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Energy and Buildings 38 (2006) 1076–1083

ENERGY and BUILDINGS

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Measuring residential duct efficiency with the short-term coheat test methodology

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Received 25 July 2005; received in revised form 17 November 2005; accepted 19 December 2005

Abstract

Assessing the thermal efficiency of a forced-air distribution system is difficult, in large part because of interactions between energy loss mechanisms and other building characteristics. This paper describes short-term coheating, a method of measuring the thermal efficiency of residential heating and cooling distribution systems in situ, and presents the results of a series of studies that utilized the short-term coheat methodology. Short-term coheat tests were conducted in 53 residential buildings including both site-built and manufactured housing. The magnitude of the distribution efficiency, defined as the ratio of the energy required to heat the building if there were no duct losses to the actual heating energy required, ranged from less than 50% for homes with disconnected ducts to more than 90% for well sealed and insulated systems. Duct retrofits were also performed at 20 of the test sites and, following the retrofits, on average, the homes required 16–17% less heating energy. These results show that residential distribution system losses can be responsible for substantial energy loss and that duct retrofits are a viable energy conservation strategy for homes with distribution systems located outside of the conditioned space.

Keywords: Heating system; Duct efficiency; Forced-air; Duct air leakage; Single-family homes; Manufactured homes; In-situ measurements

1. Introduction

Energy losses and gains through residential HVAC duct systems can have a profound influence on heating and cooling energy use. In heating mode, ducts located outside of the conditioned space, such as in attics and crawlspaces, can lose heating capacity by both conduction and air leakage. In cooling mode the ducts can lose cooling capacity by conduction and air leakage, and in addition, there can be more complex impacts on air conditioning because of possible increased latent loads on the coil due to return-side air leakage. Although there are recent attempts to promote the installation of residential HVAC ducts within the conditioned space, much of existing and new US housing stock still has fully or partially exterior ducts.

A series of studies in the late 1980s and early 1990s quantified energy losses due to ducts in unconditioned spaces. Robison and Lambert [1] estimated an average distribution efficiency loss of 12% in 20 Oregon homes. Parker [2] found that homes heated with electric furnaces used 21% more energy for heating than did homes heated with baseboards, when normalized by floor area. In this same study, Parker found that the homes with baseboards had 41% less infiltration, which also impacts energy use. Cummings et al. [3] found that 24 Florida homes had air-conditioning energy use reduced by 18% after duct repairs were made.

These studies initiated a serious research effort aimed at quantifying the effects of duct leakage on energy use and, more generally, the distribution efficiency of residential thermal distribution systems. Losses due to conduction across duct walls have been acknowledged for a long time. There has also been acknowledgment that leakage has the potential to be significant. In 1960, Carrier [4] stated that experience indicated that residential supply duct leakage averaged 10%, with installation practice the greatest variable. They reported measured supply-side leakages of 5–30%, and recommended a 10% value when estimating loads if all ducts are in unconditioned spaces.

The first mention of duct leakage in the ASHRAE Handbook was in the 1975 edition of the Equipment volume [5], which had

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doi:10.1016/j.enbuild.2005.12.008

two paragraphs on the subject. These paragraphs refer to duct leakage as ‘‘related to static pressure and joint type’’, and states that ‘‘if leakage is uncontrolled, energy will be wasted, and the system may fail to perform as specified’’. However, it also simply recommends that ‘‘transverse joints be sealed where static pressures are above (249 Pa) 1.0 in. water’’. This characterization of duct leakage implies an assumption that the ducts are put together well, and that the leakage is at seams and joints. There is no concern expressed about ducts that have been poorly installed, with possible partial or complete disconnects or poorly cut attachment holes. There is also no concern expressed about leaks at pressures on the order of typical residential systems, which usually have much lower pressures, even at the plenums.

By 1989, ASHRAE had added a section in the Handbook of Fundamentals regarding duct leakage [6]. This expanded on the discussion in the Equipment volume, and described different duct ‘‘leakage classes’’, where the duct leakage class is the leakage in cubic feet per minute (cfm) per (9.3 m^2) 100 ft^2 of duct surface area at a pressure of (249 Pa) 1.0 in. water. Mention is made of standards from as far back as 1972 to test the leakage of ducts. Again, however, there is an implied assumption that the leakage is at seams and joints.

