

I

INDUSTRY CORNER

EFFICIENCY AND COMFORT THROUGH DEEP ENERGY RETROFITS: BALANCING ENERGY AND MOISTURE MANAGEMENT

Aaron Lubeck, GC,¹ and Francis Conlin, PEx²

Preservationists must accept the need to improve the energy performance of the existing building stock. We simply cannot ignore the fact that the electrical power that runs our buildings contributes substantially to global warming and climate change. Let's be clear that meeting sustainable energy targets will require substantially improving building envelope performance.

Carl Elefante, *The Greenest Building Is the One That's Already Built*

INTRODUCTION

Homes that survived to be called "historic" did so because they worked; that is, they delivered a level of performance that met the owner's expectations and tolerance level without catastrophic damage to the home, pocketbook, or surrounding environment. Home performance expectations have changed and now include a desire to use less energy while at the same time realizing a level of comfort that includes air conditioning and constant temperatures in all rooms. In order to meet these performance expectations, old homes often require some "re-engineering."

Increasing insulation will advance energy efficiency goals, reduce costs, and make a home more sustainable but by itself is insufficient, and, often, it can also upset the moisture balance resulting in unexpected mold and sick building syndrome. Improvement in moisture management design is a critically important consideration whenever energy efficiency is increased; however, many projects fail to address moisture adequately. This article will walk through the process of insulating and air sealing a house (two very different activities, sometimes combined, sometimes not), and shed particular light on how different approaches encourage or discourage moisture problems.

KEYWORDS

air barrier, energy auditing, energy retrofits, envelope, historic retrofits, insulation, moisture control, old houses, recommissioning, reengineering, residential design, thermal, wall systems

THE DEEP ENERGY RETROFIT

Improving thermal performance can be a relatively complicated task, particularly in walls. To understand insulation, air infiltration, and how they can disrupt moisture control, let us first start with some definitions.

Definitions

- A *deep energy retrofit* is the process of super-insulating, air sealing older properties and

upgrading of the heating and cooling systems, with the intent of reducing energy consumption by 50% or more.

- *Heat* is a type of energy that transfers from one body to another.
- *Insulation (thermal barrier)* is a material that resists heat transfer through a building assembly.
- The *thermal envelope* is the boundary (usually insulation) that defines the conditioned (heated and cooled) area of a structure.

1 Aaron Lubeck, GC, Founder of Trinity Design | Build, author of *Green Restorations: Sustainable Building in Historic Homes*, and lecturer at Duke University's Nicholas School for the Environment. He developed and re-constructed 209 N Gregson, a 1927 building that achieved LEED-Platinum. Email: aalubeck@gmail.com.

2. Francis Conlin, PE, Senior Engineer for Southern Energy Management (SEM), a Building Science and Renewable Energy Provider based in North Carolina. SEM has certified over 6,000 homes for the EPA Energy Star Program and has recently initiated an existing building energy retrofit division.

- *Building envelope* consists of the entire exterior physical shell, including conditioned and non-conditioned areas.
- *Building assembly* is a collection of building components that form a unit. A wall is a building assembly; wall insulation is one element in that assembly.
- *Air infiltration (or air leakage)* is caused by gaps in the building envelope that allow uncontrolled airflow around structures and insulation.
- An *air barrier* is a system of materials that block air infiltration by using continuous surfaces and transitions that prevent air movement. Generally the air barrier is aligned with the thermal envelope.
- *Moisture management* is a series of strategies to prevent excessive moisture accumulation in buildings and their assemblies.
- *Moisture barrier* is a material used to manage moisture movement. Until recently codes focused only on vapor barriers (which do not limit water entry from infiltration).
- *Housewrap* is a synthetic material that functions as a weather-resistant barrier, preventing rain from getting into the wall assembly while allowing water vapor to pass. It may also serve as an air barrier if it is sealed carefully at its seams.
- *Condensation* is a liquid that forms from water vapor in warm air after coming in contact with a sufficiently cold surface. Condensation starts as droplets; significant condensation is often mistaken for a roof or plumbing leak.

A major function of the building envelope is to separate the outside environment from the inside. In opposition to this, natural systems tend toward equilibrium, not separation. In buildings this means that the:

- Heat provided by a furnace is driven toward colder winter temperature outdoors.
- Higher pressure in ducts leaks air out to the lower pressure of a vented attic.
- Moisture from a wet crawl space migrates into the drier floor joists above it.

Considering that the natural environment to which buildings are exposed is dynamic, and that heat, air, and moisture movement are inseparably

interconnected, one can imagine why casual retrofit decisions in a high performance design can lead to problems.

A classic example of the interaction between heat, air, and moisture is a wall assembly of a leaky, uninsulated house. Historical window flashing usually allows some water in the wall cavity during a rain event, but as heat leaks through the walls the water is removed. After a well-intended insulation and air leakage upgrade that does *not* address moisture, the volume of water that enters the wall cavity during a rain event is unchanged, but the heat passing through the wall is significantly less. The drying power of the wall is now lower than the wetting capacity resulting in higher and possibly damaging levels of moisture accumulation in the wall cavity. Buildings undergoing deep energy retrofits require a reengineering of these envelope systems to improve the moisture performance in concert with its energy efficiency improvements.

