#4709

Is That Attic Crawl Necessary?

by Laurie Cameron

GRASP's approach to Philadelphia's predominant vernacular housing type—the rowhouse—shows how testing and monitoring of retrofit techniques can customize local auditing and weatherization efforts for better savings. And what they've found out about flat roofs, thermal bypasses, and attic ventilation has a lot of relevance beyond the rowhouse neighborhoods of the East Coast.

The rowhouse, as prevalent as it is in Northeastern and Mid-Atlantic cities such as Boston, New York, Baltimore, and Washington, D.C., is still poorly understood; it has proven especially resistant to traditional weatherization methods. In Philadelphia, the local Low-Income Weatherization Assistance Program's (WAPs) shell treatments strongly emphasize repairs and replacements. Common repairs include door and prime window replacement, glass replacement, and sheetrocking or plastering of large holes in walls and ceilings. In fact, the weatherization program could be characterized as a repair program of last resort. In some cases, auditors walk away from houses altogether; quite often blower-door-guided air sealing work is not done because the budget has been spent on insulation and repair of large thermal envelope holes and basic heater repair/replacement.[1]

The state of unweatherized buildings, of course, is even more dismal. The mean pre-weatherization annual fuel usage in weatherization program rowhouses in Philadelphia is slightly higher than the corresponding figure in a recent study of houses in Minnesota![2]

This result is indicative of both the inherent inefficiency of the older rowhouse stock and of the high degree of deterioration that results from the poverty of the occupants. It is not rare to come across houses in which a blower door fan running at maximum speed will produce less than a 15 Pascal pressure difference. That is because a large proportion of low-income weatherization houses have multiple large unintentional holes through the thermal envelope.

Traditional attic insulation often fails to achieve expected savings, because the dynamics of air infiltration peculiar to rowhouses—especially the many thermal bypasses from the house to the attic—severely cut back on the insulation's effectiveness.

What Is A Rowhouse?

Generically, a rowhouse is any structure on a separately deeded piece of ground that shares a common sidewall—called a party wall—with one or two similar structures and that is in a row of three or more such structures. Generally the structures must be one- or two-family to qualify as row*houses*.

Two houses sharing a common wall and having windows on the outer sidewalls are called *twins*. The end houses in a row often resemble twins, but they may also have become endrows—or even free-standing—late in life as a result of demolitions to either side. Like it or not, we still call them rowhouses.

Some large three-story rowhouses in Philadelphia were originally single-family but have been converted to three or more apartments. They are still called rowhouses.

A row*home* is a rowhouse being advertised for sale. A townhouse or townhome is a rowhouse that costs a lot of money.

To someone from Clover Lick, West Virginia, a block of Philadelphia rowhouses looks like one big building or a low-rise condominium. To someone from Philadelphia, a Clover Lick outhouse looks like a tool shed.

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Houses in a row, Phily style.

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Fortunately, by studying the rowhouse's construction details, and its heat and moisture transfer,[3] we at the Grass Roots Alliance for a Solar Pennsylvania (GRASP) have discovered several techniques that help to seal the bypasses, and set priorities for diagnostics and auditing of Philadelphia's rowhouses.

Construction Features of Philadelphia Rowhouses

The City of Philadelphia contains around 370,000 rowhouses, about 275,000 of which were built before 1940. There are nearly 100,000 more rowhouses in the suburbs, most of which are pre-1940. The typical pre-1940 Philadelphia rowhouse is 15–18 feet wide, two or three stories high and has the shape of one of the white keys on a piano, with a breezeway in the rear. The depth can vary from 20–60 feet, but the typical two story rowhouse encloses about 1,100 square feet of living space, while typical three-story houses run in excess of 2,000 square feet.

All walls are double brick (made of two courses of brick). The front wall rises directly from the sidewalk—unless there is a front porch. In that case, bay window framing frequently connects to the porch roof and to a coal bin in the basement underneath the porch. Some houses have bays overhanging the rear.

