Use of the Blower Door with IR/Thermal Imaging for Residential Building Diagnostics

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ABSTRACT

The infrared thermal imaging camera has become an invaluable tool in the specialized field of energy auditing and building diagnostics. By itself, the IR camera only tells half the story. The use of a "Blower Door" in conjunction with the IR camera will help to identify locations of air infiltration (and thereby heat ex-filtration) through the building envelope.

INTRODUCTION

The primary means of heat loss from buildings is by thermal conductivity through building surfaces and air movement (convection) through the building envelope. This paper will describe the symbiosis between the IR camera and the Blower Door in analyzing the integrity of the thermal boundary of residential buildings. It will outline the protocol for the use of these two diagnostic tools in evaluating residential properties for the presence and quality of installed insulation, and the location of weaknesses in the building envelope in order to develop and prioritize appropriate corrective measures.

For the purposes of this paper, we will be discussing residential building structures typically found in the northeastern region of the United States. Thermal images and discussion of findings is as viewed from the interior of a building. The presumption is that there is an acceptable "delta T" (typically ≥ 18ºF, or 10ºC) for a proper interpretation of the thermal image.

BACKGROUND

The nature of residential building structures is that they are composite in nature. In other words, they are made up of several "layers" of different materials. For example, a wall is made up of the interior layer, which may be gypsum or plaster and lath, structural framing (typically 2x4 or 2x6 timbers), an exterior sheathing material such as ship-lapped planking or plywood or "oriented strand board" (OSB) and finally, some type of protective/decorative layer such as clapboard, cedar shingles, or siding. Brick or stone are also widely used, however, the use and application of these materials is not structural but rather as a decorative "facing" for the home

CONDUCTIVE HEAT LOSS THROUGH THE BUILDING ENVELOPE

Conductive heat loss is driven by the difference in temperature between the inside and the outside. Building envelopes are typically rated using R-Value or its reciprocal, U-Value. The higher the R-Value is, the better the insulation of the building envelope element. The calculation for heat loss and an explanation of U-Value and R-Value are given in Appendix A. As discussed later, even the best insulated envelope elements can be circumvented by unwanted air leaks.

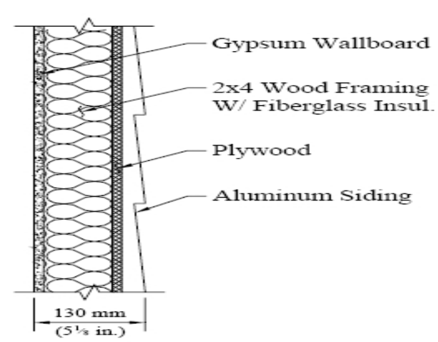


Figure 1. Cut-away section view showing the components of a typical wall in a residential structure.

The thermal imaging camera helps to identify weaknesses in the thermal boundary due to the nature of heat flow through the building envelope. Surfaces that are un-insulated or where there is missing insulation transfer heat at a different rate than similar structures that are properly insulated. The following examples vividly show the different thermal signatures for insulated vs. un-insulated walls.

EXAMPLES OF THERMAL CONDUCTANCE LOSSES

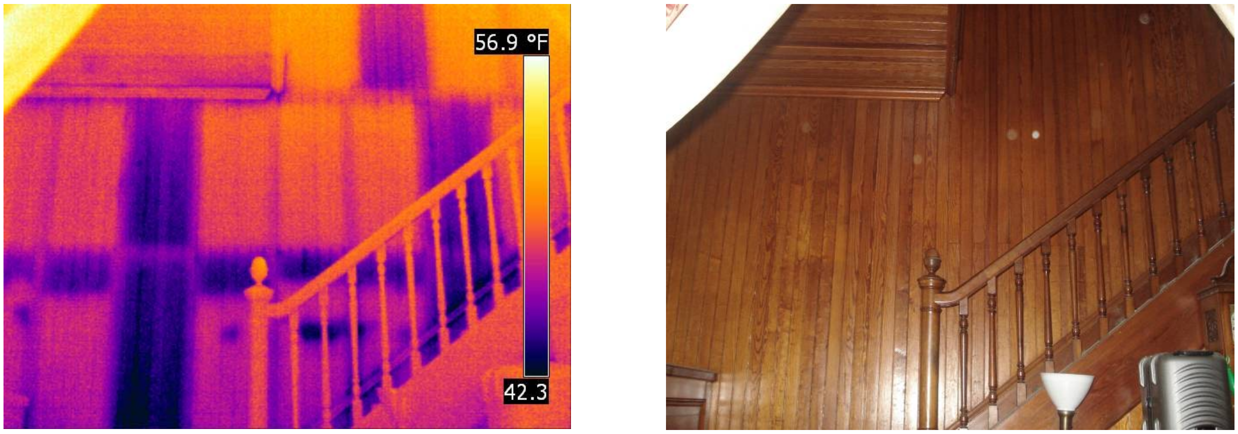


Figure 2. This IR image, taken in the winter, shows wall cavities with no insulation. Heat is lost more quickly since there is no insulation, as there is in surrounding cavity and is therefore colder than the surrounding, properly insulated wall cavities. Associated visual photo on right.