Whenever we improve energy efficiency, we need to think also about moisture. Water is the root cause of the most significant problems in houses, yet few

DEEP ENERGY RETROFIT: QUESTIONS TO ASK

- What is the building's thermal envelope and how does it differ from the building envelope?
- How is moisture managed in the attic, crawl space and wall assemblies?
- Are heating and cooling bills abnormally high—and why?
- Are ductwork, mechanicals and plumbing inside or outside the thermal envelope?
- How much and from where is air infiltrating into/out of the home?
- If the envelope is tightened, will fresh air be needed and how will it be provided?
- Is the basement or crawl space chronically wet?
- When moisture gets into an insulated wall cavity, how will it escape?
- Do you ever see condensation? Where and in which season?
- What insulation levels exist in floors, walls and ceilings and how well is it performing?
- What are your comfort, energy cost and air quality goals/expectations?

FIGURE 1. The sheathing on an old home can have up to seven times the penetrations, and the wood materials tend to be less uniform than new wood, leading to increased air infiltration. Some old homes lack any sheathing, where siding is tacked directly to studs.



remodeling projects include explicit strategies to address it. Old wall cavities, for example, are far more likely to accumulate moisture because they commonly lack several moisture management strategies common to new homes:

1. a complete rain barrier or a vapor barrier
2. flashing under windows
3. an air gap or drainage plane
4. a continuous air barrier

There is a simple reason that the accumulated moisture doesn't more often create a catastrophe: The walls on old homes have so much heat passing through them that water inside these assemblies dries out relatively quickly. In fact, there are also few significant mold-sensitive materials on an old house. The new wood and paper-faced gypsum wall board common to new construction offer food for mold, but old lumber is observed to be more mold-resistant, and plaster and masonry have no nutrients. Masonry, often massive in large old homes, can absorb and store moisture very well and release it slowly without concern. Like morning dew, the moisture simply dries out without consequence.

Thus, in an uninsulated old home leakiness is actually a friend to moisture management. But, there's a catch: the same leakiness is very bad for energy efficiency and comfort.

This article addresses, simultaneously, the retrofitting of air, moisture, and thermal barriers on an existing house, and the quandary resulting from the integral interconnection of all three. It's difficult to prioritize the three, because each is so interdependent on the other. The building code focuses on insulation, so strategies tend to focus there. But insulation does not typically address the air barriers, and it's easy to have an insulated home that remains unacceptably leaky. Further, most insulations offer no comprehensive water barrier, so it's possible to have a well-insulated home with poor drying capability, which may promote mold growth. It's possible to have a functioning moisture or air barrier without insulation, and, in fact, this may be why many old beach manors have survived the addition of air conditioning; their exteriors have been painted so many times that the layers of paint collectively create an air and moisture barrier on the exterior—with no insulation. Regardless, a complete deep energy retrofit strategy must consider all three barriers.

Attics and crawl spaces in old homes behave comparatively the same as in new construction. Attics and crawl spaces are generally open to access for upgrades without need to demolish finishes, which makes them relatively straightforward to improve. Chimneys, floor vents, plumbing, electrical, and duct penetrations are significant air leakage sites, but relatively simple to seal. Walls, however, are closed with plaster or sheetrock; plaster itself forms a rather effective air barrier. On the walls, it's the transition points that must be monitored—such as window sashes to sill, baseboards to floors—these need to form a tight seal. Wall retrofits involve finish and trim, making them more difficult and expensive, and they tend to intrude on living space—of particular concern in an occupied house. Contrary to popular belief, it's not imperative that the walls be insulated. Experience shows that significant energy efficiency gains can still be achieved without insulating walls. Particularly with old homes, the air barrier is more crucial than insulation; and as floors and attics are leakier than walls, these deserve priority.

The retrofitting of a good air barrier, even without insulation, will yield significant energy improvements. An air sealed home with *no* insulation may perform better than a leaky home *with* insulation.

We'll discuss why. We'll pay particular attention to wall strategies and their options, as walls tend to be the most complex and misunderstood challenge of many deep energy retrofits.

AIR SEALING AND AIR BARRIERS

It's crucial to recognize the difference between insulation and air sealing; in humid climates, air sealing is critically important. A common problem is that decision makers often have an "out-of-sight-is-out-

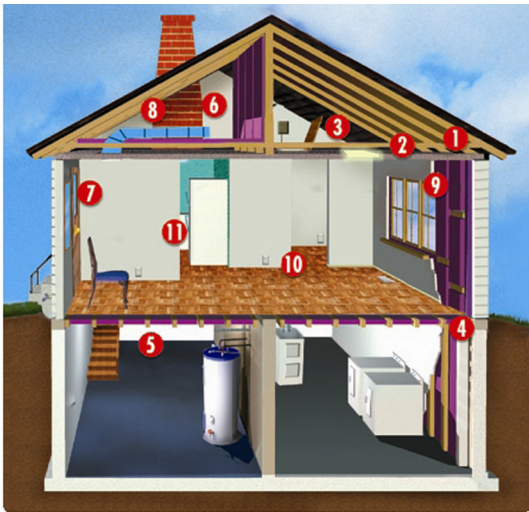
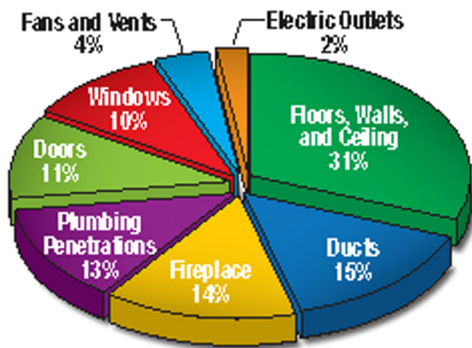
of-mind" inclination, and focus on visual problems they can literally see. In a retrofit, insulation is generally addressed while air leakage is most often overlooked—in spite of the fact that insulation delivers practically no benefit if air is allowed to leak around it. Water carried in with the air leakage is also invisible, so it's no surprise occupants have no idea what problems it causes. As a result, air sealing, arguably the most important upgrade, is usually overlooked.