It was in the latter half of the 1980s that measurement of duct leakage became more commonplace in existing homes. Some of the earliest documentation of the leakiness of residential duct systems can be found in Modera [7], Diamond [8], and Robison and Lambert [1]. The results of these studies are summarized, in terms of effective leakage area (ELA) are summarized in Modera [9]. These measurements raised the awareness that ducts often leak more than would be assumed based on their ‘‘leakage class’’, due to poor installation, failed connections, and failure of common sealing methods.

Though the tests available at the time were relatively primitive, and did not determine duct leakage under normal operating conditions of the conditioning system, these studies prompted further investigation of losses due to duct systems and the potential savings from retrofits. They also resulted in mathematical models being developed to estimate the duct efficiency based on several inputs. The first published model for duct efficiency was developed by Palmiter and Francisco [10,11] and modified by Francisco and Palmiter [12]. A similar model is the basis for a new ASHRAE standard on estimating the efficiency of thermal distribution systems [13]. These models showed that it is not enough to simply look at the leakage or the conduction. The various components of duct losses interact in complex ways. Therefore, detailed field measurements were required, both to establish the losses and potential savings and to validate the model.

The thermal efficiency of duct systems is often characterized by two different values. The first, and most simple, is the ratio of the conditioning energy delivered to the building through the registers to the conditioning energy put into the ducts by the conditioning equipment. This was referred to as the heat delivery efficiency by Palmiter and Francisco [10,11] and as the delivery effectiveness by ASHRAE [14]. The second measure of duct efficiency is the distribution efficiency. This includes more than the conditioning energy delivered through registers. It also includes such factors as recapture of duct losses and the effect of unbalanced duct leakage on the infiltration rate of the home. It is defined as the ratio of the energy required to heat the building if there were no duct losses to the actual energy required. This measure of efficiency does not include the efficiency of the conditioning equipment itself, but it does include losses on both the supply (positive pressure) and the return (negative pressure) side of the system.

The delivery effectiveness, η_{de}, is defined as:

$$\eta_{\mathrm{de}} = \frac{\sum_i Q_i \rho_i (h_i - h_{\mathrm{in}})}{W_{\mathrm{cap}}} \tag{1}$$

where i is an index that goes from 1 to the number of supply registers, Q_i the airflow rate through supply register i (m^3/h), ρ_i the density of air flowing through supply register i (kg/m^3), h_i the enthalpy of air flowing through supply register i (J/kg), h_{in} the enthalpy of the indoor air (J/kg), and W_{cap} is the measured capacity of the heating or cooling equipment (W). The power consumption that is required to meet heating and cooling loads in a building, W (W), is defined as:

$$W = \frac{W_{\mathrm{cap}}}{\eta_{\mathrm{dis}}\eta_{\mathrm{eq}}} \tag{2}$$

where η_{dis} is the distribution efficiency and η_{eq} is the equipment efficiency (both dimensionless).

Of the two duct efficiency metrics, delivery effectiveness is the easier to measure. With suitably accurate airflow, temperature, and humidity measurements at each of the registers, combined with a good estimate of the capacity of the conditioning equipment, this value can be calculated. For furnaces, the capacity of the equipment can be determined by measuring the energy input at the service meter and multiplying the input by the equipment efficiency. For electric furnaces, the equipment efficiency is assumed to be 1.0, whereas for combustion furnaces such as those utilizing natural gas and propane the combustion efficiency must be measured. For systems with compressors, it is necessary to use a combination of system airflow and temperature change across the coil (and, in cooling mode, humidity before and after the coil). Distribution efficiency, however, is much more difficult to measure. This is because the additional factors included in this value are not directly measurable. However, it is this efficiency measure that most directly relates to the total energy use, and therefore cost, required to condition a building.