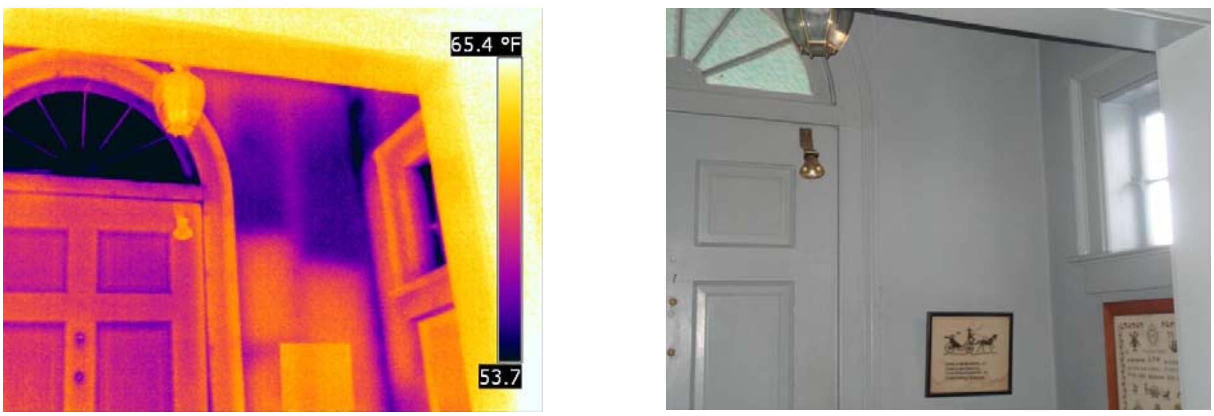


Figure 3. Thermal Image shows section of wall adjacent to the entry door where insulation is present and where it is missing. Since the resistance to heat flow (R-value) is less in the section of wall without insulation, the heat loss will be greater. . Associated visual photo on right.

Figure 4. Thermal image shows colder surface in boxed out chimney where the cavities are not insulated. . Associated visual photo on right.

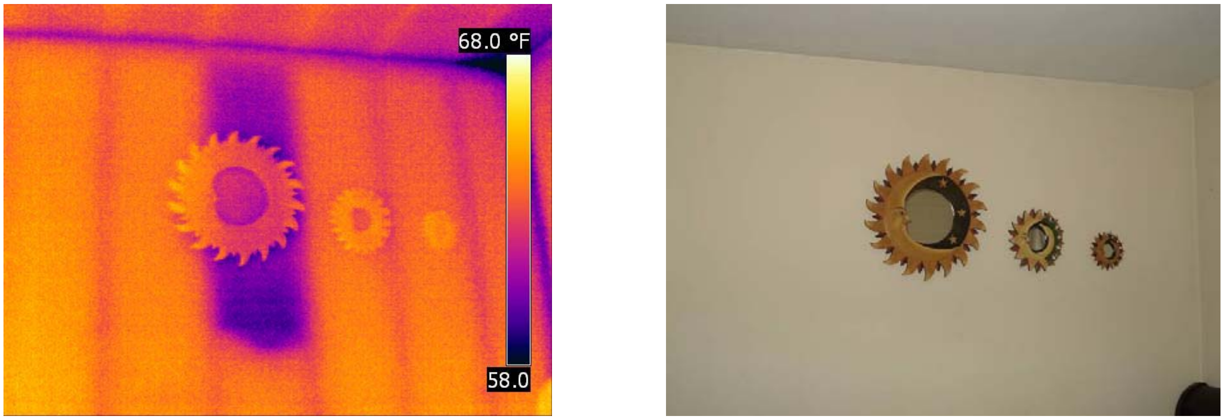


Figure 5. Missing Insulation leads to differential heat loss due to disparate thermal conductivities. Associated visual photo on right.

CONVECTIVE HEAT LOSS THROUGH THE BUILDING ENVELOPE

Air moves into and out of a building by the “Stack Effect”. The stack effect is created by the natural difference in pressure between ambient conditions outside of the building and the interior of the building.