Air leakage is sometimes quantified as air changes per hour (ACH). A complete changeover of interior air every three to four hours is a healthy benchmark, equaling six to eight air changes per day or 0.25–0.33 ACH. Old houses average 1–2 ACH, four to eight times more than ideal and ten to 20 times leakier than well-built modern homes. Old houses have so many aggregate leaks that it's the modern house equivalent to leaving the front door wide open all day. In these leakiest of old homes we're essentially camping.

Air leaks cause a variety of problems: Leaks can be so massive that the home acts like a giant chimney and may result in back drafting of combustion appliances as air chooses the easier path to the outside—resulting in flame roll out and possible carbon monoxide poisoning.

According to the U.S. Department of Energy, the most common culprits for air infiltration are, in order: floors, walls and ceilings, ducts, fireplaces, plumbing penetrations, doors, windows, fans and vents, and electrical outlets. Note that windows

FIGURE 2. Above, the sources of air infiltration. Below, a graphic of the most common culprits. Source: Energy Star/U.S. Department of Energy.



Sources of Air Leaks in Your Home

Areas that leak air into and out of your home cost you lots of money. Check the areas listed below.

- | | | |
|-------------------|----------------------------|-------------------------------------|
| 1. Window frames | 5. Water and furnace flues | 9. Window frames |
| 2. Recessed light | 6. All ducts | 10. Electrical outlets and switches |
| 3. Attic entrance | 7. Door frames | 11. Plumbing and utility access |
| 4. Sill plates | 8. Chimney flashing | |

HEAT TRANSFER, AND WHY R-VALUE IS A MISLEADING METRIC

R-value is the measure of thermal resistance; a higher *R-value* makes for a better insulator. But there is more to the story.

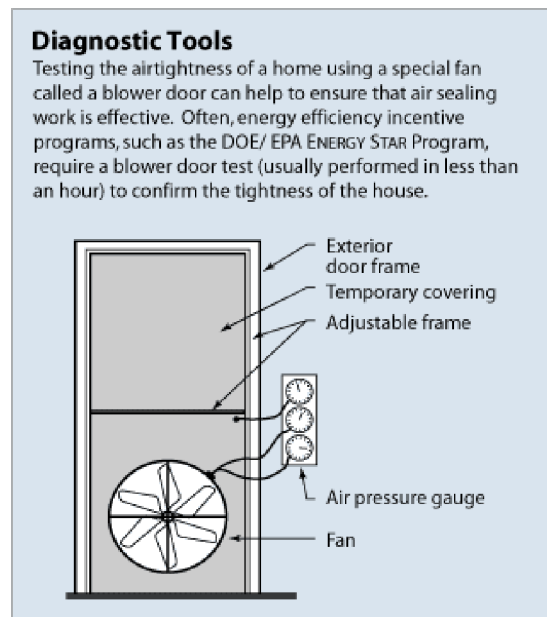
R-value only measures resistance to heat transfer by conduction, but heat has a better way to travel—through air leakage. *Air infiltration* describes uncontrolled leaks through which air flows between the inside and outside of the thermal envelope. It doesn't take too much infiltration to completely by-pass insulation, thereby defeating any of the thermal resistance benefits. Proper air sealing limits air infiltration and gives insulation a chance to work. Insulation without a functioning air barrier is wasted.

FIGURE 3. An infrared camera measures temperatures thus indicating the best and least insulated parts of the home. Source: U.S. Department of Energy.



comprise only 10% of the problem yet they receive nearly all of the marketing efforts to address the problem. Why are we overwhelmed by window replacement salesmen while there are few experts in sealing floors and ducts? Again, it's because windows are the most *visible* culprit. It's easier to sell what a prospective client can see, but that's an improper and flawed prioritization. Given that

FIGURE 4. Source: U.S. Department of Energy.



moisture sneaks into a home within an “air leakage Trojan horse,” how should we go about reducing this infiltration?

TESTS AND TOOLS

Leaks in the envelope must be identified, and there are three ways to find where a house leaks: 1) conducting blower door-directed sealing and analysis, 2) hiring an experienced energy auditor who may not use a blower door, and 3) conducting self-directed air leakage assessment.

To perform blower door-directed sealing, a professional installs a calibrated fan in an exterior window or door, closes all other windows, doors, dampers, and vents, then turns the fan on to force air either in or out of the structure. The result is an artificially high pressurization that allows leaks to be identified, for example, with an infrared camera or by using a smoke pencil directed along baseboard, sockets, windows, doors, lights, and other penetrations. The test can also measure the amount of air leakage. Once major air leaks are sealed the test is run again to assess the improvements.

