Measured Heating System Efficiency Retrofits in Eight Manufactured (HUD-Code) Homes

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ABSTRACT

This report presents the results of field measurements of heating efficiency performed on eight all-electric manufactured homes sited in the Pacific Northwest with forced-air distribution systems. These homes, like more than four million existing manufactured homes in the United States, were constructed to thermal specifications that were mandated by the United States Department of Housing and Urban Development in 1976. The test protocol compares real-time measurements of furnace energy usage with energy usage during periods when zonal heaters heat the homes to the same internal temperature. By alternating between the furnace and zonal heaters on 2 hour cycles, a short-term coheat test is performed. Additional measurements, including blower door and duct tightness tests, are conducted to measure and characterize the home's tightness and duct leakage so that coheat test results might be linked to other measures of building performance. The testing was done at each home before and after an extensive duct sealing retrofit was performed. The average pre-retrofit system efficiency for these homes was 69%. After the retrofit, the average system efficiency increased to 83%. The average simple payback period for the retrofits ranges from 1 to 5 years in Western Oregon, and 1 to 3 years in colder Eastern Oregon.

Introduction

Over the past decade, researchers and energy conservation program administrators have placed increasing emphasis on the energy impacts of forced air heating distribution systems. Researchers (Modera 1996 and others) have found that duct losses account for 30-40% of the energy usage of residential space conditioning equipment in homes with ducts outside of the conditioned space. This research has led to an increase in the number of duct air sealing and insulating programs. One of the challenges of utility duct retrofit programs is verifying system efficiency improvements and energy savings that result from duct retrofits. This report presents the measured system efficiency improvements that resulted from duct retrofits in eight older manufactured homes.

Most of the research on duct efficiency and the effect of duct retrofits has focused on site-built homes or, occasionally, newer manufactured homes. This report describes field measurements collected on eight electrically heated manufactured homes sited in the Pacific Northwest. Manufactured homes have simpler duct systems than typical site-built residences and typically contain no ducted return system. The homes in this study were built in the 1970s and 1980s to Federal Manufactured Home Construction and Safety Standards (FMHCSS), and are often referred to as HUD Code homes. There is very limited research available on the performance of heating systems in these homes and even less information available on the heating system efficiency impacts resulting from targeted duct retrofit efforts.

The measurement and analysis procedures used in this research are very similar to previous projects conducted for the Bonneville Power Administration and the Electric Power Research Institute. One study (Olson et al. 1993) found an average system efficiency of 72% for 22 site-built homes where at least 50% of the heating ducts were located outside the building's thermal envelope. A separate study conducted on six of these homes (Palmiter et al. 1995) found an average system efficiency improvement of about 16% after aggressive air sealing techniques were used on supply and return duct work. The only work of this sort which looked at manufactured homes found an average system efficiency of 83% for nine manufactured homes built to Model Conservation Standards (Davis et al. 1996). One of the only recent studies on duct efficiency in HUD-Code homes found system efficiencies of about 56% (Conlin 1996) in a study of 14 homes in New York and North Carolina.

Overview of Test Homes

Manufactured homes are not subject to local and state building codes, but are regulated by the U.S. Department of Housing and Urban Development (HUD). The structural, electrical and plumbing requirements are taken from the Uniform Building Code, Uniform Mechanical Code and the National Electrical Code. Thermal requirements were established by HUD in 1976 and revised in 1994 (HUD, 1976 & 1994). The combined standards are known as the Federal Manufactured Homes Construction and Safety Standards, or FMHCSS.

These homes are manufactured in sections in a production plant. The floor itself is framed on steel members which can accommodate axles to allow over-the-road transportation to the home site. A continuous layer of insulation is draped over the steel understructure, and wooden floor joists are framed on top of the insulation. The joists run either orthogonally to the steel frame (transverse floor) or parallel to the frame (longitudinal floor). The ducts, as well as insulation and plumbing, are installed in the buffer zone below the joists and above the underbelly insulation.

