Field Evaluation of New Manufactured Homes in the Pacific Northwest

Bob Davis, Ecotope, Inc.
David Baylon, Ecotope, Inc.
Tom Hewes, Oregon Department of Energy

ABSTRACT

Over the past 10 years, energy performance of HUD-code (factory-built) housing has improved greatly in many parts of the United States. This paper presents results of a study of 105 homes built and sited in the Pacific Northwest in 2000 and 2001. These homes are constructed to site-built energy standards about 50% better than the minimum required by HUD (HUD 1994). The field evaluation uses familiar and new tools and protocols to evaluate the performance of the heating system and building envelope. A representative random sample was drawn from all the homes sited under this program in the one-year period ending June 2001. The sample was stratified by state and study homes were recruited from the list of randomly selected homes.

The field review includes a prescriptive assessment of house set-up, combustion safety review, measurement of ventilation system performance, and measurement of duct and whole house air leakage.

The review finds that homes are performing better in at least one category (whole house air leakage) than required by the standards but can improve in others (ventilation system performance, duct leakage). Since this procedure has been used for two previous evaluations of the same manufactured home program (1993 and 1997), the study provides an opportunity to compare homes built to similar standards almost a decade ago. This comparison suggests where more improvements might be made and facilitates the recalculation of building performance in different Pacific Northwest climate regions.

Introduction

Over the last fifteen years the Northwest manufactured housing industry and the region's utilities and state agencies have maintained a partnership aimed at building and marketing energy-efficient manufactured homes throughout the Pacific Northwest (Oregon, Washington, Idaho, and western Montana). The program began as part of an energy-efficient demonstration program, developed into a large-scale acquisition effort (Manufactured Housing Acquisition Program, or MAP), and is now a largely industry-funded entity known as the Northwest Energy Efficient Manufactured Housing program (NEEM). The MAP addressed only electrically-heated homes, but the NEEM program is fuel-blind.

Quality control processes have been developed to ensure that the homes meet relatively strict energy guidelines. The quality control standards are aimed at both in-plant and in-field procedures, since home performance also depends on the quality of set-up at the home's final destination.

Over the last fifteen years, a series of four field samples have been drawn and reviewed both for compliance to the set-up specifications and to assess overall performance of ducts, ventilation and infiltration—all items that must be evaluated after the home is sited to obtain a meaningful understanding of the home's performance. These reviews assist in assessing the impacts of changes in program specification and manufacturing techniques. The basis for these reviews has been a simple random sample of homes in each state.

The most recent study, which is the focus of this paper, is based on a sample of 105 randomly selected NEEM homes built in 2001 and 2002 and sited throughout the Pacific Northwest. The sample is meant to be representative of the homes built under the program as well as of the standards that are engendered by the program. Since the efficiency standards are regional and the setup standards are controlled by individual states, the sample was designed to be representative of both the region as a whole and of each state. The results presented in this paper are for the region as a whole, as this allows the best comparison with previous studies of homes built under earlier versions of the program standards.

Sample Design

The goal of the sample design was to draw a representative sample that could address the performance of the NEEM homes on duct leakage and house tightness to establish the "fleet average" for the NEEM on these dimensions. The sample frame was constructed to get homes that had sufficient time to be occupied for a year by the time the field visit was conducted. Table 1 shows the original savings data and the final sample frame used in this study.

Table 1. NEEM Sales by State

State	Year		
	2001	2002	Sample Frame*
Idaho	560	605	644
Montana	181	163	191
Oregon	1200	1493	1490
Washington	1662	2062	1961
Total Region	3615	4341	4286

*Dealers located out of region not included in sample

A simple random sample was developed for each individual state. The regional sample was an expansion of these state samples. The sampling standard for the states was designed to deliver a sample size that could meet a 10% significance level and 90% confidence interval for each state. The regional sample was developed based on the more stringent criteria of a 5% significance rate and a 95% confidence interval. Data from the previous studies provided the necessary information to set the coefficient of variation and establish sample sizes. Since the regional requirements result in a larger sample the extra cases were allocated proportionately based on the number of homes sited in each state. That is: a minimum sample is assembled for each state and the remaining sample size is allocated roughly by percentages of the total homes in the NEEM set sample. As a result of this, the sample is stratified by state so that case weights can be assigned to each individual state and a regional summary can be prepared.

The overall sampling targets for each state were based on the assumption that the distribution of relevant variables such as envelope and duct tightness would have a coefficient of variation of approximately 25%. This assumption was made as a result of distributions observed in the previous studies. Using these criteria, a sample size was set at approximately 90 homes, with an allowance made for attrition. In individual states, the studies were done using much lower significance criteria: 90% confidence interval and a 10% significance rate. This suggests sample sizes between twenty-two and thirty five for each state.

