AIVC
#13139

Installed Performance of Two Insulation Systems During Simulated Wind Conditions

Donald P. Otto

ABSTRACT

A building's envelope is the product of the choice of framing materials and quality of craftsmanship. Exposed to weather, it may not provide the same airtight conditions in which its insulation material had been tested. Air permeable insulation offers little resistance to pressure driven, or convective, heat loss. Air impermeable insulators can additionally reduce convective, as well as conductive, heat loss by being sprayed into and sealing up sources of infiltration normally addressed by caulks and sealants. This qualitative study uses infrared thermography to demonstrate how selected areas of two building envelopes, one with an air permeable insulation and the other with an impermeable one, react to windy conditions simulated by depressurization.

INTRODUCTION

We well understand how some insulation materials perform under controlled conditions. In many cases, the actual insulator is simply air that is kept from flowing, or convecting, by another material that inhibits airflow. How effective an insulation material is depends on how well it keeps air from convecting, or moving, within the insulation material.

Some materials are closed cells, like bubbles. They completely encapsulate very small volumes of air, and their coalesced membranes provide a high degree of three-dimensional resistance to convection. Others are open celled, like a network of fibers, and can allow air to readily flow through them with even a small driving pressure, such as from wind or stack effect.

These air permeable materials rely on the walls of the chamber in which they are installed to prevent convection. Under controlled conditions, one can install an air permeable insulation in a chamber with walls tightly sealed to prevent any airflow through that chamber. But most insulation is installed in field conditions such as in house walls or roofs. These cavities have a range of penetrations of both inside and outside surfaces and are subject to thermal, mechanical, and environmental driving pressures.

As a context for this study, since air permeable insulation is so widely used, it may be useful to ask if buildings that use it can produce assemblies that perform as well under field conditions as they do under ideal conditions. A goal is to give evidence that these practices deserve either repetition or refinement. This study, therefore, is limited to being qualitative rather than quantitative.

Iowa's first five-star, HERS-rated home (Home Energy Rating System) had an envelope built to excellent energy-efficiency standards, but air infiltration into the wall cavity was apparent. Just before the drywall was installed, it was noted that the vapor barrier pillowed into the house on a windy day. The final air infiltration test certified that the house had an air exchange rate of 3.4 air changes per hour at 50 Pa (ACH-50). That implies that, should the home ever be subject to a wind speed approximating 50 Pa (about 23 mph, see derivation below), the house might have almost ten times the 0.35 ACH ventilation rate prescribed by ANSI/ASHRAE Standard 62-1989.

Some questions arise:

1. Can current building practices and envelope assemblies with permeable insulation materials keep their full insulation value in windy as well as in calm conditions?
2. If air does indeed leak into the wall cavity, is wind washing extensive or minor?
3. Can an alternative air impermeable material provide the desired airtightness?

Air infiltrating into a building's thermal envelope can reduce inside wall surface temperatures and appear as cold air leaks under winter conditions, both of which can be detected

---

Donald P. Otto is a home builder and owner of DPO Construction, Iowa City, Iowa.

by infrared equipment. This case study will present infrared scanning surveys of two homes: one with a conventional system using an air permeable insulation and the other with an air impermeable insulation. Air infiltration due to windy conditions is simulated by depressurization with a blower door. Thermal performance and any thermal defects are recorded with high-sensitivity infrared thermography.

Recent reports (Pesce and Gilg 1998; Yuill and Yuill 1997) and personal communications (Bomberg 1998; Schoenfelder 1998) indicate that air passes through an envelope not only through the wall body but above and below walls, at roof-wall junctions, at knee walls, and around window and door openings. While Yuill and Yuill (1997) report that insulation accounts for only 11% of wall air leakage, they compare air permeable insulations only. However, Pesce and Gilg (1998) report that foam-in-place (low-density urethane) insulation reduces air leakage by 20% to 50% over other air permeable materials. Examination of the relative air permeance values of various insulation materials in Table 1 may help explain the differing conclusions.

Medium-density urethane[1] (2 - 3 pounds per cubic foot, or pcf) has an air permeance considerably less than that of low-density urethane[2] (0.5 pcf). For practical purposes, medium-density urethane's air permeance is zero. For this study, in order to reduce the effect of air leaking through the insulation material as much as possible, medium-density urethane was selected.

Explanation of Terms

Components of a building's envelope are referred to by their function. But just as heat, moisture, and airflow are interrelated, the functions of the envelope's building materials also overlap. For example, foam board sheathing, while used for insulation, also acts as an air barrier, even though a separate house wrap air barrier may be installed. In addition, medium-density urethane is used as an insulator but, since it is highly resistant to air and water vapor flow, acts as its own air and moisture barrier as well.