Furring strips (½"-thick strips of wood nailed into the brick to provide a surface to attach the lath and plaster to) are used on the exterior walls. Party walls typically have plaster applied directly on the brick while interior partition walls are plaster and lath over rough 2½" by 4" studs.

Virtually every house has a full basement, at least 75% below grade, with a natural gas or #2 fuel oil central furnace or boiler. In most instances the basement has rough openings into a crawlspace under a rear wood-frame shed.

Roofs are flat (1 in 30 pitch) and built up with any number of layers of 15-pound felt adhered with hot asphalt. The vast majority have a roof cavity, or crawlspace, typically two to three feet high in front and sloping down to a foot or less in the rear.

Some roofs—called split roofs—have only a common rafter/joist between the roof deck and the top floor ceiling. Some houses have a crawlspace in the front and a split roof in the rear.

Ceiling joists in crawlspaces are usually 2" by 3½" and are supported at approximately eight-foot intervals by rough ties to the rafters.

A chimney chase, a plumbing stack chase, and furring strip channels almost always run from the basement to the roof cavity, bypassing the top floor ceiling. These make ideal heat loss paths, the "thermal bypasses" Princeton researchers uncovered in the 1970s. Houses with central air heat also have at least two duct chases running bottom to top. Most rowhouses also contain balloon-frame closets and interior partition walls that open into the roof cavity. All of the above bypasses often connect to floor cavities on their way up through the house. In short, these houses are bypass heaven.

Post-World War II rowhouses are a little larger than the pre-1940 houses. Almost all are two-story, double-brick, piano-key construction. Typically they are set back on a raised foundation, with a full basement, which is on-grade in the rear and includes a garage. The kitchen or dining room frequently extend into an overhang in the rear. Most have a skylight either at the top of the stairs or in the bathroom.

Auditing

The structural uniformity of Philadelphia's rowhouses (see box) allows for some corresponding uniformity in audit decision-making. For example, it is cost-effective to insulate any open roof cavity. All basements are within the thermal envelope except what's under an outside porch. Walls cannot be cost-effectively insulated. The only computations required in an audit revolve around the decision to replace or retrofit the heater. We developed a simple "decision tree" to handle these calculations and avoid many repetitive calculations on basically identical situations. (A decision tree is a flow chart that helps an auditor choose strategies by answering simple, step-by-step questions.) Beyond that, the auditor must look more closely at each particular house for clues as to what to recommend.

Airtightness

No figures exist for quantifying airtightness for the Philadelphia rowhouse stock as a whole. In low-income weatherization program houses, however, the mean flow through leaks in untreated houses averages about 8,000 cubic feet per minute at 50 Pascal (cfm_{50}) or, typically, 55 air changes per hour at 50 Pa (ACH_{50}). This compares to average measured leakage for typical multifamily buildings in Chicago and Minneapolis of 27–38 ACH_{50}.[4] There are four reasons the Philadelphia rowhouse rate is so high:

- The buildings are in poor repair.
- Party walls were not designed to be airtight; they contribute between 10 and 30% of blower-door measured leakage.
- Exterior brick walls on old houses frequently have leaky mortar joints.
- Basements were not designed to be airtight.

Once major holes in the thermal envelope are repaired, the median leakage falls as low as 5,800 cfm_{50}. Air sealing work assisted by a blower door brings the median down to 4,600 cfm_{50}. (See box on next page.)