The sample was drawn at random from the Super Good Cents (SGC) database that includes all homes constructed to the standards over the last three years. The database was screened to include only SGC homes constructed between June 2001 and June 2002, so that at least one year of post-siting energy usage data would be available for a parallel billing analysis. Furthermore, homes of this vintage would show the impact of aging on house and duct air sealing materials.

Table 2. Regional Field Sample Distribution

State	Frequency	Percent
Idaho	17*	16.8
Montana	5	5.0
Oregon	38	37.6
Washington	41	40.6
Total	101	100.0

*4 cases mistakenly taken from an incorrect list were not included in regional sample

Case weights were used in summarizing the regional samples presented in this report. They were based on the relative sampling of each of the states. In general, the case weights have a small impact.

Field Sample Overview

This field study assessed the quality of both in-plant construction and on-site installation. Information on compliance with prescriptive standards was collected, focusing on structural integrity and building durability. Other information is based on direct measurements of envelope air leakage, duct air leakage, and whole house ventilation system performance. Some of the most important elements of energy performance (namely, specification and proper installation of insulation and windows) are assessed by inspectors at the factory prior to the home's transportation to the building site. Measurements, such as house and duct leakage, are most meaningful after the home has been set up. Additional measurements are taken which have bearing on safety issues, such as worst-case depressurization. All of these measurements have bearing on the value of the home to the consumer.

The data collected for this study were generally of high quality, but some summaries do not include all possible cases. Furthermore, because four of the Idaho cases were not taken from the original sampling frame, they are not included in the overall data summaries. Table 3 compares homes in three different field studies. The most notable statistic in this table is the elimination of single-section homes and the growth of triple and even quad homes, with a corresponding increase in average home size.

The NEEM summaries are compared with at least two other data sets at several points in this report. The homes in those data sets were built to very similar specifications, providing great value to manufacturers and other interested parties. The original MAP study was completed in 1995 and examined about 170 homes built to the original MAP specifications in 1992-1993 (Baylon et al. 1995). A set of 25 homes in Idaho and 24 homes in Washington that were built in 1997-98 is written up in Davis (2000) and hereafter referred to as the SGC98 study. For all of these sets of homes, the maximum allowed shell heat loss rate (U_o) is about 0.053 Btu/hr °F ft^2.

Typical nominal component requirements are R-19 walls, R-33 floor, R-38 ceiling, and U-0.35 windows. The HUD minimum requirement (HUD 1994) is a U_o of 0.079 Btu/hr F ft^2. Homes built in the late 1980s during the R&D phase of MAP (the Residential Conservation Demonstration Program (RCDP)) are also included in comparisons of shell tightness.

Table 3. Basic Site Characteristics

	NEEM (2001-02) (n=105) %	SGC98 Homes (1997-98) (n=49) %	MAP Homes (1992-93) (n=178) %
Single section home	0	0	11.8
Double section home	74	73	81.5
Triple section home	24	27	6.7
Quad section home	2	0	0
Avg home size (sq.ft.)	1,769	1,750	1,433

In-Field Prescriptive Set-Up Summaries

An important part of the field review takes place mostly under the house, where the auditor looks at the structural and the related physical set up of the house. The specifications for set up are established by HUD, enforced by the appropriate state agencies and apply to all manufactured home installations (not just NEEM homes). The NEEM program does have more stringent specifications in a number of areas, especially duct specifications.

Generally, set-up compliance was acceptable; the problem areas were smooth exterior door operation, belly penetrations, and the crossover duct connection. (The crossover duct connects the heating/cooling system trunk ducts in each section of the home.) Belly penetrations have been a problem in every field study, at least in terms of the visual inspection. It is not usually known in any particular case why the membrane is damaged, but certainly some of these problems occurred after initial set-up. It is likely in these cases that needed materials (such as out-stitch staplers and appropriate patch material) were not available. Houses have become more airtight despite the persistence of this problem.