This paper provides a large dataset of distribution efficiency that benchmarks duct efficiency in homes in the Pacific Northwest, provides data for duct efficiency and energy use models, and explores the value of duct retrofits. We present a series of studies that measured the distribution efficiency using a technique called short-term coheating. The short-term coheat test protocol alternates heating the house with the conditioning equipment and with space heaters. The space heater energy consumption represents the required heating energy with no duct losses. Therefore, by monitoring the energy consumption for both methods of heating it is possible to determine the distribution efficiency of the duct system.

Coheating, the procedure of alternately heating with two different types of heating equipment, was originally proposed by Socolow [15] as a means to investigate both the efficiency of heat delivery from the furnace and the heat loss rate of the building. The coheat methodology has been used to test the thermal performance of fireplaces [16] and to determine whole-house heat loss coefficients [17]. As energy conservation efforts highlighted the importance of duct efficiency in overall energy use, Larry Palmiter proposed the idea of using short-term coheat tests to measure duct efficiency over a single night. To the authors' knowledge, this is the first occurrence of the short-term version of the coheat methodology. The first publication of this technique was in the final report for a study that was done in the early 1990s [18]. This strategy involved alternating between heating with the furnace and duct system and heating with space heaters, with the space heaters controlled to maintain the same temperature distribution as was provided with the furnace. This methodology, when done overnight during periods of roughly constant meteorological conditions, minimizes thermal mass and solar gain effects and allows a direct comparison to between the energy required to heat the home with and without a duct system, and hence the thermal distribution efficiency.

In the early 1990s, the increasing focus on duct losses in the Pacific Northwest led to five studies of duct efficiency using the short-term coheat methodology. A summary of these tests are listed Table 1. All of these studies were carried out by Ecotope Inc. and resulted in technical reports [18–23] and conference papers [12,24–30]. Some of these tests included measurements of the improvements that resulted from sealing and/or insulating duct work. The goal of this paper is to summarize all of these tests and investigate the implications for residential duct efficiency and duct retrofits. Additional short-term coheat tests of duct efficiency were conducted on two homes by Andrews et al. [31], with the modification to the methodology that the furnace and heaters were each used for half of the night rather than switching back and forth between the two. One was a two-storey home with a basement, with a conditioning system in the basement and a separate conditioning system in the attic. This home had a distribution efficiency of 63%. The second home was a double-wide manufactured home that had a distribution efficiency of 70%.

2. Methodology

The basic principle of short-term coheat testing is to alternate back and forth approximately every 2–2.5 h between the ducted central furnace and ductless space heaters. The temperature in each heating zone (typically defined as any room location with a supply register) was maintained at the same level for both modes of operation by a control system and were measured with type-T constantan–copper thermocouples centered vertically within the room and located away from any obvious sources of heat loss or gain (duct registers, windows, etc.). Temperature measurements were also made in the supply and return duct system, in the supply registers, outside, and in all buffer spaces (attics, crawlspaces, garages, etc.). The thermocouples were connected to dataloggers (Campbell Scientific 21X) that executed the control software as well as performed data management.

The procedure of the test was to operate the furnace normally with a fixed set-point for a period of 2–2.5 h. The furnace thermostat was replaced with a damped thermocouple and the deadband was chosen such that the furnace would cycle approximately six times per hour (four times per hour for gas furnaces). In the studies after 1997, the thermostat thermocouple was replaced with a Honeywell T-87 thermostat because it gave better cycling performance. After the period of furnace operation, during which the furnace cycled normally, it was turned off for the next 2–2.5 h period for the coheating. During this coheating period, heating was controlled with space heaters located in each room. The individual space heaters would operate such that the temperature in each heating zone was maintained within 0.1 °C of the average temperature recorded during the previous furnace cycle. Maintaining these temperatures was critical to avoid heating and cooling of the thermal mass. After the period of space heater operation, the control logic would switch back to furnace operation. A minimum of four periods, two for the furnace and two for the space heaters, were completed for each test. The testing protocol was completed overnight to minimize solar gains and large swings in outdoor temperature. The electricity demand of the house was measured with true power meters (AO Sperry Model SPM-2012) that were attached at the main electrical panel. All measurements were made every second and recorded as 10 s average values.