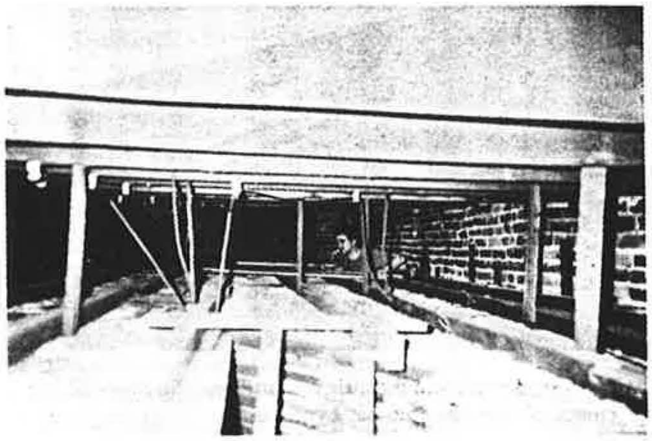
Philadelphia rowhouses that have been rehabilitated under our new air tightness specifications have tested as low as 1,450 cfm_{50}. The specifications prescribe treatments for bypasses before the new ceilings go up, proper insulation stapling, and air-sealing touch-up after the rehabilitation project is "finished." While the specifications do not directly address party-wall leakage, they do somewhat isolate the living space from the wall and ceiling cavities into which party wall leakage flows. Future city-funded rowhouse rehabilitations will be done under these specs.

Fuel Costs

About 65% of the houses in Philadelphia are natural-gas heated and most of the remainder are oil heated. The annual heating cost for a two-story rowhouse generally ranges from \$400 to \$800 at 72¢ per therm. Winters range from 4,500 to 5,000 degree-days, base 65°F (HDD_{65}).

Philadelphia is hot and humid in the summer with about 1,100 cooling degree-days. Although air conditioning isn't a bare necessity, many households use one or more window units for cooling. Central systems are relatively rare in the rowhouse stock. Summer electrical rates are quite high at 14¢/kWh.

Most reasonably well-insulated and air-sealed rowhouses can be managed to eliminate or greatly reduce the need for air conditioning: Fans can bring in cool night air and keep sleepers comfortable while cooling off the house. The cooled bricks absorb the heat of the day and by the time they are radiating at uncomfortable temperatures, the air has cooled off and fans come into play again.



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A typical attic crawlspace. Get ready to do that belly crawl!

Measly Pascals

If leakage rates are much over 5,000 cfm_{50}, most blower door fans cannot create a 50 Pascal house pressure difference, which means cfm_{50} figures must be extrapolated based upon readings at lower house pressures. A change in the slope of the air leakage curve between a pre- and post-air sealing test can—and sometimes does—show apparent *negative* reductions, even after effective air sealing has been done.

Because of the unreliability of extrapolated cfm_{50} values, GRASP uses the air flow rate at 25 instead of 50 Pascal pressure difference as the standard measure of airtightness.

Even at 25 Pa, we occasionally find a house that is so leaky that we can't get the pressure up.

For example, check out the tests below. They were done on the same house on the same day, before and after air sealing. The house is a large 3-story row with 35 windows, 5 roofing surfaces, an attic used as a bedroom—all in quite deteriorated condition. Not your most typical low-income weatherization house, but not rare either.

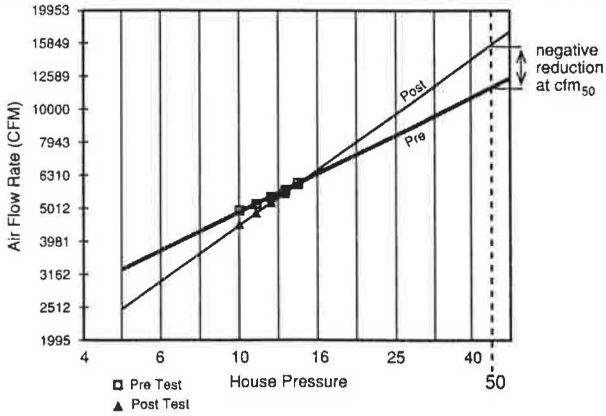
Temperature inside = 80°F Temperature outside = 87°F
Fan location = Rear door

Pre-weatherization blower-door test results:				**Post-weatherization test:**			
Ph	Pf	cfm	%Error	Ph	Pf	cfm	%Error
14	335	6,055	0	14	315	5,881	-0
13	300	5,747	-0	13	280	5,563	-0
12	270	5,468	-0	12	255	5,322	2
11	245	5,222	-0	11	210	4,855	0
10	225	5,016	1	10	175	4,454	-0
Fit = 0.995				Fit = 0.994			
C = 1,351.52		n = 0.566		C = 687.80		n = 0.815	

Pre Q25 = 8,314 Post Q25 = 9,479 Q25 Saved = –1,165
Q25 Goal = 4,495 Value of Work = 0.00

The tests appear to show that after air sealing, the house got 1,100 cfm leakier. Actually, a considerable amount of effective air sealing was done—or so it seemed. The tests both had good fits and slopes (n) within the allowable range. What happened?