Table 4. Structural & Operational Set-Up Compliance

Set-up Compliance Issue	% Complying
Skirting installed	95
Ground vapor barrier present	92
Pier supports in place under I-beam	95
Pier supports in place under ext. doors	100
Pier supports capped and shimmed	90
Footings sized and installed correctly	100
Belly penetrations sealed	59
Marriage line sealed	93
No visual problems with roofline	92
All liquid drains exit perimeter of home	89
Exterior doors operate smoothly	83
Windows operate smoothly	91
Crossover duct cut to length	94
Crossover duct connections secure	84
Crossover duct connected with sheet metal elbows*	60
Crossover connections insulated	94

*NEEM requirement (not required by HUD)

A large number of crossover ducts were installed without sheet metal elbows, even though this is a NEEM requirement. A number of homes used a splitter box for one of the main crossover connections, but this does not explain why so many homes did not use elbows, which improves the connection and seal between the crossover duct and the trunk ducts. Interestingly, the 45 cases which were identified as using elbows had a 10% higher median supply leakage fraction (which normalizes duct leakage by air handler flow) than the cases that didn't use elbows (n=32). The 17 homes in the sample that use interior crossovers (connection made at an interior gasketed seal) are not included in this comparison.

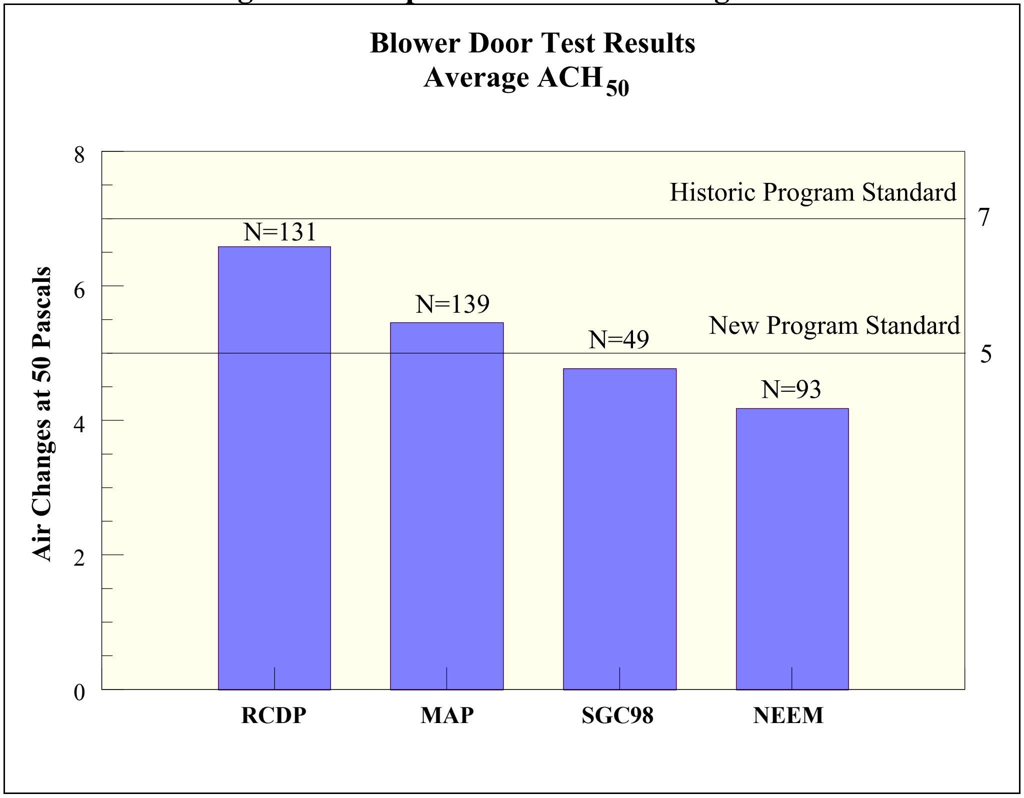
House Tightness and Ventilation

There is no doubt Northwest manufactured homes have gotten tighter over the past 10 years. Blower door testing shows manufactured homes built under the RCDP program displayed envelope leakage almost twice that found in the most recent study. Results from this dataset are discussed in Palmiter et al. 1992. Infiltration now accounts for only about 15% of the overall home heat loss rate. In-plant air sealing techniques have become standardized and the quality of in-field set-up has improved. Also, intentional air inlet vents are no longer required by the NEEM program. All of these factors have reduced air leakage (and have also made the performance of the whole house ventilation system even more important.)

Figure 1 shows the progression of house air tightness, expressed in air changes per hour (ACH) at a test pressure of 50 Pa, from RCDP through NEEM. Two y-lines are included in the graph. The upper line is based on the long-established tightness target of 7.0 ACH_{50}. This target is found by multiplying the ASHRAE (1989) natural ventilation target (0.35 ACH) by 20 to scale up from an assumed annual natural ventilation rate to the blower door testing conditions. The second line shows the NEEM program requirements for house tightness than will go into effect on July 1, 2004. This target would result in an estimated natural ACH rate of 0.25, based on dividing the ACH_{50} by 20.