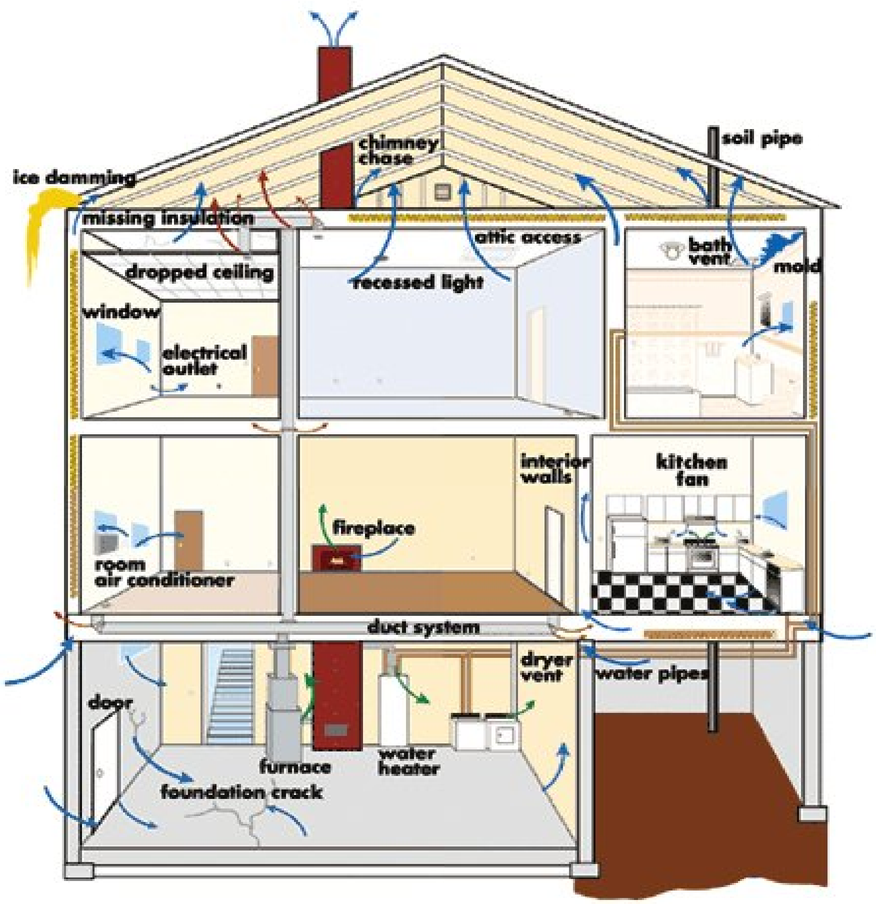


Figure 6. Diagram showing air movement into, out of and within a typical 2 – story home.

All structures have a “Neutral Pressure Plane”, which is the imaginary line below which the pressure is lower inside the building than outside the building, leading to air infiltration. Above the neutral pressure plane, the pressure is higher inside the building than outside the building, leading to air ex-filtration and thereby heat loss.

Wherever two or more of the surfaces of a structure come together, such as at the top of the foundation, band joists between floors (as applicable), interior and exterior wall intersections, walls and ceilings, walls and floors, there are gaps which act as thermal bypasses. The gaps can vary from less than 1/16” (1.59mm) to ¼” (6.35mm) or more and can allow significant heat loss. Typically this would be things like bath exhaust fans, recessed or mounted light fixtures, and gaps around doors and windows.

EXAMPLES OF BLOWER DOOR ENHANCED IMAGES SHOWING COLD AIR INFILTRATION

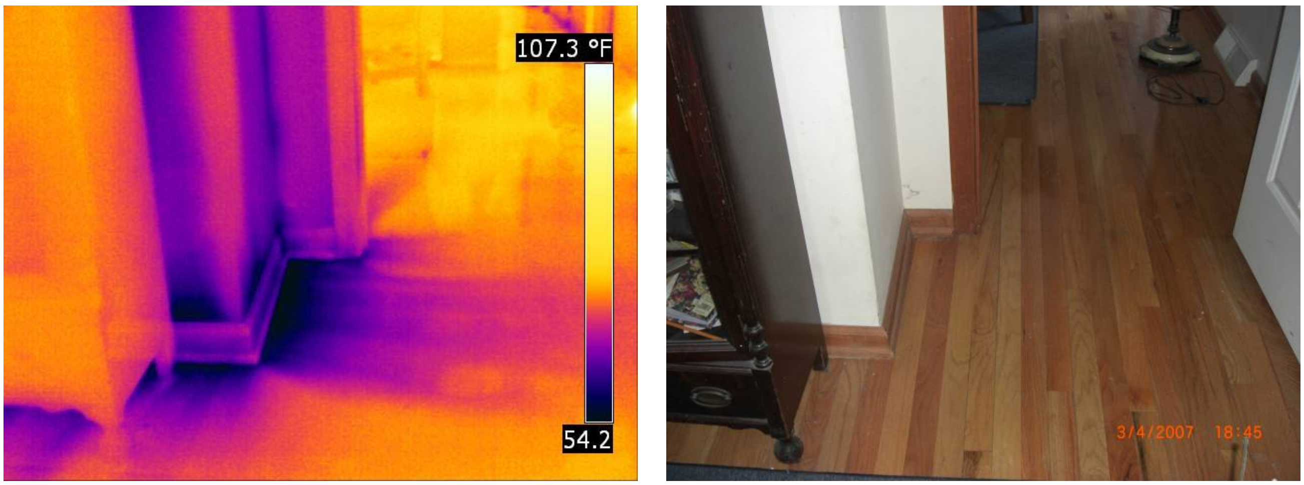


Figure 7. IR Image shows infiltration where interior wall meets the floor. This is taken above an unheated basement.

