate for manufactured homes, single-story homes with limited bottom plate air leakage. This approach is based on research done by Ecotope on manufactured homes of similar construction to MAP homes [Palmiter et al 1992].

The blower door test results in Table 3.9 show that MAP homes are much tighter than "historic" site-built or manufactured homes and tighter than recently constructed homes. Analysis of the variance in tightness between states showed that the difference between Idaho and other states was highly significant (this analysis compared Idaho with all other states, and the *t*-statistic for Idaho vs. the others was 2.35 with $p > 0.02$). The data from one manufacturer explained most of the variance. In-plant observations suggest that the materials used for sealing the bottom plate and the marriage line were likely contributors. These materials have been upgraded, and there is less variation in sealing practice now that MAP has been running for three years.

An analysis of variance was also run to compare the ACH_{50} with likely explanatory leakage variables. The one significant finding was homes with all tape and texture walls were predicted to have a mean ACH_{50} almost 20% less than homes finished with premanufactured panels. An analysis of variance run on all likely predictors of house tightness found (for 157 blower door tests with acceptable flow exponents) that the effect of tape and texture walls was statistically significant (*t*-statistic of 3.06 with $p > 0.003$).

The blower door test combines all of the home's leaks into an effective leakage area. The test is so useful precisely because of this feature. Houses built at different times to different standards can be compared on the basis of their blower door results.

Table 3.9 compares the MAP sample with other recent Pacific Northwest studies of site-built and manufactured homes.

TABLE 3.9
BLOWER DOOR RESULTS FOR NORTHWEST HOMES

Group (Study Reference)	n	House Type, Year Built	ACH_{50} (averages)
WWP, Spokane [Kennedy et al 1994]	33	Site-built, "historic"	14.3
WWP, [Kennedy et al 1994]	21	Mobile home, "historic"	13.3
NORIS I [Palmiter & Brown 1989]	134	Site-built, 1980-86	9.28
NORIS II [Palmiter et al 1990]	49	Site-built, 1987-88	7.18
"Current practice" mfd homes [Palmiter et al 1992]	29	Manufactured in late 1980s	8.75
Super Good Cents mfd homes [Palmiter et al 1992]	131	Manufactured in late 1980s	6.10
Homes in this study	157	MAP, 1992-93	5.50

With the blower door running, auditors searched for large local leaks with a smoke stick. The smoke stick produces a small amount of opaque smoke which makes a ready exit through holes in the building shell. The most common leakage sources are summarized in Table 3.10.

TABLE 3.10
MOST COMMON LOCALIZED AIR LEAKAGE POINTS

Leakage point	Number of cases	% of sample (n=178)
Windows, exterior doors, skylights	46	25.8
Marriage line	24	13.5
Wall to ceiling joint	20	11.2
Bathtub	20	11.2
Other plumbing penetrations	13	7.3

Other reported leakage points were the electrical panel, electrical receptacles (outlets), fireplace/woodstove, recessed fluorescent fixtures, and the furnace cabinet.

Ducts were tested directly to measure air leakage. Air leakage is an obvious contributor to downgrading heating system efficiency; however, there is still no widely accepted technique used to estimate efficiency loss from duct leakage. The advent of tools such as the Minneapolis Duct Blaster™ have facilitated much easier measurement of duct leakage; however, the interpretation of the results is still a matter of active discussion. Air leakage alone cannot predict system efficiency losses. Conductive losses, induced infiltration when the air handler is running, and other factors also contribute to system efficiency penalties. Efforts are currently underway to develop more reliable estimating procedures which incorporate duct leakage measurements.

Table 3.11 shows what is called "exterior duct leakage." This measurement is taken with all of the registers and the return side of the furnace sealed and with the blower door pressurizing the inside of the house in order to more or less remove leakage from the ducts back into the house from the leakage measurement. The leakage is shown with ducts pressurized to 50 Pa and 25 Pa. The 25 Pa measure is closer to the pressures commonly measured near the furnace air handler during normal furnace operation. (The median plenum pressure for 124 houses in this study for which these data were collected was 28.1 Pa.)

TABLE 3.11
EXTERIOR DUCT LEAKAGE
(Averages; Screened for Out-of-Bounds Flow Exponents)

	Ext. leak @ 25 Pa (ft^3/min)	**Ext. leak @ 50 Pa (ft^3/min)**
All (n=154)	104	157
All, weighted*	103	156
Single Wides (n=19)	51	80
Double-Wides (n=124)	101	155
Triple-Wides (n=11)	122 (median)	169 (median)

* Using blower door weights from Table 2.3

Beyond the checklist approach to compliance, we were interested in the effect of non-compliance on duct leakage. An analysis of variance was run on multi-section homes to test variables most likely to influence duct leakage. The mean exterior leakage at 25 Pa for homes with all belly penetrations sealed was 34 CFM less than the entire group of multi-section homes. A secure crossover duct connection had a similar contribution, with secure systems averaging 39 CFM less than the mean exterior leakage for all multi-section homes (A "secure" connection generally means sheet metal screws and tightening straps are used to attach the duct to the plenum collar). Series leakage tests suggest that the belly board is an effective air barrier in a manufactured home if it is made of airtight plastic and is undisturbed or patched properly. Many manufacturers use a spun polyethylene belly board that is very air-permeable relative to the denser outer layer added by other manufacturers.

Ducts in MAP homes have modest leakage rates if measured as a percentage of the flow through the air handler. Given that there is no return system, overall leakage rates (at least within a year or two of set-up) are much lower than site-built systems with comparable duct run length and furnace blower size. No statistically significant differences in state-by-state exterior duct leakage rates were found.

3.5 Infiltration and Ventilation

The MAP air sealing specifications are almost the same as the Super Good Cents (SGC) specifications [BPA 1987]. The aggressive air sealing techniques used for the SGC and MAP programs were designed to create building shells with natural air infiltration rates considerably less than those found in standard construction. Specifications also mandated a ventilation system with automatic controls, designed to ventilate the building at 0.35 air changes per hour (ACH). Manufacturers had the option of using four different systems for whole-house ventilation. The cheapest option was an integrated-spot whole-house system based on inexpensive bathroom fans controlled by 24-hour timers. Manufacturers chose this option mostly because of its low cost. The source of fresh air for the exhaust systems is operable window vents in the frames of the vinyl windows in all bedrooms, and the main living area. Currently, it is not known how much additional ventilation these vents provide, since unintentional leaks dominate air supply to the exhaust fans.

3.5.1 MAP and HUD Ventilation Specifications

As the blower door results showed, MAP homes are tighter than any other set of manufactured homes measured in the Northwest. However, there are still enough unintentional leaks in the building shell to supply two bathroom fans drawing on average about 50 CFM each. The MAP specifications follow ASHRAE Standard 62 - 1989, which is based on providing 0.35 ACH, but not less than 15 CFM per occupant, with an additional 15 CFM to be provided. For a three-bedroom home, for example, the MAP ventilation requirement is 75 CFM, since one bedroom is assumed (by ASHRAE) to have two occupants, and an extra 15 CFM is also required by MAP specifications.

Mechanical ventilation systems should also be capable of reliable augmentation of natural infiltration/exfiltration (primarily stack-driven in the Northwest) and operated long enough each day to provide effective pollutant removal. Over 90% of RCDP manufactured homes failed the ASHRAE Standard 62-89 of 0.35 air changes/hour (ACH), and tracer gas measurements of a separate group six MAP homes found an average effective ventilation rate well below 0.35 ACH [Davis, et al 1994].

Many indoor air pollutants are associated with occupancy levels. If CO_2 or biocontaminants are of concern, then ventilation specifications should be determined by number of occupants. Relative humidity levels are also closely correlated with occupancy levels. The value of 0.35 ACH is based on building volume, and has little or no correlation with the number of occupants living there.

Different types of indoor air pollutants require different methods of removal, since they are produced by different sources. The ideal ventilation system design depends on which pollutants are to be removed. The primary concern is pollutants that are associated with human occupancy, such as CO_2 and biocontaminants. Ventilation should coincide with occupancy, and the ventilation rate should be increased depending on the number of people present. A related concern is high humidity levels that can encourage the growth of fungi and introduce other allergens and irritants. Air should be exhausted at high volumes from areas in which moisture is generated, such as bathrooms and kitchens. If the primary concern is with carcinogens or irritants emitted from the home itself on continuous basis (such as formaldehyde), the home should be ventilated continuously at low volumes.

As of October 25, 1994, HUD revised its specifications to include ventilation systems installed in manufactured homes. With this specification, both HUD and MAP mandated "whole house" ventilation systems [HUD 1994]. Since these specifications only mandate that a home shall have the *capacity* to reach the 0.35 ACH level, they do not ensure that homes' indoor pollutants are being properly removed. Most of the ventilation systems installed from MAP's inception until recently used inexpensive bathroom fans that were not designed to last as long as the homes in which they are installed. Continuous low-volume ventilation and intermittent high-volume ventilation have very different effects on indoor air quality, and should be used for different purposes.

3.5.2 Average and Effective Ventilation Rates

Ecotope has examined the physical explanation for this issue in detail [see, for example, Palmiter and Brown, 1989], and has explored the difference between a building's *average* ventilation rate and its *effective* ventilation rate. The average ventilation rate is the time-weighted average of ventilation due to unintentional leakage (estimated from the blower door measurements) and intentional leakage (provided by mechanical systems such as exhaust and/or whole-house fans). The effective ventilation rate is also a combination of these two types of ventilation, and describes the rate of pollutant removal from the home's interior. The average ventilation rate is what is usually described when ventilation rates are discussed, although this is not the primary intent of air-quality standards such as ASHRAE 62 - 1989.

An illustration is useful here. Consider two identical manufactured homes with different ventilation strategies. One of the of them is ventilated continuously at 0.35 ACH, and the other is ventilated at 0.22 ACH for 23 hours a day. For one hour a day, a large exhaust fan comes on and ventilates the second home at 3.35 ACH. The *average* ventilation rate for these buildings is equivalent, as shown in the illustration.

FIGURE 3.1
AVERAGE VENTILATION ILLUSTRATION

	Case 1	**Case 2**
System	Continuous ventilation at 0.35 ACH, 24 hours a day	Continuous ventilation at 0.22 ACH for 23 hours, then 3.35 ACH for one hour (big fan turned on)
Average ACH	$\frac{0.35 \text{ ACH} \times 24 \text{ hrs}}{24 \text{ hrs}} = 0.35 \text{ ACH}$	$\frac{(0.22 \text{ ACH} \times 23 \text{ hrs}) + (3.35 \text{ ACH} \times 1 \text{ hr})}{24 \text{ hrs}} = 0.35 \text{ ACH}$

The average ventilation rate refers to the amount of heat loss associated with air leakage. When describing the ventilation strategy for Case 1 described above, we could say that there is a continuous ventilation system operating. In Case 2, there is an intermittent ventilation system; a ventilation rate of 0.22 ACH for 23 hours, and a much higher rate for one hour when a large fan comes on. In Case 2, the natural ventilation rate derived from the blower door tests (Table 3.5) is 0.22 ACH and represents the average impact of natural forces on air flow through the home (e.g., temperature-driven stack effect or wind-driven air flow).

Returning to our example, there is another measure of ventilation: the *effective* ventilation rate. This is defined as the inverse of the steady-state concentration of a pollutant with constant-source strength emitted continuously. This is a ventilation rate that describes the removal of pollutants from the air inside the home. The examples already shown assume that each has a continuous pollution source that is emitting pollution at the same rate. For purposes of illustration, we could assume that a pollutant source is inside the manufactured home, emitting its pollutant at the rate of 1 cubit per hour. The abilities of these two systems already described to remove this air polluting source are extremely different.

FIGURE 3.2
EFFECTIVE VENTILATION ILLUSTRATION

	Case 1	Case 2
Pollutant Source Strength	1 cubit/hour continuous	1 cubit/hour continuous
Average Concentration	$\frac{1 \text{ cubit / hr}}{0.35 \text{ ACH}} = 2.86 \frac{\text{cubits}}{\text{volume}}$	$\frac{1 \text{ cubit / hr}}{0.22 \text{ ACH}} \times \frac{23}{24} + \frac{1 \text{ cubit / hr}}{3.35 \text{ ACH}} \times \frac{1}{24} = 4.37 \text{ cubits / volume}$
Effective ACH	$\frac{(1 \text{ cubit / hr})}{(2.86 \text{ cubits / air volume})} = 0.35 \text{ ACH}$	$\frac{(1 \text{ cubit / hr})}{(4.37 \text{ cubits / air volume})} = 0.23 \text{ ACH}$

The average daily pollution concentration in the home with intermittent ventilation is nearly twice as high as in the home with continuous ventilation. The effective ventilation rate is lower in this home, since the large fan comes on for only an hour per day. Tracer gas testing in these homes would reveal an effective ventilation rate of 0.35 ACH in Case 1, and 0.23 ACH in Case 2. However, if we calculate the heat loss associated with the ventilation, both cases would be equivalent. It should be noted that this model assumes perfect air mixing inside the building. If all the indoor air pollution occurs during the one hour of high-volume ventilation, then Case 2 would achieve superior air quality. However, if the source emits all of the time, the pollutant removal in Case 1 is far superior.

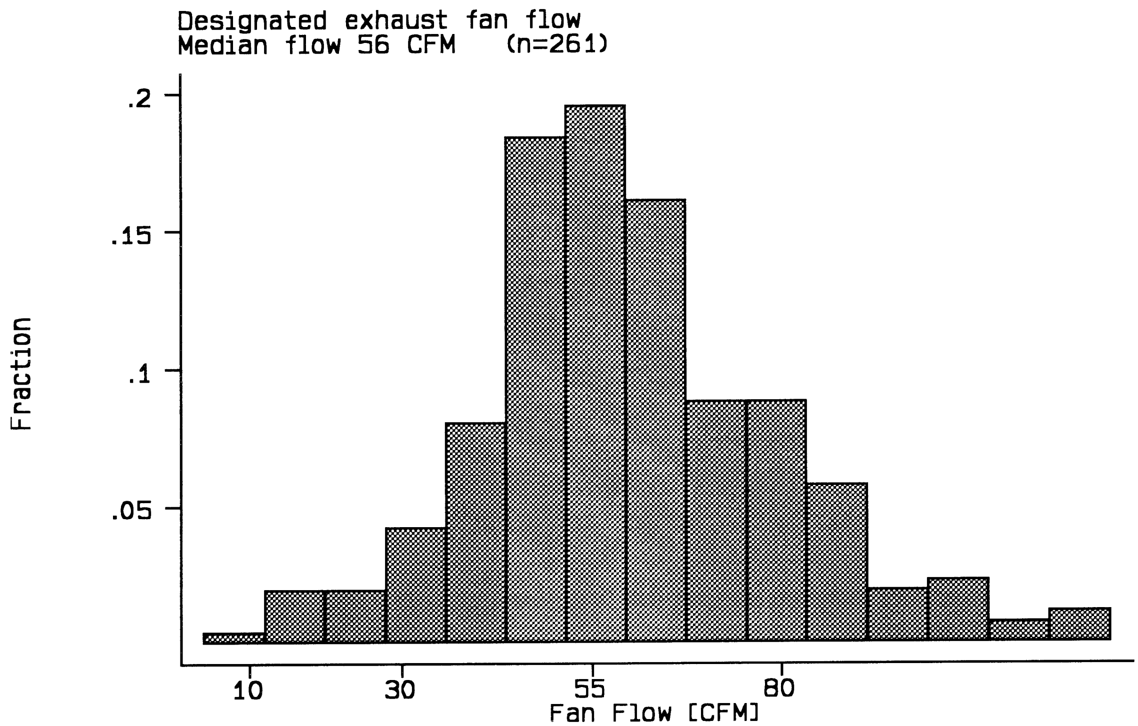
3.5.3 Ventilation Fan Interaction with Natural Ventilation

Another aspect of ventilation that requires discussion before the presentation of the results is the interaction of natural (unintentional) leakage, stack-driven ventilation and mechanical ventilation. In the past, the volume of air flow created by mechanical ventilation systems has been added to the ventilation from natural infiltration. Work at Ecotope by Palmiter and Bond [1991] has resulted in a revision of this practice.

Palmiter and Bond developed a model based on detailed tracer measurements that demonstrates the additional ventilation produced by an exhaust fan is one-half of the flow through the fan if the fan flow is less than twice the natural infiltration rate. If the flow produced by the fan is more than twice the natural infiltration rate, the total ventilation rate will be the flow through the fan. If the fan flow is less than twice the natural infiltration rate, then the total ventilation rate will be half of the fan flow, plus the natural infiltration rate. The fan must overcome the stack pressure distribution within the building; fan flow must be strong enough to reverse the flow through the highest leaks in the building before it will dominate the building's ventilation. The model assumes a uniform distribution of leaks and a neutral pressure level halfway up the outside wall.