The trunk ducts are fabricated on-site from light gauge aluminum and generally have a 4 x 10 or 5 x 12 in. rectangular cross-section. The crossover duct, the duct that goes between trunk ducts on multi-section homes, is commonly round 10 in. diameter galvanized metal or 10 in. diameter flex duct. Trunk ducts in these homes are usually uninsulated. Crossover ducts are generally insulated to a nominal value of about R-4. Depending on the age and general condition of the crossover duct, the insulation has varying effectiveness. There are very few standard sheet metal fittings in these homes. Instead, most junctions are abrupt right angles, including the main T junction directly underneath the furnace.

Physical characteristics of the eight test homes are shown in Table 1. The houses ranged in size from 830 ft^2 to 1,700 ft^2, with an average of approximately 1,200 ft^2. The length of ducts (including the crossover duct) ranges from 54 ft to 132 ft. All homes in this study are heated with down-flow furnaces using electric resistance heating elements and air circulation fans. All homes had transverse floors with the exception of site T04, which had a longitudinal floor. Furnace size ranges from 11.3 kW to 22.5 kW. In each case, the furnace was found to be more than adequately sized for the heating loads encountered during testing. Furnaces are generally oversized by at least a factor of two in manufactured homes; even homes with relatively high heat loss often have oversized furnaces.

Table 1: Test Home Characteristics

Site	Year Built	House Type (# sections)	Floor Area [ft²]	Duct Length [ft]	Number of Registers	Furnace Capacity [kW]
T01	1985	Single	878	65.4	8	11.3
T02	1973	Double	1015	103.9	9	17.3
T03	1979	Double	1347	114.3	9	17.5
T04	unknown	Single	990	55.2	7	15.7
T05	1974	Double	1387	101.0	11	22.5
T06	unknown	Double	1703	138.7	12[1]	22.5
T07	1986	Single	831	54.0	6	15.2
T08	1982	Double	1383	129.8	10	16.5
Average			**1192**	**95.5**	**9**	
Median			**1181**	**106.6**	**9**	

[1] One register was sealed during the tests because it was normally blocked off by a refrigerator.

The homes were recruited for this study by the Eugene Water and Electric Board from existing lists of candidates for duct retrofit programs. All but one of the homes were located in the same residence park in Eugene, OR. Based on the relative homogeneity of thermal performance standards for manufactured homes (as mandated by HUD), these homes are representative of manufactured homes built to the 1976 FMHCSS.

To qualify for the duct retrofits and testing carried out in this research, candidates were required to have duct leakage to the outside of 250 cubic feet per minute (CFM) or greater at 50 Pa duct pressurization. This criterion was established so that the effects of the duct retrofit would be easier to identify in the short-term coheat tests. The duct leakage of these homes seems to be representative of this vintage of manufactured homes in the Pacific Northwest. A recent study of 50 Pacific Northwest HUD-code manufactured homes revealed an average duct leakage to the exterior at 50 Pascals of 326 CFM (Manclark and Hartzell 1996), slightly below the pre-retrofit average of 367 CFM for the eight homes in this study.

Measurement Protocol

The field testing for this report included duct pressurization tests, blower door tests, pressure pan measurements, and flowhood measurements. The reader is likely familiar with these tests and this part of the report will focus on the system efficiency test methodology.

The system efficiency test, commonly called coheating, measures temperatures and energy usage during alternating heating periods. The furnace is first run for a two hour period and then the each room is heated to the same internal temperature with portable space heaters. The furnace and portable heaters (coheaters) are alternated on two-hour cycles with an automated control system. No one is in the home during the test. The total time for the efficiency test is usually about ten hours, and the test is run at night to eliminate solar gain effects. The system efficiency is the direct ratio of the power consumed by the furnace and the duct system and the power consumed by the space heaters. These power measurements are corrected for significant outside temperature swings between the furnace and coheat portions of the test.

The thermostat setpoint is determined based on outdoor conditions; generally, a temperature difference of at least 30°F is desired so that the thermostat and furnace respond to typical winter ambient conditions. During the coheat period, the portable heaters in each heating zone are operated automatically by the control system to maintain the temperature in each zone to within ±0.45°F of the average temperature measured during the furnace heating period. A "heating zone" is usually any room with a heating register. Larger rooms sometimes have two registers, and so coheaters are sometimes ganged together for simultaneous operation.