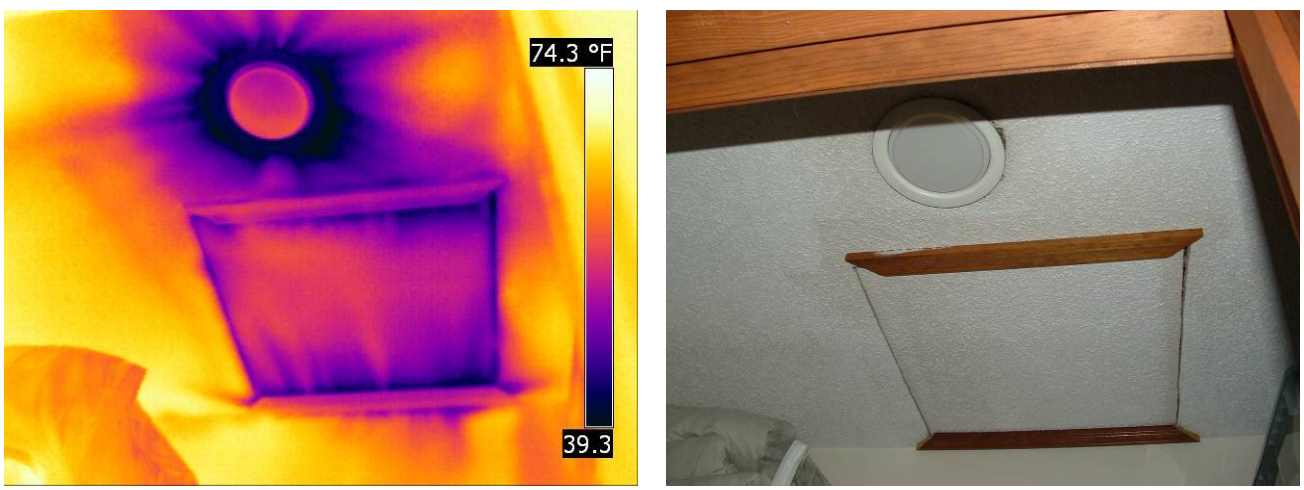


Figure 8. Blower door enhanced Image shows infiltration from around the recessed light fixture and leakage from the attic hatch.

In addition, there are penetrations through the building envelope. That would be anything that breaks a vertical or horizontal plane (walls/ceilings or floors) and are referred to as “thermal by-passes”. Examples would be plumbing chases, chimney chases, penetrations for heating system distribution, electrical penetrations, etc. All these gaps, holes or discontinuities in the building envelope allow air to move through the envelope. Other pathways for air movement occur within the wall cavity itself. As air moves through these gaps and penetrations, heat and moisture are carried with it outside the thermal envelope (or thermal boundary) leading to heat loss and/or mold and/or moisture damage.

EXAMPLES OF THERMAL BY-PASSES

Figure 9 gives a good example of a thermal bypass via a pipe chase. Figure 10 gives an example of a thermal bypass via a chimney chase and Figure 11 for an attic partition wall. All these examples show considerable heat lost to the outside world.

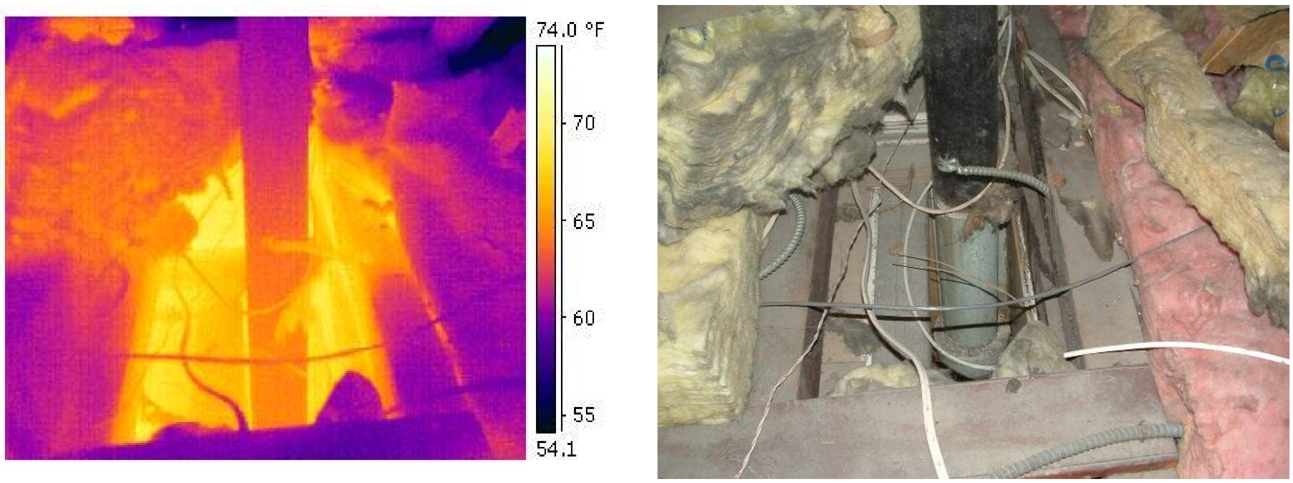


Figure 9. IR Image shows the heat escaping through the pipe chase and leaking into the attic. Image right shows how much bigger the opening is than the soil pipe shaft.

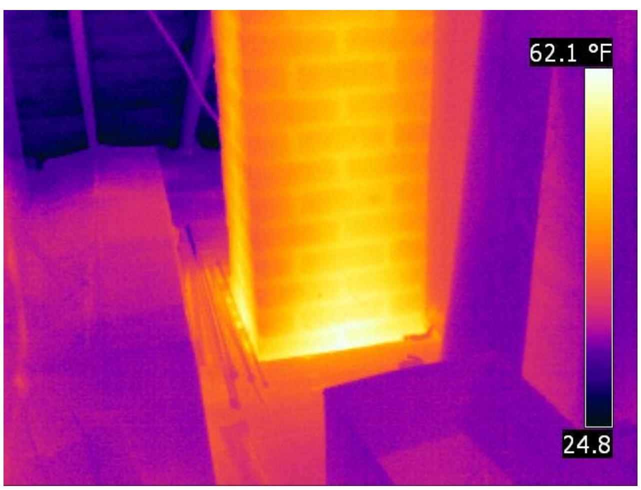


Figure 10. IR image of thermal bypass at chimney chase.

