Should the Walls of Historic Buildings Be Insulated?

WILLIAM B. ROSE

If the days of cheap energy are gone, why the hesitation about wall insulation?

Fig. 1. Infrared thermograph of a building eave area of Oldfields, Indianapolis Museum of Art, Indianapolis, showing warm surfaces (light) and cold spots (dark). The attic floor is insulated, and the walls are not. The walls were in good condition despite high indoor humidity. Courtesy of the Hillier Group.

Introduction

Historic buildings, like all buildings, must be operated with a commitment to energy economy. Current estimates of remaining petroleum reserves argue against wasteful practices in construction and building operation, especially in regard to space conditioning. However, even with that concern in mind, there is the possibility that the answer to the question posed in the title should be no. There are two principal reasons to consider not using insulation. First, thermal insulation will accelerate the degradation of exterior materials, although the rate of acceleration is open to speculation and question. Second, of all the energy-conserving strategies for historic buildings, thermal insulation in walls may be low on the list of likely strategies to have an effective payback.

Thermal Insulation and Degradation of Exterior Materials

Thermal insulation retards heat flow through building-envelope assemblies. Any wall assembly is made up of several insulating components, including interior and exterior air films, which play an important role in determining the temperature of interior and exterior building materials. Infrared thermography can provide a clear distinction between the insulated and uninsulated parts of a building by showing differences in surface temperature. An infrared thermograph of the area around the eaves shows warm spots as light shades and cold spots as dark (Fig. 1). The uninsulated clay-tile walls of this building were in good condition despite several winters of indoor humidification to levels of 50 percent and higher.

The principle linking temperature and durability in building materials is this: for the same moisture concentration in the air, materials that are kept warm are dry, while materials that get cold are wet. This relationship between temperature and wetness is evident with wood, for example. The sorption isotherm for wood is well known.[1] It shows the dependence of wood's moisture content on relative humidity. For the same relative humidity, wood has roughly the same moisture content regardless of the ambient temperature at which the relative humidity is achieved (Fig. 2). Figure 3 shows the standard psychrometric relation between temperature and vapor pressure.[2] Figures 2 and 3 can be combined to show the relationship between temperature and wood moisture content at a single value of vapor pressure (Fig. 4). What is clear from Figure 4 is that at cold temperatures, a large difference in material wetness may occur for small differences in surface temperature.

During cold weather wall insulation leaves exterior materials colder. (Insulation also leaves interior materials warmer, which greatly increases its desirability.) The wetting effect presented in the discussion above is independent of the indoor humidity and the effects of interior vapor protection. For more than 50 years, the wetting effects of insulation alone have been masked by the association of the vapor-barrier discussion to wall wetness.[3] This attachment of the vapor-barrier discussion to the issue of wall wetness is most apparent in National Park Service Preservation Brief 3, which, in its current form, gives the impression that care in vapor-barrier selection and placement is sufficient protection against wetness when insulation is added to walls (an updating of Preservation Brief 3 is underway by the National Park Service). The aim here is to show that part of the wetness of exterior materials is independent of vapor-barrier design, specification, and installation.[4]

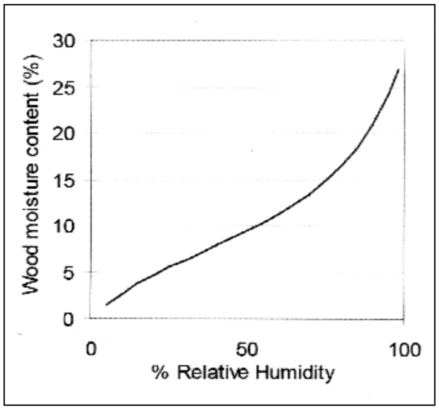

Fig. 2. The sorption isotherm for wood, which compares wood moisture content to relative humidity at several different temperatures (°F). All charts by the author.

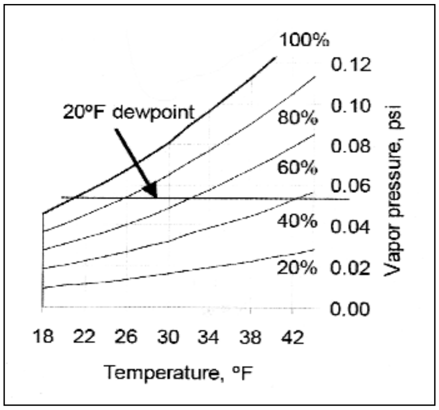

Fig. 3. The relationship of vapor pressure in the air to temperature, showing in particular that at a single vapor pressure (any horizontal line) relative humidity is a function of temperature.