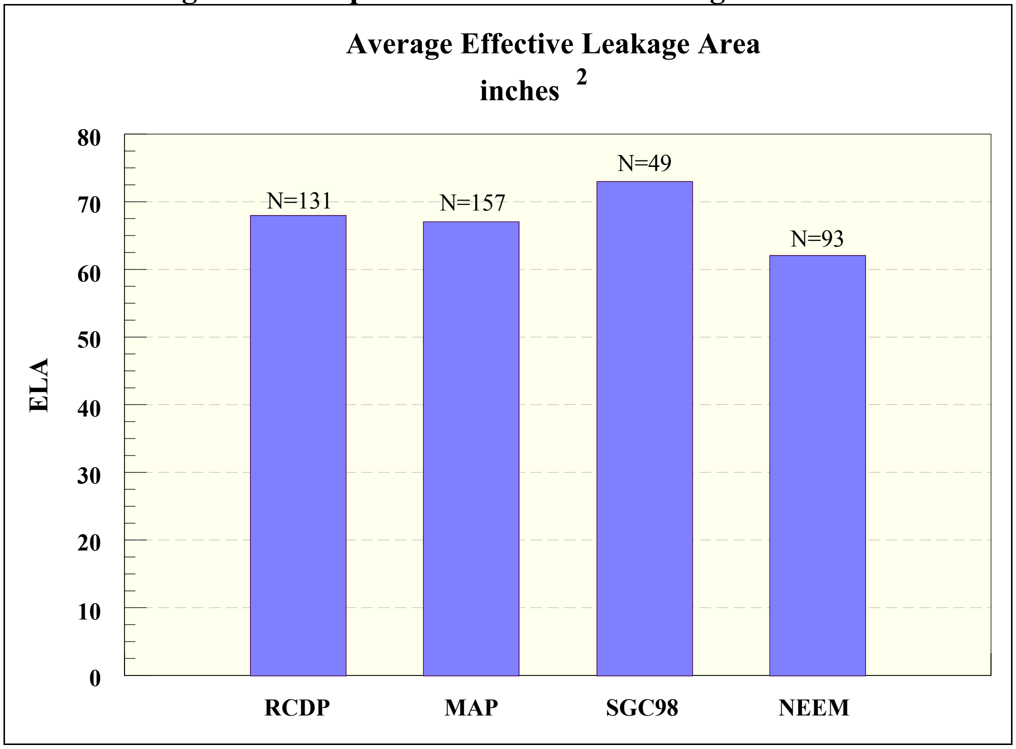
In the NEEM sample, the minimum measured ACH_{50} is 2.33, and the maximum ACH_{50} is 7.45. Only 19 cases have an ACH_{50} over 5.0; 2 are over 7.0 ACH_{50}. The standard deviations in most categories are very similar to the SGC98 study; both of these studies show less scatter than the original MAP results, which should is an indicator of successful quality control. Results are also expressed in effective leakage area (ELA) in Figure 2. Even though the average NEEM house is about 20% larger than the average MAP house, the ELA has decreased in most comparisons. (That is, ACH results are normalized by house size, while ELA is not.)

Figure 1. Comparison of Shell Air-Tightness



Single section homes and blower door tests with questionable flow exponents are excluded from the summaries.

Figure 2. Comparison of Effective Leakage Area



Whole House Ventilation System Performance

The requirement for a whole house ventilation system in Northwest manufactured homes predated the 1995 HUD requirement by several years. A combined spot/whole house approach has been used by Northwest manufacturers to meet the requirement until relatively recently, when whole house fan specifications changed and required a higher-performing class of fan which meets a 1.0 sone rating and is designed for continuous use. Over 2/3 of the homes in this study used a dedicated whole house fan installed in the hallway as the whole house ventilation system. Almost all whole house fans (84%) use a manual switch for control; about half of these systems use a high wall or closet switch to differentiate the fan control from a light switch.