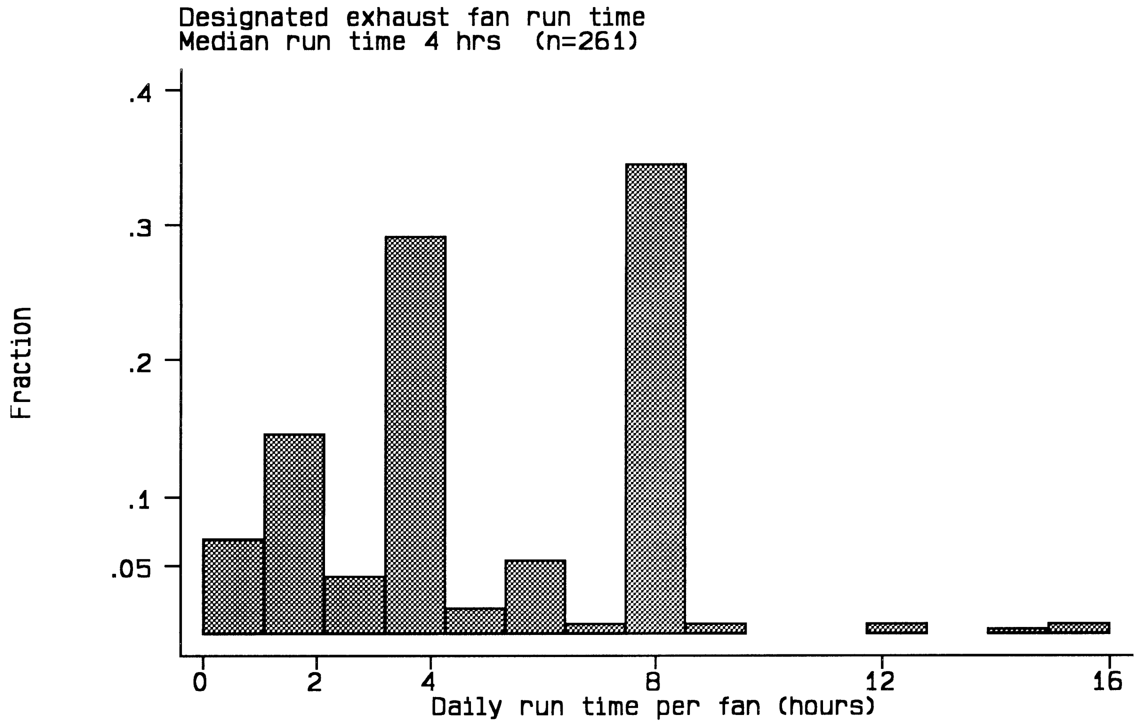
The preceding information was included so as to explain the results of studying whole-house ventilation systems in MAP homes. Figure 3.3 shows the distribution of exhaust fan flow rates for the MAP sample.

FIGURE 3.3
FLOW RATES OF MAP BATH FANS



This distribution reflects the flow measurements for 261 bath fans. The most common median flow rate for the fans is 56 CFM, close to the nominal rating of the fan, installed with an external static pressure of 0.1" w.g. In over 80% of the cases, the fans were one model made by one manufacturer. Figure 3.4 shows the distribution of daily run time for these fans. The data apply to fans that were operational at the time of the audit and that were connected to operating timers (that is, the timer pins or timer knobs were in place).

FIGURE 3.4
RUN TIMES OF MAP BATH FANS



There is a large peak at eight hours, which is twice the number of hours given in the MAP specifications for factory timer setting per fan. The median run time is four hours. Some manufacturers in smaller homes actually set the fans to run eight hours if there was only one fan required under the MAP specifications. What this shows is that within a year of siting, the home's most common reading on the exhaust fan timeclock was what had been set at the factory. This was also found in the RCDP study of manufactured homes. In the RCDP study, however, the specifications required a two-hour run time on each whole-house exhaust fan. Therefore, two hours was the most common run time found on the timer settings.

In most of these homes, two bath fans on timers were needed to meet the MAP specifications, because the most widely used bath fan was rated at about 50 CFM at 0.1" w.g. and the average MAP home had three bedrooms requiring a total rated fan flow of 100 CFM at 0.1" water gauge.

Summary statistics for natural and fan-added ventilation are shown in Table 3.12. The contribution from exhaust fans is calculated from the auditor-measured flows and reported run-times and time-of-day operation. Ecotope used field audit information to account for fan operation overlaps to ensure the fan contributions were not overcounted. Where appropriate, the fan induced ventilation is reduced by one-half because of its interaction with the building's leaks and the stack effect.

TABLE 3.12
SUMMARY VENTILATION STATISTICS

Measure	n	units	average*
Natural ventilation	177	ACH	0.218
Natural ventilation	177	ft^3/min	42.2
Fan-added ventilation	173	ACH	0.042
Fan-added ventilation	173	ft^3/min	8.1
Combined ventilation	173	ACH	0.26
Combined ventilation	173	ft^3/min	50.2

* Averages are weighted with the state-by-state blower door weights found in Table 2.3.

A few points are worth noting. The average total air change rate (natural plus mechanical contributions) for this sample of MAP homes is 0.26 ACH, 0.01 ACH less than the natural infiltration rate of RCDP manufactured homes [Palmiter et al 1992]. This total air change rate is based on blower door tests, rather than tracer gas tests (used in RCDP). Natural infiltration decreased, on average, by about 0.05 ACH between RCDP manufactured homes and the first set of MAP homes, with the MAP ventilation system making up the difference.

The average amount of ventilation added by the whole-house ventilation system is less than 10 CFM. During the times of the year when the stack effect is not pronounced (summer and much of the spring and fall), the mechanical ventilation system is the primary source of pollutant dilution and removal. As operated, the mechanical ventilation systems in most of these homes provide very limited additional ventilation; 87% of the homes in this study fail the ASHRAE standard 62 of 0.35 ACH even when mechanical ventilation as operated is included.

Ecotope has calculated that a MAP homeowner would have to operate both exhaust fans at least 16 hours/day to ventilate the prototype 1,568 ft^2 MAP home to an effective ventilation rate of 0.35 ACH. This level of ventilation assumes that unintentional leakage is the same as reported in the preceding table. Very few MAP homeowners in the study set their timeclocks to operate exhaust fans for this long. While each house has different ventilation needs, a significant portion of MAP homes probably require more fresh air than they are currently receiving.

Recent changes in HUD's whole-house ventilation requirements, combined with work by MAP participants (the states, manufacturers, and Ecotope), have caused several Northwest manufacturers to choose whole-house ventilation systems that are better suited to the long-term fresh air needs of homeowners. These systems are based on a single whole-house fan of sufficient size to meet nominal MAP specifications for either continuous or intermittent use. The fans deliver flow rates of between 60 and 100 CFM under normal operating conditions, and draw less than 20 watts. These fans are designed for continuous operation, and, if sized properly, deliver appropriate air change rates at a reasonable cost (much less than $100/year in most climates). More exotic systems (with heat recovery), have also been analyzed for use in manufactured homes [Heller 1993], but they have not yet received much sustained interest.

4. Performance Evaluation

This review will provide performance estimates and document the heating system performance of houses built to the MAP specifications. This evaluation uses a random sample of MAP houses with no comparisons to houses built to different thermal standards.

The goal of this analysis is to assess the MAP home's heating energy requirements and their operating conditions. The overall performance levels can be compared to simulation predictions for homes built to this standard. The simulation inputs and consumption determinants for the homes' space heating requirements were assessed. Adjustments or modifications can then be made to the performance estimates (Section 5).

4.1 Data Collection

All of the homeowners that consented to the field evaluation were asked to sign a billing release. These billing releases authorized Ecotope to request individual bills from individual utilities for a one-year period. Since the studied homes were built in 1992 and 1993, the homeowners often had not lived in their home for a full year. In some cases, the homeowners had changed since the home was originally sited, and the original owners were not the occupants during the period of interest. Finally, for one reason or another, a billing release was not obtained for all the homes. Billing releases were obtained for 162 homes (homes with a full year of bills) out of 178 homes visited.

Table 4.1 presents the breakdown of these data by state. As shown, most of the difficulties associated with inadequate or unavailable bills occurred in the state of Washington. This was largely due to failure to secure the billing releases for all homes during the field visit. Other reasons for removing participants from the sample included difficulties in securing the bills from the respective utilities and the lack of homes' meter readings at regular intervals. Some utilities, particularly those in rural areas, read meters only once a year. In this event, it is the responsibility of the homeowner to read the meter monthly. When this does not occur, bills are estimated, and it is almost impossible to use such bills for billing analysis; thus, these bills were excluded from the analysis.

TABLE 4.1
USABLE UTILITY BILLS BY STATE

State	Full Sample	% of Total Possible Bills	Usable Bills	% of Usable Total
ID	40	22.5	38	23.5
MT	18	10.1	16	9.9
OR	50	28.1	48	29.6
WA	70	39.3	60	37.0
Total	**178**		**162**	

Once the billing releases were secured and the field work completed (June, 1994), the billing releases were given to Pacific Northwest Laboratory (PNL) for securing some of the bills. During July and August, 1994, PNL succeeded in securing bills for 113 homes; of these, about 80 had full 12-month bills. In October, 1994, Ecotope supplemented this data set with billing releases that had not been used by PNL. We added bills to approximately 30% of the PNL sample, so that each record would contain a year's worth of billing data. These supplemental bills reflected a billing year that began in the summer of 1993 and ended in the summer of 1994. For the half of the sample in the initial collection, the billing year began in the early spring of 1993 and ended in the spring of 1994. In a few cases, the actual year began in January, 1993 and ended in January, 1994.

Billing periods were considered comparable as long as adequate weather data could be obtained for the billing periods to allow weather normalization. During the bill collection process, information on bill estimation and supplemental information from homeowners were also collected. This enabled us to assemble a more complete record on each bill and to understand anomalous bills.

Once a complete year's worth of billing records were secured for every house, each house was assigned a weather site based on its location and climate. In general, the weather sites were assigned on the basis of geographical proximity. Following these assignments, Weather Service data were collected for each site. The Weather Service data included the high and low temperatures for each day of the year. A program was written to calculate degree-days based on these high and low temperatures. Using the billing periods specified in the bills, complete temperature records were assigned to each bill. There were a few cases for which this was not possible due to missing values in the Weather Service records, and in such cases, information from nearby weather sites was used to supplement data. In a few cases, the weather sites chosen because of their proximity did not represent the microclimates associated with the homes. Efforts were then made to assess the microclimate and assign more appropriate weather sites. There were some difficulties associated with these assignments due to lack of detailed site information for each home. The climate summaries and billing analyses were conducted using these climate sites, and we substituted other weather sites on a trial basis in difficult cases to determine which weather station was not appropriate.

4.2 Degree-Day Calculations

The characterization of climates and heating requirements is based on the construction of heating degree-days for each site. The degree-day is a construct of the U.S. Weather Service, and is calculated according to the following equation:

$$DD = T_{BASE} - \left(\frac{T_H + T_L}{2} \right)$$

DD	:	Daily Degree Days
T_{BASE}	:	Degree-Day Reference Temperature
T_H	:	Daily High Temperature
T_L	:	Daily Low Temperature

The Weather Service and virtually all climate summaries use a T_{BASE} of 65°F for calculating heating degree-days. This base temperature has been an established part of Weather Service reporting for more than 40 years, and was designed to roughly describe the factors that predict space heat in residential buildings. Unfortunately, as homes become better insulated and have more internal gains (due to appliances, lights, etc.), base 65°F degree-days are less and less useful as a space heat predictor. In relatively well insulated houses with typical modern appliances, the T_{BASE} can easily fall below 55°. This results in a very different climate characterization in terms of space heating.

For this analysis, we have characterized the climates using the traditional base 65°F degree-days. The performance prediction, however, is based on balance point degree-days derived from the regression analysis. In this data set, for example, the average building balance point (and therefore the degree-day reference temperature) is approximately 56°F. The T_{BASE} for individual houses ranges from 50° to 67°F. The determination of this balance point is a function not only of heatloss rate, but also of internal gains in the home and the thermostat setpoint used by the homeowner.

4.3 Two types of Billing Analysis

This analysis established space heating requirements for the homes built according to the MAP specifications. The central assumption in the billing analysis is that the amount of space heating in a single month is strongly related to outside temperature. This relationship can be derived by relating overall energy use to outside temperature and estimating space heat energy by reviewing usage patterns over the year.

There are several methods for assessing and estimating home heat use. The most common of these techniques is the Princeton Scorekeeping Method (PRISM) analysis [Fels 1986]. The method used in this report is adapted from PRISM, and relies on a variable-based degree-day method in which individual bills are paired with the average temperature conditions for the billing period, expressed as degree-days. A regression is established using these points, and the fit indicates the relationship between space heating and weather conditions. The actual procedure consists of an iterative process; degree-days are calculated to various bases between 50° F and 72° F. A separate regression is run for each degree-day increment, and the best fit is selected.

For most Pacific Northwest weather sites, there are months in which no degree-days occur and no space heating occurs. In western Washington and Oregon, for example, it is not unusual for space heating to be completely absent between May and October in homes built to the MAP specifications. Ecotope's regression algorithms derive space heating estimates only for those months in which heating degree-days occur. The remaining bills are used to derive non-space heating energy usage.

A balance-point degree-day base is selected from the best fit of energy use to degree-days. The regression against degree-days to this base produces a slope that expresses heating requirements per degree-day (kWh/DD) as the heat loss rate for the house. An intercept is also produced, representing the point at which the heating degree-days and heating load equal zero. The intercept represents home energy use when no space heat is present. When multiplied by the number of months in the analysis, this becomes a first-order estimate of the home's non-space heat energy use.

There is a difficulty associated with this method: non-space heat usage actually varies seasonally, depending upon outdoor temperature and hours of sunlight. The impact of these seasonal non-heating variations is well documented in Roos and Baylon [1993]. This study evaluated the submetered energy use of 150 manufactured homes built to thermal standards similar to the MAP specifications. The homes in this study were submetered so that non-space heat load variations were monitored and could be studied. Other researchers have observed similar effects and have attempted to provide solutions to this problem in evaluating regression-based billing analyses. The method proposed by Fels et al [1986] is to fit a cosine function using the regression constant. The constant (y-intercept) represents the minimum seasonal value of appliance usage, and the maximum value is described by a cosine function with an amplitude of approximately 1.15.

The research of Roos and Baylon [1993] suggests that this value (1.15) is somewhat high; the amplitude used by Roos and Baylon was 1.12. Work on other submetered data in the Pacific Northwest by Palmiter, et al [1988] suggests that a value of about 1.17 is more appropriate. For this analysis, we have used the values from the Roos and Baylon study rather than the higher values of Fels or Palmiter, since the study sample used by Roos closely approximates both the use, type and size of the MAP sample. This results in a small correction in space heat estimates from the regression and higher space heat estimates. We applied a seasonal variation to the constant, and the space heating value was reduced to account for the seasonal variation in non-space heating usages. The reduction amounted to about 14% across the sample.

A second billing analysis was then conducted using another strategy. In this case, no regression analysis was conducted. We used the billing procedure developed by Kennedy [1994]. The procedure begins with the selection of the three lowest bills of an annual billing cycle. The median of these three bills is then selected as a first-order estimate of non-space heating consumption. The Roos and Baylon adjustment is applied and the result is the monthly estimate of the home's non-space heat usage. The difference between this result and the total bill for the month becomes the monthly space heating estimate.

Seasonal variation in non-space heat usage is directly accounted for with this analysis. However, any temperature-based variation is not directly measured, since this procedure does not normalize by temperature or degree-days. This procedure is less complex than the regression analysis, but it cannot be easily applied across climate zones and different years' weather conditions. The two methods are in substantial agreement for the year studied, with a correlation coefficient of 0.985 between space heat energy estimated from the billing analysis and estimates from the regression analysis.