Power is measured directly during these alternating periods with true power meters clamped on the electrical mains. Room and supply register temperatures are measured with Type T (copper-constantan) thermocouples. The dataloggers are programmed to take readings every second and record average readings every 10 seconds.

For purposes of calculating system efficiency, the second hour of the furnace and coheat periods are compared. Interpretation of power measurements during the transition periods from coheat to furnace heating modes can be difficult, due to short-term thermal mass (lag) effects. The furnace will stay on longer to heat the duct and underfloor members which cool during the coheat period. Conversely, the first part of the coheating energy cycle requires less heating input energy than later parts in the cycle. This is because the furnace has been cycling and has heated up the floor thermal mass, reducing the overall heating load (a combination of the thermal mass load and the load due to the temperature difference between the thermostat setpoint and the outside temperature). By only using the second half of the furnace and coheat cycles to calculate system efficiency, these short term mass effects are minimized.

Retrofit Protocol

Both single and double-section manufactured homes may offer a large potential for energy savings from duct retrofits, depending on the condition and the amount of insulation between the ducts and the crawl space, the number of penetrations into the ducts, the quality of connections between the trunk ducts, register risers, and the crossover duct, and upon the amount of air leakage immediately surrounding the connection between the furnace plenum and the trunk ducts.

Air sealing is the primary focus of the repairs in this project, although the crossover duct is also commonly replaced, reducing conductive losses. The diagnostic protocol used for the retrofits relies on pressure pan measurements and visual inspection to locate the leaks, and the application of duct mastic and sheet metal to seal the leaks. Half of the homes in the study were also sealed with a prototype aerosol duct sealing machine which partially automates the sealing process. The contractor performing the work completed each retrofit in about six person-hours when using conventional methods. Average labor time increased to about ten hours when a combination of conventional and automated sealing was used. The automated duct sealer was not ideally suited to the homes in this study as most of the leaks were easily accessible and visible to crews and it was often difficult to find a suitable point of attachment for the sealing machine.

Results

Whole-House Air Tightness Results

Whole-house air leakage was measured with a depressurization blower door test. The house is tested in an "as-found" condition, with the exception of site T07 which had a whole-house ventilation air inlet which brings outside air into the return plenum. This system was sealed off for the duration of the test. The blower door test was conducted with the ductwork open to the house, so it includes ductwork air leakage. Average whole-house air tightness at 50 Pa depressurization was reduced from 2093 SCFM pre-retrofit to 1785 SCFM post-retrofit. The reduction in the blower door reading is an indirect measurement of the effect of duct-tightening repair work. The reduction in CFM_{50} and ACH_{50} (leakage normalized by house volume) is shown in Figure 1.

The natural air change rate was estimated with a model developed at Lawrence Berkeley Laboratory by Sherman and Grimsrud (1980). This model uses Equivalent Leakage Area (estimated from the CFM_4 from the multipoint blower door test) and stack height and produces a natural air change rate. The result is temperature-normalized. For these eight homes at an indoor temperature of 70°F and an average Eugene winter outdoor temperature of 46°F, this model predicted an average of 0.53 ACH before the retrofits and 0.44 ACH afterward, as shown in Figure 1.