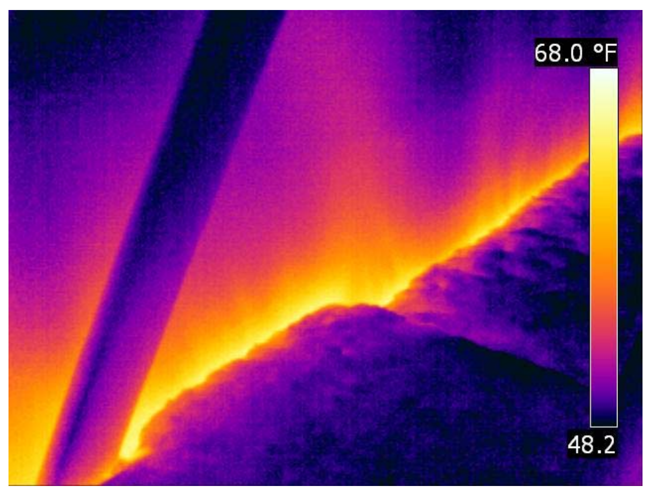


Figure 11. IR image of thermal bypass at an attic partition wall between two units of a condominium.

These types of thermal bypasses can be quite expensive in terms of energy consumption. You start adding these up and you have the equivalent of an open window in your home.

BLOWER DOOR

The Blower Door (Figure 12) is used to create an artificial pressure difference between the interior of the structure and outside of the building. The standard differential pressure for residential diagnostics is -50 Pa (Pascals, see Appendix B), which is equivalent to a 20 mph wind blowing against all sides of the structure simultaneously. The blower door quantifies the air infiltration rate in terms of “Cubic Feet per Minute”. This number is then compared to the “Building Airflow Standard” (BAS) established by ASHRAE standard 62.2-2007

For diagnostic purposes, the interior is de-pressurized with reference to the outside. As a result, the outside air is pulled through the discontinuities (gaps, cracks and holes) of the building envelope and cools (or heats) the interior surfaces

DIAGNOSTIC PROTOCOL

In order to obtain the standard pressure differential of -50 Pa with reference to the outside, the structure must be put into “winter condition”. Essentially this means that all windows are closed and latched and all exterior doors are closed.

After the house has been placed in “winter condition” the blower door is started and the house is brought to a negative 50 Pa with reference to the outside. After the blower door has been operating for about 10 minutes, the thermal camera will be able to detect the leakage points because the temperature at these locations will have been changed. As the blower door continues to run, the effect of the outside air temperature impinging on interior surfaces continues to “grow”.

Blower Door enhanced thermal images have a “wispy” appearance that emanates from the point of infiltration.

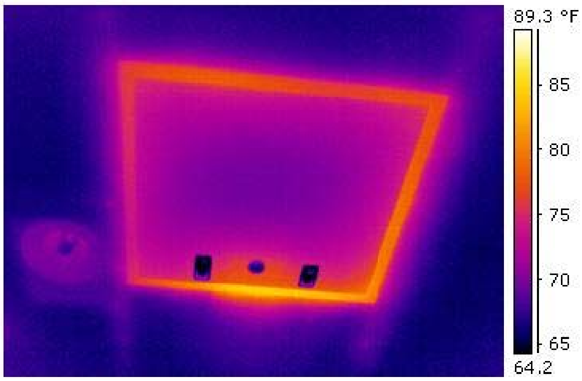
The following series of thermal images were taken over a period of 16 minutes from the time the blower door was turned on and are typical of the images seen when a blower door is used.

You will note in the following images how the warmer infiltrating air from the attic warms the cooler ceiling surface.

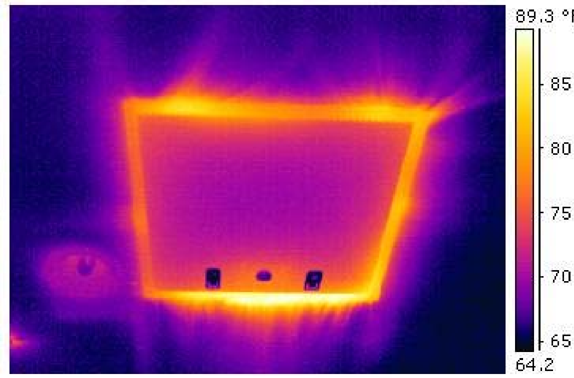
Figure 12. Blower door installed in residential outside doorway.