Both the "second-lowest bill" analysis and the variable-based degree-day regression analysis are subject to several errors. Some homes may have heat pumps operated with automatic thermostat changeovers. In such cases, it is possible to have cooling loads during fall and spring seasons that actually increase the apparent heating load for that period. In this event, both the regression and billing analyses will be biased, since they both depend upon finding a minimum value (representing a period when no space heat or cooling occurred). In the case of the regression analysis, this problem is moderately controlled, since the regression line is fit through several points. In principle, this does not necessarily determine the intercept's value. In practice, however, since this cooling is occurring over a wide range of temperatures and can occur in any month of the year depending upon certain solar conditions, the intercept and slope are both biased by additional cooling load (assumed to be space heat). As a result, space heating estimates for homes with heat pumps tend to be inaccurate. For this reason, buildings with heat pumps were excluded from the analysis of heating requirements.

4.4 Billing Sample and Screening

Table 4.2 shows the distribution of heat pumps and primary wood heat uses in this sample. A large percentage of the homes have one or the other of these conditions. We did not exclude buildings with central air conditioning from our analysis. We suspect that a fraction of the buildings with central air conditioning actually increase the apparent space heating load.

TABLE 4.2
BILLING ANALYSIS SAMPLE DISTRIBUTION: ALL CASES

State	All Homes	Heat Pump	Wood Heat	Bad Bills	Analysis Sample
ID	38	4	3	3	28
MT	16	0	1	1	14
OR	48	12	4	3	30
WA	60	4	9	3	44
TOTAL	**162**	**20**	**17**	**10**	**115**

Another problem was encountered during the study: when the state auditors reviewed these homes, they were asked to review the furnaces and the space heating, air conditioning and other electrically-powered equipment in detail. In several cases, the billing data did not correspond with data from the on-site review. For example, buildings with no reported air conditioning seemed to have summer use patterns indicative of substantial cooling loads. In most cases, we attempted to contact the homeowners, and find out if the heating equipment had changed since the original audit. In about ten cases, heat pumps or unit air conditioners had been added to the home after the on-site audits. For these homes, the last six months of their billing cycles included heat pump and air conditioning energy usage, while the first six months did not. Unless the cooling load was readily apparent and easily accounted in the billing analysis, homes in this category were excluded from the heating analysis.

A further difficulty was encountered with homes using wood heat. Although the auditors asked each homeowner whether they had a wood stove and how often they used it, and although we excluded homes using such heat, there were cases in which wood stoves were added after the audits. There were a few cases in which wood stoves provided substantial space heat, rendering the regression analysis ineffective. These cases did not produce reliable regression slopes; in some cases, the slopes were negative, suggesting that the buildings used more energy in the summer than the winter. This kind of usage pattern confuses the estimation of space heating requirements. Homes using a substantial amount of wood heat and homes with apparent wood heat were excluded from the analysis. Three homes had both a heat pump and wood use; these are shown in Table 4.2 as wood-heated but are not included in the heat pump tally.

The final difficulty with the billing analysis involved the differential loads not accounted for in seasonal adjustments or other changes made to the sample. Approximately 10% of the homes had large heated outbuildings that were included on the billing meter. The outbuildings were usually heated garages, barns, shops and offices; there were also homes with heated pump houses. This load is difficult to determine, and may vary substantially depending on individual homes and climates. Those homes with heated outbuildings noted by the auditor showed apparent energy use increases of about 2,000 kWh per year when compared with homes lacking outbuildings. Whether this apparent increase was due solely to the outbuilding or some other factors is impossible to determine without more detailed submetering and analysis.

Approximately 60% of all homes in this sample were located in rural areas. The buildings had substantial loads that would not otherwise be expected in a typical sample of single-family residences in the Pacific Northwest. These loads were associated with large exterior lights, wells and well pumps, outbuildings, shops and other supplemental uses typical of rural locations. These uses affect the seasonal variation of non-space heat energy use. Although such uses produce a bias, we do not currently have the information necessary to determine the magnitude of the effect. Some exploratory data analysis was conducted, and results are presented with the billing analysis results.

Certain criteria were used to limit the sample size so that a valid and useful analysis could be conducted. The most important of these criteria applied to the primary heating system. Buildings with heat pumps or wood heat were excluded from the analysis. Since the billing regression in each home produced an estimate of the goodness of fit (R^2) between the regression line and the actual meter reading, additional restrictions applied only to cases with R^2 values under 0.7. These cases tended to occur in localities where utilities did not read the meters monthly, but rather bi-monthly (in the case of western Washington) or annually, with intermittent meter readings during the year expected from the homeowners. These cases are shown in table 4.2 as "bad bills", and represent about 6% of the original sample. In these cases, billing errors were often so substantial that the regression analysis could not produce an adequate space heating estimate.

Table 4.3 shows the disposition of the final sample for use in the billing and performance analysis. Homes with heat pumps are separated as shown in this table, so that contrasts between the overall home characteristics can be seen. The homes with heat pumps are considerably larger than homes without heat pumps. The billing analysis restrictions result in a final sample of much smaller homes than are typical for the homes produced by this industry. The average home size for homes with primary forced-air electric heat is 1319 ft^2, much smaller than the 1568 ft^2 prototype home used in prior cost-effectiveness analyses [e.g. Baylon and Davis 1993]. This introduces a substantial bias, which we will attempt to correct in the performance analysis.

TABLE 4.3
BILLING ANALYSIS: SCREENED TOTALS

	Electric Forced-Air Furnace	Heat Pump	Wood
Area (ft^2)	1319	1716	1602
Number of Occupants	2.65	2.20	3.00
Thermostat Setting ($^{\circ}F$)	67.5	69.4	64.9
Number of Cases	115	20	17
% Rural	58.3	65	94.1
% Well Pump	24.3	30	76.5
% With Outbuildings	9.6	20	41.1
% With Air Conditioning	17.4	100.0	12.5

The actual billing analysis summaries are based on 115 homes. The various restrictions mentioned above excluded 47 homes from the analysis. The excluded cases consisted of 20 homes with heat pumps, 17 homes with wood heat and 10 homes with inadequate billing records.

4.5 Weather Site Assignments

The billing analysis was conducted in 25 weather climate zones, located throughout the Pacific Northwest. Each climate was described by the daily high and low temperatures for the billing period for each home. The individual sites were assigned to each of three climate zones, which were designed to roughly correspond to the regional climate zone map developed by the Northwest Power Planning Council (NWPPC) for long-term energy planning.

Climate zones were designed to reflect the overall variations in climate in the region. Climate Zone 1 is composed of Western Washington, Oregon and the lower Columbia/Snake Valley; it represents heating degree-days (base $65^{\circ}F$) of 5,500 or less. Climate Zone 2 is composed of the remainder of Eastern Washington and Oregon and most of Idaho, with 5,501 - 7,500 degree-days. Climate Zone 3 is composed of parts of Idaho and most of Montana, with degree-days greater than 7,500.

The actual weather site assignments correspond to these divisions. While these divisions are somewhat different from the definition of climate zones used in previous analyses of Pacific Northwest energy conservation programs, the geographic areas and climate zone distributions are very consistent with individual sites used (Portland, Spokane and Missoula) to predict performance for the MAP prototype building. The adjustments in the climate zone definition are also appropriate, given the relatively warm conditions in the climate zone during the study period (1993-1994).

TABLE 4.4
WEATHER SITE DISTRIBUTION

City	State	Climate Zone	Degree-Days Used (Average for billing periods; base 65°F)	Long-Term (1961-90) Degree-Days (base 65°F)	# of Sites Audited	# Included in Final Billing Analysis
Boise	ID	2	5747	5871	12	9
Idaho Falls	ID	3	7179	8052	3	2
Lewiston	ID	1	4940	5275	1	1
Pocatello	ID	2	7093	7207	10	6
Soda Springs	ID	3	8788	8870	1	1
Cut Bank	MT	3	8776	8999	2	2
Dillon	MT	3	7430	8255	4	4
Kalispell	MT	3	7755	8251	9	8
Missoula	MT	3	6932	7793	2	1
Astoria	OR	1	4694	5171	5	4
Medford	OR	1	4410	4713	6	4
Newport	OR	1	4662	5300	3	3
North Bend	OR	1	4449	4555	5	4
Pendleton	OR	1	5000	5284	4	1
Portland	OR	1	4125	4520	9	6
Redmond	OR	2	6623	6745	5	3
Salem	OR	1	4267	4930	15	8
Bellingham	WA	1	4350	5625	2	1
Leavenworth	WA	2	6206	6638	2	2
Olympia	WA	1	5121	5615	7	4
Richland	WA	1	4490	4824	6	3
Seattle	WA	1	4521	4906	14	9
Spokane	WA	2	6471	6891	21	18
Whidbey	WA	1	4724	5096	7	5
Yakima	WA	2	5671	5985	7	6
TOTAL					**162**	**115**

Table 4.4 lists the weather sites and degree-days used in this analysis, showing the number of homes assigned to each weather site. The degree-days used refer to the actual base 65°F degree-days calculated for the particular homes during the periods for which billing analysis was conducted. Long-term degree-days refer to the 30-year average degree-days taken from 1961 to 1990

4.6 Heating Energy Usage Estimate

The methods described here resulted in an individual space heating estimate for each of the buildings reviewed in the billing analysis. The homes with good quality bills and no apparent space heat provided by wood heat or heat pumps (115 total) were the only ones used in the analysis. Table 4.5 summarizes the results of the space heating estimated from the billing analysis. The summaries represent predicted space heating using the billing analysis method described in the previous section.

TABLE 4.5
BILLING ANALYSIS BY CLIMATE ZONE
(Averages)

Climate Zone	n	Heating (kWh/yr)	Other (kWh/yr)	Total (kWh/yr)	Area (ft^2)
1	53	5652	9449	15202	1337
2	44	6932	10801	17945	1315
3	18	9300	11985	21367	1278

Also summarized in this table are the average estimated non-space heat use and the average total electricity bill for the homes in each climate zone. There is an appreciable increase in non-space heat usage associated with a colder climate zone. There are two reasons for this:

1. Certain features of each climate zone's non-heating electricity use increase with colder temperatures. This includes energy used for hot water, well pumps and the freeze protection requirements for crawlspace plumbing, etc. in colder climates.

2. A fraction of the space heat, especially in Zone 3, is probably incorrectly allocated by both the variable-based degree-day regression analysis and by the billing analysis to the non-space heat sector. This occurs in only some houses, where the summer conditions are particularly cool. The analysis procedure is not sensitive enough to discern this effect.

In Zone 1, there are four cases in which heated outbuildings (barns, shops and greenhouses) are included in the bills. These four cases result in a 5% increase in the overall space heat estimate for the entire climate zone. This condition also exists in Zone 2, indicating that at least in these two populations, failure to account for large energy uses outside of the home can substantially bias the analysis.

TABLE 4.6
IMPACTS OF OUTBUILDINGS ON SPACE HEAT ESTIMATES

No Outbuildings Included				Outbuilding Cases		
Climate Zone	n	Heating Estimate (kWh) (Average)	Non-heating Estimate (kWh) (Average)	n	Heating Estimate (kWh) (Average)	Non-heating Estimate (kWh) (Average)
1	49	5372	9216	4	9056	12316
2	40	6567	10329	4	10577	15528
3	15	9179	11880	3	9906	12273

The field notes on the out buildings represented in Table 4.6 revealed only the most obvious and extreme examples of outbuildings. A common observation was a heated shop/garage. This kind of outbuilding could be using substantial amounts of electrical energy for the operation of shop equipment, as well as adding a seasonal heating load. In addition to this, there were three heated barns and two heated greenhouses and there were also two cases of heated add-on living spaces. These cases are included in this report's overall space heat estimate although they were built to unknown construction standards; this resulted in an apparent increase in heated square footage of 10% to 20% for these cases. These cases are relatively rare; however, additional buildings have a dramatic impact on space heating estimates, and on the variable-based degree-day regression analysis.

While outbuildings are the most dramatic of these situations, there are other important uses that have seasonal aspects and cannot be well characterized by any of our procedures. One such example is a well pump, present in about 25% of the sample homes. Although well pumps may represent a constant load through the year, freeze protection in well pumps does not. Houses with well pumps tend to have other, potentially seasonal activities, such as outdoor area lights associated with rural locations. These two effects seem to have a 300 - 500 kWh impact on the annual space heat estimate. This is a much smaller effect than the outbuildings have on the average home, but still results in an apparent 2% - 3% reduction in both the space heat and non-space heat estimates. It is important to acknowledge these biases, since they are very difficult to quantify without submetering, and since almost all other work involving regression and PRISM analyses to evaluate the MAP homes and other manufactured homes have ignored these effects.

Table 4.7 summarizes the salient inputs and outputs of the billing analysis. When reviewing Table 4.7, it is important to realize that homes noticeably smaller than the average-size home built under the MAP. The heat pumps have been removed, and observed temperature setpoints average approximately 3°F more than the temperatures used in the original SUNDAY simulations (upon which program savings and cost-effectiveness have been based). These two effects are in opposite directions; however, the effect of thermostat setpoint is much more significant than the impact of the reduced building size.

TABLE 4.7
BILLING ANALYSIS OVERALL SUMMARY

Variable	Climate Zone	n	Mean	Standard Deviation	Median
Area (ft^2)	1	53	1337	302	1280
	2	44	1315	330	1376
	3	18	1278	316	1173
Number of occupants	1	53	2.53	1.01	2.0
	2	44	2.68	1.57	2.0
	3	18	2.94	0.94	3.0
Heating setpoint (°F) (includes effect of setback)	1	53	66.8	3.96	67.2
	2	44	68.0	3.89	68.3
	3	18	68.1	2.24	68.0
Results					
Regression heating energy kWh/year	1	53	6432	2509	6039
	2	44	7935	2552	7207
	3	18	10507	2973	9894
Regression heating energy with seasonal adjustments kWh/year	1	53	5574	2454	5181
	2	44	6936	2460	6295
	3	18	9322	2903	9002
Degree Days Base 65°F during billing period	1	53	4529	282	4466
	2	44	6309	522	6351
	3	18	7759	570	7714
Degree Days at balance point	1	53	2514	896	2650
	2	44	3743	1051	3604
	3	18	5442	1444	5402
Balance point temp (°F)	1	53	57.5	4.1	58.5
	2	44	55.0	4.1	54.0
	3	18	56.9	4.9	56.5
Billing analysis ("second-lowest bill") heating energy (kWh/year)	1	53	5652	2396	5090
	2	44	6932	2278	6295
	3	18	9300	2792	8836
Other uses (non-heating) (from billing analysis) kWh/year	1	53	9449	3587	9055
	2	44	10801	4410	9352
	3	18	11985	3580	12824
Total Use (heating & other) (from billing analysis) kWh/year	1	53	15202	4282	14630
	2	44	17945	5261	17515
	3	18	21367	4836	20874

5. Recalibrating the MAP Simulation Analysis

The goal of this section is to use the results of the billing analysis and field review to recalibrate earlier energy use simulations performed with Ecotope's SUNDAY program. The recalibration should, in principle, allow the simulation to replicate the results of the billing analysis.

SUNDAY is a one-node building energy simulation program that has been used extensively by Ecotope for energy analyses since the early 1980s. SUNDAY was written by Larry Palmiter and Davis Straub of Ecotope to model energy use in residential buildings. The program takes daytime and nighttime ambient temperatures into account, as well as solar gains for eight window orientations for each day of a typical meteorological year.

SUNDAY has been benchmarked with other simulation programs and with billing and submetered data. When SUNDAY inputs (internal gains, building thermal mass, window orientation, etc.) are properly specified, SUNDAY agrees within a few percentage points on an annual basis with other detailed simulation programs and submetered heating energy data. The most relevant example of this is Ecotope's study of manufactured homes [Baylon et al 1991] studied under the RCDP program. For RCDP homes using electric resistance heat, the agreement between SUNDAY simulations and submetered space heating results was within 2%. The SUNDAY inputs were informed by energy audits that recorded the number of occupants, thermostat setpoints, setback hours and solar shading estimates. These data are used to "tune" the simulation's space heating predictions.

The simulation analysis (coupled with a cost-effectiveness optimization procedure) has developed in recent years and has been described in various reports. [See Palmiter 1982, BPA 1986, Baylon et al 1991, and Baylon and Davis 1993]. All of these references include optimizations for manufactured homes, although only the last one presents an optimization for the MAP measures. Information on optimal conservation package cost and performance was used in negotiations with manufacturers in an attempt to achieve an overall *in situ* performance similar to the optimizations' predictions.

The performance predictions from the simulation analysis are essential to developing a cost-effectiveness for the MAP conservation measures. This calculation depends on simulation runs based on multiple runs describing changes in heat requirements as the MAP measures are added to a 'base' case prototype home. In this analysis all assumptions are held constant (occupancy, thermostat set point, solar orientation, etc.) and the characteristics for the building shell are varied to account for the additional conservation measures installed with MAP.