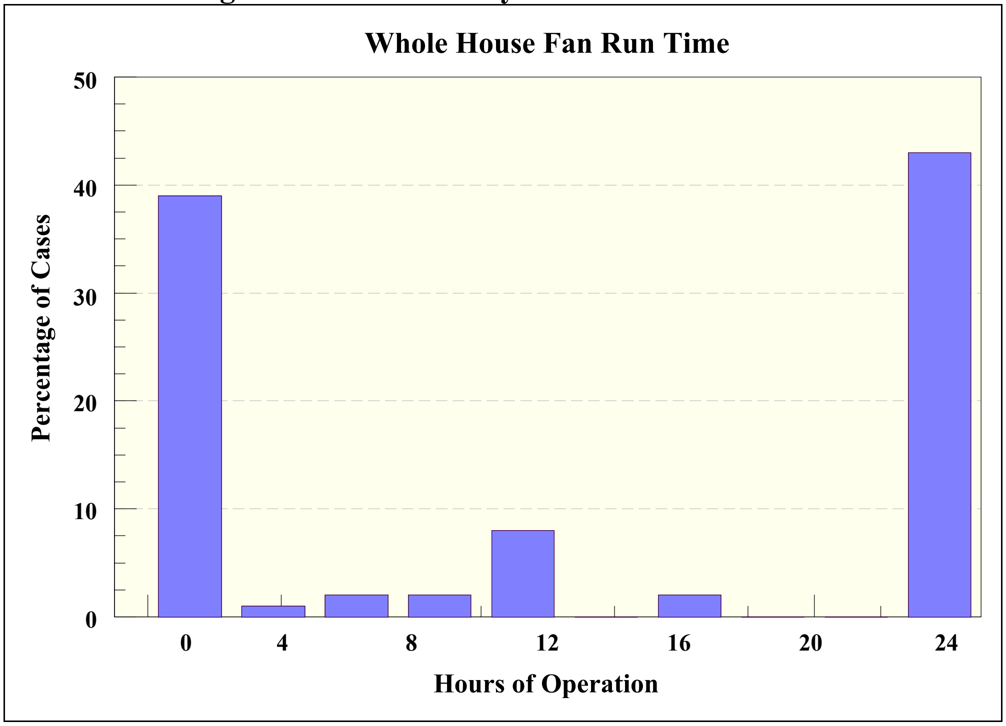
The median flow rate measured (out of 93 possible cases) for the whole house fan is 60 CFM, which is slightly less than that found in the 2000 study. There were 12 cases with measured flow rates of less than 30 CFM, and there were 2 cases with a zero reading. One of these cases had no terminus outside the building; the other had an unspecified problem.

The median fan flow rate is more than adequate to ventilate the average size of home in this study (about 1750 ft^2), using the HUD requirement of 0.035 CFM/ft^2 of floor area. However, in several cases, the delivered flow was clearly inadequate, either due to the fan being undersized based on the HUD formula or due to poor fan performance.

Assuming the fan is sized close to correctly, it must be run enough hours in the day to provide long-term effective ventilation. Given the level of natural infiltration (based on the blower door results), the required run-time is about 16 hours. Whole house fan run time has improved greatly, on average, when compared to the MAP and 2000 studies: 42% of the NEEM homeowners had their fan set to run continuously. In the 2000 study, none of the homes ran the fan continuously, and fewer than 20% of homes ran their fan for more than 8 hours/day. In the MAP study, average run-time was only 2 hours. However, there is still room for improvement: 30% of homeowners say they never use their whole house fan (63% of homeowners in 2000 said they never used the whole house fan). In several cases, this was apparently because they were confused about the need for the fan or how to turn it on; after the auditor explained the system, the homeowner usually decided to turn on the fan. It should be noted that 66% of homeowners said they had been told about the whole ventilation system at the point of sale and given at least some information on its use. Figure 3 summarizes these results.

The summary of current whole house fan use indicates that flow rates, on average, are adequate. Many more people than before are running the fan continuously. Still, there are many homes that are almost certainly under ventilated, and continuing education is needed to assist homeowners in taking full advantage of their mechanical ventilation system. It should be mentioned that field auditors noticed very, very few instances of air quality problems. The testing was mostly completed in summer months, which could mask problems that arise at other times of the year. It is very important to note that the intentional provision of outside air has also changed greatly since the last field study, where 85% of the homes contained some type of intentional leak meant to supply fresh air. NEEM home envelopes are getting tighter, but there is still enough unintentional envelope leakage (on the order of 45 in^2 in the average house) to supply the whole house fan. Manufacturers are no longer required by NEEM to provide intentional holes in the building envelope, whether these holes are window slot vents or air ducted into the furnace cabinet. Still, about 25% of the homes in this study had a duct extending from the home's exterior into the furnace cabinet; 65% of these ducts were not equipped with a damper. Of the remaining cases, all but one had dampers that were wired to open when the whole house fan turned on.

Figure 3. Ventilation System Performance



Combustion Appliance Safety Measurements

The field study identified 55 homes that contained combustion appliances other than central furnaces or water heaters. Combustion appliances used in manufactured homes are supposed to be supplied with dedicated combustion air and with an exhaust system that is sealed from the home's interior.