IR IMAGE SEQUENCE DURING BLOWER DOOR TEST

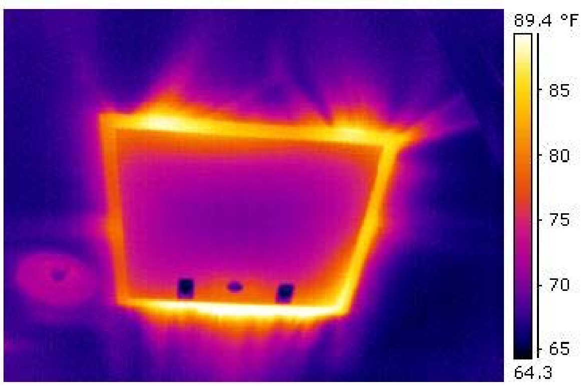
Figure 13 shows an IR image sequence of an attic hatch where warm attic air is drawn in during a blower door test. One can see before the blower door starts there is already some excess heat from the attic due to a poorly insulated hatchway.



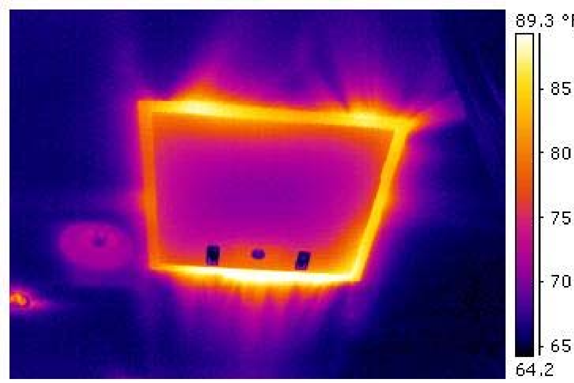
IR Image before Blower Door started



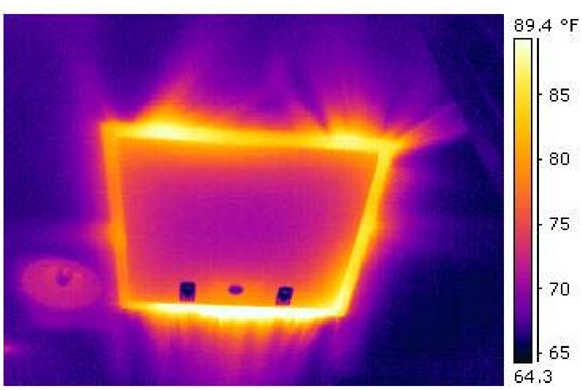
3 minutes



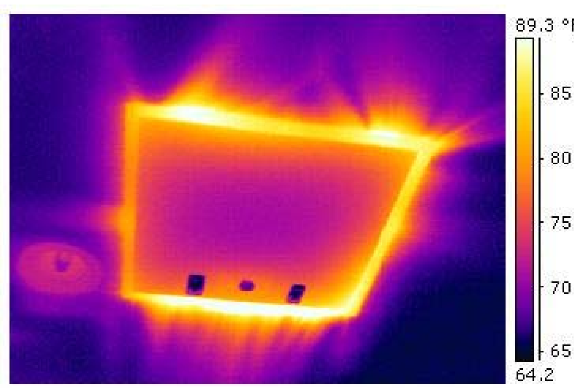
6 minutes



9 minutes



10 minutes



16 minutes

Figure 13. Sequence of IR images of attic hatch showing effect of blower door drawing warm air into living space from the attic.

But as the IR image sequence shows in Fig. 13, it gets worse, much worse during the blower door test.

OTHER IR IMAGES TAKEN DURING BLOWER DOOR TESTING

Figure 14 shows another attic hatch, this time leaking cold attic air into the living space during a blower door test.

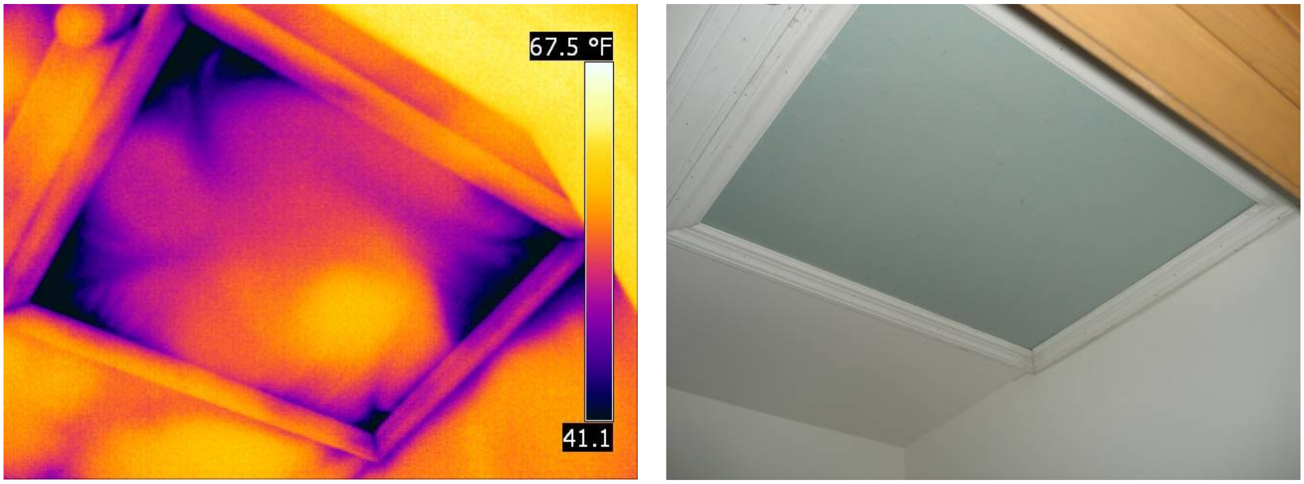


Figure 14. Thermal image shows the "wispy" effect of blower door induced infiltration. Here the outside air is colder than inside.

