A Field Study of Whole House Air Infiltration in Residences

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1. Executive Summary

A four-part study was carried out of the airtightness of houses. Two identical single-story, 1360-square-foot wood frame houses were used in the study. The tests conducted in the four-part study include:

- comparison of the effects of wet-blown cellulose and kraft-faced fiber glass wall insulation on the airtightness of a house,
- comparison of the effects of blown fiber glass and kraft-faced fiber glass wall insulation on the airtightness of a house,
- effects of various wall systems, air tightening materials and techniques on the airtightness of a house, and
- effects of sealing house components on the airtightness of a house.

From the study, the following results were concluded:

- The majority of air infiltration occurred in the ceiling (40%) and floor (36%) of the houses, and was significantly reduced by caulking and sealing. The walls and doors/windows accounted for 14 percent and 10 percent, respectively, of the houses' air infiltration.
- A comprehensive whole house caulk and seal job reduced air leakage within the houses by approximately 44 percent.
- Various wall system air tightening techniques, such as installing a housewrap, taping insulating sheathing joints or caulking and sealing, had a notable impact (nine percent) in reducing air infiltration in the houses.
- Wall cavity insulation had virtually no effect on the air tightening of the houses. The complete removal of the wall cavity insulation resulted in only a 1.5 percent increase in air leakage throughout the entire house.
- The greatest barrier to air flow through a wall was the drywall, followed by several different airtightness treatments.

15 YEARS OF PROGRESS

2. Background

Air infiltration testing, designed to compare material or construction types, has typically been conducted on wall panels under laboratory conditions. However, the intent of wall panel testing is to compare the relative performance of those materials or construction types; by themselves the results say nothing of the values of the materials tested to the entire house. For example, a wall cavity insulation might be found to have an air flow resistance 30% higher than another in a test panel. However, if cavity insulation accounts for only about 10% of a wall's resistance to air flow, the impact of that change in the flow resistance will have no significance. Furthermore, the walls typically accounts for only a minor portion of a house's air infiltration. That 30% difference in insulation performance then becomes even less significant in terms of whole-house savings.

There is a more accurate, and frequently used, test to measure the true effect one wall construction has versus another on an entire house's air infiltration. This is to use blower doors on similarly constructed houses, set side-by-side, using each of the wall constructions to be studied. The main disadvantage of this approach is that side-by-side houses are often not as similar as expected. Thus one house can be unintentionally built tighter than another. The accidental variations in airtightness from house to house may be greater than the variation caused by the differences between the constructions being studied.

To avoid this problem, the series of tests described here were carried out in sequence in the same house. For each test the wall was reconstructed in the new configuration, then the house was tested again. For example, to compare two insulation materials, the drywall and insulation were removed, and the airtightness of the house was measured. Then the insulation to be tested was installed, and the drywall replaced, and the airtightness measured again. This sequence of tests was repeated using the second insulation material. Thus everything about the house except the component being studied was kept the same.

A second house was used in this project, but only to check the consistency of the results. The same series of tests were carried out in the second house on the same set of materials and constructions.

3. Experimental Procedure

The tests reported here were performed by employees of the author using two houses provided by Owens-Corning at their Science & Technology Center in Granville, Ohio. All construction was conducted by local building and insulation contractors.

The test houses, designated "B" and "C," were 1361 square feet single story wood framed houses built in 1979 of conventional construction. They were nominally identical. The walls were constructed of 2x4 framing, plywood and wood fiberboard sheathing, and aluminum siding. The houses were heated with electric forced air furnaces. They differed slightly from occupied houses in that they did not have plumbing systems and the basement access was from the garage only. Dummy plumbing vents were used in the walls and extended through the roof. Also, the drywall was screwed in place and sealed with duct tape instead of being nailed, taped, and finished with joint compound to facilitate removal and reinstallation as the wall construction was changed during the test phases.

Air tightness of the houses was tested in both pressurization and depressurization using two different blower doors for different sets of tests carried out at different times. (However, all comparisons made were between sets of measurements made with the same blower door.) The blower door manufacturers' calibrations were used. The calibrations were checked against a sharp-edged orifice and found to be within 3% for both blower doors. The repeatability of the measurements made in the field was checked by making frequent duplicate measurements. The standard deviation of the measured whole house air leakage rates was found to be about 1% for the manually operated blower door used in the first part of the work. Later, an automatic blower door was used that gave a standard deviation of about 0.4%. This very good precision was obtained by testing only under very low wind conditions. All flows were calculated at 30 Pa pressure difference, because this pressure was in the middle of the range of the blower door tests, and the flows calculated at this pressure had the lowest standard deviation.