Notice the slopes in the figure below. The pre test n is 0.565, while the post test n is 0.815. Since 14 Pascal house pressure is a long way from 25 Pa, when the computer extrapolates the air leakage curves from 14 to 25, the curve with the higher slope shows the higher Q25.



Fixing the Big Holes

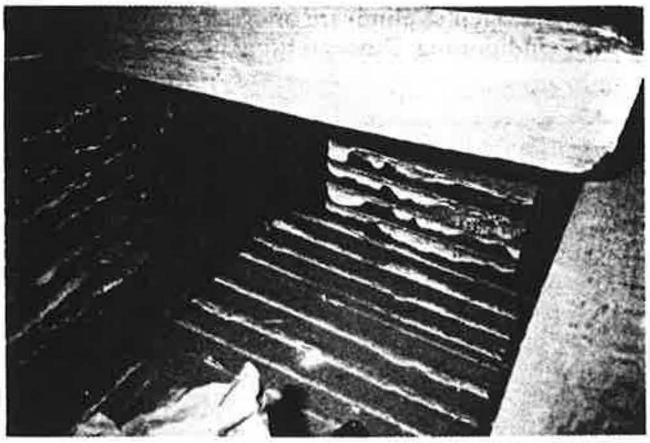
Party Wall Leakage

Between 10 and 30% of blower-door-measured air leakage happens across party walls, rather than to the outside. Party walls are constructed of hastily mortared, unfaced brick. Floor and roof joists run across buildings from party wall to party wall and are set into pockets, which penetrate the wall. Most of the party wall air infiltration comes from these joist pockets and loose foundations in the basements. While they are not airtight, the double-brick party walls are very effective at preventing the spread of fire from one house to the next; therefore Philadelphia fire insurance rates are low while air leakage is high.

Still, under most circumstances, party wall leakage is not a significant problem. Two exceptions are when an adjoining building is unheated or produces unpleasant smells or fumes. In any event leaks through party walls can be treated only in the basement and then only when the adjoining building is long-term vacant (abandoned) or non-existent (demolished).

When a rowhouse is rehabilitated, the floor and wall cavities that communicate with party walls can be isolated from living areas by sealing all penetrations behind sheetrock and using sheet goods with sealed seams for flooring.

Since most party walls are plastered directly over the brick, have no cavities, and run most of the length of the house, they make good radiators for anyone who wants to set their thermostat lower than their neighbors'. One derives an added benefit from a setback thermostat at the less fuel-conscious neighbor's expense!



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Looking down from the attic into the top of a drop-ceiling closet. Notice the stud-bay bypasses.

Roof Insulation & Bypass Sealing

Philadelphia rowhouse roof cavities are tough to crawl around in; low clearances, the imminent possibility of damaging a ceiling, live knob-and-tube wiring, frequent joist/rafter ties, and 120°F temperatures in summer make attic crawling an unpleasant undertaking at best. Also, most crews know that they can get good blower door reductions by treating bypasses from the basements.

Air pathways that penetrate into the attic near the back of flat-roof houses can be sealed near the top of the house only by cutting into them—risky and expensive—or by tight-packing cellulose insulation into those parts of the crawlspace that are otherwise unreachable. This latter technique appears to be effective and is current practice in the Philadelphia Weatherization Assistance Program.

So the question arises: is attic crawling really necessary? The first answer is a qualified yes, because it is impossible to get uniform blown insulation coverage without crawling. And it is more effective to seal chases from the attic, since sealing from the bottom leaves a convective loop open to the attic. But do savings justify the extra work for crews and inspectors?