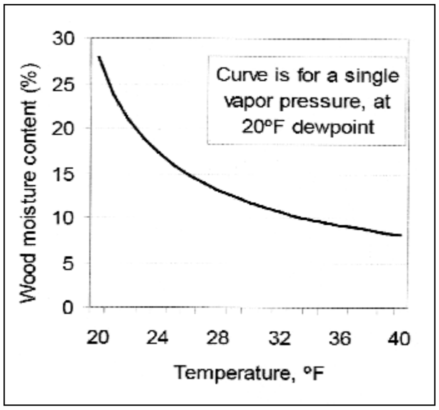

Fig. 4. The combination of findings from Figures 2 and 3 shows that for a single vapor pressure (the vapor pressure of 20-degree dewpoint air in this case), wood moisture content is a strong function of temperature.

Wetness in exterior-wall materials can originate from either inside or outside. The relative contribution of indoor moisture and outdoor humidity can be seen by using the dewpoint profile method.[5] Call indoor vapor pressure p_i and outdoor vapor pressure p_o. The profile method calculates the vapor-pressure gradient through the wall assembly from p_i to p_o. But this profile can be seen as the sum of two profiles, from p_i to 0 (representing the effect of indoor humidity only) and from 0 to p_o (representing only outdoor humidity). Figure 5 shows the profile from 0 (indoors) to p_o, and, positioned directly above, the profile from p_i to 0 (outdoors). It should be clear that the contribution from outdoors — a sizeable amount in insulated walls — is relatively unaffected by the presence or absence of a vapor barrier. In other words, a significant amount of the wetting that occurs as a consequence of the use of insulation cannot be affected significantly by any vapor-barrier strategies. During cold weather, insulation itself makes exterior materials wetter. Of course, precipitation is also a factor, so the wetting effect from outdoors is much greater than this analysis suggests.

The wetting effects of insulation are seen better using transient hygrothermal modeling. Two modeling computer programs are available and widely used: MOIST, from the National Institute of Standards and Technology (NIST), serves as a good introduction to transient modeling.[6] The program is free and easily downloadable. The material-property data were measured at NIST laboratories. Unfortunately the program is not maintained, and users who encounter problems have no recourse. WUFI, the other widely used program, was developed at Fraunhofer Institute for Building Physics in Germany, originally for the study of German historic buildings.[7] It has been adapted for use in North America by Oak Ridge National Laboratory (ORNL). An education version (not for commercial use) is available at no cost, but it provides only graphic, not data, output. WUFI, however, has the distinct advantages of being supported and allowing the effects of rain to be included. Both programs allow the components of a building-envelope assembly to be entered and hourly weather for a nearby city to be selected. Once the data on the envelope assembly are entered, it is a simple matter to run the program both with and without insulation and with and without a vapor barrier. There are several outputs for both programs available, including instantaneous and average moisture content. With such programs, the wetting effects from outdoors can be estimated.

ASHRAE steady-state analysis uses vapor diffusion as the moisture-transport mechanism. Transient analysis includes capillary transport in porous materials, as well. Capillary flow is a function of moisture content and of temperature; capillary rise is greater in smaller capillary tubes, of course, but it is also greater in cold materials. If exterior materials are wetted by rain, then cold materials have lower evaporative drying rates than warm materials. Water will reside in or on cold materials longer than it will reside on warm materials, and it will reside there at lower temperatures. In short, cold temperatures keep porous materials wetter for longer in three ways: from natural equilibrium wetting from the outdoor air; from greater capillary conductivity at low temperatures; and from retarded rates of drying following wetting by precipitation.

Dryness usually enhances building durability, while wetness provides the occasion for many types of distress. Decay fungi become active in wet organic materials.[8] Metal corrosion tends to occur on damp surfaces where the surface-water film permits access to both water and oxygen.[9] Spalling and efflorescence in masonry materials is usually associated with high water content. Can the magnitude of moisture-caused degradation associated with the thermal effects of insulation be estimated? Only roughly, it turns out.