Some energy experts have enough experience with homes and with blower door tests that they feel comfortable identifying leaks *without* the aid of a blower door. Many leakage sites are so common to old construction that experts will just look in the usual places and correct accordingly. Usually this includes chimney penetrations, plumbing vents, HVAC penetrations, and tub surrounds. These obvious leaks should be sealed up before a blower door test anyway, unless quantifying the improvement is of some value. Regardless, it is a good idea to have a blower door test afterwards to see if any large issues were overlooked, and to assess if a tight home has adequate ventilation.

Locating air leaks does not require a professional. A poor folks' blower door test can be performed with a window fan and incense; simply install one or more fans in a window and seal with cardboard and tape. Because a window fan will not be as powerful as the professional rig, and pressurization is usually easiest to see, it's best to set the fan to blow air *into* the house. This will cause smoke from the incense to zip into any leakage site in the house. While this doesn't quantify air leakage, it does direct the retro-fitter to where air sealing is needed.

FIGURE 5. A blower door, operated by a building scientist at Southern Energy Management, assesses a home for air leakage.



WALLS

While we've established that walls are usually not the primary source of air leakage, they usually can benefit from air sealing. Plaster and baseboards do not leak that much, though windows and doors often require addressing. Different siding materials leak at different rates: German clapboard, for example, can be excessively leaky, failing to form an air barrier, but may be of little consequence in an uninsulated house with plaster. Air leakage through walls can contribute to a drafty and inefficient house; the greater risk comes from the water vapor such air leakage can carry.

MOISTURE MANAGEMENT AND BARRIERS

When water accumulates inside a building assembly the results can include structural damage, reduced air quality, and failed insulation. Pathways for water accumulation into building assemblies are the best way to keep a home healthy and dry.

Water in a home comes from three primary sources.

1. rainwater and groundwater
2. plumbing
3. vapor

Rainwater must stay away from the house. Roof leaks can be checked by inspecting for deterioration and exterior trim for functioning flashing, which should flash from ridge to ground like scales on a fish. Wide eaves or functional gutters make sure water is discharged far from the foundation. Drought resistant plants should be used adjacent to the home because plants that require heavy watering lead to excessive amounts of water against the foundation. Finally, to prevent *groundwater* from entering the envelope through the earth, a polyethylene vapor barrier is typically installed on any dirt crawl space floor and up any wet walls; this feature is often absent in old homes.

Plumbing leaks can go on for years without being noticed, adding dollars to utility bills and potentially causing moisture damage to the envelope. Increased water bills are one indication of a problem; also recommended is a periodic check of the crawl space or basement for pools of water.

Vapor is airborne water in a gaseous state, and is the most often-overlooked source of building moisture problems. We know that water vapor comes from humid air outside the home, but inside the home it also comes from the everyday pleasures of hot showers and baths, tea kettles, and plants. Properly sized and operated bath and kitchen vents are required to move vapor outside the home where it

belongs. These mechanisms become more important as the envelope is tightened. Vapor is measured in terms of *relative humidity* (RH), the ratio of the amount of water vapor present relative to the maximum amount the air can hold at a given temperature. Hot air can hold much more water vapor than cold air, which is why summers are more humid and winters are more dry. As temperatures drop the water vapor reaches its dewpoint, where it condenses into water or ice; outside we call this moisture fog, rain, or snow, but trapped inside a tight building assembly we call it trouble.

Relative humidity is also a major input into comfort, an occupant requirement that has changed dramatically over the last century. The average homeowner feels most comfortable with relative humidity between 40 and 65%. Above 65% RH humans feel sticky. Below 40% RH we feel dry, desire moisturizers or humidifiers; we get sinus headaches, itch and scratch, and generate static electricity. Structurally, low humidity can cause plaster and finishes to shrink and crack.

Though minimizing humid air *infiltration* is crucial, in a tight home relative humidity may be largely dictated by human behavior. Breathing alone produces 1/4 cup of water per hour, while cooking pasta produces five pints. Your average shower puts 1/2 pint of water into the air. This is significant because introducing only ten pints of water into a 2,000-square-foot house can cause its relative humidity to jump from 15 to 60%, of most concern in a tight house. Then there may be a short-term need to dehumidify or push this excessively humid air out of the house. Houses are dehumidified by air conditioners, and proper use of bath and kitchen fans. Many modern green homes set bath fans to automatically run to ventilate a tight home and expel moisture and stale air from the home at fixed times during each day.

WALLS AND VAPOR RETARDERS

Our understanding of walls has increased dramatically in the past 10 years. For decades building code wall assembly specifications ignored air leakage, but instead required a vapor barrier to be installed on the inside of a wall assembly in an effort to minimize vapor diffusion. Recently, building scientists have recognized that this practice was causing prob-

MOLD

Mold is a microscopic fungus and a common result of moisture problems in homes. Many people are allergic to mold; some claim that it causes illness. Regardless, it is not a welcome sight in a home. Mold requires five conditions to grow. Eliminate any of the five and you'll eliminate mold growth:

1. Mold spores—mold spores are found almost everywhere.
2. Mold food—any carbon-based material including wood, drywall paper, paint, carpet, and even dust.
3. Oxygen.
4. Temperatures between 40–100°F.
5. Relative humidity in excess of 70% (Katz 2009).