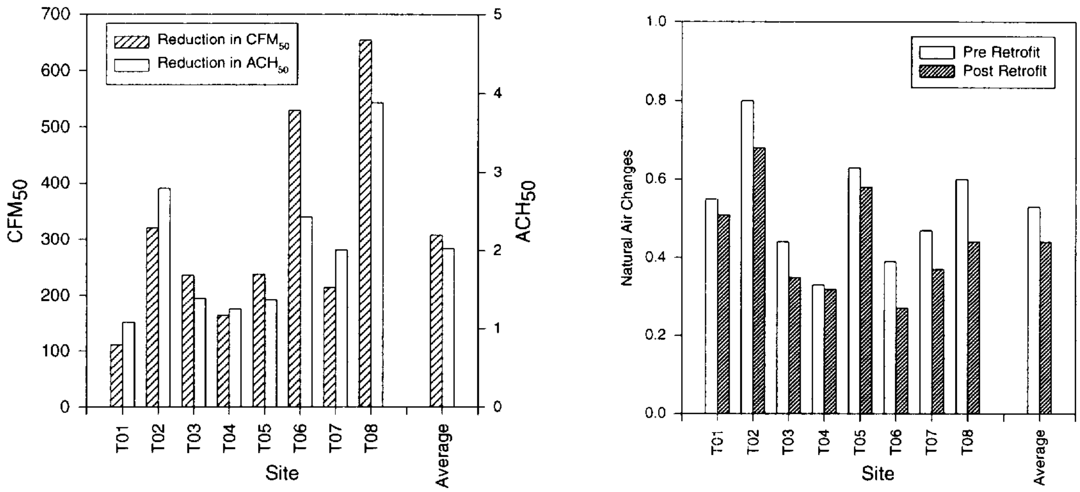

Figure 1: Reduction in Whole House Air Leakage and Natural Air Change Rate

Duct Leakage Results

Duct leakage is often used as a surrogate measure of the efficiency of a duct system. Duct leakage results, as measured with a Duct Blaster™, for these homes appear in Table 2. Exterior leakage at 50 Pa is the figure commonly compared in duct tightness studies, and was also used in recruiting homes for this study. Average exterior duct leakage at 50 Pa decreased from 367 SCFM to 73 SCFM due to retrofits.

Ductwork in manufactured homes generally operates under smaller average static pressures than the 50 Pa used for the test. In each home, static pressure was measured at each register during furnace operation and averaged. The average static pressure was measured to be 11.3 Pa before the retrofit and 13.5 Pa after. For all homes, the mean exterior duct leakage at average operating static pressure decreased from 179 SCFM to 31 SCFM after the retrofit. Duct Leakage at Average Static pressure appears in Table 2 and graphically in Figure 2.

Table 2: Duct Leakage

Site	Exterior Duct Leakage at 50 Pascals [CFM]		Average Static Pressure [Pa]		Exterior Duct Leakage @ Average Static Pressure (ASP) [CFM]		Reduction In Exterior Leakage at ASP [%]	Average Pressure Pan [Pa]	
	Pre	Post	Pre	Post	Pre	Post		Pre	Post
T01	220	59	10.9	10.9	94	24	74	1.1	0.15
T02	545	138	6.4	7.5	256	54	79	4.3	0.37
T03	289	60	7.7	13.1	117	25	79	2.6	0.11
T04	276	78	14.0	19.0	144	45	69	2.2	0.11
T05	278	37	16.0	17.3	151	22	85	1.2	0.11
T06	708	140	10.8	7.3	316	47	85	5.9	0.55
T07	247	31	14.2	18.2	126	16	87	2.1	0.00
T08	448	36	10.3	14.3	227	18	92	9.3	0.06
Average	**376**	**72**	**11.3**	**13.5**	**179**	**31**	**81**	**3.6**	**0.18**
Median	**283**	**60**	**10.9**	**13.5**	**148**	**25**	**83**	**2.4**	**0.11**

[1] The static pressure is determined by inserting a small diameter Pitot tube through a supply register grille and using the static pressure tap to determine the pressure in the supply duct a few inches upstream from the register. These data were estimated from multiple duct leakage tests for site T01 because the register louver spacing was not wide enough to admit the tube.