EXPERIMENTAL DESIGN

Rationale

Calm wind produces very little pressure, and both permeable and impermeable insulators should perform similarly. Higher wind speeds increase pressure exponentially and can easily force air leaks through air permeable insulation. If the envelope has holes in its air barrier and if the outside air temperature is cold, one might expect air leaks to cool interior wall surfaces during depressurization. If the envelope is built using an air impermeable insulation, such as a sprayed material that conforms to irregular wall surfaces and seals voids, one might expect to see less cooling of interior wall surfaces with depressurization.

TABLE 1
Air Permeance Values of Selected Building Materials (Appendix II, CHBA 1995)

Material	Measured Leakage @ 75 Pa L/s per m^2 (values rounded)
Cellulose insulation, spray on	86.95
6 in. glass fiber wool insulation	36.73
3 ½ in. low-density urethane insulation*	1.6 (manufacturer's figure
Spunbonded polyolefin film	0.18
½ in. gypsum board	0.02
5/8 in. flakewood board	0.01
6 mil polyethylene film	0.00
3 ½ in. medium-density urethane†	0.0
1.5 in. extruded polystyrene	0.00

* Low-density and medium-density urethane figures are not in the CHBA *Builders' Manual* but are inserted for comparison.

† Air permeance values for medium-density urethane vary with a wide range of application conditions. For construction purposes, the value is essentially zero.

Procedure

To simulate wind-induced infiltration, the homes were depressurized to 50 Pa with a blower door. An infrared camera was used to show any cooling of wall surfaces, whether the air leaks from the outside surface remained behind the dry wall or emerged through the inside surface. In order to determine any cooling induced by infiltration, reference scans were taken before depressurization to compare with scans during depressurization.

Even though the wall and ceiling insulation values are similar in both homes, the insulation in Residence 1 is air permeable, while in Residence 2 it is not. In Residence 1, exhaustive air sealing of the entire envelope was performed to control infiltration and provide an airtight cavity for the insulation. In Residence 2, no separate air sealing was performed within the wall or roof cavities other than to conscientiously apply the urethane insulation (see "Construction Details" below). Relying on the low vapor permeability of the insulation (see footnote 1), no separate vapor barrier was used. The same sealing techniques were used between the wall and floor and around the windows, however.

A depressurization value of 50 Pa was chosen to coordinate with Home Energy Rating System (HERS) tests rather than to simulate a variable regional wind speed. Any insight gained from this study might more easily apply to HERS ratings. Average wind speed in eastern Iowa (average air speed

---

[1] Medium-density urethane, at 2 pcf to 3 pcf, is a closed-cell structure and has an air permeance of about 0.0 and a vapor permeance of 0.7 perm for a 3.5 in. section.

[2] Low-density urethane, at 0.5 pcf, is an open-cell structure and has a manufacturer's published air permeance of 1.6 liters per second per square meter at 75 Pa for a 3.5 in. thick section and 1 liter per second for a 5 in. section. Vapor permeance is 14 perms for a 3.5 in. section and 10 perms for a 5 in. section.

over 24 hours) varies seasonally from 11 mph to 13 mph in the spring, down to 9 mph to 11 mph in the fall (Hillaker 1998).

Using the following equation, wind pressure can be derived from wind speed.

$$Wp = C_1 C_p D\,(Ws^2/2)\ 248.84\ \text{Pa/in.}$$

where

Wp = wind pressure (Pa),
C_1 = unit conversion factor = 0.0129,
C_p = wind surface pressure coefficient = 0.80 when normal to the surface,
D = air density, about 0.075 lb/ft^3,
Ws = wind speed, mph.

Thus, a 50 Pa pressure translates into a 22 mph to 23 mph wind blowing perpendicularly against all the envelope surfaces at once. Comparing average seasonal wind speeds of 9 mph to 13 mph, the corresponding pressures amount to 8 Pa to 16 Pa, respectively. Since a goal of this study was to actively seek out thermal defects under somewhat severe but reasonable wind conditions, it seems reasonable to use 50 Pa depressurization.

CONSTRUCTION DETAILS

Overall, the envelope construction and R-values of the two homes are similar: Residence 1 had wall R-26 and ceiling R-46; Residence 2 had wall R-26 and ceiling R-45. All R-values are those reported by the manufacturers and are for insulation only. (For example, 1 in. polyisocyanurate, R-7, plus 6 in. fiberglass, R-19, equals R-26; 6 in. urethane, R-7.5 per inch, equals R-45.) Values for items such as wood framing materials, house wrap, and surface air films are not included. Please see Figures 1, 2, 4, and 5, which show typical wall and roof sections of Residences 1 and 2, and Table 2, which compares the components of the two envelopes.