Over the coming winter GRASP will conduct field research to compare fuel savings achieved by a combination of air sealing and tight packing in the attic to those achieved by air sealing bypasses from the basement and standard insulation.

Venting and Moisture Control

Current practice in most weatherization programs—as well as new construction—applies the rule that one square foot of venting be provided for every 300 square feet of attic area. For the most part, Philadelphia roofs get two vents, the purposes of which are to allow winter moisture and summer heat to escape.

Research has found that passive ventilation does not have a significant impact on summer heat gain.[5]

In our research, in the process of developing an accurate and reliable model of attic thermal and moisture performance in flat roofed rowhouses, we determined:

- Vents on flat roofs are nearly always exfiltrating in winter—that is, they don't draw in any air; they just exhaust heated air from the living space.
- Roofs are often tighter to the outside than the ceiling is tight to the attic crawlspace.

The consequence of these two conditions is that, without thorough sealing of bypasses, on average about half the potential savings of insulation are eroded by increased exfiltration caused by installation of roof vents.

The correct conclusion to be drawn is not necessarily that vents shouldn't be installed; it is that ceiling bypasses need to be plugged in a cost-effective manner.

Attic Entry and Inspection

Since actual crawling in the roof cavity appears necessary, and since code requires vents to be installed, it makes sense to gain entry from the roof rather than the living space because:

- the top floor ceiling will not be breached,
- adequate size venting holes must be cut anyway,
- it will make much less mess in the living space,
- no one has to be home in order to insulate, and
- the flat roof is a safe working platform.

At one point it was thought that access through a hatch was necessary to inspect attic insulation. In Philadelphia there were two problems with this concept. First, inspectors rarely, if ever, unscrewed the hatches to look through them—perhaps because a lot were caulked shut and those that weren't delivered an insulation shower. Second, when inspectors did try to check the attic, they usually found the insulators had built up a berm around the hatch so there wasn't enough clearance to get their head up to look.

Enter the infrared scanner; five minutes on a hot or cold day and you know where the voids are.

Rear Sheds and the Thermal Envelope

Rear sheds contribute disproportionately to rowhouse leakage because:

- they are usually deteriorated and impossible to air seal cost-effectively,
- they often contain the kitchen and cannot be isolated from the rest of the living space, and
- they all have leaky crawlspaces underneath that connect to the basement.

The rear shed is one of the auditor's trickiest thermal envelope decisions. While the crawlspace is virtually always defined as outside, the shed itself is not so easy a call in cases where it isn't the kitchen. While the goal is to consider the shed outside whenever possible, the wishes of the occupants and the way they actually use the shed will tend to be the determining factor. The final call is ideally the result of a conversation—a negotiation—between an occupant who has been informed of the options and their costs and benefits, and a professional and concerned auditor.

Basements

A common feature of the Philadelphia rowhouse is the extension of basements under outside front porches to form what was originally intended to be a coal bin. Although many wooden porch floors have been replaced by concrete and the front window sealed shut, the under-porch space is at best a giant refrigerator in the winter and in most cases also infiltrates enough cold air to lower basement temperatures 10–15°F below living space temperatures. This temperature differential makes the floors cold upstairs and drives some strong convection currents.

The solution is to build an air-tight partition directly under the I-beam that supports the brick front wall. It is typical to find grills cut into the main trunks of duct systems in basement-under-porch houses. Once the partition is in place, the duct grills can be sealed and more air will be delivered to living areas, and it will be delivered at higher temperatures, since the ducts will be in a warmer environment.

Although a few of the "crawlspaces" under rear sheds are actually big enough to crawl through, crews are reluctant to spend the time and misery insulating the pipes or ducts that they characteristically contain, and inspectors are reluctant to tell someone else to do what they wouldn't do themselves. The fall-back position, then, had become to leave the crawlspaces connected to the basement so pipes wouldn't freeze.

But did the pipes freeze anyway?