Decay of solid wood materials in wood-frame walls is usually associated with poor flashing details or soil contact.[10] Decay is rarely due to the presence of insulation as described here. The most common form of damage on wood-frame walls from the combined effects of temperature and ambient vapor pressure is paint peeling. The principal causes of paint peeling are

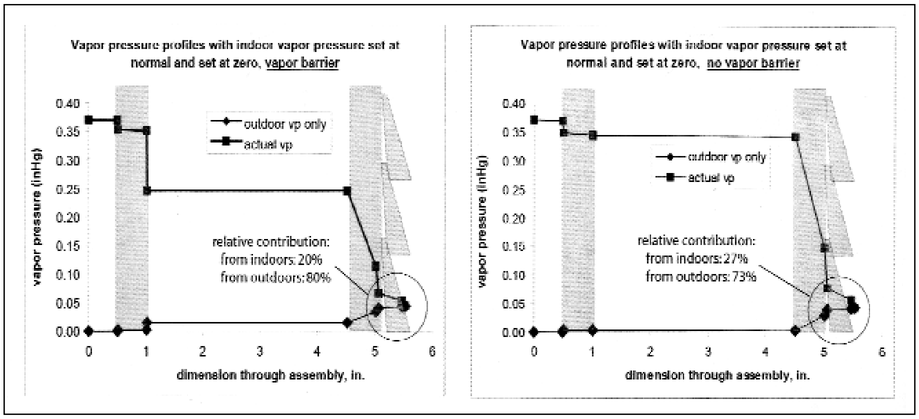

Fig. 5. ASHRAE-profile analysis of wood-frame walls with and without a vapor barrier. A vapor-pressure profile through a wall can be seen as the sum of two profiles, with the interior and exterior vapor pressure set to 0 respectively. Both diagrams show the profile 0 (indoors) to p_o (outdoors), and placed directly above it, the profile from p_i (indoors) to 0 (outdoors). Breaking the standard profile into two parts shows the relative contribution of indoor and outdoor humidity. Both with and without a vapor barrier, much of the water in exterior materials comes from outdoors.

poor substrate preparation, low-quality paint, poor priming, and poor detailing where rainwater is channeled.

In the 1930s complaints of house painters about paint peeling on insulated buildings led to a study of moisture in building envelopes at the U.S. Forest Products Laboratory in Madison, Wisconsin, first by F. L. Browne, a paint chemist, and later by L. V. Teesdale, a senior researcher. The standard moisture-control strategies of the past 50 years (attic ventilation, vapor barriers, crawl-space ventilation) originated with Teesdale in 1937. He recognized that the temperature reduction of exterior materials in insulated buildings led to wetting: "insulation, because of its efficiency in reducing heat loss, lowers the temperatures within the wall and thus sets up the condition that increases the amount of moisture that may accumulate."[11]

But he was such a strong supporter of insulation for buildings that he narrowed his recommendations to the use of vapor barriers and attic ventilation, and the wetting effects of insulation alone dropped out of sight.

In masonry assemblies wetness may appear as efflorescence, hastened loss of mortar in joints, or, in severe cases, spalling. In cold brickwork the evaporation of bound water absorbed into the brick is retarded, resulting in longer periods during which the water may freeze. In cold brickwork capillary movement of water is also accelerated. In buildings subject to rising damp, cold conditions may cause water to rise higher in the wall, and the water may carry efflorescing salts.

To estimate the severity of distress that can be caused by insulating masonry walls, the best approach is to bracket the range of possible conditions. Parapets, landscaping fences, wing walls, garden structures, and garages are all examples of unheated assemblies. They often show greater distress than building walls nearby. The unheated assemblies may, in many cases, be more exposed to weather than the more protected walls of buildings, so a straight comparison of condition may be misleading. Parapets and garden walls weather on two sides, not just one. In particular, building details such as overhangs usually provide much more protection to masonry than any detailing provided to parapets or garden walls. Nevertheless, the heated and unheated bracketing conditions of building walls can be roughly estimated from such observations, while recognizing that there are other significant weathering effects besides the lack of heat. Professionals should take note wherever possible of the condition of parapets and unheated masonry work in the landscape with varying levels of weather exposure. In particular, professionals should note whether buildings that have been insulated have shown an increase in distress after the insulation was installed.

