Measured Duct Leakage and Resulting Envelope Pressure Differences

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Abstract

As concern about IAQ has increased, forced-air distribution systems are being viewed as a potentially important factor in preventing the transport of indoor and outdoor pollutants. Duct leakage can be a confounding factor in attempts to use the forced-air system for this purpose. Leakage from outside into the return side of the system brings outdoor air directly into the distribution system through the leak. Supply leakage depressurizes the house which increases infiltration of outdoor air through the envelope. This paper presents results from three projects on field measurements of duct leakage, covering 77 homes in three regions of the U.S.: the Pacific Northwest, Wisconsin, and Central Illinois. These homes range in age from new to over 100 years old. Changes in house pressures due to duct leakage are reported. Duct leakage results are also compared to predicted changes in infiltration based on blower door results and infiltration models.

Introduction

Reduction of air leakage through building envelopes is frequently pursued both as a means of reducing energy use and for preventing contaminants from entering the living space. Typically, this takes the form of air sealing unintentional holes between the living space and outdoors/unconditioned spaces and then providing mechanical ventilation, which allows the air from outdoors to be controlled and, if desired, filtered and/or tempered prior to entering the occupiable space.

As buildings are made tighter, unbalanced airflows have a greater impact on pressure differences between indoors and outdoors as well as between interior zones. Unbalanced flows often take the form of exhaust ventilation or supply ventilation, which are intentional and can be shut off when desired to manage envelope pressures. Unbalanced airflows can also take the form duct leakage in forced-air conditioning systems, which is unintentional. This leakage can either pressurize or depressurize the building relative to outdoors, depending on whether the leakage is greater on the supply or return side. Unbalanced duct leakage can therefore increase the challenge of controlling both pressures and airflows within buildings in order to manage the indoor environment.

This paper presents data that show the influence of duct leakage on building pressures for varying levels of envelope leakage in 77 residential buildings in the United States. While it is generally understood qualitatively that duct leakage can cause pressure changes across the building envelope, and that tighter buildings are more subject to pressure changes from unbalanced flows, these results demonstrate these issues quantitatively. More details of each of these studies can be found in the project final reports[1,2,3].

Methodology

The primary data required for this evaluation are the leakage of the building envelope, the supply and return duct leakages to and from outside, the volume of the house, and the changes in house pressure caused when the air handler for the forced-air system operates. For the evaluation of the impact of duct leakage to inside in homes with basements an assessment of leakage to inside is also required.

A common method of assessing duct leakage to outside is the duct pressurization test, which uses what is essentially a small blower door attached to the duct system with all of the registers or grilles sealed. The test is traditionally performed at a duct pressure of about 25 Pa. When the ducts are pressurized the flow through the fan is an estimate of the leakage at the pressure in the duct system. If a blower door is used to simultaneously pressurize the house to the same pressure as the duct system, then the leakage between the ducts and indoors is eliminated and the remaining measured leakage is to outside only. However, this leakage estimate is unlikely to replicate normal operating conditions and may over- or underestimate the leakage depending on whether the 25 Pa duct pressure is greater or less than the pressure in the ducts at the leaks under normal air handler operation.

As a result, a different method of estimating duct leakage to outside was used for the primary analysis in this paper. This method, called the nulling test, estimates leakage to outside only under normal operating conditions. The basic principle behind the test is to “null” out the pressure change caused by the operation of the air handler fan using a calibrated fan in the building envelope. In principle, a blower door could be used for this fan, but because of the generally very small envelope flows induced by the duct leakage the fan that was used was the same type of fan as is used for the duct pressurization test described above.

The nulling test has two components, one test to get unbalanced duct leakage (i.e. different between supply and return leakage) and one to get estimates of supply and return leakage separately. However, because it is the unbalanced leakage that determines the degree of pressure change due to air handler fan operation only that portion of the test is included in this analysis.