Air tightness measurements were made to determine the air flows through the different components of the house's outer surface. One of these sets of measurements used a new technique (to be described in a later paper) to measure the air flow entering the house through the basement, then through the basement ceiling into the ground floor of the house. Another set of measurements was made with the interior surfaces of the outer walls, including the doors and windows, covered with tightly taped polyethylene. The reduction in airflow gave the combined contribution of these two components. Then the polyethylene was cut over the windows and doors, and tightly taped around their edges, to separate the contribution to leakage of the windows and doors from that of the walls.

4. Test Sequence

Four series of tests were carried out. The first series of tests compared the effects of wet-blown cellulose and kraft-faced fiber glass insulation on the airtightness of each of the two houses. In the second series of tests, the effects of blown fiber glass and kraft-faced fiber glass insulation on the airtightness of the houses were tested.

The third series of tests measured the effects of various wall systems, air tightening materials and anti-infiltration techniques on the airtightness of the test houses. In this series, the following components and systems were studied:

- drywall and R-13 kraft-faced batts
- housewrap over untaped foam sheathing
- housewrap over fiberboard
- taped foam sheathing
- caulking and foaming of the wall cavity
- untaped foam sheathing
- vinyl siding
- aluminum siding

For each of these components, the flow resistance was calculated as:

$$Rf = ((P)^{0.5}/Q \; [s\text{-}Pa^{0.5}/m] \ldots\ldots (1)$$

where Q = flow [m^3/s of leakage per m^2 of surface area]
and ΔP = pressure difference [Pa]

In the fourth series of tests, the effects of sealing house components on the airtightness of the test houses were measured. First drywall and insulation was removed and the wall cavities were caulked and foamed. Then the attic insulation was removed and the attic was caulked and foamed. Next, the basement ceiling and the basement perimeter were foamed. Finally, the furnace duct outlets in the floor were sealed. (Since the ducting was entirely in the basement, sealing these outlets had the same effect as sealing the furnace and ducting would have had.)

5. Results and Discussion

Distribution of Leakage: The most significant result of this study, because of its impact on all the conclusions reached, is the distribution of air leakage among the components of the house envelope.
It was found that the majority of air leakage occurred through the ceiling and partitions (40%) and from the basement (36%) of the houses. About 75% of the air leakage from the basement entered the house through

the ducting and 25% through the floor over the basement. The walls accounted for 14 percent and the doors and windows accounted for 10 percent of the houses' air leakage.

Another important finding was the resistance to air flow of the various wall components. It was found that the drywall contributed 69% of the total resistance to air flow of the walls, the siding and sheathing contributed 20%, and the insulation accounted for only 11%.

Impact of Insulation Type: Considering that the wall insulation accounted for only 11% of the flow resistance in a leakage path that accounted for only 14% of the flow, it is not surprising that no airtightness difference was found when a house was tested using different wall insulation types. This was true when kraft-faced glass fiber batt insulation was compared with wet-blown cellulose fiber insulation, and when it was compared with blown in glass fiber insulation. In fact, the complete removal of the wall cavity insulation resulted in only a 1.5% increase in whole-house air leakage.

Flow Resistance of Wall Elements: Table 1 shows the results of the measurements of the flow resistance of wall components.

Table 1. Flow Resistances of Wall Elements

Material	Flow Resistance	s-Pa0.5/m
Drywall + R-13 KFB	5500	Δ 33%
Housewrap & untaped foam	5000	Δ 26%
Taped foam sheathing	3400	Δ 26%
Caulk and foam the cavity	3200	Δ 19%
Housewrap (over fiberboard)	3100	Δ 26%
Vinyl siding	1900	Δ 24%
Al. Siding and sheathing	1400	Δ 7%
Untaped foam sheathing	600	Δ 8%
Aluminum siding	400	Δ 25%

It is not surprising that the error estimates for the high flow resistances are high, because these resistances cause very low flows, which are insignificant relative to the whole house leakage. However, the nature of the errors in this study is that they will tend to be in the same direction and of the same approximate magnitude for the entire series of tests. Therefore the relative magnitudes of these resistances are more accurately known than the absolute values, and it is likely that the comparison between the various materials is valid.

Flow resistances in walls are not simply additive. If a wall was made of several uniformly permeable layers, then the resistances could be added, but real walls are composed mostly of layers of very impermeable materials with cracks and holes allowing air leakage through them. The resistance of a wall assembly made up of such components will depend on the alignment of these cracks and holes. To illustrate this point, consider a sheet of plywood with a one inch round hole in the middle of the bottom half. Adding a second identical sheet of plywood with the hole aligned will not double the resistance to air flow. In fact, it won't increase it appreciably. However, if the second sheet of plywood is reversed, so that its hole is in the top half, and the sheets are again aligned, the flow resistance will be many times higher than for a single sheet. This is because the flow resistance of the holes is now insignificant. The flow resistance of the crack between the two sheets from one hole to the other is now the controlling factor.