Figure 15 shows an example of a poorly constructed outside door frame. This appears to be more a construction lack of caulking problem rather than a weather-stripping problem. Often blower door testing indicates problems that can be fairly easy to fix with weather-stripping or proper caulking/sealing. Compared to other problems such as missing insulation the infiltration/exfiltration repairs can be much less intrusive and

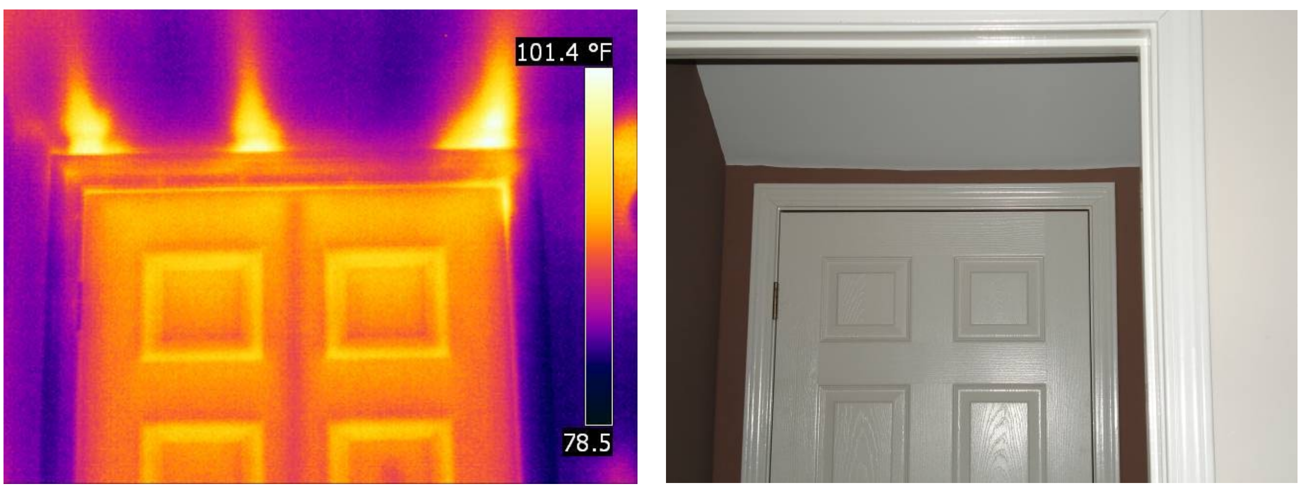


Figure 15. IR image indicates air Leakage along the top of molding. Temperature outside the thermal boundary is higher than inside

much less expensive. The energy cost savings not to mention the reduction of potential moisture/mold problems make blower door/IR thermography an extremely valuable energy conservation team. Not only does IR find the problem but as the IR images show, it is an extremely valuable documentation tool.

Figure 16 is yet another example of air leakage found during blower door testing. This time it is an attic doorway. Often these are treated as interior doors when they should be considered exterior. Weather stripping and perhaps some insulation added to the attic side of the door would really improve this problem. And it is a very inexpensive and quick fix.

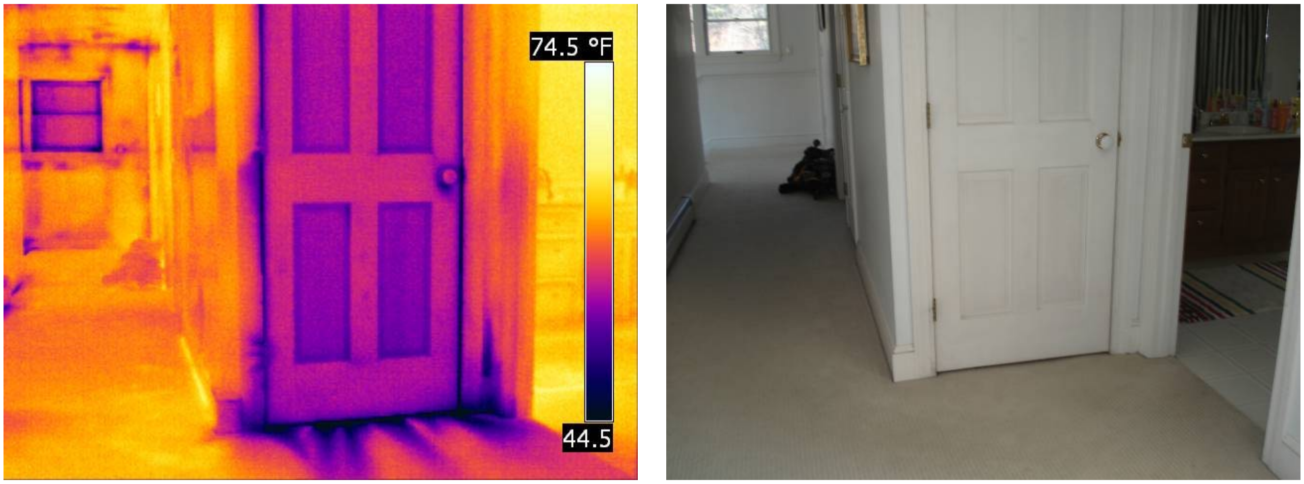


Figure 16. IR image showing air Leakage at the bottom of attic access door.