The selection of individual measures for the MAP was not based on the cost effectiveness of the entire package, but on the cost-effectiveness of individual measures (once corrections for interactions among these measures have been made). This was because of BPA's requirement that individual conservation measures meet its cost-effectiveness criterion in order to be included in a conservation program.

In order to establish package savings, it must be determined what kinds of measures would have been included in the home in the absence of the program. This is a crucial assumption, since the relative performance against the base case will establish the program's overall expected savings and cost-effectiveness. Incorrect assessments of the "base case" could result in the utility paying for conservation that might be achieved anyway because of manufacturers' and homebuyers' current purchasing decisions. Savings must therefore be carefully placed in the context of the particular levels of incentives and utility goals provided.

5.1 HUD Base Case

In 1976, the Department of Housing and Urban Development (HUD) was given authority to regulate the construction, health and safety standards for the manufactured housing industry. These standards included a minimum level of thermal performance, and specified insulation levels, glazing performance and heating system sizing. The standards mandated in 1976 were consistent with construction standards current at that time, including the proposed energy codes of the late 1970s.

The standard was defined using a U_o (the sum of the conductive heat losses of all building components -- windows, walls, doors, floors and ceilings -- divided by the total area of all those components). This became the average U-value for the building. In the 1976 standards, the U_o was set at 0.126 Btu/hr °F ft^2 or less for homes built in the HUD climate zone which includes all of the BPA service territory. Since this standard was set, the manufactured home consumer demand for insulation has substantially increased; manufacturers have used various designs and products that reduce homes' overall heat loss rate to less than this standard. Most manufacturers interviewed in the late 1980s reported that their homes had a U_o of between 0.105 and 0.11. In some cases, windows were added to the basic package by the homebuyer, and this caused the U_o to increase and approach the HUD maximum allowable U_o.

During the latter part of the 1980s and into the 1990s, good quality insulation was made widely available in the manufactured home marketplace in the Pacific Northwest. This was partly because many BPA and utility programs supported high insulation levels, and partly because home buyers chose improved insulation standards. Reasonably-priced insulation packages were routinely purchased by manufactured home buyers. It is impossible to attribute this change to any single cause, and it is difficult to determine what insulation levels would have been typical in the absence of the utility programs that later became the MAP program.

A specific package of conservation measures was developed for the MAP negotiations with home manufacturers. This package was based on the Residential Conservation Demonstration Project (RCDP) manufactured housing program survey conducted in 1988 and 1989. The survey work indicated that manufactured homebuyers were routinely purchasing approximately $800 worth of insulation upgrades [Baylon et al 1991]. Since this insulation upgrade was not mandated by any manufacturer or regulatory standards, the upgrade amount probably represents an average value. For purposes of the optimization and cost-benefit analysis, particular insulation levels were assumed; this resulted in a 10% to 15% decrease in the building's U_o, from that specified by the manufacturer. The RCDP manufactured home survey found a U_o of 0.095 as the "most common" value reported by manufacturers this U_o became the "base case" for MAP cost-benefit analyses performed by Ecotope in 1991 and 1993.

Beginning in April, 1992, all electrically heated manufactured homes sited in the Pacific Northwest were built to the MAP specifications. In exchange, BPA and the region's utilities paid $2500 incentive to the manufacturers for each electrically heated home produced to these specifications. These specifications mandated a series of insulation and window measures designed to reduce the U_o to 0.053, less then half the HUD thermal specifications at that time. Through their MAP incentive payments, directly paid to the manufactures, Bonneville and the utilities offset most of the incremental costs of the additional features mandated by MAP. The consumer decisions associated with insulation or window performance were masked by the MAP specifications; that is, only MAP homes were available to nearly all of the Northwest manufactured homebuyers, since 95% of these homes had electric heat and all electrically-heated manufactured homes had to meet MAP specifications.

The MAP was based on the incremental cost on each measure in the program meeting a cost-effectiveness criteria. From a societal perspective, the resources expended to achieve these higher performance levels in manufactured homes are cost-effective on an individual measure basis.

In 1993, after much debate and study, HUD proposed a new standard to update the 1976 insulation standard. The new standard took effect on October 25, 1994. The new standard requires a U_o of 0.079, which implied an increased space heating efficiency in manufactured homes of about 20% over the most common practice U_o of 0.095. The basis for the new standard was a series of studies conducted by PNL in the late 1980s [Conner et al 1992]. The manufactured home industry will use particular insulation and window upgrades to achieve this standard.

For purposes of the optimization and cost-benefit analysis, the change in the HUD standards changed the "base case". These changes resulted in a reduction in the overall price of the MAP package (since the new HUD standard subsumes some of the MAP measures), thus reducing the amount of incentives offered by the utilities to manufacturers to meet the MAP specifications. The absolute performance and efficiency of the homes built to MAP specifications were not affected by a change in the HUD "base case". Only the utility cash incentives to achieve this performance were impacted.

5.2 Factors Affecting Energy Use Simulations

The analysis of individual energy conservation measures and their impact on manufactured home energy use has depended on the development of an analytical prototype manufactured home. Use of the prototype allows the relationship between various measures to be fixed so that the cost and energy saving benefits of the individual measures (e.g. window improvements, added ceiling insulation, improved wall insulation) can be analyzed. The whole-house heat loss rate (UA) implied by the standard practice developed from RCDP manufacturers' surveys was used as a basis for establishing potential savings from the MAP package in the context of the prototype approach.

Factors other than heat loss rate that contribute to homes' overall performance, cost-benefit analysis and energy use predictions are the homeowners' characteristics and lifestyles. These include thermostat setpoint, the amount of internal gains generated by heat-producing appliances in the home, the number of persons living in the home, etc. The performance predictions generated by the optimization and used in the cost-benefit analysis reflect the predicted space heat energy usage. The energy used at the meter is a combination of space heating energy use and other non-heating energy uses, such as hot water, lighting (interior and exterior), electrical appliances, and energy use in outbuildings. For purposes of the initial cost-benefit analysis and optimization, the simulations of space-heating energy use were run using certain assumptions about the MAP homes' average characteristics. These are included in Table 5.1:

TABLE 5.1
PERFORMANCE ANALYSIS INPUTS

Characteristic	Units	Original MAP Optimization Prototype	Average from Audits Climate Zone 1	Climate Zone 2	Climate Zone 3
Floor Area	ft^2	1568	1337	1315	1278
Thermostat Setpoint	°F	65	66.8	68.0	68.1
UA	BTU/°F - hr	314	270	279	272
Infiltration	ACH	0.35	0.24	0.29	0.31
Duct Efficiency	(%)	0.99	0.86	0.86	0.86

The field inspection was a random sample, representing the characteristics of the average MAP home. For purposes of performance estimation, only a fraction of these homes (those with primary forced-air electric resistance space heating) were used in the billing analysis in the previous section and for purposes of comparison to the SUNDAY optimization analysis.

As shown in Table 5.1, the homes built and evaluated with the billing analysis differ markedly from the prototype home used to estimate MAP program savings [Baylon and Davis 1993]. Several factors must be considered when making this comparison. The first is the size of the home. In the billing analysis, homes were approximately 20% smaller than the prototype home, and this reduced the overall heat loss rate by approximately 17% versus the prototype. This would result in a reduction of the space heating energy requirement by a similar percentage. There are, however, other equally significant variations: the simulation used a thermostat setpoint of 65° F, but the actual survey of thermostat setpoints revealed that the average thermostat setting for the entire region was 67.8 °F. This 2.8° F difference more than compensates for the reduced house size by increasing the temperature difference between ambient and house interior and hence the home's heat loss rate.

Blower door tests were used in the field study to assess the homes' relative air tightness. Correlations between door test results and tracer gas measured infiltration rates was used to establish estimates of home infiltration rates [Palmiter and Bond 1991]. These tests showed an increase of approximately 25% in envelope tightness, and thus an estimated 25% reduction in natural ventilation over that assumed in the original prototype. Furthermore, in the original MAP prototype assumptions, a certain amount of ventilation was expected from the BPA-mandated designated fan ventilation system. A minimum 8-hour run time (2 fans each set to run 4 hours/day) was mandated as a factory setting for homes' ventilation systems. Field auditors were asked to review the ventilation fans' timer settings, and the results of these settings were included in the infiltration heat loss estimates in Table 5.1. Fan run times and flows were such that only a modest increase in ventilation (< 0.05 ACH on average) and additional heating load were added due to their operation. The overall impact of the increased tightness and a reduction in the total amount of fan run time resulted in a 25% decrease in heat loss due to infiltration.

The final and most significant adjustment to the prototype analysis resulted from a review of manufactured homes' furnace and ducting efficiency [Davis et al 1994]. These tests were complete and included the effects of cross-over ducts, air flow balance duct leakage and other system effects in manufactured homes ducting systems. In the original simulation analysis, a duct and heating system equipment model [Kennedy 1991] was used to adjust the steady-state floor heat loss rate. Key inputs to the model were based on only one set of field data (the only applicable field data available at the time) and did not account adequately for the range of conditions in manufactured homes.

Ecotope had concluded that an insulated duct with R-33 belly insulation below it and (in some cases) an airtight belly board, would have very limited energy losses and a modest effect on reducing overall heating system efficiency [Davis and Baylon 1992]. Since this was an assumption that was not based on extensive empirical evidence, a study was conducted to discover the relative efficiency of the MAP duct system. This detailed real-time efficiency study of six homes [Davis et al 1994] indicated that MAP heating distribution systems had a significant effect on reducing heating system efficiency. The average heating system efficiency (including recovered heat) was 86%, meaning that 14% of the heat generated by the furnace was not delivered to the home as useful heat. This heat loss occurred due to air leaks and conductivity from the trunk and crossover ducts into the belly area and crawlspace. Almost every simulation run using the MAP assumptions would therefore underpredict space heating by this amount. In order to compensate for the duct losses, all of the SUNDAY simulation heating estimates were divided by 0.86.

An effort was made to match SUNDAY simulations with the estimated space heating from the billing analysis. Rather than calibrate the SUNDAY runs to climate zones represented by one weather site (as in the original simulations), we attempted to match the SUNDAY runs to each of the weather sites for which we have sufficient information (5 or more homes). Table 5.2 shows a comparison between billing data collected for the seven sites used for this calibration exercise; it also shows the assumptions used in the calibration.

TABLE 5.2
COMPARISON OF SIMULATION INPUT ASSUMPTIONS AND FIELD DATA FOR SELECTED WEATHER SITES

Climate Zone	Weather Site	N	Degree Days (base 65 °F)		Thermostat Setpoint (°F)		Field Sample Floor Area	Field Sample UA	Revised Simulation Assumptions		
			Bills	SUNDAY	Bills	SUNDAY	(ft²)	(BTU/°F - hr)	Internal Gains (BTU/hr)	Solar Multiplier	UA (BTU/°F - hr)
1	Portland	6	4158	4786	66.9	66.0	1193	254	2000	.45	260
	Salem	6	4263	5177	67.1	64.0	1301	257	2000	.40	260
	Seattle	9	4558	5444	66.2	64.0	1502	301	2000	.25	300
2	Boise	9	5772	5821	68.7	68.0	1432	291	3500	.70	290
	Pocatello	5	7306	7191	67.7	67.0	1441	302	3400	.80	300
	Spokane	13	6429	6819	67.8	66.4	1214	250	2800	.50	250
3	Kalispell	6	7764	8437	67.8	65.7	1278	274	3000	.60	225
	Full Sample	162	5569		67.6		1405	279			
	Screened Sample	115	5716		67.5		1319	265			

The fourth and fifth columns present a comparison between the heating degree-days at base 65°F (as recorded at weather sites during the 1993-94 billing analysis time period) and the actual degree-days in the SUNDAY weather file. The SUNDAY weather file is based on Typical Meteorological Year (TMY) data, constructed from 30-year average temperatures between 1951 and 1980. The particular winters involved in the billing analysis (1993 and 1994) were relatively warm compared with long-term averages for most of the listed weather sites. In order to calibrate the SUNDAY runs, which use the TMY data, an adjustment had to be made based on the average temperature difference between the 1993/1994 winters and the TMY average temperatures. To arrive at a suitable adjustment, SUNDAY inputs were changed until a match with the billing analysis was achieved. This adjustment was made by reducing the thermostat setpoint from each of these groups of homes (in column 6) by the amount of the balance-point adjustment. This produced an adjusted thermostat setpoint (column 7). The thermostat setpoint adjustments in Table 5.2 range from less than a degree in several climates to in excess of 2°F in Seattle, Washington and 3°F in Salem, Oregon.

The adjustments are not made using base 65° F degree-days, but instead by using the balance-point degree-days found in the billing analysis for each house. These degree-days are calculated based on the outside temperature at which the heating system comes on. The heat loss rate of MAP homes is such that a balance point of 65° F is much higher than the actual balance point in most cases.

The actual floor areas and heat loss rates as measured and calculated during the field study were used to revise the original simulation. The amount of glazing was calculated based on 12% of the floor area, which was the average glazing percentage of the population of homes sited during the first year. The window area was distributed equally amongst the four cardinal directions.

The solar multiplier is used by the SUNDAY program to adjust the amount of solar gain utilized in a home to offset space heat. Although the average temperature adjustments described above reflect the comparison of two recent years of temperature records with TMY tapes, no similar solar data records are available for these weather sites.

The variation in total solar energy available can be quite dramatic from year to year. It is not surprising that a substantial variation can be observed in the estimation of the solar multiplier. We do not have direct evidence to suggest that this or any other shading coefficient is correct; however, part of the purpose of the calibration process is to arrive at a shading coefficient that roughly corresponds to actual site conditions for most of these homes.

The solar multiplier used in this analysis represents not only the amount of shading on the windows and sunlight allowed into the space, but also an adjustment that estimates the actual sunlight received by these sites during the 1993 -1994 billing years versus TMY data. The estimate is based on Ecotope's judgment, and includes an inference about the voluntary shading devices used by home occupants.

The final input to be re-examined is internal gains. Internal gains offset space heating requirements by supplying "waste" heat from occupants, lighting, and some appliances. Many important energy uses within the home have little impact on space heating. This includes almost all domestic hot water usage, and laundry appliances such as washers and dryers.

The 1993 MAP cost-effectiveness simulations assumed that internal gains were 3,000 BTU/hr in each house. This was based in large part on the submetered data collected for the RCDP sample [Baylon et al 1991]. This study, while conducted strictly on manufactured homes, included homes much larger (1,500 ft^2, on average) than the homes in this billing analysis; RCDP homes also had more occupants (3/home) than MAP homes (2.6/home). Internal gains in most MAP homes should therefore by adjusted downward relative to earlier assumptions. For purposes of the recalibration, an effort was made to ensure that these internal gains were within a reasonable ranges (approximately 2,000 BTU/hr minimum, and 3,500 BTU/hr maximum). Internal gains shown on the right-hand side of Table 5.2 were chosen (after all other changes discussed above were made) to match the space heating found from the billing analysis for the weather sites listed in the table.

5.3 Results of Simulation Recalibration

Table 5.3 presents the results of the calibration exercise in the seven selected climates. The match between the simulation (with duct inefficiencies taken into account) and the billing analysis (which includes the duct inefficiencies) is within 1% at most weather stations. This is not surprising, since we allowed the internal gains to vary by almost a factor of two, and the solar multiplier to vary by more than a factor of three.

TABLE 5.3
SPACE HEAT COMPARISONS FROM BILLING ANALYSIS: SELECTED CLIMATES
(Averages)

Climate Zone	Weather Site	n	Heating (kWh - yr)		Normalized Heating (kWh/ft^2 - yr)	
			Bills	Sim	Bills	Sim
1	Portland	6	4968	5038	4.32	4.22
	Salem	6	4414	4428	3.94	3.40
	Seattle	9	6602	6553	4.25	4.36
2	Boise	9	5849	5776	4.16	4.03
	Pocatello	5	7712	7713	5.50	5.35
	Spokane	13	6918	6986	5.77	5.75
3	Kalispell	6	9848	9837	7.84	7.84

The space heating energy was normalized by floor area. This resulted in an average space heating estimate of approximately 4.1 kWh/ft^2 in Zone 1, about 5.5 kWh/ft^2 in Zone 2, and nearly 8.0 kWh/ft^2 in Zone 3 climate. When the simulation results compared with the billing analysis, the agreement is within about 6% in Climate Zone 1 and less than 2% in Climate Zones 2 and 3. As stressed in Section 4, the variation, scatter and quality of the billing analysis in Zone 1 seems to be subject to substantial error. The level of disagreement between simulations and billing results in Zone 1 is expected to be considerably higher than in Zones 2 and 3.