These appliances are mostly wood stoves and gas fireplaces. Some homes had multiple combustion appliances. The auditor was asked to confirm whether the appliance was direct-vented; in 85% of the cases, the answer was affirmative. This is concerning, since these homes are getting much tighter and the potential for back drafting is significant. In fact, in 6 sites, homeowners said they had experienced back drafting in their home. Half of these cases had the problem whenever the furnace came on. It is apparent that homeowners are not uniformly aware of the back drafting problem that is likely when they install after-market combustion appliances that are either not directly vented or are installed improperly.

A worst-case depressurization test was performed in all homes containing combustion appliances. The objective of this test is to establish the amount of draft pressure that is required to overcome the operation of the various fans and the heating system. The worst-case test was performed by closing interior doors and turning on exhaust fans; this combination reduces the amount of "free" air available for burning fuel, since the combustion zone is smaller with the doors closed and the house is being depressurized by fan operation. If there are supply duct leaks, the house is further depressurized when the air handler operates.

The average and median values for these homes in worst case conditions are close to 20 Pa, which approaches the Canada Mortgage and Housing Corporation action level of concern for closed combustion appliances (CMHC 1998). It should be noted that the average home is ventilated at about 5 ACH per hour when the air handler and typical exhaust fans (one whole house fan, dryer fan, and two spot ventilation fans) operate. The likelihood that they operate simultaneously with all interior doors closed is relatively small, but can occur. Homeowners were informed of the potential for this problem when the house was configured in this way.

An indoor CO measurement was conducted in most cases where combustion appliances were found. The results are shown in Table 5. Only very small amounts (less than 4 ppm) of CO were measured in four cases; it is plausible these readings could be due to a zeroing problem on the meter. This suggests that, at least at the time of the audit, there was little or no cause for concern. The results of the worst-case depressurization test, however, suggest that homebuyers should be informed about the need to correctly install after-market combustion appliances.

Table 5. Combustion Safety Measurements

	Worst Case Depressurization (WCD) (Pa)	WCD with only air handler running (Pa)	CO measured in living space (ppm)
Average value (n=39)	-19.4	-7.4	N/A
Median value	-17.9	-5.8	N/A
Range	-4 to -47	-0.5 to -28	0-4; 35/39 cases were 0

No case weights applied.

Heating and Cooling System

A major focus of the study was evaluating the efficiency of the heating/cooling system. All of the homes in this study contained a central, ducted heating/cooling system, which the auditors inventoried and measured duct leakage, air handler flow, and operating static pressure.

The percentage of homes with central electric forced air is very similar to the SGC98 set, but the number with heat pumps has doubled and the number with gas or propane furnaces has halved. The percentage of homes with central air conditioning (including heat pumps) is about the same as in 2000 as well, but there are more heat pumps providing the cooling. In the MAP study, all homes used central electric systems; only 12% of these cases were heat pumps. The equipment distribution for this study is shown in Table 6.

Table 6. Central Heating & Cooling System Survey

	% of NEEM cases that have
An electric furnace (elements + fan only)	54
A heat pump (HP)	24
A furnace fired by natural gas or LPG	22
Central air conditioning (other than HP; includes evaporative cooler (2 cases))	19
Overall cases with central air conditioning	43
Gas/propane furnace with central AC	7*