Pressures were measured across the envelope with and without the air handler fan operating. Data collection and fan speed control was automated. The duration of the measurement depended on the amount of wind present during the test. The pressure measurement period was determined largely qualitatively, with the focus being to measure for a long enough period to have the standard error of the envelope pressure measurement be about 0.3 Pa or less. This was generally achievable, but on particularly windy days this was not possible.

Test Sample

The sample presented here includes 50 homes from the Pacific Northwest (PNW, typically within one hour drive of Seattle), 16 from Wisconsin, and 11 from Central Illinois. The PNW and Illinois homes were primarily occupied homes, ranging from recently built to about 100 years old. The Wisconsin homes were all new homes, and most of them were built with the intention of qualifying for energy efficiency credits.

The homes were largely a sample of convenience, with limited physical characteristics required for participation. The PNW and Illinois homes were mostly chosen to have most or all ducts in unconditioned spaces such as vented crawl spaces or attics. The Wisconsin homes were chosen to have at least some ductwork outside of the conditioned space despite the fact that most homes in Wisconsin have all ducts within the conditioned space. Other than these physical characteristics, no effort was made to choose homes with known duct leakage.

Results

Table 1 shows several pertinent characteristics of the test sample, separated by project, including floor area, house leakage, and duct leakage characteristics. The Wisconsin study, being newer homes with most of the ducts located inside the conditioned space, had homes that were larger, tighter, and with less duct leakage to and from outdoors.

Figure 1 shows the change in house pressure caused by unbalanced duct leakage. This figure is broken into four different panels, each representing a different range of building airtightness levels. The upper left panel shows homes that have less than 4 ACH50. The lower right panel shows homes that are greater than 12 ACH50. The remaining two panels show intermediate ranges of airtightness, between 4 and 8 ACH50 for the upper right panel and between 8 and 12 ACH50 for the lower left panel.

These graphs show that the house pressure changes more rapidly with increasing unbalanced duct leakage for the tighter homes and much less rapidly for the leakiest homes. The two intermediate ranges are similar to one another.

The tightest homes were mostly from the Wisconsin study, which also tended to have modest leakage to outside because most of the ducts were in the basement. This limits the unbalanced duct leakage range for this portion of the data. However, there is still a definite trend of a substantially steeper relationship, and a regression of house pressure change on unbalanced duct leakage showed the steeper change to be statistically significant.

Regressions were done on all four of the subsets of data. All four regressions had constants that were not statistically significant, but the regression coefficients were all significant at the 95% confidence level. For the tightest homes, the regression coefficient was -0.020, meaning that the house pressure changed by 0.020 Pa for each cubic foot per minute of unbalanced duct leakage. For the two intermediate levels of house envelope leakage, the results were similar, with the 4 ACH50 to 8 ACH50 homes having a regression coefficient of -0.0077 and the 8 ACH50 to 12 ACH50 homes having a regression coefficient of -0.0081. The leakiest homes had a regression coefficient of -0.0042. These results suggest that the tighter homes have about 5 times the envelope pressure change as the leakiest homes for equivalent unbalanced duct leakage.

Table 2 shows estimates of outdoor air brought in to the home due to duct leakage. These estimates are based on a model developed by Palmiter and Bond[4] which has the feature of considering both the change in airflow through the building envelope and the additional air that comes in directly via the duct work. The portion of the model that accounts for the air that comes in directly through the ductwork uses the return leakage flow rate and then reduces that leakage rate by the fraction of the air handler flow that leaks to outside via leakage in the supply ducts. The estimated natural infiltration was estimated using the leakage from the blower door test and the procedures in ASHRAE Standards 119[5] and 136[6] to account for building height and local weather.

This table shows the expected trend of increasing natural infiltration with leakier building envelopes. It also shows that, on average, the tightest homes also had the lowest unbalanced duct leakage and the homes between 8 and 12 ACH50 had the highest unbalanced duct leakage. As stated previously, the tightest homes were usually the new homes in the Wisconsin study which had most of the ducts inside the conditioned space, so the result that the unbalanced duct leakage to and from outside is the smallest for this group is no surprise.