- Basement air leaks behave exactly the opposite of the way roof vents do; they constantly infiltrate. Warm air, then, would reach the pipes from the basement only if the openings to the basement were quite large—usually not the case.
- Frozen pipes in this climate almost always result from infiltrating (moving) cold air—rarely from cold still air.

Under this logic, sealing off the crawlspace might cure a pipe freezing problem, but virtually never cause one. No freeze-ups have happened in the last two winters since we have been using this technique.

Chases and furring-strip channels that run from the basement all the way up to the roof cavity often blow air when a fan depressurizes the house, even after they have supposedly been sealed from above. In practice it is impossible to tell where this air is entering the thermal envelope, since the chases are usually coupled to wall/floor cavities and the furring channels run along exterior brick walls with old mortar joints. As we said before, it's better to seal the top than the bottom if only sealing the chases once.

Regardless, we encourage crews to air seal chases in the basement if they blow air, even if they've supposedly been sealed from the attic as well.

Garages

Most garages in the rear of on-grade basements in post-1940 stock are quite open to the outside, to the basement, and, in a lesser degree, to the living space above. Usually it is a simple matter to isolate the garage from the rest of the basement. The partition wall between the garage and the corridor to the rear outside door of the basement usually has easily sealed holes where the joists come through.

Porch Roof and Front Bay Windows

Exterior porch roofs are never airtight. Bay window framing is open to the roof and allows cold air directly into the bay and often into the floor system. So the bays and front bedroom floors are usually cold. This condition remains one of the major loose ends in the Philadelphia Weatherization Assistance Program, as no treatment specification has been tested or passed on to crews. GRASP is uncertain, at this point, about the cost-effectiveness of cutting open and then closing the porch roof in order to tight-pack or otherwise air seal the bays.

Conclusion

Rowhouses in Philadelphia constitute a uniform stock, which greatly limits treatment options and simplifies audit decisions. At the same time they possess peculiar characteristics—some shared by all rowhouses, some not—which require specialized treatments.

The Philadelphia stock displays very high air-leakage rates partly because of design characteristics of party walls and basements, but mainly because of age and deterioration. Repair of large thermal envelope holes both consumes the lion's share of the budget and contributes most of the air-leakage reductions achieved in low-income weatherization programs.

Flat roof cavities (attics) present access problems, which make them hard to air seal and insulate properly. In the Philadelphia climate it is doubtful that roof venting is needed—provided bypasses are well sealed.

Since brick-wall shells last indefinitely, much of the Philadelphia stock will be rehabilitated sooner or later. At that point it is possible to reconstruct, insulate, and air seal rowhouses so as to make them both comfortable and energy-efficient. ■

Endnotes

1. Among program managers, staff, and advisors there is constant soul searching over the question of whether any house should be excluded if someone actually lives in it over the winter. The negative side of the argument is that an extremely neglected and deteriorated house is likely to be abandoned; and indeed that has occasionally happened after considerable WAP investment.
2. Annual fuel usage in Philadelphia is 1,460 therms. In Minnesota, it's 1,380 therms, according to L. Shen, Nelson, G., et al., "The M200 Enhanced Low-Income Weatherization Project," Minneapolis, MN: University of Minnesota, 1990.

3. M. Blasnik, "Attic Insulation Performance, Air Leakage, and Ventilation: Measured Results in Flat Roof Rowhouses," *Proceedings of the 1990 Summer Study on Energy Efficiency in Buildings*, Washington, DC: 1990, The American Council for an Energy-Efficient Economy.
4. M.P. Modera., Diamond, R.C., and Brunsell, J.T., "Improving Diagnostics and Energy Analysis for Multifamily Buildings: A Case Study." LBL-20247, Lawrence Berkeley Laboratory, April 1986; and R.C. Diamond, Modera, M.P., and Feustel, H.E., "Ventilation and Occupant Behavior in Two Apartment Buildings." LBL-21862, October 1986.
4. C.K. Wolfert, and Hinrichs, H.S., "Fundamentals of Residential Attic Ventilation." Princeville, Ill.: 1974, H.C. Products Co.