Air sealing for Residence 1, apart from details shown in the drawings, included installing continuous, compressible foam gaskets under the entire perimeter of all exterior walls. All penetrations through top and bottom plates, through sheathing and siding, and all of the band joists were caulked. Electrical boxes were continuous plastic, and the only holes in them were at knockouts opened by the electricians. Instead of using gaskets, the holes were caulked and later checked with a smoke pencil during depressurization. Recessed ceiling lights were of airtight construction. Ceiling-mounted fixtures, including exhaust ventilation ducts and fire sprinkler escutcheons, were caulked to the dry wall.

Air sealing around windows included taping the nailing flanges to the house wrap on the outside and using foam backer rod to seal between window and door frames and their rough openings on the inside (expanding foam was not used). Routine visual inspections were made during the entire construction process.

Air sealing for Residence 2 was largely accomplished by relying on the spray-applied, medium-density urethane.[3] For example, urethane was sprayed behind and around electrical boxes and eliminated the need to further seal them. Also, since it is a spray and expands on contact, urethane conforms to irregular surfaces and seals up holes and cracks. Wall to floor joints and window to rough opening gaps were treated as in Residence 1, however.

TABLE 2
Comparison of Envelope Construction Details

Detail	Residence 1	Residence 2
Walls		
Siding	Vinyl	Cedar boards
Air barrier	House wrap, taped joints	House wrap, continuous
Sheathing	1 in. polyisocyanurate (R-7)	1 in. polyisocyanurate (R-7)
Framing	2 × 6 wood frame	6 × 6 post and beam w/ 2 × 4 curtain
Insulation	Fiberglass batts (R-19)	Sprayed urethane (R-19)
Vapor barrier	6 mil polyethylene	None besides urethane
Fin. wall material	½ in. gyp. dry wall	½ in. gyp. dry wall
Insul. R-value	R-26	R-26
Ceilings, Roof		
Shingles	Asphalt	Asphalt
Underlayment	Asph. sat'd felt	Asph. sat'd felt
Sheathing	½ in. o.s.b.	½ in. plywood
Rafters	14 in. tall wood I-beams	9 ½ in. tall wood I-beams
Air chutes	Cardboard	None
Insulation	F.G. batts (R-46)	Sprayed urethane (R-45)
Vapor barrier	6 mil polyethylene	None besides urethane
Fin. ceiling mat.	5/8 in. gypsum dry wall	½ in. gypsum dry wall
Insul. R value	R-46	R-45

Notable Differences

One particular difference to note is that no separate vapor barrier was applied in Residence 2. The 2½ in. of urethane in the walls and 6 in. in the ceiling provide the vapor barrier to avoid condensation.

Additionally, even though house wrap was applied, it was used as the building paper specified by the cedar board siding's manufacturer and not as the wall system's air barrier, although it performed both functions. In this case, house wrap was used because it was the best overall product for the client's home.

---

[3] A sample of the medium-density urethane installed in Residence 2 was measured to have an approximate density of 2.9 pcf.

EQUIPMENT AND TEST PROCEDURES

Infrared scanning was performed with a color infrared focal plane array radiometer with a thermal sensitivity of 0.07°C (0.13°F) and spatial resolution of 65,536 pixels per image.

Initial thermal images of selected interior surfaces were made under static ambient conditions to establish a baseline condition. A depressurization level of 50 Pa was maintained for 20 minutes to allow potential thermal defects to appear. A second thermal image was made of the same interior surfaces under the depressurized condition. The same process was completed for both residences. Independent third parties operated the blower door and infrared equipment. Detailed operation procedures are available from them. Inside to outside temperature difference during the field tests was between 15°F and 25°F.

Areas addressed in both homes were the intersections of exterior walls with each other, with roofs, and with knee walls and wall openings, such as windows, doors, and electrical penetrations.

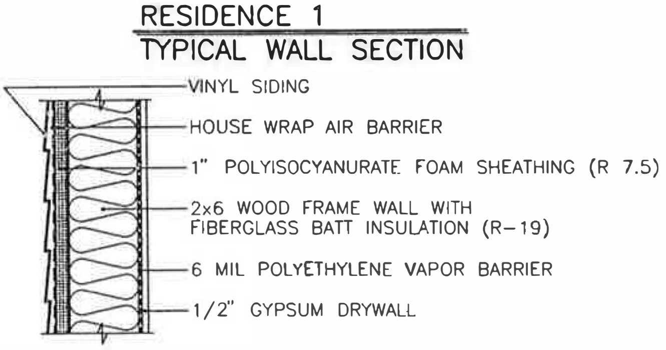


Figure 1 *Typical wall section of Residence 1 (air permeable insulation with separate air and vapor barriers).*