Since mold spores and food are everywhere, and humans consider oxygenless spaces with temperature ranges below 40 and above 100°F to be rather inhospitable, that leaves relative humidity level as the only available condition for controlling mold growth. Relative humidity is controlled through air conditioning operation, dehumidifiers, ventilation and envelope tightening.

Of note for preservationists, plaster and uninsulated wall cavities offer no mold food, so mold is rare in historic homes. In the South, mold is a near given on unkempt homes built from 1950 on, but I've never seen it on even the most dilapidated of homes built between 1900–1920. For old home purists, this demonstrates another environmental benefit of plaster over gypsum wallboard.

Any old house project introducing insulation and sheetrock must manage moisture and humidity accordingly. These new building materials create an environment supportive of mold growth. If you do install sheetrock in moisture-prone areas, be sure to keep the base at least 1/2 inch above the floor where it cannot wick standing water. Never use water-resistant greenboard sheetrock for tile base; use concrete backerboard instead. Any paper-faced sheetrock is inferior in a wet environment and subject to mold growth; consider fiberglass based gypsum board instead.

lems in humid climates where water vapor is driven from outside to inside. Specifying that the vapor retarder should go on the warm side of the insulation didn't really help matters in most parts of the

country particularly in mixed climates; the “warm side” depends on the season, and the direction of vapor flow switches, making vapor retarders potential problems in both seasons.

Moisture trapped in the wall cavity for extended periods of time can shorten the life of the home. Besides rain leaks, water also enters a cavity by *diffusion* through assemblies or is carried in through air leakage. Air leakage can carry with it a massive amount of water and has been cited to transfer 100 times more water into wall cavities than diffusion. Moisture is one of the most underappreciated reasons why air sealing an insulated house is so important; according to the Forest Products Research Lab, “Moisture problems caused by moving air are much more common; problems caused by diffusion are very rare.”

It is likely that the majority of the problem was air leakage all the time and a polyethylene “vapor retarder” essentially created a good air barrier for cold climate homes that was benign during their mild summer months.

Many other factors punch holes in the accepted dogma of vapor retarders: oil paint, for instance, does not allow vapor to pass through it and can serve as a second vapor barrier effectively trapping moisture in the wall. Because of such issues, builders (and the building code) are shying away from installing vapor barriers in wall assemblies in humid and mixed climates but still consider it important in cold climates.

INSULATION AND THE THERMAL BARRIER

Heat, air, and moisture are interdependent and move constantly through a home. Thermal barriers are commonly paired with air barriers. Such an assembly would stop heat and air transfer simultaneously, which will also address the majority of moisture transfer. To understand how this is accomplished and barriers are specified, keep these few simple rules from thermodynamics in mind:

- Hot air rises and cold air falls.
- Hot air typically carries more moisture than cold air.
- Air is subject to laws of mass flow and fluid dynamics, making hot, humid air prone to condense on colder surfaces.

- Colder surfaces will condense moisture first.
- In winter, warm air rises via *stack effect*, promoting cold air infiltration at the base of a building.

This basic understanding of heat transfer yields some obvious conclusions.

- If we seal the top of the envelope, warm air cannot be lost through it in winter.
- If we seal the bottom of the envelope, cold air cannot be sucked in through it in winter.
- The reverse of the previous statements is true in summer.
- If we seal both, we dramatically stop airflow from the stack effect.
- If we minimize temperature differentials around ductwork and cold water pipes, condensation is less likely to form on their surfaces; this is one reason to place ducts inside the conditioned space.

A building science paradigm shift is currently altering the thermal envelope strategy. Ever since insulation became the norm about 60 years ago, architects and contractors believed they should only insulate occupied space, installing insulation below the first floor’s joists and above the top floor’s ceiling. There was no need to heat, cool, or insulate unoccupied space, which was seen as a waste of money. But this strategy left uninsulated voids in the crawl space and attic where the thermal envelope—the conditioned area heated and cooled—did not match the building envelope. More important, if any air sealing occurred it was done at the building envelope, not in line with the insulation. Now most building scientists reject this as flawed design and argue that air leakage is important, and since it is more effective and simpler to air seal at the building envelope, then this is a better place to insulate as well. Many homes have been improved by expanding the thermal envelope to *match* the building envelope and effective air barrier through sealed crawl space and sealed attic designs.

SPACES BELOW AND ABOVE

Crawl spaces, basements, and attics, being leaky and subjected to natural and human-made extremes, can be the greatest contributor to a deficient thermal envelope. Homeowners fill crawl spaces and basements with heat-producing equipment and random junk that often absorbs moisture. Vented crawl

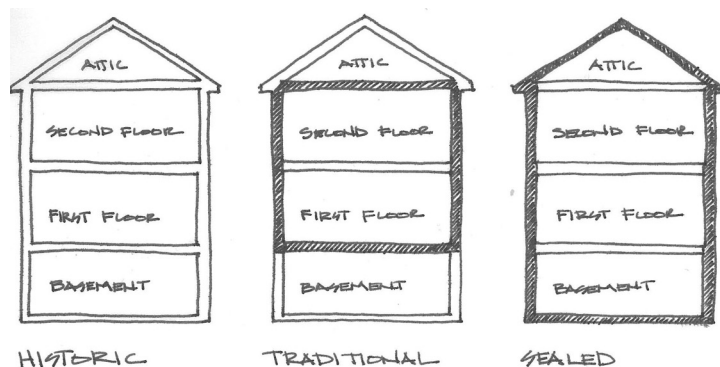


FIGURE 6. Left, a historic home has little or no insulation. Center, a traditional thermal envelope leaves uninsulated voids in the crawl space and attic—the attic floor and the basement ceilings are usually poor air barriers. Right, the thermal envelope is aligned with the building envelope and air barrier, a strategy increasingly seen as better building science.