Ecotope revised inputs for the prototype used to evaluate the cost-benefit optimizations and overall performance of MAP. The revised prototype simulation inputs are summarized in Table 5.4. In this table, the entire regional sample has been combined so that the representative character of the random sample can be used to establish a regionally valid prototype home.

TABLE 5.4
COMPARISON OF PROTOTYPE BUILDING SIMULATION INPUT ASSUMPTIONS
(Averages; numbers in parentheses are standard deviations)

	Field Sample	1993 Simulation Prototype	1995 Recalibrated Prototype
House size (ft^2)	1405 (353)	1568	1400
UA (MAP) (Btu/hr °F ft^2)	279 (58)	315	270
UA (HUD)	N/A	586	375
Thermostat Setpoint (°F)	67.6 (3.8)	65	67
Internal Gains (Btu/hr)	N/A	3000	2500
Solar Multiplier	N/A	0.45	0.45
Duct Efficiency	N/A	0.99	0.86

* Includes heat loss from infiltration. Infiltration values are 0.24 ACH in Zone 1, 0.29 ACH in Zone 2, and 0.31 ACH in Zone 3.

Table 5.4 also presents the impact of the HUD standards on the same prototype. The new HUD standards require a maximum U_o of 0.079. Because of the particular combination of insulation and windows used by some manufacturers to build a HUD-code home, the resulting U_o is less than 0.079. Since manufacturers built homes to insulation standards with familiar nominal R-values (R-38, R-33, etc.), the overall U_o is often not exactly 0.079 Btu/hr °F. For purposes of this analysis, we have assumed an improvement on the 1994 HUD standard U_o of 0.079 of about 1.5%, although this may be somewhat conservative. Since the MAP is currently in place, and since manufacturers in our region build only to this standard, it is impossible to directly observe how manufacturers would meet the new HUD standard in the absence of the MAP.

The MAP heat loss rate is based on a U_o of 0.053. Many manufacturers improve on the standard as a result of their particular manufacturing techniques (building to a U_o of about 0.050). The difference between the two heat loss rates (MAP and new HUD) should be consistent even if the actual heat loss rates are somewhat less than the nominal standards in both cases.

The floor area employed in the recalibrated prototype is consistent with the entire sample of homes from the field analysis. The billing analysis focuses only on homes with forced-air electric resistance space heating. The homes with heat pumps were noticeably larger than the homes with electric heat; however, they were eliminated from the billing analysis since the heat pump performance and interaction with air conditioning made the billing analysis extremely suspect. For this reason, the simulation results from the prototype analysis cannot be directly compared to the billing analysis, although they could be assumed to be consistent with the underlying space heating requirements of individual homes. This would be true even if particular homeowners used heat pumps or wood heat.

TABLE 5.5
REVISED SIMULATION RESULTS COMPARISON BY REPRESENTATIVE CLIMATE ZONE AND REGION-WIDE

Regional Sitings %	Climate Zone (representative weather site used in simulation)	Annual Heat Energy Without Duct Efficiency Correction (kWh)	Annual Heat Energy With Duct Efficiency Correction (kWh)	Revised Prototype Simulation Results (Normalized)		Normalized Billing Analysis Results*	
				kWh/ft^2-yr	kWh/DD	kWh/ft^2-yr	kWh/DD
62.5	1 (Portland)	4135	4808	3.43	1.01	4.26	1.25
33.6	2 (Spokane)	7462	8677	6.20	1.27	5.36	1.10
3.9	3 (Missoula)	8819	10255	7.33	1.32	7.59	1.20
	Region (weighted)		6321	4.68	1.13	4.78	1.19

* These are results for all cases in each Climate Zone that met the screening criteria: 53 cases in Zone 1, 44 cases in Zone 2, and 18 cases in Zone 3.

The simulation results, for purposes of regional simulations, are presented in Table 5.5. As in previous studies, the results have been subdivided into three climate zones that are represented by single weather sites. In the previous analysis, climate zones were represented by Seattle, Spokane and Missoula; however, as can be seen in Table 5.2, the Seattle site has considerably more heating degree-days than the Portland site, or than the average of Climate Zone 1 (the western Cascades and lower Columbia Valley). The Portland long-term heating degree-days seemed to better represent the average long-term heating degree-days for weather sites contained in Zone 1.

In Table 5.5, the space heating estimates have been normalized by floor area and base 65° F degree-days. The simulation normalizations use prototype floor area and average degree-days between 1951 and 1980. These normalized results differ somewhat from the space heating comparisons in Table 5.3. Space heating predictions are somewhat lower in the Portland climate and somewhat higher in

Climate Zone 2 (Spokane). Note that the building heat loss rates did not change appreciably, but internal gains and thermostat setpoints did.

Comparing Table 5.5's normalized heating results with the billing analysis results in an even larger disagreement. The billing analysis estimates space heating to be about 22% higher in Zone 1 than in the simulation, and about 20% lower in the simulation for Zone 2, when normalized by home size or degree-days. We believe the overall discrepancy is due less to internal gains differences than biases in the billing analysis, influences of outbuildings and bi-monthly bills in Zone 1, and other errors in specifying thermostat setpoint, heat loss rate and solar effects that are artifacts of this sample and not of the population of MAP homes.

When the data from the first year of the MAP were reviewed, sitings by climate zone were tabulated and regional weights were calculated. Table 5.5 also includes an estimate of regional weighting based on the siting of manufactured homes in the first year. The regional averages presented in Table 5.5 reflect these weights. Agreement between the billing analysis and simulation results on a regional basis is within 3% when normalized by the prototype floor area and weighted by climate zone.

Table 5.6 shows the estimated savings in space heating when the simulated energy use of homes built to MAP specifications is compared with the 1994 HUD prototype (which has the UA specified in Table 5.4).

TABLE 5.6
MAP SAVINGS RELATIVE TO HUD 1994 STANDARDS

Climate	Annual Heating (kWh)		Savings	
Zone	**Revised MAP**	**HUD 1994**	**kWh/yr**	**kWh/ft^2 - yr**
1	4808	8714	3906	2.79
2	8677	14390	5713	4.08
3	10255	16877	6622	4.73

Both the MAP and HUD homes have been simulated with identical input assumptions (except UA). As shown in Table 5.4, thermostat setpoint, internal gains, solar gains, duct efficiency, etc. are the same. Both runs assume similar occupant behavior in regard to energy use. This assumption is difficult to validate, since occupancy may change and other factors such as utility rate increases make certain levels of space heating more problematic, especially in homes with relatively poor insulation. For this reason, the simulation analysis is not usually directly comparable to an analysis based on utility bills. In this case, we would assert that this is a fair comparison; the analysis isolates only those items directly affected by the MAP incentive program (overall home heat loss rate). Savings from the MAP program over the HUD 1994 standards range from 3,900 kWh per year in Zone 1 to 6,600 kWh per year in Zone 3. The HUD base case home is further described in Section 6 so that individual building components and HUD and MAP component packages can be described in a cost-effectiveness calculation.

5.4 Comparison with RCDP Submetered Data

Given the variation between billing results and the re-tuned SUNDAY results in some Zone 1 climates, a comparison was made between the MAP billing results and the submetered heating data for manufactured homes built under the RCDP (Super Good Cents standards.) The submetered data allows a check on the accuracy of both the billing data and the re-tuned simulations. The comparison is done for all valid cases in Climate Zones 1 and 2. (There were only 4 valid Zone 3 RCDP cases.) The thermal performance of RCDP manufactured homes was about 10% worse than MAP specifications (U_o of about 0.060 Btu/hr °F for RCDP homes versus 0.053 Btu/hr °F for MAP), but the homes are much closer in expected performance than other comparisons would provide. The full analysis of RCDP manufactured homes is found in Baylon, et al [1991] and Roos and Baylon [1992].

These RCDP submetered results are compared with the MAP billing analysis in Table 5.7. The RCDP results are for the heating season running from April, 1989 through March, 1990. As in the MAP summary, the RCDP analysis screens out primary wood heat, heat pumps, and anomalies which cannot be classified as cooling or other seasonal loads. Note the number of cases in the two analyses is very similar.

TABLE 5.7
COMPARISON OF RCDP SUBMETERED HEATING RESULTS WITH MAP BILLING ANALYSIS

RCDP

Zone 1 (n=45)	Average	SD
home size (ft^2)	1364	222
89-90 heating kWh	5572	1563
kWh/ft^2-yr	4.10	1.07
HDD_{65}	4590*	
Zone 2 (n=44)		
area (ft^2)	1591	236
89-90 heating kWh	7555	1743
kWh/ft^2-yr	4.87	1.19
HDD_{65}	5829**	

MAP

Zone 1 (n=53)	Average	SD
home size (ft^2)	1337	302
annual heating kWh	5652	2396
kWh/ft^2-yr	4.26	1.60
kWh/ft^2-yr (no outbuildings (n=49))	4.12	1.48
HDD_{65}	4529	
Zone 2 (n=44)		
area (ft^2)	1315	330
annual heating energy (kWh)	6932	2316
kWh/ft^2-yr	5.36	1.46
kWh/ft^2-yr (no outbuildings (n=40))	5.31	1.50
HDD_{65}	6309	

* Weighted average of Bellingham 3 SSW (5 cases), Olympia (7 cases), Portland (4 cases), Sea-Tac (26 cases), Coupeville (5 cases).

** Weighted average of Redmond, OR (18 cases), Spokane (14 cases), Yakima (17 cases)

The tables show that the MAP billing data agrees very well with the RCDP submetered data. Especially in Zone 1, where the average degree-days are in close agreement over the two periods studied (4590 degree-days in RCDP, 4529 degree-days in MAP), the normalized heating energy use per square foot differs by less than 2%. In Zone 2, the weather did not fit as closely, and the RCDP homes appear to have used less energy per square foot than the MAP homes. The Zone 2 sites were colder by about 10% on average during the MAP billing analysis than during RCDP. The difference in normalized heating energy between RCDP and MAP is of similar size.

The comparison between submetered heating data and estimated heating energy from the billing analysis is reassuring, because it shows a close agreement in average use between two sets of homes with very similar thermal characteristics. More confidence can be placed in the recalibrated SUNDAY simulations, and the analysis can proceed to a recalculation of program costs and benefits based on prototype homes built to MAP and new HUD specifications.

6. Cost-Effectiveness of MAP Conservation

The goal of this section is to use the recalibrated SUNDAY model to establish MAP's performance and cost-effectiveness relative to the HUD 1994 standards. This is somewhat problematic, since these standards went into effect approximately two and a half years after MAP began. Since the MAP accounts for 100% of all electrically heated homes and more than 97% of all manufactured homes sited in the region, the characteristics of homes constructed to the HUD standards could vary considerably in the absence of MAP. A minimum cost package complying with HUD standards was developed using the component cost information developed for MAP. Since a "base case" home built to the 1994 HUD standards has not yet been studied *in situ*, the cost-benefit analysis presented here is based on a hypothetical method for meeting the HUD standards, and by extension, the MAP specifications.

The cost-effectiveness analysis in this section uses the information developed in Sections 4 and 5 and updated conservation measure costs to determine the cost-effectiveness of MAP conservation measures and optimum packages.

6.1 Conservation Measure Cost Estimation

Since 1989, conservation measure costs for manufactured homes have been under study. This process involved detailed interviews with manufacturers, suppliers and secondary sources. In general, this method is used to determine the retail costs of conservation measures as reflected in the final retail cost of the home.

Table 6.1 presents the actual MAP incremental measure costs. These costs are based on Ecotope's work, documented in Baylon and Davis [1993]. Window and door costs, determined through interviews with manufacturers and suppliers, are included. The costs in Table 6.1 vary slightly from the older costs [Baylon et al 1991], as window and blown-in ceiling insulation costs have been updated to reflect cost changes. These changes are relatively minor (less than 10% of any one measure cost).

The costs shown here are material costs to the manufacturer and retail costs to the home buyer. A retail markup of 2.16 was applied to the material cost. This mark-up structure was carefully documented in Baylon and Davis [1991]. The retail cost includes all taxes and dealer mark-ups.

The method of cost collection depends on the manufacturers reporting factory mark-up and wholesale price structure. While there is remarkable agreement among manufacturers, the nature of these estimates would tend to deliver upper end mark-up estimates. When homes are actually sold in a competitive market, we would expect the mark-up structure to be adjusted on a case-by-case basis to make the sale.

The window costs are calculated relative to a double-glazed, non-thermally broken aluminum frame window commonly used in the industry before 1992. Each window upgrade cost represents the extra cost per square foot of window to improve upon the thermal performance of the base window. The incremental cost of windows was updated in 1993, and reflects material costs associated with the competitive market for vinyl windows and the extensive impact of MAP on the quantity of vinyl windows produced and sold. Window costs also reflect the reduced costs in low-emissivity coatings which became available in 1993.

For the ceiling, floor, and wall insulation measures, the base is noted in the measure column and the prices are for the insulation upgrade alone. Where a change in wall framing occurs, the upgrade refers to the cost of moving from 2 x 4 studs to 2 x 6 studs. The cost of framing lumber is based on $500 per thousand board feet (MBF) cost to the manufacturer. The insulation costs are mostly generated by insulation suppliers. Insulation costs can be volatile, depending upon economic conditions and the relationships between the manufacturers and the suppliers. The values used here for insulation are identical to the ones used in 1993, and represent an approximate median value for the cost of fiberglass batts and blown-in insulation.

TABLE 6.1
MAP CONSERVATION MEASURE PRICES

Component	Measure Upgrade	Materials Cost ($/ft^2)	Retail Price (to consumer) ($/ft^2)
Window (Base is double-glazed, aluminum frame)	Aluminum frame w/ storm window	2.11	4.56
	Vinyl frame	2.85	6.17
	Vinyl w/low-ε	3.80	8.21
	Vinyl w/argon & low-ε	4.19	9.07
Wall	R-11 - R-19	.06	.12
	R-19 - R-21	.07	.15
	frame change ($400/MBF)	.17	.37
	frame change ($500/MBF)	.21	.45
Floors	R22 - R33	.07	.15
Attic Ceiling (blown mineral wool)	R-19 - R-25	.05	.10
	R-19 - R-30	.09	.19
	R-19 - R-38	.15	.33
	R-19 - R-49	.24	.52
Vaulted Ceiling	R-19 - R-25	.05	.10
	R-19 - R-30	.09	.19
	R-19 - R-38	.15	.33
Door (20 ft^2)	U-0.39 $\Rightarrow$ U-0.19	2.10	4.54

6.2 Prototype Development

In order to conduct a cost-benefit analysis and determine performance estimates for the MAP package, the prototype recounted in Table 5.4 was further developed, and individual components were specified. These components are consistent with a 1,400 ft^2 double-wide home (28' x 50') with 12% glazing and 50% vaulted ceiling area. The area of each component was used to determine the cost and performance of the prototype home. The U-values and costs were applied to these components just as they would be applied to determine the performance of an actual home built to the MAP specifications.

TABLE 6.2
PROTOTYPE COMPONENTS
HUD 1994 STANDARDS/MAP STANDARDS

Component	Area (ft^2)	HUD 1994 U-Value ($BTU/hr-^{\circ}F-ft^2$)	MAP (Optimized) U-Value ($BTU/hr-^{\circ}F-ft^2$)
Wall	1021	0.056	0.056
Floor	1400	0.044	0.033
Attic	700	0.032	0.032
Vault	705	0.032	0.032
Windows	168 (12%)	0.80	0.35
Door	40	0.39	0.19
Infiltration (ACH)		0.28	0.28
Internal Gains (BTU/hr)		2500	2500
Solar Multiplier		0.50	0.45
UA^* ($BTU/hr-^{\circ}F$)		370.2	271.2
U_o^{**} ($BTU/hr-ft^2-^{\circ}F$)		0.0779	0.0534

* Includes heat loss from infiltration
** Does not include heat loss from infiltration

6.2.1 Constructing the "Base Case"

The "base case" home is a manufactured home constructed with various components such that the U_o of the home comes close to the HUD Climate Zone 3 target of 0.079 $BTU/hr-ft^2-^{\circ}F$. Since the UA is allowed to "float" to reach the target U_o, the resulting U_o is slightly different from the ones presented in Table 6.2. The maximum HUD U_o has improved significantly relative to the 1976 standard; some of the components used to meet the 1992 MAP specifications are now needed to meet the new HUD standard. The MAP target U_o of 0.053 BTU/°F hr-ft^2 has not changed. In order to meet the MAP standard, a manufactured home must have a certain overall heat loss rate. The rate is defined by a cost-optimized package of conservation measures. The total cost of this package will vary in both the HUD base case home and the MAP home depending on what goes into the base case.