The electrical demand of the house was analyzed by first determining the baseline electrical consumption. Although all obvious electrical loads were turned off for the duration of the test, a baseload of between 20 and 150 W of electrical demand typically remained. The distribution efficiency, η_{dis}, was then determined to be:

$$\eta_{\text{dis}} = \frac{W_{\text{heaters}} - W_{\text{baseload}}}{W_{\text{furnace}} - W_{\text{baseload}}} \tag{3}$$

where W_{heaters} is the average whole-house power consumption for the second half of the period that space heaters were

Table 1
Ecotope coheat studies of duct efficiency

Study name	Number of homes	Location	Type of residence	Duct retrofits	References
HEATAG	24	WA, ID, MT, OR	Site built	6	[18,19,24]
MAP	9	WA, ID	Manufactured—MAP Program	0	[20,25]
HUD	8	OR	Manufactured—HUD code	8	[21,26,27]
GAS	8	WA	Site built	6	[22,28]
ASH152	5	WA	Site built	0	[12,23,29,30]

Table 2
Floor areas and envelope air tightness

	n	Floor area (m^2)				Blower door airtightness at 50 Pa (ACH_{50})			
		Mean	Minimum	Median	Maximum	Mean	Minimum	Median	Maximum
HEATAG	24	156	73	157	252	9.6	2.9	9.2	15.7
MAP	9	133	79	158	189	4.6	3.2	4.2	7.5
HUD	8	111	77	110	158	14.5	10.6	14.6	21.5
GAS	8	159	114	146	245	10.2	6.3	10.7	13.7
ASH152	5	113	84	116	155	12.7	9.0	11.7	18.9

operating (including the baseload), $W_{baseload}$ the baseload power consumption, and $W_{furnace}$ is the average furnace output capacity plus baseload power consumption for the second half of the period of furnace operation. $W_{baseload}$ was typically a small correction (<1% of $W_{heaters}$). The second half of each period was used to avoid the transients that resulted from excess heat being thermosiphoned from the duct system during the first few minutes of the coheat period, and from the extra energy that was required to warm up the thermal mass of the HVAC system at the beginning of each furnace period.

In addition to the main short-term coheating tests, several other tests were completed, including blower door measurement of building air tightness (Energy Conservatory Model 3 with digital pressure gauge), pressurization testing of the interior and exterior leaks in the supply and return duct system (Energy Conservatory Duct Blaster), airflow measurement at the registers (Pacific Science Technology Fast-1 Flow Hood), air handler flow measurement (several techniques including hotwire anemometer, temperature rise, Energy Conservatory Duct Blaster Flow Matching, Energy Conservatory True Flow Plates). Additional tests that were carried out on some houses included an SF_6 tracer gas decay test, and the nulling and Delta-Q tests to measure duct leakage at operating conditions [30,32–34].

In some homes in some studies, duct retrofits were completed to determine the impact on duct efficiency. The retrofits consisted of an experienced contractor diagnosing duct leaks and applying duct mastic, fiberglass mesh, and mechanical fastening to remove air leakage. In some retrofits in the HUD study, severely compromised duct insulation was also replaced. Insulation was also added as appropriate in the GAS study. In addition, in half of the homes in the HUD study, a new technology for automating duct sealing [35] was used.

3. Results and discussion

3.1. Site characteristics

Table 2 shows some pertinent building characteristics. The minimum and maximum values are provided to show the range of house sizes tested, and the median is shown because of the small sample size. The HEATAG and GAS studies both included a number of larger, two-storey homes. The MAP study tested newer manufactured homes which are smaller, on average, than site-built homes, but still larger than the older manufactured homes tested in HUD. The ASH152 homes were of similar size to the older manufactured homes. The tightest homes in the sample were the energy-efficient manufactured homes in the MAP study. These homes were designed to have very little infiltration and to get their ventilation air from a mechanical ventilation system. The leakiest homes were the older manufactured homes in the HUD study.

3.2. Air handler flow

In order to model the impact of duct leakage on thermal efficiency, it is necessary to have an estimate of the flow through the system in order to calculate the capacity of some heating systems, to normalize the duct leakage flows, and to calculate conduction efficiencies of the ducts. Fig. 1 shows the air handler flows measured in four of the studies, for the number of homes n indicated beneath each study. In this figure, the ‘‘whiskers’’, which are the horizontal lines above and below the box, represent the largest values that are within approximately three standard deviations from the mean. In the event that there is a data point outside of three standard deviations, it is indicated by a small circle above or below the whiskers at the value of the data point. Air handler flow was not measured in the HEATAG study, which was done prior to the development of some of the required test equipment.