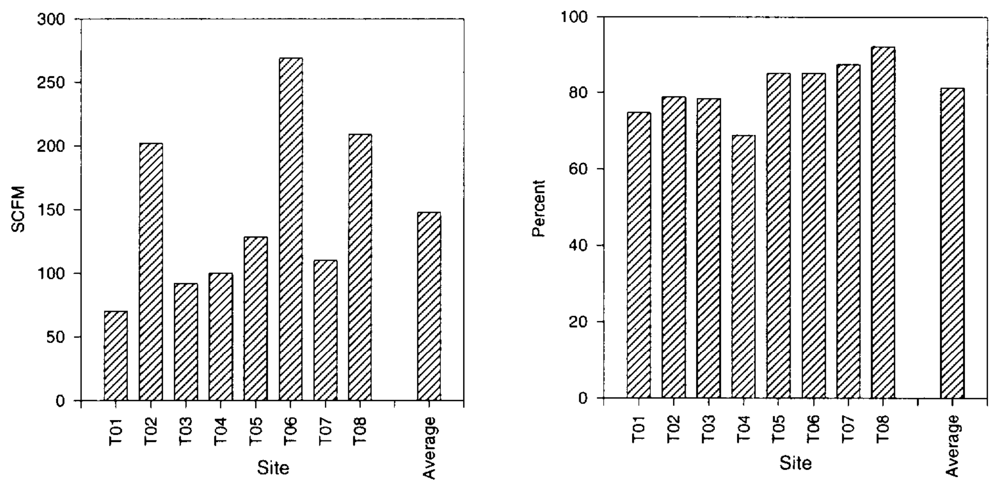

Figure 2: Absolute and Percentage Reduction in Duct Leakage at Average Static Pressure

Pressure pan tests were an integral part of the diagnostic duct sealing protocol. The test was conducted with the house depressurized to 50 Pa. The pressure pan was attached to a digital manometer and placed sequentially over each register. Duct air leaks and their proximity to the register being measured contribute to a pressure differential across the pan. Results of zero or close to zero generally indicate that there are limited or no leaks nearby. At some sites, the sum of the pressure pan measurements at all registers was huge before retrofit, usually indicating partially or fully disconnected crossover ducts or large leaks near the air handler. The average sum of pre-retrofit pressure pan readings before retrofit was nearly 34 Pa. This value is somewhat misleading because of the very large readings at sites T02, T06 & T08. The median of the sum of pressure pan measurements, 19.4 Pa, is more representative. Following the retrofit, the median sum of pressure pan measurements was 1.1 Pa. Average pressure pan results appear in the last two columns of Table 2.

System Efficiency Results

System efficiency is the primary focus of this research. System efficiency is a measurement of the rate of heat delivery from the furnace to the heated space during furnace cycling and includes any recovery of duct losses back into the home. System efficiency was measured directly during successive overnight coheat tests before and after the retrofit. Average heating system efficiency increased from 69% to 83%. The pre-retrofit average is considerably higher than the 55% estimated system efficiency reported for 14 HUD CODE Homes built to the 1994 FMHCSS (Conlin 1996). The system efficiency results are presented in Table 3 and are shown graphically in Figure 3.

Table 3: System Efficiency

	System Efficiency [%]		Reduction in	Efficiency Loss [%]		Retrofit
Site ID	**Pre**	**Post**	**Energy Use [%]**	**Pre**	**Post**	**Efficiency [%]**
T01	83.2	93.3	10.8	16.8	6.7	60.1
T02	54.3	71.6	24.2	45.7	28.4	37.9
T03	78.9	81.6	3.3	21.1	18.4	12.8
T04	85.5	94.9	9.9	14.5	5.1	64.8
T05	79.6	89.1	10.7	20.4	10.9	46.6
T06	60.9	71.4	14.7	39.1	28.6	26.9
T07	70.7	80.8	12.5	29.3	19.2	34.5
T08	40.4	76.9	47.5	59.6	23.1	61.2
Average	**69.2**	**82.5**	**16.7**	**30.8**	**17.5**	**43.2**
St. Dev.	**16.0**	**9.2**	**1.5**	**16.9**	**11.4**	**32.5**
Median	**74.8**	**81.2**	**11.6**	**25.2**	**18.8**	**42.3**