Table 6.3 presents four options for meeting the new HUD standards by varying the glazing and wall specifications. In options 2 and 4, the 2x6 wall is included in the "base case", and does not impact the cost of MAP. In options 1 and 3, the MAP cost includes a wall framing upgrade. For all of the options, the less expensive insulation choices are varied to compensate for the impacts of wall and window combinations.

The most costly combination to get from HUD to MAP is Option #2. This path is also the cheapest to meet HUD standards. Even though the wall framing upgrade is part of the HUD package and not included in the MAP package cost, upgrading the windows from aluminum-double glazed to vinyl low-ε argon is very expensive. When storm windows are used in the HUD base case and a wall framing upgrade is included in the MAP package (Option #3), the cost is reduced for the MAP package and increased for the HUD package compared to Option #2. Option #2 cannot be used for a higher glazing package (15% of heated floor area), since the resulting U_o exceeds HUD requirements.

TABLE 6.3
MAP PACKAGE RETAIL COSTS FROM VARIOUS HUD BASES

Base Case Option	12% GLAZING	15% GLAZING
Option 1	1,663	1,914
Option 2	1,915	N/A
Option 3	1,724	2,041
Option 4	1,359	1,853

HUD Option 1: R-11 wall, wall framing @ $500/MBF, vinyl windows with clear glazing
HUD Option 2: R-19 wall, double-glazed aluminum frame window
HUD Option 3: R-11 wall, double-glazed aluminum frame window with storm window
HUD Option 4: R-19 wall, framing lumber @ $500/MBF, double-glazed non-thermally broken aluminum frame window with storm window

6.2.2 "Base Case" Selection

The most costly HUD package for homes with 12% glazing is Option #2, with R-19 walls (2 x 6 framing) and non-thermally broken aluminum windows in the HUD base case. This option is more costly than most options with 15% glazing. The amount of glazing in this package is consistent with homes observed in the field.

It should be noted that use of this option as the representative HUD base case assumes that the manufactured home industry will use aluminum windows in the absence of MAP. There is some evidence to suggest that this is not the case, and thus Option #1 would be more applicable. In this event, the total cost of the MAP package would be reduced, and MAP conservation cost-effectiveness would be improved by about 15%. This change would not affect the incremental cost of the last measure in the package, since it is not impacted by the "base case". The remainder of this chapter assumes that Option #2 is used as the base case.

6.3 Levelized Cost Analysis

Table 6.4 summarizes the results of the optimizations and the levelized cost calculations for the MAP package compared to the HUD package. These levelized costs represent long-term utility life cycle costs, expressed in terms of mills per kWh saved. The optimization presented here does not use a cost-benefit cutoff as did the original analysis. Rather, it refers to the current MAP standard and uses a combination of measures to meet the standard for the prototype home at the least cost.

TABLE 6.4
PERFORMANCE OF MAP
VS. HUD PROTOTYPE HOME

					Levelized Costs	
Climate Zone (site used)	**1994 HUD space heating (kWh/yr)**	**MAP space heating (kWh/yr)**	**Savings kWh/yr**	**MAP Package Retail Cost ($)**	**Cumulative Mills/kWh**	**Incremental* Mills/kWh**
1 (Portland)	8364	4737	3627	1915	28.8	33.8
2 (Spokane)	13888	8574	5314	1915	19.7	22.8
3 (Missoula)	16299	10129	6170	1915	17.0	19.6
TOTAL			4293		25.4	29.6

* Levelized cost of most expensive measure
Financing assumptions are 4.8% discount rate and 45 year measure life.
Yearly space heating estimates include an adder for 86% heating system efficiency.
TOTAL line is weighted by zonal sitings (Table 5.5).

There are several important differences between the cost-benefit analysis presented in Table 6.4 and previous cost-benefit analyses [Baylon et al 1991, Baylon and Davis 1993]. The first is that the discount rate used to evaluate the utility and regional costs has been changed from 3.0 to 4.8% per year. This reduces long-term savings values, and causes in an increase in the MAP long-term investment costs. This results in a 33% increase in long-term apparent costs. We believe that 4.8% represents a relatively high real discount rate, and reflects the current financing status of the investor-owned utilities in the region. For the BPA and the public utilities, this value is undoubtedly high, although we are not certain of the current utility or societal discount rates.

As shown in Table 6.4, the average cost of a MAP package in Zone 1 is approximately 29 mills per kWh saved, with the most expensive conservation measure costing about 34 mills. The most expensive measure is an exterior door upgrade from an outswing door to a metal skin, foam core door. This option meets the usual utility investment criteria.

When 15% glazing is assumed, the cost-effectiveness of the total MAP package does not change (since the package cost does not change appreciably). The incremental cost of the most expensive measure changes, since more expensive measures are required to meet the MAP specifications. In the worst case (HUD Option #3), the cumulative package cost increases by about 6%, and the incremental cost increases by about 12%.

Table 6.4 also presents a regional cost average for the entire program. The regional average is weighted by the distribution of sitings among the various climate zones. The regionally-weighted cost of the MAP package is approximately 25 mills per kWh saved.

As stated before, the savings and levelized costs are based on the simulated performance of new HUD homes, which have not been constructed in large numbers in the region at the time of this writing. It is assumed that if the HUD homes had been constructed, they would have been operated in the same way as MAP homes and would have the same appliances, occupant lifestyle and other factors that contribute to energy consumption.

We have not attempted to construct a consumer cost-benefit analysis for the MAP homes, as was done in previous analyses. All the information collected suggests that aggregate consumer energy-efficiency preferences are consistent with the HUD package assumed here. The MAP's impact on the Pacific Northwest consumer has resulted in a substantial market for vinyl-frame windows in manufactured homes. If the consumer had already selected vinyl-frame windows, the costs of the MAP package would be considerably reduced. If the consumer had demanded a home with greater efficiency than the current HUD standard, and which was more efficient than homes demanded in 1989 and 1990, the cost of the MAP package could be much less than that suggested here.

The most expensive change in the MAP package is the change from double-glazed, non-thermally broken aluminum windows to double-glazed vinyl-frame windows. This change alone represents approximately 60% of MAP package costs and savings. If the HUD base contained this measure (with all other features remaining the same), the U_o of the HUD base case home would improve to about 0.065. This would reduce the MAP package savings and increase the apparent cost of MAP energy savings. This glazing option would reduce the total original outlay for this package from $1,915 to $878. This change would change the overall levelized cost of the resulting MAP package from 25 mills/kWh to 27 mills/kWh.

7. Conclusions

7.1 The Search for a "Base Case"

With certain important qualifications, the MAP homes have been shown in this analysis to perform in a manner consistent with prior predictions. A crucial qualification is the reduced heating system distribution efficiency and a proportional increase in the expected energy requirements for MAP homes' space heating. This reduces the MAP homes' space heating performance but increases the cost-effectiveness of the measures installed in the homes. Other aspects of manufactured home performance under this program change as a result of occupancy, as observed in the field. Beyond the distribution efficiency changes, these changes cancel each other out, producing only limited adjustments in savings estimates.

Homes built to HUD thermal specifications have not been constructed in the Pacific Northwest region independent of the MAP market. Thus, there are no observed energy bills or occupant behaviors that we can ascribe to either a typical HUD home or a sample of HUD homes. As with all previous cost-benefit analyses, this problem is readily solved using simulations. The SUNDAY simulation estimates heating energy usage based on input assumptions such as thermostat setpoint, internal gains, and solar effects in the context of a given conductive heat loss rate. The projected savings from the MAP specifications versus new HUD standards presume that both the MAP and HUD thermal specifications are met as precisely as possible by the manufacturers. The incremental change in heat loss rate can be predicted with relative accuracy. The SUNDAY program subsequently predicts the energy savings associated with this change in heat loss rate. We believe that this is an accurate method for estimating savings, since all of the major components for determining heating energy requirements are held constant, except the building's heat loss rate.

The savings projected by this method are actually engineering estimates. These savings might or might not be revealed through a billing analysis. Homes built to the 1994 HUD standards might or might not be operated in such as way as to achieve these savings. Nevertheless, for purposes of establishing long-term home performance and occupancy factors, the engineering performance is the most appropriate way to project savings associated with the variation between HUD and MAP homes. The costs associated with this method are relatively easy to establish. The only uncertainty is the response of manufacturers to the HUD standard over time. It is not clear whether they would meet the standard precisely in their manufacturing and marketing. If they exceed the HUD standard, the MAP package savings would be reduced. If the homes are built to levels better than the HUD standards, they would be closer to the MAP specifications. The change in heat loss rate and heating energy consumption associated with MAP improvements would be reduced.

For purposes of the regional cost-benefit analysis, this would not in any way affect the incremental cost-benefit or the optimization. Once the upper limit of cost-effective conservation is established at 35 mills per kWh saved, the MAP package itself will not change, regardless of consumer demand or HUD-mandated insulation packages. The only relevant issues are whether these costs are included in the calculation of the utility incentive to the manufacturer. In either case, the societal cost-benefit is identical, and this package is still very economically desirable.

If manufactured homes are to be energy efficient, utility energy planners must ensure that they meet MAP specifications. Quality control inspections, set-up training and general oversight will result in benefits to the consumer that will more than compensate for associated administrative costs. In this way, both the region and individual consumers will benefit from these energy conservation measures.

7.2 Comparisons With Previous Evaluations

The homes reviewed were sited during first year of the MAP. There are two other evaluations of this group of homes conducted to date. The first of these was conducted by Lee et al [1994], and the second by RER, Inc. [1994]. Both of these evaluations used billing and econometric analyses to establish the MAP homes' performance levels, and to make comparisons between MAP homes and homes not built to such standards. In both cases, savings comparisons were estimated from these homes, and resulting savings were approximately half of the savings reported here. Neither of these studies included "base case" homes that conclusively embodied the historic (pre-October, 1994) HUD energy use standards, and these studies also did not necessarily ensure that the two sets of homes had comparable occupancy behavior.

It is our contention that the "base case" in both the PNL and RER evaluations was undermined by homes built to standards well above those estimated. The savings presented in the reports are not based on a "base case" that accurately reflects the thermal performance level of manufactured homes built before there were any organized conservation programs for manufactured homes in the Northwest. The surveys conducted as part of the RCDP set this thermal performance level at U_o of about 0.095. Instead, the "base case" in both reports reflects a pooled thermal performance, closer to the 1994 HUD thermal specifications ($U_o = 0.079$). The savings estimated by RER and PNL range from 2,880 to 3,420 kWh per year in for homes with primary electric heat.

Error bands associated with the billing and simulation analyses are relatively large (35% to 40%), given other factors such as occupancy, climate, and thermostat setpoint. This error is not associated with either method *per se*, but with individual occupancy in homes and the variations in occupants' lifestyles and energy use. We do not believe that the cost of space heating in MAP homes appreciably influences this effect. Occupants set their thermostats at levels that are comfortable to them, and use appliances, equipment and lights in ways that correspond to their lifestyle. The heat loss rate of individual homes probably does not affect these decisions.

This discrepancy could be resolved using a direct comparison between two manufactured homes: one built to the MAP specifications, and one built to the 1994 HUD thermal specifications. The two homes would be identical except for their insulation levels, and should include various appliance and occupancy effects designed to simulate actual occupancy and hold these effects constant between the two homes. The space heating required to maintain a particular thermostat setpoint in these two homes could be metered and the savings calculated exactly. It is the conclusion of this report (and of any simulation-based engineering analysis) that once these factors are held constant, actual long-term savings from changes in heat loss rate can be illustrated. This simple experiment would test the veracity of this claim.

7.3 Comprehensive MAP Performance

Leaving aside the efficiency correction for the furnace and heating distribution system, MAP homes perform almost identically to the cost-benefit predictions made at the beginning of the program. It is clear that work must be done to improve the distribution efficiency of manufactured homes, and that special attention must be paid to adequate home structural support, crossover ducts, and belly boards. We believe that these issues should be addressed with additional study and design work on the part of manufacturers. It is also clear that quality control in the factory and during set-up has improved manufactured homes' air tightness and infiltration characteristics. Homes built to the MAP specifications are noticeably tighter than RCDP manufactured homes analyzed by Palmiter, et al [1992]. This level of air tightness suggests the continuing need for additional mechanical ventilation. Although ventilation systems installed under MAP were used consistently, they were not used sufficiently to counteract the increased tightness resulting from the MAP specifications. The new HUD standard encourage installation of a ventilation system similar to those installed in MAP homes. This standard, combined with continuing efforts, should result in improved ventilation and indoor air quality in manufactured homes. All three of these issues (incremental performance, heating system efficiency and improved ventilation) need additional research and engineering efforts.

Since its inception, MAP has delivered a vastly improved manufactured home to the consumer. The MAP provides manufactured homes that are built to a very high standard, and result in improved occupant comfort and reduced occupant energy bills. As a result, homes built during this program have provided a cost-effective regional resource with substantial benefits to the region's utilities, homeowners and ratepayers.

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9. References

ASHRAE. 1989. *Ventilation for Acceptable Indoor Air Quality.* American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. Atlanta, GA.

Baylon, D. and B. Davis. 1993. *Cost-Effectiveness of the Manufactured Homes Acquisition Program (MAP).* Prepared for Bonneville Power Administration under Contract No. DE-AM79-91BP13330.

Baylon, D., B. Davis, I. Brown, M. Kennedy, M. Lubliner, and S. Onisko. 1991. *Manufactured Homes Thermal Analysis and Cost Effectiveness Report.* Prepared for Bonneville Power Administration under Contract No. DE-AM79-87BP35738.

Baylon, D., B. Davis and M. Lubliner. 1990. *Manufactured Homes Cost Data Analysis Report.* Prepared for Bonneville Power Administration under Contract No. DE-AM79-87BP35738.

Bonneville Power Administration (BPA). 1987. *Super Good Cents Technical Specifications.* Division of Residential Programs. Portland, OR.

Bonneville Power Administration (BPA). 1986. *Findings on Model Conservation Standards: Cost-Effectiveness and Consumer Economic Feasibility.* Division of Residential Programs. Portland, OR.

Conner, C., A. Lee, R. Lucas, and Z. Taylor. 1992. *Revision of the Energy Conservation Requirements in the Manufactured Home Construction and Safety Standards.* Prepared for HUD under a Related Services Agreement with the U.S.D.O.E., Contract No. DE-AC06-76RLO1830. Pacific Northwest Laboratory, Richland, WA.

Davis, B., L. Palmiter and J. Siegel. 1994. *Field Measurements of the Heating Efficiency of Electric Forced-Air Furnaces in Six Manufactured Homes.* Prepared for Bonneville Power Administration under Contract No. DE-AM79-91BP13330.

Davis, B. and D. Baylon. 1992. *Manufactured Homes Acquisition Program: Heat Loss Assumptions and Calculations; Heat Loss Coefficient Tables.* Prepared for Bonneville Power Administration under Contract No. DE-AM79-91BP13330.

Drazen, G. 1994. *Manufactured Housing in Washington State: Monitoring Compliance With MAP Set-up Specifications.* Prepared for Bonneville Power Administration. Washington State Energy Office, Olympia, WA.

Fels, M. 1986. *PRISM: An Introduction.* <u>Energy and Buildings</u>, Volume 9 (1986), pp. 5-18.

Fels, M., J. Rachlin, and R. Socolow. 1986. *Seasonality of Non-Heating Consumption and Its Effect on PRISM Results.* Energy and Buildings, Volume 9 (1986), pp. 139-148.

Heller, J. 1993. *MAP Ventilation and Heat Recovery System Cost/Benefit Analysis.* Prepared for Bonneville Power Administration under Contract No. DE-AM79-91BP13330

HUD. 1994. *Manufactured Home Construction and Safety Standards.* Revised Part 3280 of Title 24. United States Department of Housing and Urban Development.

Kennedy, M. 1994. *Energy Exchanger Program: Heat Load Estimation Procedures.* Prepared for Washington Water Power Company under Contract No. R-0157-93.

Kennedy, M., P. Francisco, J. Heller, B. Manclark, and L. Palmiter. 1994. *Energy Exchanger Installation Quality Assurance Study.* Prepared for Washington Water Power Company under Contract No. R-0166-93.

Kennedy, M. 1991. *A Simplified Heating System Equipment Model.* Prepared for Washington State Energy Office, Contract No. 88-04-21.