The trend in the additional outdoor air caused by duct leakage is comparable to the trend seen for the unbalanced duct leakage itself, with the low-unbalanced leakage duct systems of the tightest houses inducing little air and the high-unbalanced leakage duct systems of the 8-12 ACH50 homes having the most induced outdoor air.

The trend is very different with regard to average change in envelope pressure corresponding to these results, however. The leakiest houses, which averaged about six times the unbalanced duct leakage as the tightest houses, averaged a somewhat smaller house pressure change due to the duct leakage. The implication is that, had the tight homes had more ducts in unconditioned spaces and had those ducts been of comparable leakiness to the systems in the leakiest houses, the house pressure changes would have been much greater and had a much greater impact on attempts to manage house pressures.

Conclusions

This paper shows unbalanced duct leakage can cause substantial unintended changes in house pressure. Though the tightest homes in the study had the lowest average unbalanced duct leakage because most of the ductwork in these homes was within the conditioned space of the homes, the pressure changes resulting from unbalanced duct leakage were substantially higher in these homes for comparable levels of unbalanced duct leakage. This could have implications for airflow control using barometric dampers and drafting of atmospherically-drafted combustion appliances. Therefore, it is of great importance to ensure that duct systems in tight houses are also made to have low leakage.

References

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Table 1. Test home characteristics.

	Mean	Minimum	Median	Maximum
Floor Area, m^2 (ft^2)				
PNW	153 (1646)	65.7 (707)	151 (1626)	249 (2683)
Wisconsin	353 (3795)	127 (1372)	354 (3810)	586 (6306)
Illinois	157 (1687)	106 (1144)	167 (1800)	204 (2200)
House Leakage, m^3/s @ 50 Pa (CFM50)				
PNW	1.09 (2309)	0.36 (766)	1.00 (2109)	2.32 (4921)
Wisconsin	0.66 (1406)	0.17 (370)	0.65 (1374)	1.44 (3044)
Illinois	1.07 (2277)	0.56 (1181)	1.05 (2223)	1.51 (3193)
House Leakage (ACH50)				
PNW	11.0	3.8	9.3	29.0
Wisconsin	3.3	0.8	2.4	13.2
Illinois	10.3	6.7	11.1	14.7
Supply Leakage, m^3/s (CFM)				
PNW	0.049 (103)	-0.001 (-2)	0.041 (86)	0.168 (356)
Wisconsin	-0.006 (-12)	-0.088 (-186)	0.000 (1)	0.021 (45)
Illinois	0.080 (168)	-0.003 (-7)	0.064 (136)	0.181 (384)
Return Leakage, m^3/s (CFM)				
PNW	0.044 (92)	-0.019 (-40)	0.031 (66)	0.197 (417)
Wisconsin	0.006 (12)	-0.083 (-176)	0.003 (6)	0.086 (182)
Illinois	0.050 (106)	-0.006 (-13)	0.037 (79)	0.173 (367)
Unbalanced Leakage, m^3/s (CFM)				
PNW	0.005 (11)	-0.151 (-320)	0.010 (21)	0.140 (296)
Wisconsin	-0.011 (-24)	-0.080 (-169)	-0.005 (-10)	0.006 (12)
Illinois	0.030 (63)	-0.033 (-69)	0.016 (34)	0.119 (253)

Table 2. Estimated introduced outdoor air based on seasonal average weather, means per tightness group.