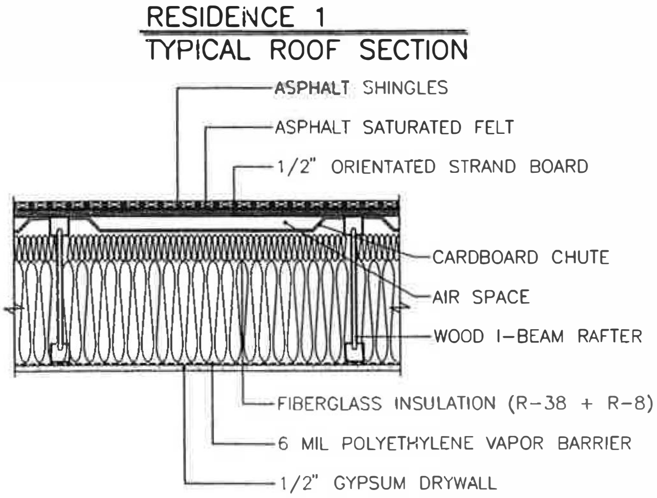


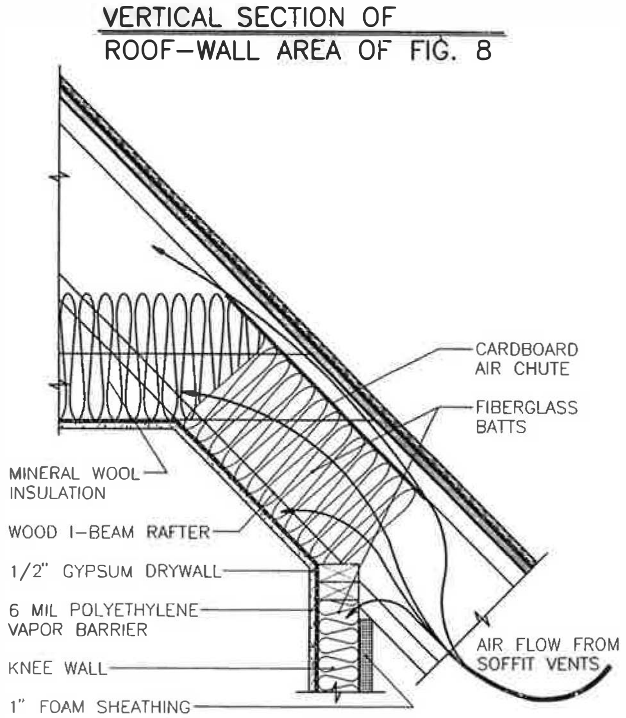
Figure 2 *Typical roof section of Residence 1 (air permeable insulation with separate air and vapor barriers).*

RESULTS

Representative areas of the two residences are shown in Figures 6 through 10. The results are displayed as pairs of thermal images. In each, the image on the left is the pre-blower door condition, and the image on the right is during depressurization. The images shown are in grayscale transcribed from the original color images. The locations of areas with significant changes in temperature are noted with arrows, and the temperatures are digitally displayed. Areas without significant temperature changes are displayed without arrows. Temperatures are expressed in degrees Fahrenheit, as extrapolated from the original color image temperature scales.

Conditions during testing were maximum light winds of 10 mph and exterior temperatures between 50°F and 60°F. Interior temperature was 75°F in Residence 1 and 73°F in Residence 2.

Localized air leaks at the Residence 1 dining room and attic dormer were confirmed by smoke pencil.



Note: Potential areas of windwashing of insulation from soffit vents. Also note that the foam sheathing on the knee wall can act as an air barrier, but only when applied in a continuous system.

Figure 3 *Air permeable insulation. Detail of knee wall-roof-ceiling area of Figure 8. Curved arrows indicate path of airflow from soffit vents. Note that foam sheathing does not extend to the top plates of the knee wall and allows airflow to penetrate insulation. Without an effective air barrier extending to the air chute, air can flow into the roof and ceiling insulation.*