BUILDING ENVELOPE

▨ = INSULATION

spaces and attics feature intentionally installed vents that allow free air to flow underneath and over the home. The vents are intended to allow moist air out but they also, inadvertently, let it in. Termites love heat and moisture, and both are pervasive problems that can contribute to structural failures.

Anyone who has suffered through a commando scoot into their musty, wet, cricket-infested crawl space can conclude that something is not right; if you've been in a 140°F vented attic on a 90°F day you'd draw the same conclusion. Further, vented attics can produce horrific operating environments for any resident cooling equipment creating a huge negative drag on efficiency. Why pay big dollars to cool air, use it, and then return it to a boiling 140°F environment for re-cooling? For these reasons, attics are also being sealed.

Sealed attics slow heat loss by insulating and air sealing the sloped roof deck instead of the attic floor. This keeps heating bills from going, almost literally, through the roof. In the summer, sealed attics stop heat transfer from the sun into the attic, blocking heat transfer to the living space, creating a far superior operating environment for HVAC and humans. Sealed attics do not require soffit vents, ridge vents, or attic fans, saving installation expense. Decorative vents in some old houses can be retained to keep their decorative elements while removing their ventilation function.

Today's sustainable building trend of aligning thermal envelope with the building envelope is

contributing to better moisture management. Once sealed, the whole house operates within more consistent temperature and relative humidity ranges. Insects and moisture are then kept out of the house, air quality is correspondingly improved, energy bills drop, and the house lives a longer, healthier life.

CONDENSATION EXAMPLES

A study of crawl spaces (Advanced Energy 2008) showed how traditional foundation wall vents, that were intended to remove moisture, actually added moisture in humid climates.

When outside air with a dew point of 73°F entered the crawl space and encountered an object cooler than 73°F, the water vapor from the air condensed to form liquid water and dripped below to form puddles. Supply ducts, cold water pipes, the crawl space soil, and even the wood framing above were often lower than the 73°F dew-point. Condensation may be robust if the homeowner conditions the house below 72°F (Dastur & Davis 2005).

In their study, vented crawl spaces routinely were observed above 70% RH for the vast majority of the summer (a level cited to promote mold growth), while closed crawl spaces were above this benchmark less than 5% of the time. The study concluded that the moisture extremes were caused by venting the crawl spaces. Higher RH in the crawl space puts susceptible materials at a higher risk of mold growth, while closed crawl spaces keep moisture levels low.

INSULATIONS

Now that we’ve discussed where insulation should go, let’s discuss what it actually is. *Insulation* is a material that resists heat flow. It keeps heat where you want it: out during summer and in during winter. R-value is the measure of thermal resistance, the higher the number the better the insulation is rated to perform. The residential code prescribes a minimum R-value that new construction must obtain for each region of the U.S.—a benchmark few old homes meet. Old homes often have no insulation, yielding a huge opportunity for operational improvement.

Ideally the thermal envelope is the heated, cooled area that is aligned with continuous insulation. In an old house with heated and cooled areas, however, forming a continuous thermal barrier may be cost prohibitive. Walls, for example, are particularly difficult to insulate, though they are not particularly difficult to air seal. Luckily, significant energy reduction can result from attic and floor insulation alone, with the wall cavities left un-insulated but air sealed.

Insulation barriers work best in tandem with the air barrier. In a traditionally insulated house, the attic’s floor will be insulated and air sealed, forming the top of the thermal envelope. Soffit and ridge vents allow air flow into and out of the attic, where the attic remains within the building envelope but outside the thermal envelope.

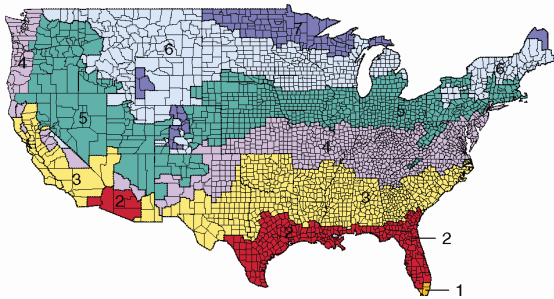
The shingles and roofing felt create the moisture/ water barrier, so the moisture barrier is separated from the air barrier. In this common attic design, there is no moisture barrier preventing vapor from entering the attic area via air infiltration, where it can condense. The risk of such condensation is the primary function of the attic venting requirement: to provide enough airflow to dry out the attic and prevent moisture accumulation. The code requirements for attic venting serve the same purpose our old home’s leaky and uninsulated walls, however unintentionally, once served.

Superinsulated homes exceed the DOE’s recommended values. It should be noted, however, that each additional inch of insulation has diminishing returns. If there is already R-30 in the attic, it is not likely worth the expense to add marginally more; if on the other hand you have R-20 or less, you might consider adding at least the minimum recommended for your area—if your utility rates are higher, add more. Some sustainable builders take the viewpoint that as long as they’re installing they may as well add a little above code requirements.