These results show that the majority of systems had between 0.38 and 0.47 m^3/s of air handler flow. Most of the systems that did not fall in this range had less flow, but no system in these

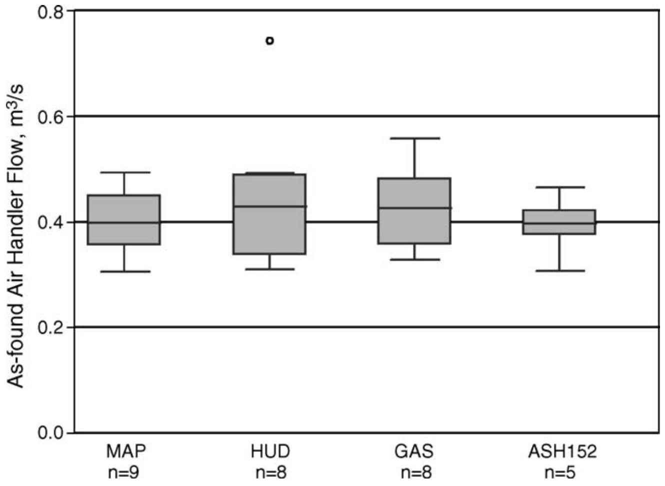

Fig. 1. Air handler flows for four studies. HEATAG study not included because the method of measuring air handler flow measurements used in the other studies was not yet developed.

studies had airflows below 0.3 m^3/s. The GAS houses tend to have somewhat more system flow, primarily because these houses were larger. The MAP homes have a similar range of air handler flow as the HUD homes despite being larger because the insulation characteristics are significantly better, allowing for smaller heating systems. There was one home in the HUD study that had a particularly large air handler flow, at nearly 0.75 m^3/s.

3.3. Duct leakage

Fig. 2 shows the duct leakage test results for supply leakage to outside at 25 Pa. This is different than leakage at operating pressures. Until recently there were no simple methods for measuring leakage at operating conditions in the field, and the standard technique for estimating duct leakage to outside was to measure it at an artificially induced pressure inside the ducts of 25 Pa relative to outside. Even in those studies where a better estimate of leakage to outside at operating conditions is available, the results are presented at 25 Pa to make it possible to compare across studies. Results are not available for the HEATAG study because it was not recognized at the time that it was important to differentiate between leakage to inside and leakage to outside. Also, the equipment typically used to perform these measurements was not available during the first phase of the project.

Fig. 2 suggests that the MAP homes had very low leakage levels compared to the rest of the homes, with the largest leakage about 0.045 m^3/s at 25 Pa reflecting the smaller HVAC system size and attention to duct sealing in the construction of these homes. Both the HUD and ASH152 studies have median leakages of about 0.094 m^3/s at 25 Pa. There is no distinct median line in Fig. 2 for the HUD study because there was a subset of these homes that all had leakage to outside of about 0.094 m^3/s at 25 Pa. The GAS homes had the largest median leakage at slightly more than 0.12 m^3/s at 25 Pa. Just as with air handler flow, the HUD homes had both the largest inter-quartile distance (i.e. the largest box) and the greatest range from minimum to maximum duct leakage at 25 Pa.

One feature of this graph is that the median is always significantly closer to the lower portion of the boxes, and that the lower whisker is always closer to the box than the upper whisker. This indicates that the majority of each set of homes had a leakage level that was relatively consistent, but that there were a few homes with much greater leakage. This reinforces the conclusion of other studies that leakage levels can vary widely across houses, and that the large leakage cases are represented by a small subset of homes with large, possibly catastrophic, leakage. These large leakage cases are often the result of disconnected ducts or other installation problems such as large gaps where smaller ducts take off from larger ducts.