As shown in the first column of Table 3, the average pre-retrofit system efficiency is 69%. The average post-retrofit system efficiency of the eight homes, 83%, is very close to the average system efficiency reported for nine manufactured homes constructed to Model Conservation Standards (MCS) (Davis et al. 1996). Although duct insulation levels were lower in the HUD-code homes (increasing conduction losses), average post-retrofit air leakage in these homes (3.8% of air handler flow under normal operating conditions) was less than in the MCS homes (6.2% of air handler flow under normal operating conditions). Also the average duct length in the MCS homes was 113 feet, considerably longer than the average length of 96 feet for the homes in this study. These factors are strong contributors to the convergence in average system efficiency between the two groups of homes. The average reduction in space heating energy requirements resulting from the retrofits was 17%, as shown in the third column. This is based on the average of the individual site energy use reductions, not on the average pre- and post-retrofit values, and is about the same as for six site-built homes which received comprehensive duct air sealing retrofits (Palmiter et al. 1995).

The fourth and fifth columns of Table 3 show the pre- and post-retrofit efficiency loss, respectively. The loss is the system efficiency subtracted from 100%, and it averaged 31% pre-retrofit and 18% post-retrofit. The retrofit efficiency, defined as the fraction of the loss that was eliminated by the retrofit, is shown in Table 3. The mean retrofit efficiency was 43%.

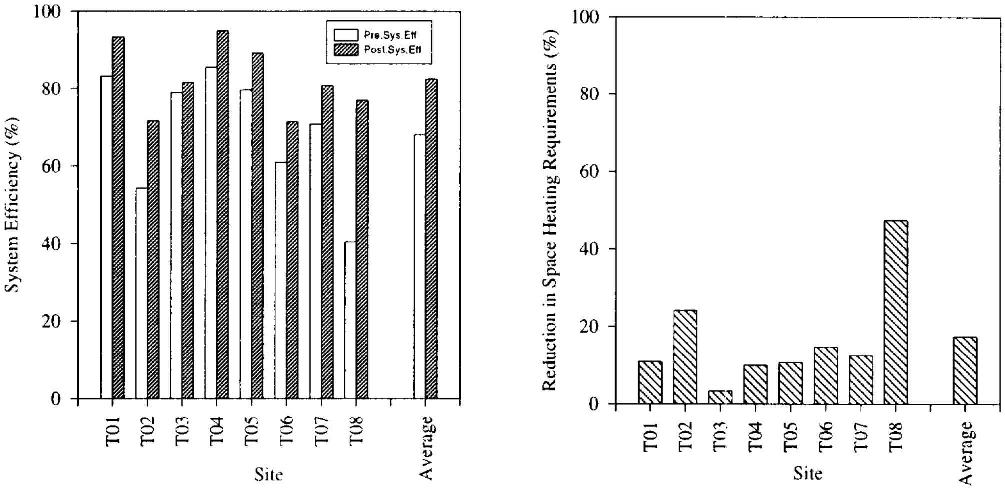

Figure 3: System Efficiency and Percentage Reduction in Space Heating Requirements

In general, the measured system efficiencies are believed to be a slight underestimate of the actual system efficiency. This discrepancy was caused by a systematic bias in temperature measurements when the automated system was in coheat mode. The effect of this problem is quite small, tending to underestimate the system efficiency by 3-5%. Furthermore, the savings that are calculated from the pre- and post-retrofit system efficiency measurements are essentially unaffected because this problem affected both measurements roughly equally.

Estimates of Seasonal Energy Impacts and Retrofit Economics

The system efficiency improvements measured in this report are useful in and of themselves; however, potentially more interesting is the improvement in annual heating energy requirements resulting from the retrofits. It can sometimes be misleading to look at efficiency as a measure of savings. For example, a large percentage savings of a small absolute loss may be less than a small percentage savings of a large loss. Additionally, a reduction in duct leakage does not necessarily mean an equivalent reduction in duct losses.

To evaluate system efficiency improvements in a broader context, a cost-benefit analysis was performed based on 1) prototype whole-building heat loss rates which bracket the 1976 FMHCSS thermal requirements; 2) the actual dimensions of the test homes; 3) average system efficiency improvement; and 4) retrofit cost estimates. Electric utilities can use this information to estimate the desirability of funding duct retrofit programs in the manufactured housing sector.

