FIELD INVESTIGATION OF RESIDENTIAL HEATING DUCT LEAKAGE

David Robison and Les Lambert
Lambert Engineering

INTRODUCTION

Central forced-air heating systems are the most common residential type. The heating system suffers energy losses from conductive heat loss and air flow leakage from the heating ducts. In addition to inefficiencies during operation, leaks in heating ducts can contribute to air infiltration. The cracks and crevices in the heating ducts increase the potential for small air leaks when the furnace fan is not operating. This mechanism is referred to as "passive" infiltration to distinguish it from the "active" air losses during fan operation. Some indication of the influence of duct losses has been noted in regional monitoring projects (Parker, 1987). A Federal power marketing agency sponsored the Residential Standards Demonstration Project (RSDP) to document the performance of energy efficient homes. Homes in this program include Model Conservation Standards (MCS) homes, representing state-of-the-art energy efficiency. Another group of "current practice" homes represent a control group.

Duct leakage may be relatively easy and cheap conservation measure. These considerations have led to two related studies of duct leakage. The first is a before-and-after study to identify residential duct leakage and determine the effects of retrofit repairs. The second is a test-reference experiment, comparing leakage and energy use of homes with and without ducting. The latter analysis relies on statistical inferences drawn from the large group of RSDP homes.

A field study investigated duct leakage in a small number of the RSDP homes. A site visit was made to these homes and attempts were made to identify duct leakage by several different methods. Technicians then attempted retrofit repairs on duct leaks and repeated the test procedures. In addition, these homes are being monitored to identify any change in energy usage that can be attributed to duct repairs. The goal of the field study was to examine total leakage attributable to the forced-air heating system, the major sources of air leaks, preventative or repair strategies and diagnostics.

The primary goal of this test-reference investigation is to improve the accuracy of retrofit energy savings estimates. Engineering estimates of space heat energy typically fail to offer good predictions of actual energy usage. Heating system inefficiencies may account for some of the discrepancy. Determination of the energy impact of duct leakage requires evaluation of two seasonal quantities -- estimation of passive infiltration due to the presence of heating ducts and estimation of additional fan-driven ventilation due to furnace operation.

METHODOLOGY

The methodology to investigate duct leakage is an application of existing residential test methods. Interpretation of the results, however, is more difficult. Theoretical models to describe the interconnection of various air loss mechanisms are not fully developed. The investigative methods suffer from limited precision and repeatability. Finally, the homes exhibit variable response depending on weather and other factors.

The blower door is a way to measure the air flow versus pressure difference characteristics of a structure. To the extent that the ductwork can be "shut off" or isolated, a sequence of measurements with ducts open and ducts sealed can be made. By subtraction, a rough idea of the flow versus pressure difference characteristics due to the ductwork is obtained. One measure of house leakiness is the 4 Pascal Effective Leak Area (ELA). An alternative leakiness measure is the volumetric flow rate at 50 Pascals pressure difference.

Infiltration air flows interact in ways that are not obvious. Passive infiltration occurs normally as a result of wind and stack effects driving air through the house. However, the passive infiltration can be affected when the furnace fan operates. The fan can induce a net positive or negative pressure in the house. Unbalanced leakage, if it occurs, will affect passive infiltration. Modera and coworkers have suggested that the unbalanced portion of the air flow should be added in quadrature with stack and wind induced infiltration (Modera, 1985). Kiel and Wilson have suggested that, for large fan-driven exhaust flows, simple linear addition of the flows is a better estimator (Kiel, 1987).

In this study, we improved on a variation of blower door testing which may be a useful field technique. The desired information from blower door testing is a plot of log Q versus log P for only the duct leaks. The blower door information for the whole house is of limited utility because the flow quantities are imprecisely determined. It is more useful to measure duct leakage flows directly. For this purpose, a low velocity flow hood was used. The supply and return sections of the ducts were isolated from each other by applying a seal at the furnace fan. Then all the registers and grille were sealed except for one supply register and one return grille. The house was pressurized and depressurized with the blower door. This allows air flow into and out of the open grille to be measured directly with a flow hood. At the same time, it was necessary to measure the pressure in the duct. With some experimentation, it appeared that an effective average pressure could be measured which was representative of the entire duct.

Sulfur hexafluoride tracer gas tests were used during the to measure fan-driven air exchange directly. Comparison of the fan-on and fan-off ACH measurements gives an indication of the net change in ventilation due to fan operation.

A primary goal of the project is to reconcile energy estimating procedures and monitored energy usage. A preliminary method of estimating the energy impact of duct losses has been developed. However, monitoring to verify the estimate procedure is still underway.

STUDY RESULTS

Statistical Study of Monitored Houses

To verify the suggestion that duct leakage occurs on a large scale, a statistical analysis was undertaken on a large sample of the RSDP homes. The homes were separated as Model Conservation Standards (MCS) and control group homes. They were then classified as ducted or unducted. Differences due to the presence of ducts were significant in both groups but even more noticeable in the control group sample. Ducted homes have 12% to 22% more leakage and 13% to 40% higher energy usage, for MCS and control group homes respectively.

Leakage Characteristics of Ducts

Conclusions from leakage measurements include:

(1). Duct leaks increase the blower-door measured ELA of a house by an average of about 11%. The average distribution is 3.3% in supply and 8.7% in return ducts.

(2). This amount of leakage is consistent with that observed for the 50 Pascals air exchange.

(3). The flow hood measurements are consistent with, but more precise than whole-house blower door testing.

(4). Differences in leakage produce a net pressurization in most homes during furnace fan operation.

(5). Interactions between fan-induced air exchange and passive air infiltration appear more consistent with linear addition of air flows rather than addition in quadrature.

Energy Impacts

The amounts of air loss attributable to duct leakage are deceptively small. A better measure of their impact is the energy impact estimates. The estimated savings averaged 376 kWh/ year. Estimated heating efficiency loss caused by the duct leaks is not simply the volumetric loss, but includes some estimate for the increased run time caused by the duct leaks. Levelized cost of the repairs is estimated at 10 to 13 mills/kWh, using 3% and 6% discount rates respectively.

CONCLUSIONS

(1). Duct leakage repair or avoidance constitutes an easy energy efficiency improvement. It is cost-effective to include duct repair in residential retrofit programs, such as utility-sponsored weatherization. Code requirements, such as MCS, should articulate and enforce duct installation standards for any new housing that includes forced-air heating systems.

(2). More research is needed to quantify the impact and extent of duct leakage in current housing stock. The homes in this study are probably better constructed than the norm. In particular, there was been no study of natural gas-heated homes. This oversight is of particular concern because the health impacts of combustion appliances may be significant. Models to understand the complexities of interacting air flows in buildings are not adequate. Further research could provide very beneficial insight into low cost-opportunities for energy conservation.

(3). The precision of blower door testing to measure infiltration is questionable. Further testing of whole-house air flow is not recommended as a technique to quantify the small air flows involved in duct leakage. The flow hood technique initiated in this study shows potential as a more accurate method for quantifying duct leakage.

REFERENCES

Kiel, D. E., and Wilson, D. J., "Influence of Natural Infiltration on Total Building Ventilation Dominated by Strong Fan Exhaust", ASHRAE Transactions, 93(2), pp. 1286-1299, 1987.

Modera. M. and Peterson, F., "Simplified Methods for Combining Mechanical Ventilation and Natural Infiltration", LBL-18955, Lawrence Berkeley Laboratory, January, 1985.

Parker, Danny, "Performance Results From the Residential Standards Demonstration Program", draft report, NWPPC, Capital Station, Helena, MT 57620, January, 1987.