3.4. Duct efficiency

Fig. 3 depicts both the measured pre-retrofit heat delivery efficiency and the pre-retrofit distribution efficiency for the five studies. One home in the HUD study did not have reliable results for the pre-retrofit distribution efficiency, reducing the number of cases shown in the figure from 8 to 7. The median heat delivery efficiency ranges from 51% for the ASH152 homes to 71% for the MAP homes. There is no heat delivery efficiency for the GAS study because heat delivery efficiency was not a major concern in this study, and most of the homes had too many registers to monitor all of them during the testing. The median distribution efficiency ranges from 64% for the GAS homes to 83% for the MAP homes.

In most of the studies, the difference between the medians is about 10 percentage points, with the distribution efficiency being greater. Distribution efficiency is usually larger because of the regain of heat from duct losses to buffer spaces to the conditioned space. It is possible to have distribution efficiencies lower than heat delivery efficiencies. This will occur when the supply leakage is sufficiently larger than return leakage, such that the house is depressurized. If the additional outdoor air that is then brought in to the home requires more conditioning than is recovered via regain from buffer spaces, the distribution efficiency will be lower than the heat delivery efficiency.

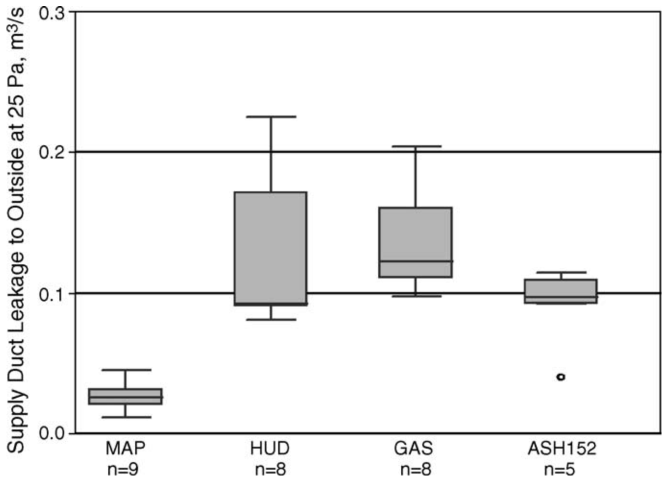

Fig. 2. Supply duct leakage. HEATAG study excluded because measurement techniques for separate supply and return leakage were not yet developed.

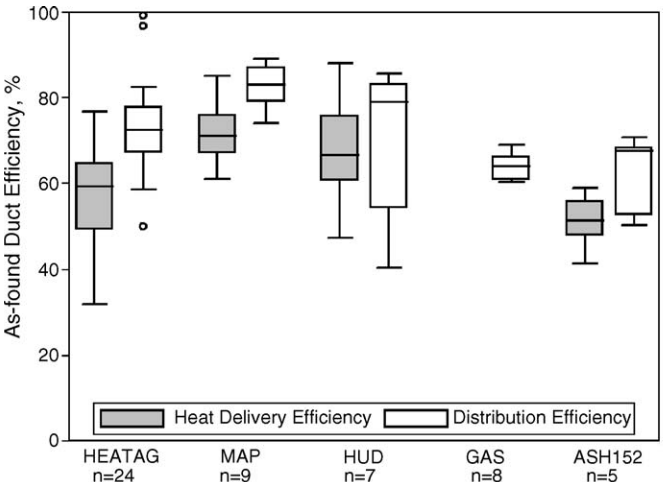

Fig. 3. As-found heat delivery and distribution efficiencies. Heat delivery efficiency was not measured in the GAS homes.

For each of the HEATAG and MAP studies, the mean percentage of ‘‘lost’’ heat (i.e. heat that is not delivered through the registers) that is recovered as useful heat by the house is between 35 and 40%. This amount of regain shows that assessing the performance of a heating unit based solely on the heat delivered through the registers will often exaggerate the problems associated with duct efficiency losses. However, if the heat is not delivered through the registers it is more likely that individual rooms will be cold, sometimes resulting in occupant complaints. The ASH152 homes had a much smaller percentage of the lost heat recovered by the house, at a mean of about 22%.