Modern insulation comes in three forms:

- 1. Blankets, including fiberglass batts, blue jeans, some with vapor retarder facings
- 2. Blown-in, including dense-packed and loose-packed cellulose, fiberglass and rock wool, vermiculite, and perlite.

FIGURE 7. Recommended Total R-Values for New Wood-Framed Houses. Source: U.S. Department of Energy.



Zone	Gas	Heat Pump	Fuel Oil	Electric Furnace	Attic	Cathedral Ceiling	Wall		Floor
							Cavity	Insulation Sheathing	
1	✓	✓	✓	✓	R30 to R49	R22 to R38	R13 to R15	None	R13
2	✓	✓	✓		R30 to R60	R22 to R38	R13 to R15	None	R13
2				✓	R30 to R60	R22 to R38	R13 to R15	None	R19 - R25
3	✓	✓	✓		R30 to R60	R22 to R38	R13 to R15	None	R25
3				✓	R30 to R60	R22 to R38	R13 to R15	R2.5 to R5	R25
4	✓	✓	✓		R38 to R60	R30 to R38	R13 to R15	R2.5 to R6	R25 - R30
4				✓	R38 to R60	R30 to R38	R13 to R15	R5 to R6	R25 - R30
5	✓	✓	✓		R38 to R60	R30 to R38	R13 to R15	R2.5 to R6	R25 - R30
5				✓	R38 to R60	R30 to R60	R13 to R21	R5 to R6	R25 - R30
6	✓	✓	✓	✓	R49 to R60	R30 to R60	R13 to R21	R5 to R6	R25 - R30
7	✓	✓	✓	✓	R49 to R60	R30 to R60	R13 to R21	R5 to R6	R25 - R30
8	✓	✓	✓	✓	R49 to R60	R30 to R60	R13 to R21	R5 to R6	R25 - R30

TABLE 1. Comparison of Insulation Products.

Insulation	R-value per inch	Cost	Installed	Ease of retrofit	Life cycle toxicity	Sealing ability
Fiberglass	3.2	\$	Staples between studs, joists, and rafters, paper facing warm side.	Requires open stud cavity or gut job. Sizes are 16 o.c. or 19.2, other widths require precise cutting. DIY.	Some is high VOC, some not	**
Rock wool	3.2	\$	Poured into attic bays, blown into walls through 4" holes.	Easy in attic; walls requires a 4" hole cut and repair. Exploratory holes must be cut to ensure complete coverage. Infrared cameras also test for coverage. No longer used.	Excellent	*
Blow in / loose-fill cellulose	3.2	\$	Blown in or machine sprayed.	Common retrofit, machines available for rental at big box stores. DIY, great for tight areas and around obstructions.	Some is high VOC, some not	*
Closed-cell spray foam	7	\$\$\$\$	Sprayed in place by professionals.	Requires open stud cavity. Some slow-rising foams can be used for injection behind existing plaster or sheetrock, but are cost prohibitive.	Highly toxic when sprayed, inert within seconds. Toxic if burned.	*****
Open-cell spray foam	3.5	\$\$\$\$	Sprayed in place by professionals.	Requires open stud cavity.	Highly toxic when sprayed, inert within seconds. Toxic if burned.	****
Extruded polystyrene (XPS)	5	\$\$	Glued in place as 4x8 boards (basement slabs, foundations).	Cut to size, typically used as sheathing and not used in stud cavities.	Inert, toxic if burned.	***
Expanded polystyrene (EPS)	4	\$	Same as extruded polystyrene.	Cut to size, typically used as sheathing and not used in stud cavities.	Inert, toxic if burned.	***
Polyisocyanurate (Polyiso)	7.5	\$\$\$\$	Foil-faced boards meet flame spread requirements where other foams do not. Sealed crawlspaces, wall sheathing.	Cut to size, typically used as sheathing and not used in stud cavities.	Less harmful manufacturing than other plastics, still toxic if burned.	****
Perlite, vermiculite	2.5	\$	Loose fill, poured in place, often used in concrete block walls.	Rarely used any longer. Old materials may contain asbestos. Still used in lightweight insulating concrete.	Excellent (except for asbestos material).	*

3. Foam, including expanded polystyrene (EPS), extruded polystyrene (XPS), and open and closed cell polyurethane spray foam (SPF).

The insulation market today is dominated by batts for basic construction and spray foam for higher end construction. Batts are the cheapest and most common cavity-fill insulation. Blown-in materials are common for horizontal applications and some wall retrofits. But open cell and closed cell spray foam insulation are the best available products on the market, particularly for sealing historic homes.

I try to talk old home clients out of batt insulation, because batts are specifically made for fixed-width stud cavities. Old houses are filled with irregularly sized stud and joist cavities (ranging from 17, 18, or 23 inches in a single wall). In these cases, the installer must cut batt insulation to size. Unless the installer is a pro (and many are not), you'll end up with voids or over-packed insulation, and insulation does not perform when it is compressed beyond its recommended depth.

Remember that R-value does not consider air infiltration, which mistakenly implies that all insulations with the same R-value will work the same. By their nature, spray foams both insulate *and* air seal; this is the core reason spray foam insulations offer such superior performance in older leak-prone homes. Also, unlike nearly every other insulation, closed cell spray foam works as a moisture barrier. An inch and a half of closed cell spray foam can prevent more heat loss than batt insulation up to eight inches thick. It can yield heating and cooling costs 1/2 that of other insulations and 1/4 the operating costs relative to having no insulation.