Some exterior wood and masonry walls may be so sufficiently robust that the addition of insulation produces no significant change in the service life of those materials. Wall finishes that

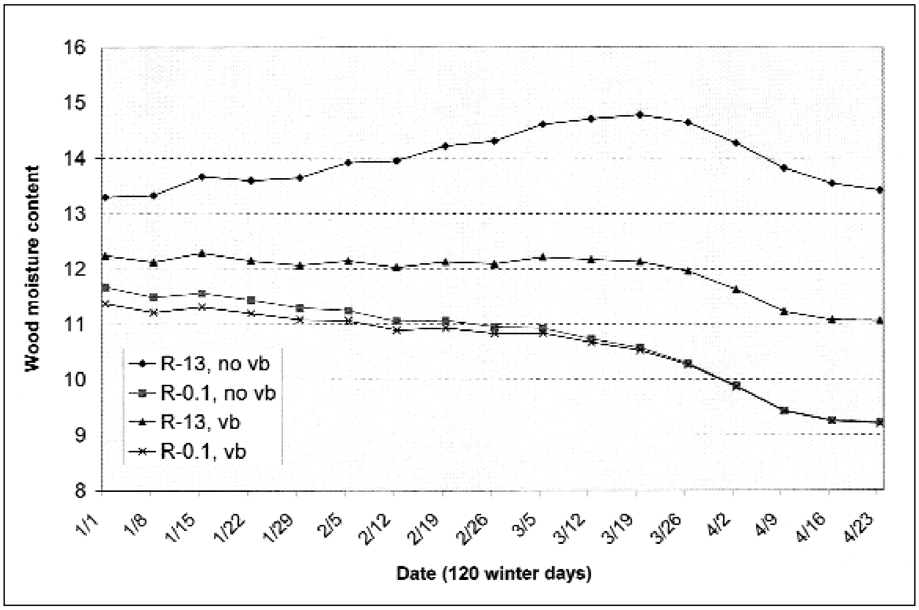

Fig. 6. Moisture content of clapboard, estimated using MOIST. Assume plaster interior, wood-frame cavity, and wood sheathing. Note that the clapboards of the two insulated walls are wetter than the clapboards of the two uninsulated walls. In this example, all of the moisture contents are low enough to resist biological degradation. However, paint finishes may be affected.

appear uniform in condition — that show the same performance regardless of whether they protrude from the building or not — are probably good candidates for insulation. Wall finishes that show a wide variation in performance with differences in configuration may show worsened performance with the addition of insulation. While it is difficult to estimate the extent to which adding insulation may shorten the service life of claddings and finishes, adding insulation generally does not enhance service life. Generally the temperature and moisture effects of adding insulation are small; thus they have minor effect on performance (Figs. 6 and 7). But if the exteriors are noticeably subject to weathering effects, then the incremental change associated with adding insulation may be more significant. Professional judgment must come into play, based on the apparent robustness of exterior materials and finishes and on the professional's observations of the performance of unheated structures.