The HUD study had several homes with distribution efficiency lower than heat delivery efficiency, such that the overall mean recovery of lost heat is only about 7%. Since these homes are manufactured homes, there is no exterior return duct system and no return leakage. Having large supply leakage will then produce distribution efficiencies that are lower than the heat delivery efficiencies. The fact that the median distribution efficiency is higher than the median heat delivery efficiency in this study again shows the influence of a small subset of homes with catastrophic supply leakage. Even though the MAP homes are also manufactured houses, they do not have distribution efficiencies lower than heat delivery efficiencies. This is because the leakage levels are smaller, as shown in Fig. 2.

Fig. 3 shows that even the best homes (MAP) had a median heat delivery efficiency no greater than about 70%. Heat delivery efficiencies often dropped below 50–60%, with the worst individual house, in the HEATAG study, close to 30%. These results show that it is common for ducts to lose between 30 and 50% of the equipment capacity prior to exiting the registers, through a combination of leakage and conduction.

Based on median distribution efficiency for all studies, the energy losses typically range from 20 to 40%, even after factors such as ‘‘lost’’ heat recovered as useful heat by the home are considered. However, in one case in the HUD study losses were nearly 60%. This was a two-section (double-wide) home that had a crossover duct that was disconnected from the furnace, such that one entire half of the house was not getting conditioned air through the registers. On the other end of the efficiency spectrum, one site in the MAP study had the ducts located above the floor insulation for the home. This resulted in the highest MAP as-found heat delivery efficiency, 85%, and a distribution efficiency of 87%, with the majority of losses associated with leakage.

One question that has been the topic of some debate is the extent to which homes with basements recover lost heat. It is thought by some that basements recover nearly all of the heat because the basements are much better connected to the living space than the outdoors. The counter-argument is that the basements are still in significant thermal connection with the outdoors through the ground. In the HEATAG study, two homes with basements were evaluated. These two homes had distribution efficiencies near 100%, and are the two HEATAG outliers with high efficiency depicted in Fig. 3. These high efficiencies occurred despite the lower heat delivery efficiencies, meaning that nearly all of the heat from the furnaces was making it into the home as useful heat, even if it did not all come through the registers. While two homes are not sufficient to generalize, these results do suggest that homes with basements can recover nearly all of the lost heat.

Fig. 4 shows the improvement in distribution efficiency for the three studies at which duct retrofits were performed, which reduces the sample size in HEATAG from 24 to 6 homes. One home in each of the HUD (T06 pre) and GAS (G03 post) studies did not have reliable results for either the pre- or post-retrofit case, reducing the number of cases shown in Fig. 4 from 8 to 7. These results show that significant improvements were made in each of the studies. The median in the HUD study did not change significantly because the house that defined the median had very little actual improvement despite the fact that most of the leakage sites in the ducts were sealed. The pre-retrofit duct leakage to outside in this home was 0.093 m^3/s at 25 Pa, and the post-retrofit leakage was 0.018 m^3/s at 25 Pa. This indicates that, under normal operation, the leaks in this house were at low pressures, such that the impact is greatly overestimated by the leakage test at 25 Pa. All other homes in that study showed greater improvement. These results suggest the importance of duct leakage tests at operating conditions, such as those presented in Francisco et al. [32].

On average, the energy required to heat the homes decreased by about 16% in the HEATAG homes, corresponding to an average reduction by 44% of the efficiency loss. The HUD study showed very similar results, with an average reduction in space heating requirements of 16% and a reduction of efficiency loss by 43%. The GAS study showed about a 17% reduction in space heating required, which is very similar to the other studies, but this corresponded to only about a 36% reduction of efficiency loss despite the fact that insulation was added to many of the ducts in this study in addition to air sealing.