A SIMPLE SOLUTION: SPRAY FOAM

Spray foam is accepted as the best available insulation for its superior air sealing and its equal or better thermal values compared to traditional batts. Air sealing is particularly important in historic homes, which are exceedingly drafty. It is important that contractors and homeowners understand and take measures to address the ways houses were built differently 70+ years ago. Understanding how different foams deal with water and old house wall assemblies is imperative to evaluating their real costs and ben-

efits, and this understanding is the primary reason for my preference of closed cell foams on old houses.

There are two types of foam: open cell and closed cell. Open cell is light and has a spongy texture. It resists moisture absorption but can retain water and does allow water vapor to pass through. Closed cell foam is a rigid structural product that does not retain water or allow water vapor to pass through. Either product is applied in the same way, blown through a compressed air nozzle into a stud or roof cavity. Within seconds it expands from 50 to 150 times its original size and closes all air leakage pathways.

To avoid water in the wall, most new builders install an exterior housewrap. The housewrap keeps air-driven moisture out, but has a high permeability rating that allows for vapor trapped in the cavity to escape. In cold climates, where wintertime condensation in the wall cavity is a real possibility, a vapor barrier installed between sheetrock and studs keeps vapor from diffusing from a humidified home into the cavity.

Old homes often have no housewrap or other type of weather barrier, leaving no barrier between outside moisture (such as rain and snow) and the stud cavity. Wind-driven rain and moisture from infiltration and condensation have an easy path into the cavity where it can wreak havoc on any moisture-absorbing insulation. Water-saturated insulation has

FIGURE 8. Spray foam insulation fully fills the stud cavities, simultaneously insulating and air sealing.



a greatly reduced thermal value and is a playground for insects, mold, and other undesirables.

The logic is simple. 1) The leaky nature of old homes makes them susceptible to moisture issues, 2) moisture risks are increased through deep energy retrofits, and 3) all insulations absorb water except closed cell spray foam. Thus, closed cell spray foam is the best choice for historic retrofits.

The installation of the closed and open cell foams is relatively similar, though each requires different preparations and cleanup. Since it can absorb moisture, open cell requires a housewrap or other moisture barrier to protect it. Closed cell requires no such barrier. Open cell is over-sprayed beyond the stud cavity and the overage trimmed off with a hand saw after spraying, while closed cell is sprayed to 2- to 2.5-inch depths and requires no such cleanup.

As an added and often overlooked benefit, closed cell adds structural rigidity to the home. Many old houses are underframed because they were built prior to the emergence of the structural engineering profession and closed cell foam is a structural product that provides sheer strength and resistance to lift by locking studs and rafters in place.

CONCLUSION

Deep energy retrofits will benefit older and historic properties provided that they include both energy efficiency and moisture management design considerations. These retrofits should strive to keep energy improvements in balance with increased moisture control. A key, and often overlooked, element of the energy and moisture balance is air leakage. Air leakage in many ways is more important than insulation as excess air leakage can completely defeat any insulation benefit.

Ultimately, improving the thermal envelope makes old homes more affordable over the long term and reinvigorates the promise that the already built home is the greenest. Retrofitters of older properties

must be careful to not create new or exacerbate old problems. The Hippocratic Oath applies; first, do no harm, and this requires understanding building science in addition to the construction trade. Those avoiding such harm while simultaneously improving comfort and efficiency should find themselves very satisfied with the deep energy retrofit process, and most important, the results.

REFERENCES

- Advanced Energy. 2009. *A Quick Reference on Closed Crawl Spaces*, p. 4. Cited online September 25, 2009. advancedenergy.org/buildings/knowledge_library/crawl_spaces/pdfs/Closed%20Crawl%20Spaces_Quick%20Reference.pdf
- Dastur, Cyrus, and Bruce Davis. 2005. "Closed Crawlspaces Do Double Duty." *Home Energy* magazine (2005 Special Issue). Cited online July 3, 2009. environmentalbuilding.net/docs/cs_article_home_energy_mag.pdf.
- International Code Council. *International Residential Code, 2006*. Section R806.4 and 408.3.
- Katz, Arnie. *Survival of the Molds*. 2009. Advanced Energy website. Cited online August 13, 2009. advancedenergy.org/buildings/knowledge_library/indoor_air_quality/survival_of_the_molds.html.
- Lubeck, Aaron. 2010. *Green Restorations: Sustainable Building and Historic Homes*. Gabriola Island, BC: New Society Publishers.
- Lstriburek, Joe, Peter Yost, and John Straub. *Insulation Retrofits on Old Masonry Building*. Building Science Corporation, Green Building Advisor Podcast, Building Science Fundamentals.
- Lstriburek Joe, Peter Yost, John Straub, et al. 2010. "Air Barrier or Vapor Barrier?" Building Science Podcast: Air leaks are a big source of moisture problems that lead to bugs, mold, and rot in homes. March 10, 2010.

NOTE

The article focuses on experience in mixed humid climates, particular the southern United States. As such, readers should recognize the author's regional bias, and consider climate specifics of their design environment. Barriers strategy may be very different in the extreme cold of Canada, or the extreme dryness of Arizona.