* 2 these cases have separate evaporative coolers

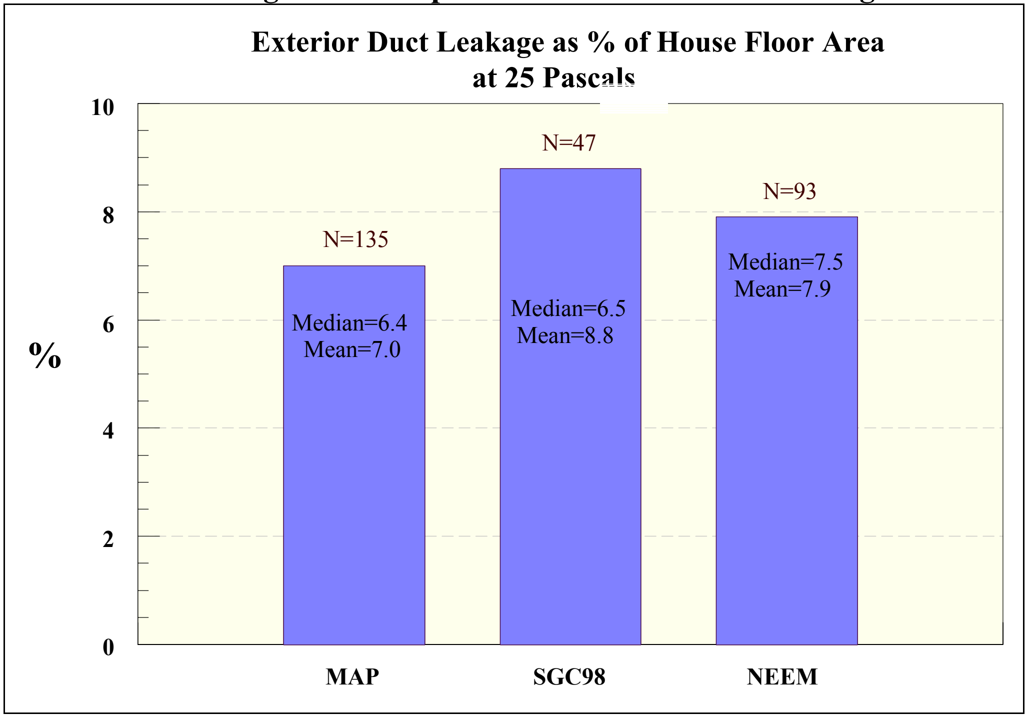
**Other than central natural gas or LPG furnace

Duct Performance

Thermal shell standards for energy-efficient manufactured homes don't have much farther to go in the Pacific Northwest. However, duct performance can still improve. Duct sealing requirements in the NEEM program have changed to require mastic, but these changes are not reflected in the NEEM dataset, since only two manufacturers used mastic as part of their typical installation practice in 2001. The most commonly used duct "sealant" is aluminum tape coated with butyl rubber or acrylic adhesive.

Figure 4 shows the comparison of supply duct leakage in the three most recent studies. (Duct leakage was not measured directly in the RCDP study; the tools did not yet exist to do this). The leakage is expressed as a percentage of the home's heated floor area to allow comparison across data sets. The graph shows normalized leakage has not improved in the last ten years. For comparison, note the Energy Star exterior duct leakage target is 3% of floor area; however, it is generally expected that the duct leakage test will be performed in plant rather than after set-up, so the in-plant target is now a *total* duct leakage of 6% of floor area. (The total duct leakage includes duct leaks to both inside and outside of the home's air barrier.)

Figure 4. Comparison of Exterior Duct Leakage



The field auditors were asked to assess sealant failure rates at furnace and register boots. It was not always possible to evaluate the furnace boot, depending on the line of sight, but out of 73 cases where the evaluation could be performed, 22 (30%) had some amount of sealant failure. Register failure was much higher, with 53 out of 101 sites (52%) having some amount of sealant failure at the registers. In general, the use of even high quality tape as the primary sealant (thicker butyl rubber vs. thin acrylic), has meant that duct leakage has not decreased. This means heating system performance will be degraded and represents one of the significant remaining areas where NEEM homes can be improved.

Airflow and Supply Leakage Fraction

Duct leakage targets, as discussed above, are now commonly expressed as a percentage of floor area. In order to estimate the effect of duct leakage on heating system distribution efficiency (and therefore on overall space conditioning energy requirements), it is necessary to know the percentage of conditioned air that is lost. To accurately measure system airflow, both a calibrated flow plate and duct pressurization fan were used. This comparison was done in order to provide insight into the accuracy of the flow plate in systems that do not contain a ducted return. Static pressure was measured with a long Pitot tube in several registers at each site and averaged. The results of the airflow measurements are shown in Table 7.

Table 7. Furnace Airflow and System Static Pressure

	Mean	**Median**
Air handler flow using flow plate; n=81	1,075 CFM	1,047 CFM
Air handler flow using duct pressurization fan; n=97	1,087 CFM	1,070 CFM
System static pressure; n=99	24.7 Pa	22.4

Case weights applied

The supply leakage fraction (SLF) is found by determining the flow equation for exterior duct leakage and then applying it using the average system static pressure at normal operating conditions at each site to estimate the duct leakage to outside. The supply leakage fraction is the percentage of conditioned air that is not delivered to the home's interior during normal heating or cooling operation. It is difficult to scale the SLF directly from the air handler flow and duct leakage at 25 Pa since the operating pressure can vary quite a bit from home to home (even though the average is very close to 25 Pa). In all cases, the SLF is quite a bit larger than the normalized exterior duct leakage at 25 Pa shown in Figure 4 since the average air handler flow is about 1100 CFM and the average home size is about 1750 ft^2. The results are shown in Table 8.