Lee, A., Z. Taylor, D. Schrock, L. Sandahl, R. Chin, and D. Kavanaugh. 1994. *MAP Evaluation.* Review Draft. Prepared for Bonneville Power Administration. Pacific Northwest Laboratory, Richland, WA.

Olson, J., L. Palmiter, B. Davis, M. Geffon and T. Bond. 1993. *Field Measurements of the Heating Efficiency of Electric Forced-Air Systems in 24 Homes.* Prepared for the Washington State Energy Office under Contract No. 90-05-12.

Palmiter, L., T. Bond, I. Brown, and D. Baylon. 1992. *Measured Infiltration and Ventilation in Manufactured Homes.* Prepared for Bonneville Power Administration under Contract No. DE-AM79-91BP13330.

Palmiter, L., I. Brown and T. Bond. 1991. "Measured Infiltration and Ventilation in 472 All-Electric Homes". *ASHRAE Transactions*, 1991. Atlanta: American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

Palmiter, L. and T. Bond. 1991. "Interaction of Mechanical Systems and Natural Infiltration." Presented at the AIVC Conference on Air Movement and Ventilation Control Within Buildings, Ottawa, Canada.

Palmiter, L., I. Brown, and T. Bond. 1990. *Northwest Residential Infiltration Study, Cycle II: Infiltration and Ventilation in New Electrically Heated Homes in the Pacific Northwest.* Ecotope, Inc., Seattle.

Palmiter, L. and I. Brown. 1989. *Northwest Residential Infiltration Study, Volume 1: Analysis and Results*. Prepared for the Bonneville Power Administration under Washington State Energy Office Subcontract No. 88-24-01.

Palmiter, L., I. Brown, and M. Kennedy. 1988. *SUNDAY Calibration: Informal Progress Report*. Prepared for the Bonneville Power Administration under Contract # DE-AM79-87BP35738.

Palmiter, L. 1982. *Potential for Conservation of Electrical Energy in Northwest Residences*. Prepared for Battelle-Pacific Northwest Laboratories.

Regional Economic Research, Inc. 1994. *Regional Impact Evaluation of the Manufactured Home Acquisition Program (MAP)*. Prepared for Idaho Power Company, PacifiCorp, and Portland General Electric.

Roos, C. and D. Baylon. 1993. *Comparison of PRISM Results With Submetered Energy Use Data in Manufactured Homes*. Residential Construction Demonstration Project, Cycle II. Prepared for Bonneville Power Administration under Contract No. DE-AM79-91BP13330.

Roos, C. and D. Baylon. 1992. *Non-Space Heating Electrical Consumption in Manufactured Homes*. Residential Construction Demonstration Project, Cycle II. Prepared for Bonneville Power Administration under Contract No. DE-AM79-91BP13330.

Appendix: MAP Field Protocol

MAP OCCUPANT SURVEY

Site ID#_________ (use state abbrev. and add database #) Date________________

Occupant

Name:___________________________Address:____

City, State_______________________________Zip________

Phone_____________________________________

Electric Utility_____________________________ Dealer/location______________________________

Set-up crew_________________________

Person filling out this report/Agency_______________________________________

1. How long have you lived here? ______ months
2. How many people live in this home? Age 12 and under______ Aged 13-18______ Aged 19-65 ______ over 65 ________
3. Was natural gas available when you purchased your home? _____yes _____no
4. Do you remember the natural gas hook-up fee? Amount______ Don't know __________
5. What did you learn about the energy-efficiency of this house when you were considering its purchase (check all that apply)? Better individual components (windows, walls, floors, etc.)______ Overall lower energy use and energy bills_____ Smaller load placed on regional energy supply_____
6. Who told you the most about these features (check one)? Dealer____ Family/friend____ Utility rep____ Advertisement____ Other (specify) __________________
7. What was the most important factor which influenced your decision to purchase a MAP home? Lower energy bills ___ Uses less energy ("green" factor) ____ more comfortable ____
8. Did you receive information or instructions on your ventilation system when you purchased your home? ____yes______no If yes, describe the information you received, and from whom:____
9. Please describe your home's ventilation system and its operation:

____

____

10. Is your ventilation system noisy?____yes ____no Noise location__________________________

(The following questions (especially q's 13-14) are most applicable to homeowners who have resided in their home through a heating season. For shorter-term homeowners, you may use your judgment.)

11. Has this home been as efficient as you expected? ________yes________no

12. Are there any especially hot or cold areas in your house?______yes_______no

Which area(s)? ____

13. Do you use anything other than your furnace for heat? ______yes _____no_____
(If yes, skip to middle of page 4 and ask questions about type and use patterns of heating equipment other than a forced-air electric furnace or heat pump.)

14. How do you generally operate your thermostat? (See next page for heating and cooling settings.)

15. Have you noticed any condensation or mildew in the house?_____yes _____no

16. Is your house ever stuffy, humid, or too dry? _____yes _____no

17. Do you notice drafts in your home? _____yes _____no

Please describe where and when any of the above problems occur:

____

____

18. Do you leave your window vents open to supply fresh air? _____yes _____no

In order to understand and improve this program we are reviewing the electrical energy bills of the homes we survey. We would like to include your bills in this review. We would keep these bills confidential and use them only in combination with bills from many other homes. Would you be willing to allow us to collect your bills from your utility? (If so, ask them to sign the release or leave it with a stamped addressed envelope.)

A short energy questionnaire will be mailed to you within two months. The BPA would greatly appreciate your cooperation in filling it out and returning it in the SASE provided.

MAP WALK-THROUGH SURVEY:
VENTILATION, HEATING SYSTEM, SET-UP
(see equipment list on page 10)

BASIC INFORMATION:

1. Manufacturer ______________________ Model _________________________
HUD #:___________________________ MAP #:________________________

____Single Wide
____Double Wide
____Triple Wide

____Other
Describe: ____
____

2. Attach a sketch of the floor plan with accurate exterior dimensions. Put a north arrow on the sketch. Sketch in interior rooms and show the locations of the heating registers. Calculate house volume and write on the sketch.

3. Perform a quick visual inspection of the ducts. Use a mirror. Especially check duct runs that extend to problem areas identified in the occupant survey. Note problems on sketch.

4. Photograph house and site. Include at least one picture of the surrounding area in each direction from the home and one picture of the home from the street. Include any other photos which might explain the home and site (i.e. outbuildings, unusual exterior lighting, etc.). Describe any additional details which might be interesting: ______________________________________
____
____

Heat Sources:

Is there an electric furnace? ______yes ______no
Make and Serial # ____
Capacity (kW) ____________
Is there a heat pump installed? ______yes ______no
Make and Serial # Outside unit____________________Inside unit______________
Is there air conditioning? ______yes ______no
Make and Model # ____
Capacity/EER ________

Thermostats:

Is there a setback thermostat?___yes____no (If no, setback could still be done manually).
Heating setpoint ____°F Setback ____°F Setback duration_____ hrs/day
Cooling setpoint (for heat pump or other central system) ____°F Setback ____° F
Setback duration ____ hrs/day
Individual air conditioner setting ____° F Frequency of use _____ days/year
Typical duration of use _____ hrs/day

Air Quality/Ventilation:

Technician's observations of odors or moisture
____None ____Odors ____Moisture _____Mold/Mildew
Location and Description:____
____
____

Note any conditions which may significantly affect air quality or ventilation (e.g. smokers, solvents, aquarium):
____
____

Note on floor plan if there are any non-standard vented windows installed (i.e., not installed according to MAP specifications).

Combustion Appliances:
(Units fueled by fossil fuels or biomass: natural gas, kerosene, wood, etc.)

Type (stove, portable heater, etc.)	Fuel	Outside combustion air (hard ducted)?	Used how many days/year?

Electric Appliances/Other Loads

	# of appliances or units	
Portable electric heater	__________	Used ________ hrs/day
Water bed heater	__________	
Well pump	__________	
Shop equipment	__________	
Freezer(s)	__________	
Room air conditioners/other coolers	__________	Describe:____________________
Other (outbuildings, etc.)		

____

Water heater size________gal. Make ______________ Model _________________
EF (efficiency)_____
Tap temperature ______°F

Fans:

List all fans*. Include designated fan(s), clothes dryer, rangehood,+ etc. Measure flow if possible.

Description (designated (has automatic control), spot exhaust, dryer, rangehood)	Make and Model	Flow (cfm)	Daily run time	Noisy?	Disabled by occupant?

Humidity and Temperature Measurements:

(Note: measure indoor temperature before doing blower door test)

Room	Wet Bulb	Dry Bulb	% Relative Humidity	Temperature
Outside	______	______	______	______
Living Room	______	______	______	______

* Common range hood fans

Ventline PR7 Right-angle turn in exhaust duct
Ventline PH7 Straight duct out
Ventline PI7 Kitchen island application

Common bath fans

Ventline P2062
Ventline S550 Light/fan combination (need 3 of these if used in 4-bedroom home)

+ Dryer and rangehood flow measurements do not need to be taken at every home, but instead can be done when there is enough extra time (say, in 1/4 or 1/5 of the homes visited). You will probably need to use a stepladder to reach the range hood cap on the outside wall of the home.

Set-Up Review

Conduct a review of set-up quality and operational features of the home:

Crawlspace:

Yes	No		Comments
		Is skirting in place?	
		Is there a ground vapor barrier?	
		Are pier supports in place under I-beam with at most 6' O. C. spacing?	
		Are pier supports in place under exterior doors?	
		Are pier supports installed per manufacturer's markings?	
		Are pier supports properly capped and shimmed?	
		Are footings present under pier supports?	
		Is crossover duct cut to length?	
		Are crossover duct connections secure?	
		Are crossover ducts connected with sheet metal elbows?	
		Are crossover connections insulated (no exposed metal)?	
		Are belly penetrations sealed?	
		Is marriage line sealed?	

Crossover duct size__________ Describe any unusual T's, Y's, or junction boxes:

Operations:

Yes	No	
		Do exterior doors operate smoothly?
		Do exterior doors seal against the weather-stripping?
		Do windows operate smoothly?
		Do window fresh-air vents operate properly?

Comments:

Ventilation:

Yes	No	
		Does the attic have a mechanical ventilation system?
		VentilAire II (Intertherm)
		Blend Air (Coleman)
		Does the attic have passive vents?
		Continuous soffit vents?
		High vents in each section?
		Gable end vents?
		Is the furnace filter clean?

Comments:

AS-FOUND BLOWER DOOR TEST

Set-up: Close all windows and doors to the outside (except door which will receive blower door). Open all interior doors, close all dampers and doors on wood stoves and fireplaces. Make sure blower door is set to depressurize the house. Ensure that furnace and (gas-fired) water heater can not come on during test. Make sure all fans are off (including make-up air fan). Close window inlet vents.

Make and model of blower door used ______________________________

Put interior cover plate on the blower door. Using a digital pressure gauge, measure the pressure across the house envelope with reference to outside. (Make sure you have connected the proper tube to the "reference" channel of the pressure gauge.) Record reference pressure ________ Pa.

Turn blower door on and depressurize house to about 25 Pa with respect to outside. Use the most restrictive flow opening possible to obtain this pressure difference. (This is good general practice.)

House pressure	_______Pa
Orifice ratio/Range/Ring size	_______
Flow pressure	_______Pa
Flow	_______CFM (calculate or use table)

Next, depressurize house to 50 Pa with respect to outside.

House pressure	_______Pa
Orifice ratio/Range/Ring size	_______
Flow pressure	_______Pa
Flow	_______CFM (calculate or use table)

Smoke stick review

Set up the blower door to pressurize the house, turn it on, and use your smoke stick to look for interior leaks. Focus on the marriage line. Also check the furnace cabinet, especially at the wall/ceiling boundary.

Marriage line bowed: Yes_____ No_____(leaks in the middle but not the ends)
Marriage line cupped: Yes_____No_____(leaks at the ends but not the middle)
Note type of interior finish: ____ tape and texture ____ panel

Survey the rest of the house with a smokestick and note the principal leaks other than the marriage line. If there are no significant leaks enter none; otherwise list principal areas you think may be compromising the tightness of the home: ______________________________

____

AIR HANDLER MEASUREMENTS

Make-up Air System:

Classify the make-up air system installed in the home.

None	
Blend Air™ (Coleman)	
VentilAire™ II (Intertherm)	
Passive duct (POS or VentilAire™ I)	

Make-up duct diameter _______inches

Note if the make-up damper is jammed or otherwise inoperable.

____

____

(Further measurements to be determined)

Air Handler Flow Measurement:

Set-up: All zones with duct work should be opened to outdoors and each other where possible. Turn on air handler with fan switch or by turning up the thermostat so the furnace comes on.

(1) Use a Pitot tube (with tubing attached to the static pressure tap) to find the static pressure in the supply cabinet when the air handler is on. The tube can often be inserted on the left side of the air handler cabinet through a small gap near the blower mounting channel. The sensing end of the Pitot tube should be positioned near the inside wall of the blower cabinet. Leave the probe in place for the next several measurements. If the Pitot tube won't fit, an alternate tip (e.g., athletic inflation needle) will be required. Use 5-second averaging on the pressure gauge, waiting at least 15 seconds for the reading to stabilize.

Furnace operating static supply pressure ________ Pa

(2) Measure the supply air temperature after five minutes of furnace run time. This temperature should be measured as close to the outflow from the furnace as possible. (This will require some ingenuity. A suggested approach is to go in from the nearest supply boot and get as close to the furnace as you can with whatever device is available. If using a hand-held thermocouple thermometer, you can probably get pretty close. Take the highest reading you can find, and don't let the measurement probe touch the duct wall.)

Supply temp_________°F

DUCT LEAKAGE TESTS

Set-up: Turn furnace breakers off.
Open door or window to outside to assure adequate source of supply air.
Seal all registers securely with tape or plastic bags.

Attach the duct blaster to the furnace so that it acts as the furnace blower. To do this, either remove the air handler fan and attach the Duct Blaster™ snorkel to the mounting flange or seal the return opening (above the furnace filter) with cardboard and tape, do the same to the front of the furnace cabinet, and attach the snorkel to a hole cut into the template.

Total leakage (50 and 25 Pa)

Pressurize the duct system to about 50 Pascals with smallest flow ring possible; measure the supply plenum static pressure using the Pitot tube as placed earlier, or put Pitot tube through the cardboard template if the furnace blower is not removed. Use 5-second averaging on the pressure gauge, waiting at least 15 seconds for the reading to stabilize.

Supply pressure	____________	Pa (near 50 Pa)
Blaster Ring #	____________	
Blaster flow pressure	____________	Pa
Flow	____________	CFM (from table)

Repeat the procedure at 25 Pa static pressure.

Supply pressure	____________	Pa (near 25 Pa)
Blaster Ring #	____________	
Blaster flow pressure	____________	Pa
Flow	____________	CFM (from table)

Duct Leakage to outside (50 and 25 Pa)

Set-up: Blower door set to pressurize heated space.
Internal doors of heated space open.
Connections from heated space to outdoors (windows and doors) closed.
Supply registers remain securely sealed.
Pressure gauge and hoses set up so that house pressure is read with respect to outside and duct pressure is read with respect to house.
Blower door and Duct Blaster set up so their fans' air streams are shielded from one another.
Pitot tube in place to measure duct pressure.

In this test, you will pressurize both the interior of the home and the ducts to as close to the same pressure as possible. The test will be carried out at 25 Pa and 50 Pa. Use the 5-second average on the pressure gauge; wait at least 15 seconds on this setting for the reading to stabilize. First pressurize the house to 50 Pascals with respect to outside. Turn on the Duct Blaster™; increase speed until the duct pressure (with respect to the house) is 0 ± 0.2 Pa. Use a ring with as small an opening as possible for the Duct Blaster™. Reread the house pressure and adjust the blower door (if necessary) to approach 50 Pa pressure difference between house and outside. Again read the duct pressure with respect to house and adjust the blaster until this pressure difference is 0 ± 0.2 Pa. Finally, pull off one of the input hoses and hook up a hose from the Duct Blaster™ fan tap in order to get the blaster flow pressure. Use the pressure/CFM table in the blaster manual to find the flow.

House pressure (WRT outside) ____________ Pa (near 50 Pa; use 5 second average)
Duct pressure (WRT house) ____________ Pa (near 0 Pa; use 5 second average)
Blaster Ring # ____________
Flow pressure ____________ Pa
Flow ____________ CFM (from table)

Repeat above procedure at 25 Pa house pressure.