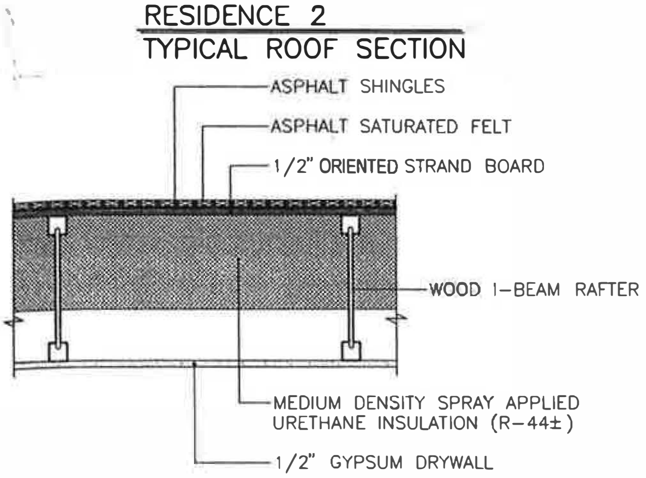


Figure 4 *Air impermeable insulation of a typical roof section.*

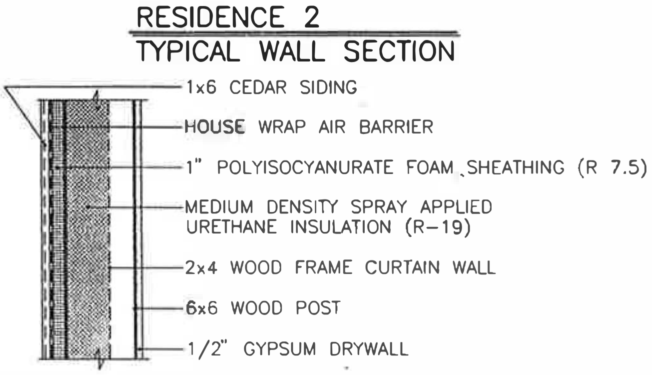


Figure 5 *Air impermeable insulation of a typical wall section.*

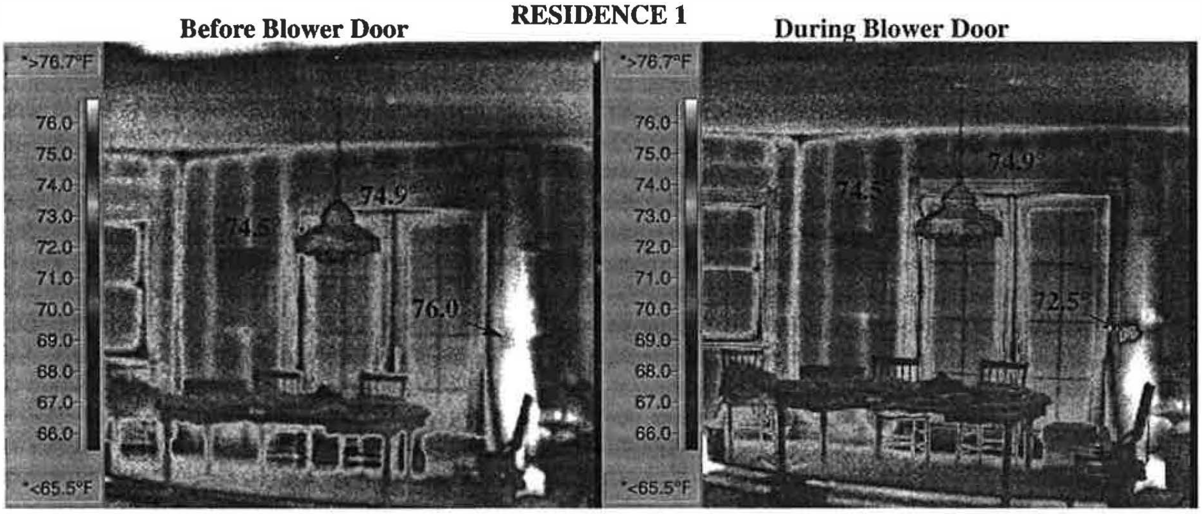


Figure 6 *Air permeable insulation in the dining room. No significant change in wall temperatures was detected except at a wall switch at the right side of the French doors.*