In spite of this caution, the resistances listed above give a reasonable indication of the effects of these components in real walls. This is because the measurements were made in walls in which the components that were likely to interact in this way with those being measured were in place. Thus, for example, the airtightness of a particular kind of siding was measured by measuring the airtightness of a complete wall with and without that siding placed over the sheathing, and not by measuring the airtightness of a wall with siding over bare studs.

One problem with the measurement and interpretation of flow resistance data in systems as complex as house structures is the presence of parallel paths. For example, air that flows in through the outer components of the wall of a house (e.g. the siding and sheathing) can then enter the house through the inner components of the wall (e.g. the kraft paper and drywall), or it can leak into the ends of the partitions, then into the house through leaks in the partitions. When calculating the flow resistance of the drywall, two approaches are possible. Either the flow through only the inner surface of the outer wall can be considered, in which case the drywall is an almost perfect cover, or the flow through its outer surface can be considered, in which case the drywall has a set of major cracks (at the ends of the interior partitions) patched roughly by 2x4s. In previous work, the former approach was taken, and the flow resistance of the drywall and the outer wall were reported at 77% and 12% of the total wall resistance respectively. In the present work, the latter approach was taken, and the percentages became 69% and 20% of the total wall resistance.

Sealing House Components: Sealing the ceiling and interior partitions reduced the total air leakage into the houses by about 22% of the original unsealed value. Sealing the walls reduced it by about 9%. Sealing the floor and the basement walls (but not the ducting) made a 13% difference, for a total change of 44% of the original unsealed value.

Sealing the heating system's air vents through the floor before the basement was sealed reduced the air leakage of the house by 32% of the original unsealed value, and after the basement was sealed, the impact was 19%. Sealing these vents would be expected to have the same effect as perfectly sealing the furnace and the ducting in the basement. Thus the sealing of the furnace system has the potential to reduce sharply the infiltration into a house when the furnace is off. The impact on infiltration when the furnace is on will depend on the pressurization of the ducting by the furnace fan and on the locations of the leaks.

Reliability of Results: The high precision that was obtained in the blower door tests is not an indication of the reliability of the results obtained in this study. A greater source of error is unintentional changes to the remainder of the house while a particular component was studied. Some such unintentional changes were noted during the research project, and their impacts could be avoided by not comparing any readings made before and after these changes occurred. For example, an underground phone line was installed to one of the houses. The disturbance of the soil around the foundation significantly changed the leakage into the basement.

There were several occasions when the same measurement was made at two different times during the project. These provided an opportunity to check the repeatability of the measurements. For example, the flow through the walls of House C was measured after the walls had been caulked and foamed, and both before and after the ceiling and the basement had been caulked and foamed. The measured flow through the walls was 70 cfm both times. The window and door flow before and after the sealing of the ceiling and basement was 136 and 138 cfm respectively. These two sets of tests were made just a couple of weeks apart. A longer period, about ten months, passed between two tests of the window and door leakage of House B. The measured change was from 70 cfm to 106 cfm. This 36 cfm change may be experimental error, or it may be an accurate measure of the change to the window and door leakage that occurred over that ten month period.

In another set of tests, the overall airtightness of House C was measured, then the house was left untouched for three months and tested again. The two results were 775 and 786 cfm. The difference, 11 cfm, is 1.5% of the total flow.

In summary, the agreement between pairs of measurements that would be expected to agree is good enough that confidence can be placed in the conclusions drawn from comparisons of whole-house air tightness measurements in the present study.

This conclusion can not necessarily be extended to the results of the basement leakage measurements. Basement leakage measurements are subject to greater errors than whole-house measurements. This is because they are based on three separate measurements made under two different house conditions.

Two sets of measurements were made of the air flow through the basement of House C, at different times but with the house in the same condition. Those two sets of measurements gave air flows through the basement of 324 cfm and 310 cfm. This difference is consistent with the standard deviation of 18 cfm in the 11 tests that made up the first set of measurements.

The agreement between all these sets of tests that were available for comparison is good enough to validate the conclusions reached about the distribution of leaks in the two test houses. Since these houses were of typical construction, the results would be expected to apply reasonably well to other houses of the same type.

6. Conclusions

This study has provided data on the importance (or lack of importance) of the various air flow paths through two test houses, and of the flow resistances of several wall elements. In particular, the difference between the leakages through walls insulated with kraft-faced fiber glass batts, blown-in fiber glass insulation, and wet-blown cellulose fiber insulation was found to be insignificant.

It was found that caulking and foaming the walls, ceiling and basement reduced the air leakage of the houses by 44%.