House pressure (WRT outside) ____________ Pa (near 25 Pa; use 5 second average)
Duct pressure (WRT house)____________ Pa (near 0 Pa use 5 second average)
Blaster Ring # ____________
Flow pressure ____________ Pa
Flow ____________ CFM (from table)

TEST EQUIPMENT:

1. Complete blower door test equipment, including manual (Retrotec, Minneapolis, or Infiltec)
2. Smoke bottle
3. Flowhood with known calibration
4. Calibrated thermometer (hand-held thermocouple-type best)
5. Sling psychrometer or other humidity measurement device
6. 35 mm camera with flash and film, or Polaroid camera with film
7. Flashlight or headlamp (hard hat-mounted even better) and extra batteries
8. 100' tape measure
9. Extension cord and power strip
10. Extension mirror
11. 2 screwdrivers (standard and Phillips), nutdriver or socket set for furnace cabinet nuts.
12. Duct Blaster™ with all necessary accessories and manual
13. Masking tape, duct ("temporary") tape, scissors, cardboard for duct blaster template
14. Digital manometer (2-channel best) with short and long hoses, hose adapters, extra batteries
15. Pitot tube and athletic inflation needle
16. Extra batteries
17. 6' stepladder

DEPARTURE CHECKLIST:

________ All registers untaped
________ Furnace filter in place
________ Furnace buttoned up and operable
________ Check thermostat setting
________ Check for tools and equipment, especially under house

MAP OCCUPANT SURVEY

Site ID#_________ (use state abbrev. and add database #) Date________________

Occupant

Name:___________________________Address:____

City, State________________________________Zip________

Phone___________________________________

Electric Utility______________________________ Dealer/location_____________________________

Set-up crew_________________________

Person filling out this report/Agency_______________________________________

1. How long have you lived here? ______ months
2. How many people live in this home? Age 12 and under______ Aged 13-18______ Aged 19-65 ______ over 65 ________
3. Was natural gas available when you purchased your home? _____yes _____no
4. Do you remember the natural gas hook-up fee? Amount______ Don't know ___________
5. What did you learn about the energy-efficiency of this house when you were considering its purchase (check all that apply)? Better individual components (windows, walls, floors, etc.)______ Overall lower energy use and energy bills_____ Smaller load placed on regional energy supply____
6. Who told you the most about these features (check one)? Dealer____ Family/friend____ Utility rep____ Advertisement____ Other (specify) ___________________
7. What was the most important factor which influenced your decision to purchase a MAP home? Lower energy bills ___ Uses less energy ("green" factor) ____ more comfortable ____
8. Did you receive information or instructions on your ventilation system when you purchased your home? ____yes______no If yes, describe the information you received, and from whom:____
9. Please describe your home's ventilation system and its operation:

   ____

   ____
10. Is your ventilation system noisy?____yes ____no Noise location__________________________

(The following questions (especially q's 13-14) are most applicable to homeowners who have resided in their home through a heating season. For shorter-term homeowners, you may use your judgment.)

11. Has this home been as efficient as you expected? _______yes_______no

12. Are there any especially hot or cold areas in your house?_____yes______no

Which area(s)? ____

13. Do you use anything other than your furnace for heat? _____yes ____no____
(If yes, skip to middle of page 4 and ask questions about type and use patterns of heating equipment other than a forced-air electric furnace or heat pump.)

14. How do you generally operate your thermostat? (See next page for heating and cooling settings.)

15. Have you noticed any condensation or mildew in the house?____yes ____no

16. Is your house ever stuffy, humid, or too dry? ____yes ____no

17. Do you notice drafts in your home? ____yes ____no

Please describe where and when any of the above problems occur:

____

____

18. Do you leave your window vents open to supply fresh air? ____yes ____no

In order to understand and improve this program we are reviewing the electrical energy bills of the homes we survey. We would like to include your bills in this review. We would keep these bills confidential and use them only in combination with bills from many other homes. Would you be willing to allow us to collect your bills from your utility? (If so, ask them to sign the release or leave it with a stamped addressed envelope.)

A short energy questionnaire will be mailed to you within two months. The BPA would greatly appreciate your cooperation in filling it out and returning it in the SASE provided.

MAP WALK-THROUGH SURVEY:
VENTILATION, HEATING SYSTEM, SET-UP

(see equipment list on page 10)

BASIC INFORMATION:

1. Manufacturer ____________________ Model ______________________
   HUD #:__________________________ MAP #:______________________

____Single Wide ____Other
____Double Wide Describe: ______________________________________
____Triple Wide ____

2. Attach a sketch of the floor plan with accurate exterior dimensions. Put a north arrow on the sketch. Sketch in interior rooms and show the locations of the heating registers. Calculate house volume and write on the sketch.

3. Perform a quick visual inspection of the ducts. Use a mirror. Especially check duct runs that extend to problem areas identified in the occupant survey. Note problems on sketch.

4. Photograph house and site. Include at least one picture of the surrounding area in each direction from the home and one picture of the home from the street. Include any other photos which might explain the home and site (i.e. outbuildings, unusual exterior lighting, etc.). Describe any additional details which might be interesting: ____________________________________
____
____

Heat Sources:

Is there an electric furnace? ______yes ______no
  Make and Serial # ____
  Capacity (kW) ____________
Is there a heat pump installed? ______yes ______no
  Make and Serial # Outside unit____________________Inside unit_______________
Is there air conditioning? ______yes ______no
  Make and Model # ____
  Capacity/EER ________

Thermostats:

Is there a setback thermostat?___yes____no (If no, setback could still be done manually).
Heating setpoint ____°F Setback ____°F Setback duration_____ hrs/day
Cooling setpoint (for heat pump or other central system) ____°F Setback ____° F
  Setback duration ____ hrs/day
Individual air conditioner setting ____° F Frequency of use _____ days/year
  Typical duration of use _____ hrs/day

Air Quality/Ventilation:

Technician's observations of odors or moisture

____None ____Odors ____Moisture _____Mold/Mildew

Location and Description:____

____

____

Note any conditions which may significantly affect air quality or ventilation (e.g. smokers, solvents, aquarium):

____

____

Note on floor plan if there are any non-standard vented windows installed (i.e., not installed according to MAP specifications).

Combustion Appliances:

(Units fueled by fossil fuels or biomass: natural gas, kerosene, wood, etc.)

Type (stove, portable heater, etc.)	Fuel	Outside combustion air (hard ducted)?	Used how many days/year?

Electric Appliances/Other Loads

	# of appliances or units	
Portable electric heater	__________	Used ________ hrs/day
Water bed heater	__________	
Well pump	__________	
Shop equipment	__________	
Freezer(s)	__________	
Room air conditioners/other coolers	__________	Describe:__________________
Other (outbuildings, etc.)		

____

Water heater size________gal. Make _____________ Model _________________

EF (efficiency)_____

Tap temperature ______°F

Fans:

List all fans*. Include designated fan(s), clothes dryer, rangehood,+ etc. Measure flow if possible.

Description (designated (has automatic control), spot exhaust, dryer, rangehood)	Make and Model	Flow (cfm)	Daily run time	Noisy?	Disabled by occupant?

Humidity and Temperature Measurements:
(Note: measure indoor temperature before doing blower door test)

Room	Wet Bulb	Dry Bulb	% Relative Humidity	Temperature
Outside	________	________	____________	________
Living Room	________	________	____________	________

* Common range hood fans

Ventline PR7	Right-angle turn in exhaust duct
Ventline PH7	Straight duct out
Ventline PI7	Kitchen island application

Common bath fans

Ventline P2062	
Ventline S550	Light/fan combination (need 3 of these if used in 4-bedroom home)

+ Dryer and rangehood flow measurements do not need to be taken at every home, but instead can be done when there is enough extra time (say, in 1/4 or 1/5 of the homes visited). You will probably need to use a stepladder to reach the range hood cap on the outside wall of the home.

Set-Up Review

Conduct a review of set-up quality and operational features of the home:

Crawlspace:

Yes	No		Comments
		Is skirting in place?	
		Is there a ground vapor barrier?	
		Are pier supports in place under I-beam with at most 6' O. C. spacing?	
		Are pier supports in place under exterior doors?	
		Are pier supports installed per manufacturer's markings?	
		Are pier supports properly capped and shimmed?	
		Are footings present under pier supports?	
		Is crossover duct cut to length?	
		Are crossover duct connections secure?	
		Are crossover ducts connected with sheet metal elbows?	
		Are crossover connections insulated (no exposed metal)?	
		Are belly penetrations sealed?	
		Is marriage line sealed?	

Crossover duct size__________ Describe any unusual T's, Y's, or junction boxes:

Operations:

Yes	No	
		Do exterior doors operate smoothly?
		Do exterior doors seal against the weather-stripping?
		Do windows operate smoothly?
		Do window fresh-air vents operate properly?

Comments:

Ventilation:

Yes	No	
		Does the attic have a mechanical ventilation system?
		VentilAire II (Intertherm)
		Blend Air (Coleman)
		Does the attic have passive vents?
		Continuous soffit vents?
		High vents in each section?
		Gable end vents?
		Is the furnace filter clean?

Comments:

AS-FOUND BLOWER DOOR TEST

Set-up: Close all windows and doors to the outside (except door which will receive blower door). Open all interior doors, close all dampers and doors on wood stoves and fireplaces. Make sure blower door is set to depressurize the house. Ensure that furnace and (gas-fired) water heater can not come on during test. Make sure all fans are off (including make-up air fan). Close window inlet vents.

Make and model of blower door used ________________________________

Put interior cover plate on the blower door. Using a digital pressure gauge, measure the pressure across the house envelope with reference to outside. (Make sure you have connected the proper tube to the "reference" channel of the pressure gauge.) Record reference pressure ________ Pa.

Turn blower door on and depressurize house to about 25 Pa with respect to outside. Use the most restrictive flow opening possible to obtain this pressure difference. (This is good general practice.)

House pressure	_______Pa
Orifice ratio/Range/Ring size	_______
Flow pressure	_______Pa
Flow	_______CFM (calculate or use table)

Next, depressurize house to 50 Pa with respect to outside.

House pressure	_______Pa
Orifice ratio/Range/Ring size	_______
Flow pressure	_______Pa
Flow	_______CFM (calculate or use table)

Smoke stick review

Set up the blower door to pressurize the house, turn it on, and use your smoke stick to look for interior leaks. Focus on the marriage line. Also check the furnace cabinet, especially at the wall/ceiling boundary.

Marriage line bowed: Yes_____ No_____(leaks in the middle but not the ends)
Marriage line cupped: Yes_____No_____(leaks at the ends but not the middle)
Note type of interior finish: ____ tape and texture ___ panel

Survey the rest of the house with a smokestick and note the principal leaks other than the marriage line. If there are no significant leaks enter none; otherwise list principal areas you think may be compromising the tightness of the home: ____________________________________

____

AIR HANDLER MEASUREMENTS

Make-up Air System:

Classify the make-up air system installed in the home.

None	
Blend Air™ (Coleman)	
VentilAire™ II (Intertherm)	
Passive duct (POS or VentilAire™ I)	

Make-up duct diameter _______inches

Note if the make-up damper is jammed or otherwise inoperable.

____

____

(Further measurements to be determined)

Air Handler Flow Measurement:

Set-up: All zones with duct work should be opened to outdoors and each other where possible. Turn on air handler with fan switch or by turning up the thermostat so the furnace comes on.

(1) Use a Pitot tube (with tubing attached to the static pressure tap) to find the static pressure in the supply cabinet when the air handler is on. The tube can often be inserted on the left side of the air handler cabinet through a small gap near the blower mounting channel. The sensing end of the Pitot tube should be positioned near the inside wall of the blower cabinet. Leave the probe in place for the next several measurements. If the Pitot tube won't fit, an alternate tip (e.g., athletic inflation needle) will be required. Use 5-second averaging on the pressure gauge, waiting at least 15 seconds for the reading to stabilize.

Furnace operating static supply pressure ________ Pa

(2) Measure the supply air temperature after five minutes of furnace run time. This temperature should be measured as close to the outflow from the furnace as possible. (This will require some ingenuity. A suggested approach is to go in from the nearest supply boot and get as close to the furnace as you can with whatever device is available. If using a hand-held thermocouple thermometer, you can probably get pretty close. Take the highest reading you can find, and don't let the measurement probe touch the duct wall.)

Supply temp_________°F

DUCT LEAKAGE TESTS

Set-up: Turn furnace breakers off.
Open door or window to outside to assure adequate source of supply air.
Seal all registers securely with tape or plastic bags.

Attach the duct blaster to the furnace so that it acts as the furnace blower. To do this, either remove the air handler fan and attach the Duct Blaster™ snorkel to the mounting flange or seal the return opening (above the furnace filter) with cardboard and tape, do the same to the front of the furnace cabinet, and attach the snorkel to a hole cut into the template.

Total leakage (50 and 25 Pa)

Pressurize the duct system to about 50 Pascals with smallest flow ring possible; measure the supply plenum static pressure using the Pitot tube as placed earlier, or put Pitot tube through the cardboard template if the furnace blower is not removed. Use 5-second averaging on the pressure gauge, waiting at least 15 seconds for the reading to stabilize.

Supply pressure	____________	Pa (near 50 Pa)
Blaster Ring #	____________	
Blaster flow pressure	____________	Pa
Flow	____________	CFM (from table)

Repeat the procedure at 25 Pa static pressure.

Supply pressure	____________	Pa (near 25 Pa)
Blaster Ring #	____________	
Blaster flow pressure	____________	Pa
Flow	____________	CFM (from table)

Duct Leakage to outside (50 and 25 Pa)

Set-up: Blower door set to pressurize heated space.
Internal doors of heated space open.
Connections from heated space to outdoors (windows and doors) closed.
Supply registers remain securely sealed.
Pressure gauge and hoses set up so that house pressure is read with respect to outside and duct pressure is read with respect to house.
Blower door and Duct Blaster set up so their fans' air streams are shielded from one another.
Pitot tube in place to measure duct pressure.

In this test, you will pressurize both the interior of the home and the ducts to as close to the same pressure as possible. The test will be carried out at 25 Pa and 50 Pa. Use the 5-second average on the pressure gauge; wait at least 15 seconds on this setting for the reading to stabilize. First pressurize the house to 50 Pascals with respect to outside. Turn on the Duct Blaster™; increase speed until the duct pressure (with respect to the house) is 0 ± 0.2 Pa. Use a ring with as small an opening as possible for the Duct Blaster™. Reread the house pressure and adjust the blower door (if necessary) to approach 50 Pa pressure difference between house and outside. Again read the duct pressure with respect to house and adjust the blaster until this pressure difference is 0 ± 0.2 Pa. Finally, pull off one of the input hoses and hook up a hose from the Duct Blaster™ fan tap in order to get the blaster flow pressure. Use the pressure/CFM table in the blaster manual to find the flow.

House pressure (WRT outside) ____________ Pa (near 50 Pa; use 5 second average)
Duct pressure (WRT house) ______________ Pa (near 0 Pa; use 5 second average)
Blaster Ring # ______________
Flow pressure ______________ Pa
Flow ____________________ CFM (from table)

Repeat above procedure at 25 Pa house pressure.

House pressure (WRT outside) ____________ Pa (near 25 Pa; use 5 second average)
Duct pressure (WRT house)______________ Pa (near 0 Pa use 5 second average)
Blaster Ring # ______________
Flow pressure ______________ Pa
Flow ____________________ CFM (from table)

TEST EQUIPMENT:

1. Complete blower door test equipment, including manual (Retrotec, Minneapolis, or Infiltec)
2. Smoke bottle
3. Flowhood with known calibration
4. Calibrated thermometer (hand-held thermocouple-type best)
5. Sling psychrometer or other humidity measurement device
6. 35 mm camera with flash and film, or Polaroid camera with film
7. Flashlight or headlamp (hard hat-mounted even better) and extra batteries
8. 100' tape measure
9. Extension cord and power strip
10. Extension mirror
11. 2 screwdrivers (standard and Phillips), nutdriver or socket set for furnace cabinet nuts.
12. Duct Blaster™ with all necessary accessories and manual
13. Masking tape, duct ("temporary") tape, scissors, cardboard for duct blaster template
14. Digital manometer (2-channel best) with short and long hoses, hose adapters, extra batteries
15. Pitot tube and athletic inflation needle
16. Extra batteries
17. 6' stepladder

DEPARTURE CHECKLIST:

________ All registers untaped
________ Furnace filter in place
________ Furnace buttoned up and operable
________ Check thermostat setting
________ Check for tools and equipment, especially under house