Table 8. Supply Leakage Fraction

	Mean%	**Median%****
Based on TrueFlow® AH flow (n=76)*	13.4	11.4
Based on Duct Blaster® (DB) AH flow (n=89)	12.2	11.1
Results from SGC98 study	15.4	13.8

* The lowest SLF was calculated at 1.6%; the highest was 46.4%.

** The median comparison is most robust for the most recent data sets. There were only 49 cases in Davis et al. 2000.

The most recent version of Ecotope's duct model (specially adapted to manufactured homes), estimates the impacts of the measured duct losses and includes regain. Results are expressed for representative Northwest climates. The overall effect on a gas heating systems can be found by taking electric furnace results and dividing them by the combustion efficiency of the gas furnace. Table 9 shows that for the average leakage (12.5% SLF) that characterizes the NEEM sample, there is an increase of heating energy between 367 and 866 kWh per year versus the performance level that conforms to Energy Star requirements (SLF of 5%). The average for the region is about 520 kWh. It should be pointed out that a significant number of homes are being built with an SLF of 5% or less. At this leakage level, the duct system efficiency is over 94%, and very little of the conditioned air is lost into the crawlspace. A home with the NEEM label should be attaining system efficiencies closer to 1 than to 0.9 (or certainly 0.8).

Table 9. System Efficiency Effects**

Duct Leakage (SLF)	**System efficiency****	**Heating Energy use (kWh)***				
		Portland	**Seattle**	**Boise**	**Spokane**	**Missoula**
5%	0.944	6296	6840	10026	11637	14860
10%	0.91	6532	7095	10400	12072	15416
12.5%	0.892	6663	7239	10610	12316	15727
15%	0.874	6801	7388	10829	12569	16051
Savings		367	399	584	678	866

*Electric furnace only; separate analyses have been run for heat pumps but are not included in this report.

**System efficiency of 1 means no duct losses.

Duct systems have not improved appreciably over the last decade despite huge improvements in other home components and installation practices. Recent changes in duct material and NEEM sealing requirements (requiring mastic) should improve this situation.

Summary

This study tracks the development of energy efficient manufactured homes in the Pacific Northwest in the past 15 years. Several key findings that arose from this review:

- The average house size of homes built in 2001 is 1769 ft^2. House size is very comparable to the homes built in 1997-1998 but 20% larger than the homes in the early MAP program (1992-1993). The number of single section homes built to energy-efficient standards has declined to about zero. Triple- and quad-section homes are increasingly popular.
- Houses are getting tighter, according to the blower door results. The average air leakage rate at 50 Pa is 4.2 air changes/hour, which represents a tightening of almost 25% over the original MAP average. The median effective leakage area (ELA) for double-section homes has decreased by about 12% despite the substantial increase in house size.
- 2/3 of homes in the study have dedicated whole house fans and a substantial fraction of homeowners are using their whole house fans. However, a significant minority (30%) does not turn them on. This finding may have health implications.
- About half of homes in the study use central cooling, with more than half of these homes using a heat pump.
- Duct systems are about 20% leakier than in the 2000 study and about 10% leakier than in the original MAP study (when the comparison is normalized by house size).
- The median supply leakage fraction is 11-13% for the homes in the NEEM sample (depending on the measurement technique used); that is, about 11-13% of heated or cooled air is not delivered through the registers. This amount of duct loss translates into an increase in required heating energy of between 10-20%.

References

ASHRAE, 1989. *ASHRAE Standard 62-1989: Vnetilation for Acceptable Indoor Air Quality*. American Society of Heating, Refrigerating, and Air-Condition Engineers, Inc.

Baylon, D., B. Davis, L. Palmiter. 1995. *Manufactured Home Acquisition Program: Analysis of Program Impacts.* Prepared for Bonneville Power Administration under Contract No. DE-AM79-91BP13330, Task Order #71945.

CHMC, 1988. *Chimney Safety Tests Users' Manual: Procedures for Determining the Safety of Residential Chimneys.* Canada Mortgage and Housing Corporation Information Centre.

Davis, B, A. Roberts, D. Baylon. 2000. *Summary of SGC Manufactured Home Field Data (1997-98 Sitings in Idaho and Washington).* Prepared for Idaho Department of Water Resources- Energy Division.

Francisco, P., D. Baylon, B. Davis, and L. Palmiter. 2004. "Heat Pump Performance in Northern Climates," *ASHRAE Transactions*, Vol. 110, Part 1.

Francisco, P., D. Baylon, and L. Palmiter. 2002. *Estimating Deeed Savings from Residential Ducts,* Ecotope Report to the Regional Technical Forum, Portland, OR.

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

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.