The majority of homes in the HEATAG and HUD studies had post-retrofit distribution efficiencies in excess of 80%. The majority of the GAS homes had post-retrofit distribution efficiencies between 70 and 80%. All houses that received

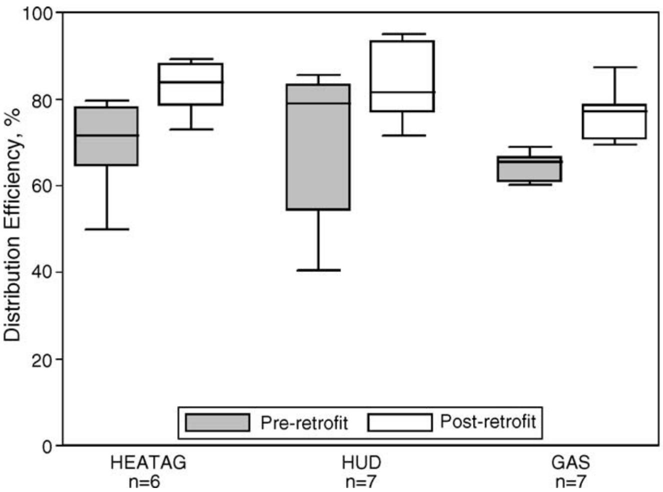

Fig. 4. Distribution efficiency before and after retrofits in the three studies that included repairs.

retrofits had final distribution efficiencies of at least 70%. For the two studies on site-built homes that are shown in Fig. 4, the majority of homes had post-retrofit distribution efficiencies that were higher than the highest pre-retrofit efficiencies within the same study. This was not the case in the HUD homes, despite the substantial improvements in efficiency following retrofit. This is partly a result of the ducts being within the belly space, which puts limits on the amount of air sealing that can be done and makes it difficult to add insulation.

These results show that targeted duct retrofits can result in substantial energy savings. However, they also show that even with these retrofits it is very difficult to completely eliminate measurable energy losses from these systems, highlighting the need to prevent problems via good installation.

4. Conclusions

Short-term coheating, though an admittedly challenging field methodology, has been extremely valuable. It is, to date, the only method of directly measuring the distribution efficiency of duct systems in homes, and can be an important mechanism for verifying retrofit effectiveness. These tests have also provided significant insight into the types of holes in ducts that lead to significant leakage and energy penalties, and other types and locations that can be sealed with little benefit.

The only other way to assess actual improvements due to retrofit is to use models that incorporate measured inputs to provide efficiency estimates. The results from these models are only as good as the input data. At this point, methods for obtaining the required inputs, particularly the duct leakage flows, are questionable. Even newer methods for estimating duct leakage at operating conditions can produce errors that may significantly skew the assessment of the retrofit, although improvements have been made in this area. Furthermore, measurement of duct surface area for purposes of assessing conduction losses can be time-consuming, and in some cases nearly impossible due to restricted access. The factors that differentiate distribution efficiency from delivery effectiveness are difficult to quantify independently.

Short-term coheat testing has been beneficial in the development of models. The tests have identified certain physical phenomena that play an important role in the overall energy consumption of conditioning systems, which helps to prioritize focuses of duct retrofit efforts. They have also provided a means of evaluating both the models and the methods for determining the inputs to the models [36]. As a result of this knowledge, it has been possible to implement the models into standards, such as ASHRAE Standard 152 [13].

The results of the short-term coheat testing on the types of houses evaluated in these studies show that homes often lose 20% or more of the heat provided by the conditioning equipment. All three studies that included retrofits showed a reduction in heating energy of about 16%, corresponding to a reduction in efficiency loss of 35–45%. This result cannot be extrapolated to all homes, because these homes are all from one region in the United States and were typically selected to have significant leakage to outside. However, the short-term coheat testing has been effective at verifying that targeted duct retrofits can result in substantial energy savings, despite the fact that noticeable losses remain.

Short-term coheat testing has also shown that a significant fraction of heat that is lost by the ducts before reaching the registers can be recovered as useful heat by the house. This difference between the total useful heat and the heat that actually enters the home via the registers shows that efforts to identify homes with major efficiency losses by focusing on the registers may often be misguided and lead to substantial attempts to improve ducts with little realized improvement. Short-term coheating has also verified that it is possible to have overall distribution efficiencies less than what is apparent based on the heat that comes through the registers due to the increase in load from induced outside air infiltration.

Acknowledgments

The projects presented in this paper were funded from a variety of sources, including the Bonneville Power Administration, the Eugene Water & Electric Board, Puget Sound Energy, the American Society of Heating, Refrigerating, and Air Conditioning Engineers, and Brookhaven National Laboratory.

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