It was not always possible to confirm wall and ceiling U-values for the homes in this study. This is not critical, since the FMHCSS gives little leeway for overall house heat loss. The U_o is the overall heat loss rate of the house divided by the square footage of the skin of the house (area of windows, doors, opaque walls, roof, and floor), and does not include air infiltration heat loss. Use of a prototype home, based on actual physical dimensions of the test homes and the nominal requirements of the FMHCSS (with some revisions for observed characteristics of the homes) facilitated a solid estimate of retrofit cost-effectiveness.

The homes in this study fell into three categories of heat loss, based on the results of physical site audits. The first prototype has a U_o of about 0.15Btu/hr °F ft^2 and either pre-dates the 1976

FMHCSS or has excessive single-pane glazing area. The homes in the second category are built in accordance with the minimum 1976 FMHCSS thermal specifications (U_o - 0.126 Btu/hr °F ft^2). The third prototype incorporates somewhat higher levels of insulation and better-performing windows than the HUD-minimum for that time, responding mostly to consumer demand. The estimated U_o for these homes is 0.094, which is very close to the value found in a study of the most common manufactured home sold in the Pacific Northwest (MAP) in the late 1980s (Baylon et al. 1992). The thermal performance of construction components for each category appear in Table 4.

Table 4: Insulation R-Values By Component Category

U_o [BTU/hr °F ft^2]	0.147	0.126	0.094
	R or U-Value of Component		
Wall	R-4	R-7	R-11
Floor	R-7	R-7	R-11
Ceiling-attic	R-11	R-11	R-19
Ceiling-vault	R-11	R-11	R-19
Single glaze aluminum frame window	U-1.20	--	--
Double pane aluminum frame window	--	U-1.0	U-0.85
Door	U-0.40	U-0.40	U-0.19

Annual base heating load (no duct effects included) for each of the test homes was determined by first calculating a whole-house heat loss rate (UA), which is the product of the appropriate prototype U_0 and the actual physical dimensions of the home. The heating usage was then simulated with *Sunday® 3.0* for each prototype home as sited in Portland and Redmond, Oregon. Portland represented sites west of the Cascades, with approximately 4,800 heating degree days (base 65°F). Redmond represented a site typical of that found just east of the Cascades, with annual heating degree days of approximately 6,800 (base 65°F).

The next step was to apply the system efficiency improvement measurements taken during the retrofits to the heating loads to estimate duct loss impacts. This process relied on the assumption that the system efficiency measured during the short-term coheat protocol is representative of the duct losses throughout the heating season – that is, the amount of duct loss measured during the test will adequately describe annual heating energy impacts if applied directly to the baseline energy use.

The short-term coheat tests were conducted under larger indoor-outdoor temperature differences (averaging about 36°F) than encountered on average during a Eugene winter. The average Eugene outdoor temperature (NREL 1994) during the primary heating months of November through March is 44°F (and therefore the average indoor-outdoor ΔT is 26°F, assuming a thermostat setpoint of 70°F). Actual seasonal system efficiency is therefore probably somewhat higher than measured, assuming the house is operated by the occupants as it was during the research. The difference between the pre- and post-retrofit system efficiency, however, should not change, even if the furnace and ducts were subjected to colder-than-average conditions during the efficiency test than would be encountered on average during the heating season.

It should be noted that all coheat tests were done with all interior doors open, a condition which tends to improve overall system efficiency by reducing infiltration/exfiltration during air handler operation. Rooms with supply registers which are isolated by door closure will experience net pressurization during air handler operation, while the rest of the home will experience increased depressurization relative to outside. This effect has been documented in Tooley and Moyer (1989) and elsewhere. Some amount of interior door closure is customary during normal conditions, and these closures could decrease system efficiency noticeably.

These caveats aside, the energy and cost savings resulting from the retrofit are presented in Table 5.