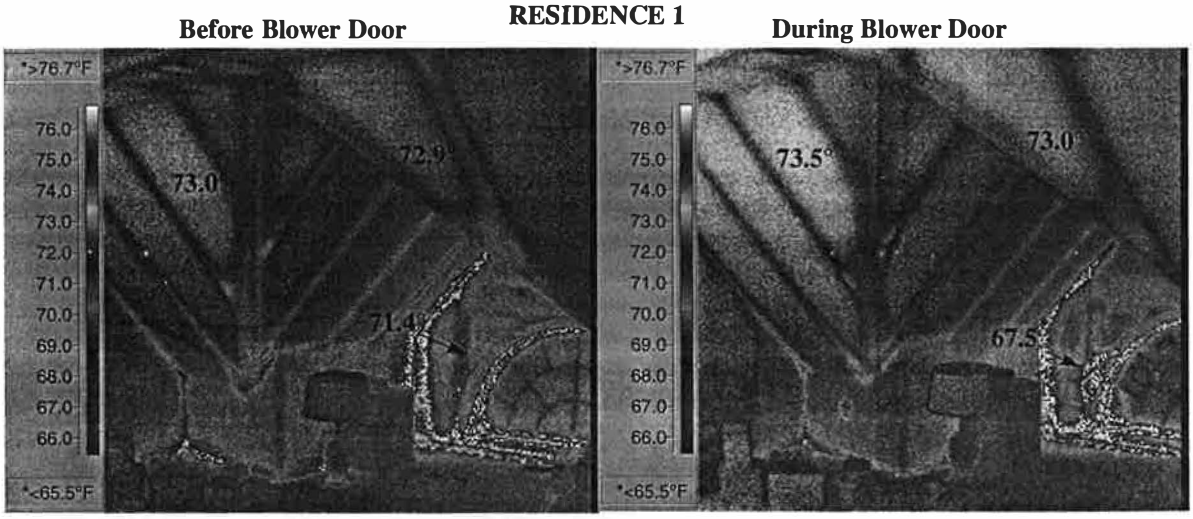
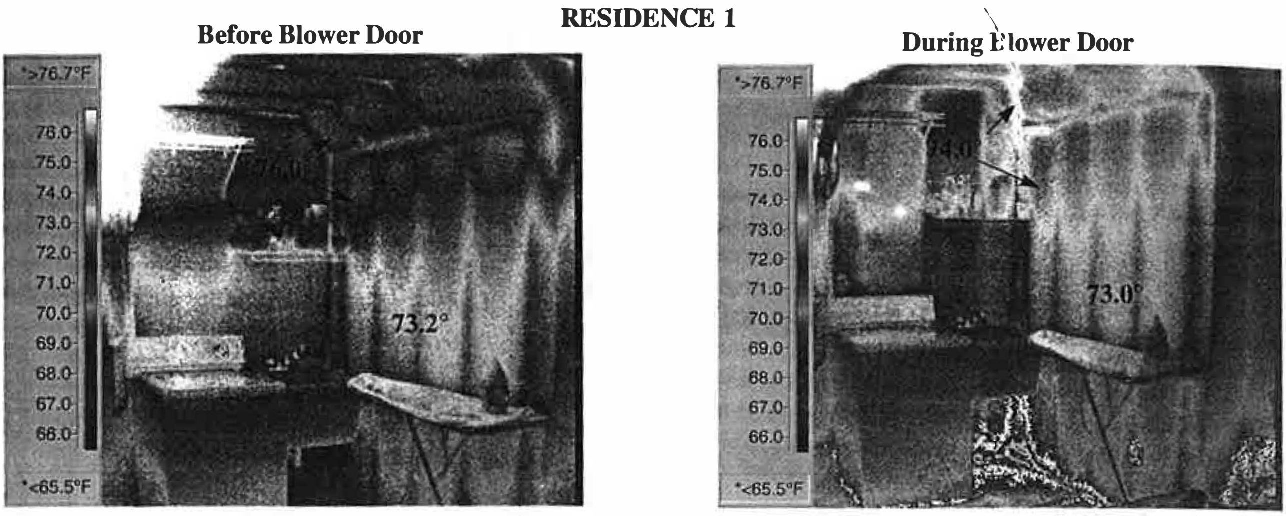


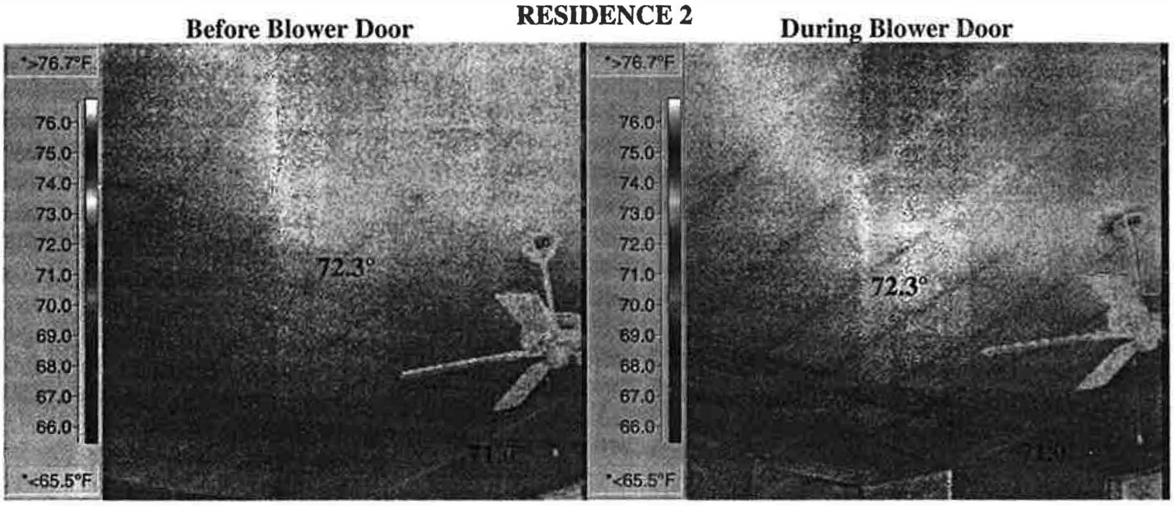
Figure 7 *Air permeable insulation in the attic dormer. No significant change in roof temperature is evident, but infiltration at the left side of the half-round window and at the outlet to the left of the lamp can be seen.*