	Natural Infiltration, m^3/s (CFM)	Unbalanced Duct Leakage, m^3/s (CFM)	Added outdoor air due to duct leakage, m^3/s (CFM)	Average change in house pressure, Pa
ACH50 < 4	0.032 (69)	0.006 (13)	0.004 (9)	0.39

4 < ACH50 < 8	0.039 (82)	0.032 (67)	0.021 (44)	0.66
8 < ACH50 < 12	0.054 (113)	0.049 (104)	0.035 (75)	0.86
ACH50 >12	0.073 (154)	0.037 (79)	0.023 (48)	0.34

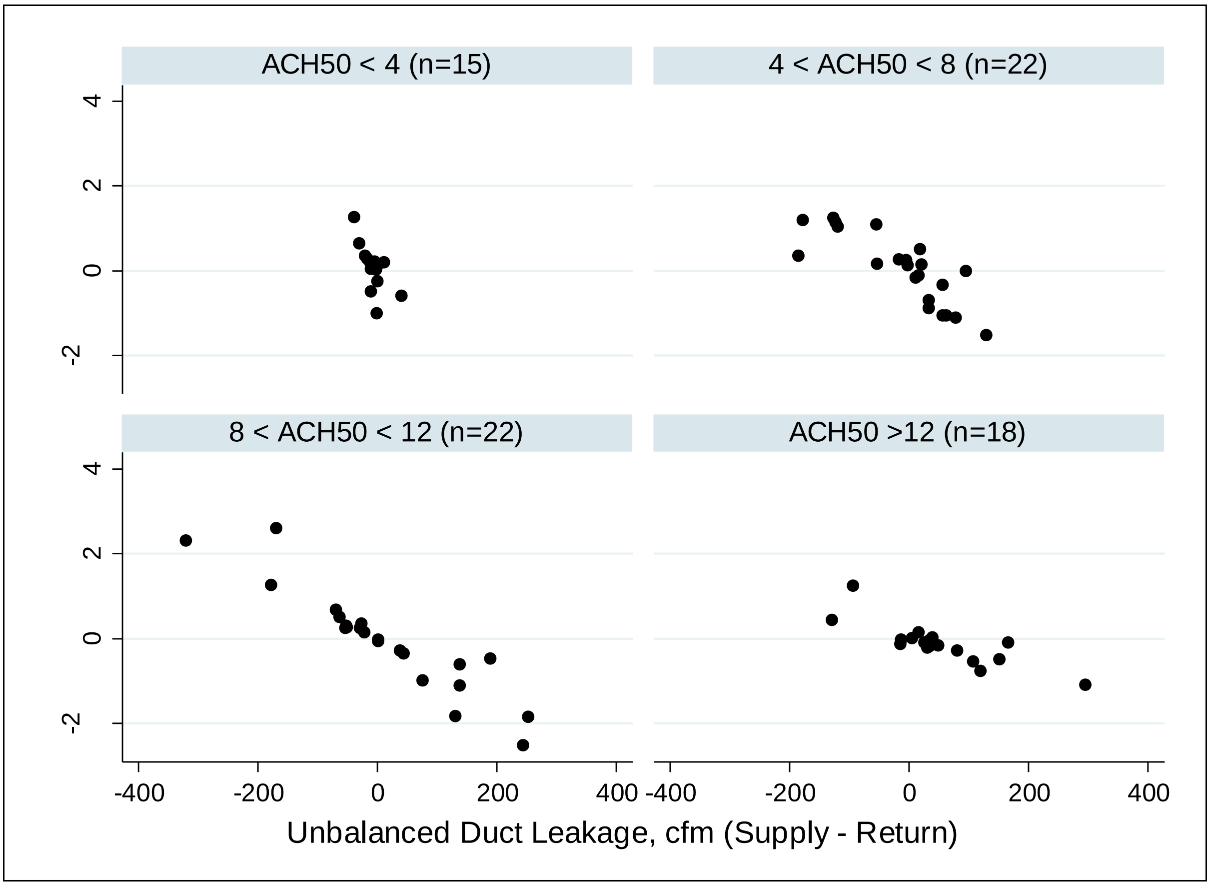

Figure 1. Change in house pressure vs. unbalanced duct leakage for 4 groupings of ACH50. Divide by 2119 to convert from cfm to m^3/s.