SUMMARY

IR thermography is an extremely cost-effective tool for finding missing/damaged insulation in building envelopes. And when the IR thermography is used in conjunction with blower door testing, the IR camera will locate the infiltration points and provide a visual cue as to the severity of the infiltration. Seeing the difference in temperature between the surfaces and how far the effect reaches will enable the experienced thermographer to assess the severity of the breach. When the air flow data from the blower door is analyzed, a priority on air sealing measures can be assigned and corrective measures implemented. Follow-up testing can readily verify the efficacy of repairs made.

REFERENCES

- ASHRAE Standard 62.2-2004, Ventilation and Acceptable Indoor Air Quality in Low-Rise Residential Buildings
- ASHRAE Standard 62.2 User's Manual
- Building Performance Institute Technical Standards for Building Analysis and Building Envelopes

APPENDIX A

The one dimensional conductive heat transfer equation is given by:

$$Q = U x A x \Delta T$$

Where: Q = Heat Lost thru the Surface (Btu/Hr)
U = Thermal Conductivity of the Surface (Btu/(Hr Ft^2 °F)) *
A = The Area of the Surface (Ft^2)
ΔT = The Difference in Temperature Between Inside and Outside (°F)

* This number is based on the composition of the material(s) that make up the surface

<u>All</u> materials have a coefficient of thermal conductivity (k), expressed as Btu/Hr ft^2. We are most familiar with the term "thermal resistance", or R-value. The R-value is the inverse of thermal conductivity (U).

Expressed algebraically, **R = 1/U** and **U = 1/R**

NOTE: Although R-values are additive through the wall, U-Values are not. The R-values must first be added and then the inverse taken to arrive at U-value.

In a composite structure, we have to add the R-values of each of the materials. So in the case of our typical wall structure comprised of: ½" gypsum wallboard, 2x4 wood framing (16" on center), 3-1/2" of fiberglass batt between the framing, ¾” plywood sheathing and aluminum siding (leaving out the interior and exterior air film layers) we would have –

Material	R-Value/Inch	Total R-Value
Gypsum Wallboard	R = 0.9/inch	0.45
Fiberglass Batt Insulation	R = 3.1/inch	11.0
Plywood Sheathing	R = 1.25/inch	0.94
Aluminum Siding	R = 0.6/inch	0.10

The composite R-value is the addition of the R-values of the materials that make up the wall. Therefore,

$$R_{total} = 0.45 + 11.0 + 0.94 + 0.10 = 12.5 \text{ (Hr Ft}^2\ {}^{o}\text{F)/BTU and } U = 1/R = 1/12.5 = 0.08 \text{ BTU/(Hr Ft}^2\ {}^{\circ}\text{F)}$$

The higher the R-Value or lower the U-Value, the better the energy conserving ability of a building envelope. One must balance quality of life with R-Value, however, as windows have an R-Value of anywhere from R-1 for a single pane window to about R-3.5 for double glaze, low emissivity windows. Compared to good quality constructed envelopes of R-12.5 to R-24, depending on construction, one can see the best insulated home wouldn’t have any windows. This is unlikely.

APPENDIX B

Units of pressure can be very confusing if you’re not used to working with them. Pressure is force per unit area. Most of us are familiar with atmospheric pressure at sea level being 14.7 psi (pounds per square inch). Tire pressures are usually about 32 to 35 psi. A Pascal (Pa) is a unit of pressure equal to 145.04×10^{-6} psi. That’s a small number. One psi is 6,894 Pa. So atmospheric pressure in Pascals is 101,325 Pa. A 35 psi tire is 241,290 Pa. A pressure differential of 50 Pa = 0.00725 psi ≈ 1 psf (pound per square foot). That’s not a big pressure difference, but that’s all you need to see the effects of poorly constructed building envelopes. Scientists arrived at this number as that’s the kind of pressure difference a home can see in a 15 to 20 mph wind.

ACKNOWLEDGEMENTS

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Howard Vics graduated from Northeastern University in 1985 earning a Bachelor of Science degree in Engineering, with an emphasis in heat transfer and material science. He is an ITC certified Level II thermographer and holds certifications in building analysis and home energy rating from the Building Performance Institute.

Howard lives in upstate NY and conducts home energy audits, using Infrared Thermography for heat loss analysis to develop insulation and energy conservation strategies for single family residential and multi-family buildings and for commercial real estate applications. He also does building diagnostics, home performance assessments and energy conservation consulting.

In addition to his independent consulting and thermography business, Howard teaches Building Science courses and he is a participating contractor in New York State’s Home Performance with Energy STAR program. He is a nationally certified Energy Rater, performing energy ratings of new, single family and multi-family buildings and he serves on the operations board for the local chapter of Habitat for Humanity.