RESIDENCE 1

Before Blower Door

During Blower Door

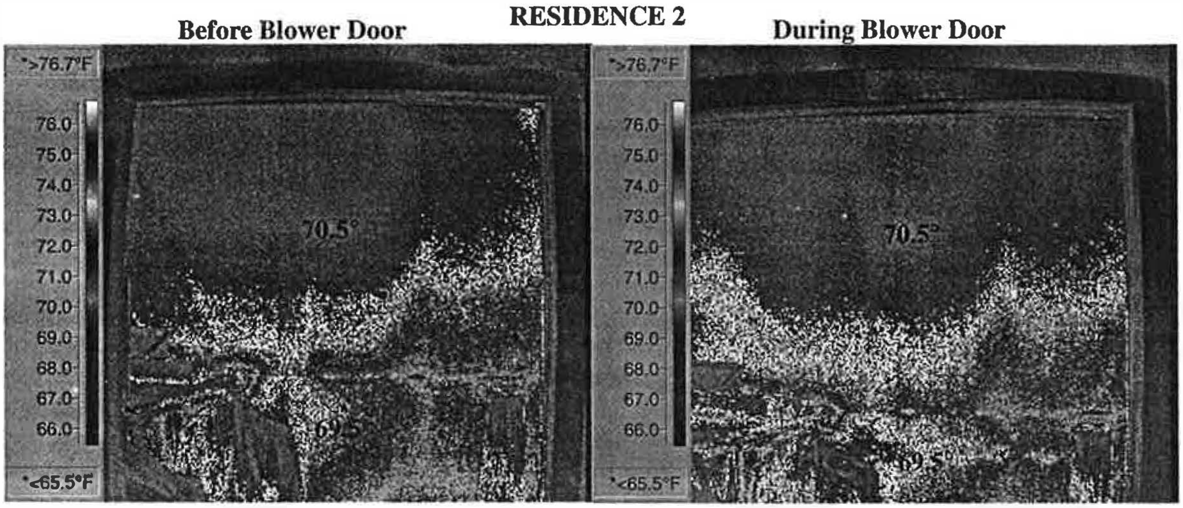
Figure 8 Air permeable insulation in the laundry room above the garage. The wall at right is a knee wall under the garage roof with about 1 ft of roof slope visible at upper right. Significant cooling of the envelope is evident at, and just below, the intersection of the knee wall with the roof. Upon inspection, the air barrier (foam sheathing) did not reach the top plates and left about 1½ in. of insulation exposed. No air barrier had been installed within the roof plane at the knee wall intersection. Please refer to details in Figure 3, the drawing of the vertical section of that area.


RESIDENCE 2

Before Blower Door

During Blower Door

Figure 9 Air impermeable insulation in the bedroom, vaulted ceiling. While ceiling temperatures range from 74°F to 71°F (perhaps due to stratification), no temperature change is evident during depressurization. Thin lines are rafters.


RESIDENCE 2

Before Blower Door

During Blower Door

Figure 10 Air impermeable insulation in the unheated walk-in closet in the bedroom, sloped ceiling and knee wall. While surface temperatures range from 71°F to 67°F, no temperature change is evident during depressurization.

DISCUSSION

1. *Effect of an incomplete system.* Upon inspection behind the laundry room knee wall, even though an air barrier (1 in. foam sheathing) had been installed on the knee wall, it ended just below the double top plate, leaving some fiberglass insulation exposed. The sheathing/air barrier had not been continued within the roof plane above the wall. Wind washing of that area is likely (see Figures 8 and 3).
2. *Wall and ceiling construction methods with regard to impact on infiltration.* Even though one home was built with studs and the other with post and beam and curtain wall, the wood framing itself accounts (thermally) only for a lower insulation value compared to the insulation. In both homes' envelopes, the amount of lumber is about the same. In Residence 1 (2 × 6 studs), 1 in. foam sheathing plus house wrap provide an effective air barrier, even though the insulation is permeable (see Figures 6 and 7). Further, when the air barrier is incomplete or missing, wind washing can occur (see Figures 8 and 3).