Table 5: Energy Savings

Site	Floor Area [ft^2]	Energy Savings [W]	Normalized Savings[1] [W/ft^2]	Building U_o[2] [Btu/hr•ft^2•°F]	Annual Savings [kWh]		Annual Savings[5] [$]	
					Redmond[3]	Portland[4]	Redmond	Portland
T01	878	372	0.42	0.126	1454	928	73	46
T02	1015	965	0.95	0.152	6243	4098	312	205
T03	1347	295	0.22	0.126	631	419	32	21
T04	990	430	0.43	0.094	874	557	44	28
T05	1347	636	0.47	0.126	2064	1372	103	69
T06	1703	1592	0.93	0.126	3528	2376	176	119
T07	831	422	0.51	0.094	1062	664	53	33
T08	1383	3773	2.73	0.152	23370	15663	1168	783
Average	**1187**	**1061**	**0.83**	--	**4903**	**3260**	**245**	**163**
Median	**1181**	**533**	**0.49**	--	**1759**	**1150**	**88**	**57**

[1] Savings per square foot of floor area.
[2] Heat loss rate of home divided by area of all building surfaces.
[3] Based on home sited in Redmond, OR (6,800 HDD_{65}).
[4] Based on home sited in Portland, OR (4,800 HDD_{65}).
[5] Assuming energy cost of $0.05/kWh.

The major cost in non-automated manufactured home duct sealing is labor. The retrofit costs were based on a labor cost of 35$/hr and a nominal material cost based on the amount of mastic, sheet metal, and replacement duct used at each house. Based on the cost of each retrofit, the simple payback period ranges from 1 to 5 years in Western Oregon and 1 to 3 years in colder Eastern Oregon. It is more difficult to draw conclusions on the cost of automated duct sealing as the version of the machine tested was a prototype and real cost data are not yet available.

The payback periods compare favorably to other energy conservation measures, especially insulation upgrades or replacement windows. Furthermore, this type of retrofit offers considerable savings at much less disruption to the homeowner than window replacement or insulation retrofits (particularly when only hand-sealing is required). As crews become more skilled in duct sealing, this investment will yield even more attractive benefits to the homeowner.

Conclusions

The results from this research on eight electrically-heated HUD-Code manufactured homes indicate aggressive duct air sealing retrofits can result in sizable savings in annual heating energy. Conventional air sealing, generally taking approximately one half day for an experienced two-person crew to complete on a single- or double-section manufactured home, resulted in the elimination of about 80% of duct air leakage and an improvement in the efficiency of about 17%. Combining conventional methods with an automated aerosol duct sealing system reduced duct leakage slightly further but required considerably more time for system set-up and break-down.

Converted into dollar savings, these retrofits offer paybacks ranging from one to five years, depending on the level of leakage and the relative severity of the climate in which the home is sited. Conventional air sealing techniques are certainly within the reach of most weatherization crews. Given that this type of home is commonly encountered in many areas of the United States, this retrofit should be viewed as a serious conservation opportunity by utilities, especially in parts of the country where the heating climate is severe and electricity is more expensive. In these cases, a duct retrofit can offer conservation payback economics which can rival any of the more customary retrofits (such as increased levels of insulation and building shell air sealing with caulking and weatherstripping).

The study was carried out on a very limited number of homes. The testing methodology, and its expense, limited the size of the test sample. However, given the thoroughness of this testing methodology and the relative homogeneity of HUD code manufactured homes, the results should be viewed as reliable. It would be desirable to repeat this testing methodology in more manufactured homes in order to further generalize the results. One-time air and duct leakage measurements are within the capabilities of many field crews, but they do not provide sufficient explanatory power in and of themselves to estimate overall heating system efficiency. It is hoped that more research of this kind will identify quicker and less costly methods to estimate heating system performance. This coheating research has already contributed to the development of simplified models of duct efficiency (Palmiter 1996, Palmiter & Francisco 1997, ASHRAE 1996); the model inputs can be determined with a much simpler testing protocol. Until these models become widely accepted, it is suggested that a larger sample of this type of home be studied to more accurately be able to make generalizations about the performance of the heating systems and the potential for energy savings through retrofits in manufactured homes.

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