   In Residence 2, (post and beam plus curtain wall) the wall and ceiling insulation values are about the same as for Residence 1, but urethane acts as its own vapor and air barrier as well. In fact, a separate vapor barrier was omitted in Residence 2 (6 mil polyethylene acts also as an air barrier; see Table 2), and no thermal defects could be found anywhere (see Figures 9 and 10). One might expect, however, that a hole in a functional air barrier, regardless of the type of insulation used, would show itself as a localized leak through a hole in the inside surface.
3. *Evolution of building materials.* One cannot hold a framing crew responsible for minor imperfections in building materials. Core voids, slight gaps, and warps do not affect minimum structural requirements. But the majority of air leaks in the envelope occur where materials do not come in full contact. Building practices evolve to produce materials that, just by their presence, accommodate these imperfections. Using an expanding, spray-applied insulation accommodates irregular surfaces and seals leaks that would have to be otherwise addressed.

Using urethane in Residence 2 was much less labor intensive. Since no thermal defects could be found, it appears easier to achieve a complete thermal, moisture, and air barrier with it. Urethane is two to three times more expensive, but it replaces other steps and may become more economical when potential benefits are maximized: 2 × 4 walls can replace 2 × 6 walls, separate air and moisture barriers can be eliminated, air sealing costs can be reduced, and perhaps structural material costs can be reduced.

CONCLUSIONS

1. If building envelopes require thermal, moisture, and air barriers, these functional barriers must be installed completely in a complete system in order to perform as designed. Figures 6 and 7 show large areas where surface temperatures change little, if at all, under depressurization. The system is essentially complete in those areas.
2. Both homes performed well under normal and depressurized conditions, but Figures 8 and 3 demonstrate wind washing where one component, the air barrier, is partially missing.
3. Air permeable insulation can be successfully used if a functional air barrier is complete.
4. Spray-applied urethane can be successfully used to provide a continuous thermal barrier that also appears to function as an air barrier.
5. The quality of the installation is paramount. Materials do not perform where they are not placed. Pesce and Gilg (1998) and Yuill and Yuill (1998) support similar conclusions.

Questions for Further Study

1. How do other insulation materials, with a range of air permeabilities, perform under depressurization?
2. The insulation in these two residences was installed with great care. How do insulation materials, as typically installed, perform?
3. Is the air permeance of low-density urethane significant? How does it compare with medium-density urethane?
4. What effect would a four- or fivefold increase in the inside-to-outside temperature difference make?

ACKNOWLEDGMENTS

The infrared thermal imaging equipment was made available by Iowa State University and the Iowa Energy Center. Operation of the equipment in Iowa City for this study was supervised by Theodore Smith, Ph.D., Professor of Mechanical Engineering, University of Iowa.

Blower door equipment is owned and operated by Energy Rated Homes of Iowa, Claude Papesh, Director.

Just as in the construction of the homes themselves, this study would have been impossible without the enthusiastic and dedicated collaboration of many individuals. I owe this study to the contributions of:

- Floyd Barwig, Ph.D., Director of the Iowa Energy Center
- Alan Bergeron and Kathy O'Malley, North Liberty, Iowa
- Mark Bomberg, Building Systems, Saskatchewan Research Council, Canada
- Gary Harding Construction, Iowa City, Iowa
- Harry Hillaker, Iowa State Climatologist, Ankeny, Iowa
- Curtis Klaassen, P.E., Manager of the Energy Resource Station of the Iowa Energy Center
- Wendell Marine Construction, West Liberty, Iowa
- Dan Moeller, Energy Specialist, MidAmerican Energy

- Claude Papesh, Director of Energy Rated Homes of Iowa
- Andrew Price, Graduate Research Assistant, Department of Mechanical Engineering, University of Iowa
- James Pusack, Iowa City, Iowa
- James Schoenfelder, AIA, Energy Coordinator for Iowa City, Iowa
- Theodore Smith, Ph.D., Professor of Mechanical Engineering, University of Iowa, Iowa City
- Mike Untrauer, Untrauer's Drafting Service, Iowa City, Iowa
- John Webster, Control Systems Administrator, Energy Resource Station, Iowa Energy Center

REFERENCES

Bomberg, M. 1998. Personal communication. Summer.

CHBA. 1995. *Builders' Manual*. Ottawa, Ontario: Canadian Home Builders' Association.

Hillaker, H. 1998. Personal communication. Summer. Mr. Hillaker is the State Climatologist at Iowa's Department of Agriculture and Land Stewardship.

Pesce, M., and G. Gilg. 1998. A field study of alternative wall insulation products. NAHB Research Center, Upper Marlboro, Md.

Schoenfelder, J. 1998. Personal communication. Summer.

Yuill, G., and D.P. Yuill. 1997. A field study of whole house air infiltration in residences. EEBA Excellence in Building Conference Proceedings.