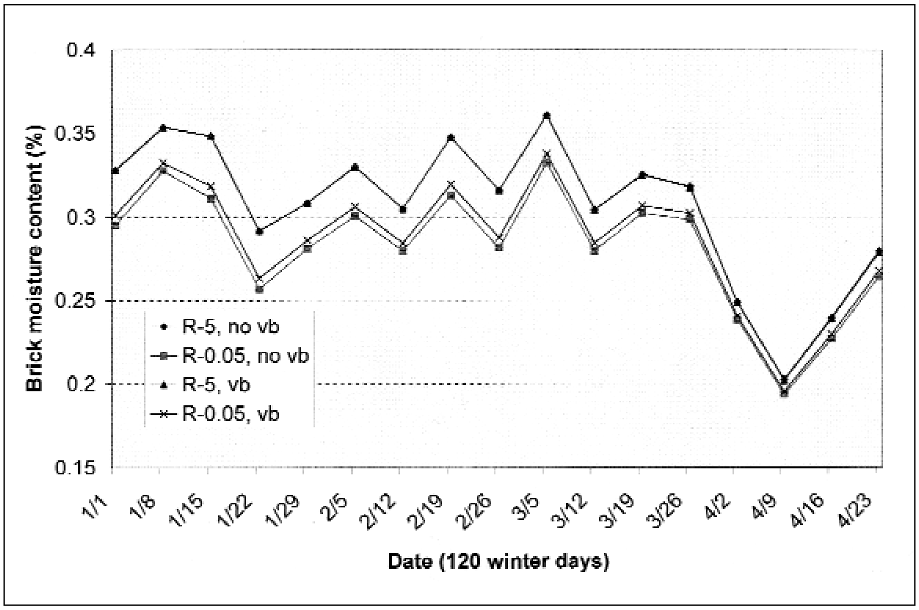

Fig. 7. Moisture content of brick (estimated at a depth of half inch inward from the exterior) in two-wythe construction with furring and plaster interior. Note that the exterior brick in the two insulated walls is wetter than the exterior brick in the uninsulated walls. (Note also that the wall with the vapor barrier is slightly wetter than the wall without a barrier, indicating the strength of wetting from the outside.) For most brickwork this difference in moisture content would not translate to a significant difference in performance.

Strategies for Improving Energy Efficiency in Historic Buildings

Older buildings are considered by many to be wasteful of energy. This perception is far from correct. The embodied energy in the building materials is often a fully depreciated investment and one that stands up to many life-cycle cost analyses.[12] The U.S. Department of Energy's data on energy consumption shows that older residential buildings have higher energy usage for space conditioning and that houses built during the 1970s energy crisis show the greatest energy economy.[13] But the data also show that commercial buildings have increasing energy expenditures with later dates of construction. Many factors may contribute here, including air-conditioning, lighting, and ventilation improvements occurring in newer buildings (Fig. 8).[14]

The first question to ask in energy-retrofit considerations of historic buildings is this: does the energy-use profile need correction at all? It may not.

Energy-use questions usually arise in the course of planning for major work, often a change in use or size of the building. A building code such as the 2003 *International Existing Building Code* identifies four levels of intervention and specifies appropriate levels of compliance with provisions that would apply to new buildings. The bigger the job, the closer the existing building will be expected to be brought to levels of code provisions for new buildings.

There are several factors that affect the space-conditioning costs in historic buildings. Ranking these factors depends on the peculiarities of the building, climate, and use, of course. A general ranking of these factors, based on the author's experience, would include:

1. *Air-conditioning*. Buildings that shift to the use of air-conditioning usually see a jump in space-conditioning costs. No one saves energy with the installation of air-conditioning. Much of the energy consumed with air-conditioning is dehumidification. Money spent on dehumidification is wasted in leaky buildings.
2. *Infiltration*. All buildings require conditioning for air that enters. Large buildings with air-handling units may have larger air-change rates (so higher conditioning costs), due to building pressurization or depressurization. As mentioned above, air-tightness is very desirable in buildings with air-conditioning. Infiltration is the wild card in energy estimates and use.
3. *Temperature and humidity settings*. Allowing drift of interior conditions with changes in outdoor conditions within a comfortable range is often the most economical practice. Heating during cold periods is, of course, beneficial for building durability. Controlling indoor conditions to narrow variance over daily and seasonal fluctuations is rarely recommended. For more information on settings, see the *New Orleans Charter for Joint Preservation of Historic Structures and Artifacts*.[15]
4. *Equipment efficiency*. Older combustion equipment intentionally ensured that a large percent of the heat generated was used to heat the chimney to ensure better evacuation of combustion products (including moisture) from the building. With improvement in energy efficiency of heating equipment, conditions at natural-draft chimneys require consideration. Newer condensing equipment helps ensure good evacuation of combustion products by mechanical rather than natural buoyancy means.

5. *Windows*. During winter much heat loss occurs through windows; during summer much of the cooling load occurs by solar gain through windows. Both of these concerns can be addressed by making use of shutters on the outdoors and drapes and blinds on the indoors. Preservationists rarely recommend window replacement for historic buildings. Storm windows, on the other hand, are regularly recommended.
6. *Attics*. Old attics were partially conditioned spaces: small amounts of insulation in the floor allowed the roof assembly to stay free from frost during cold weather. Attic ventilation began to be recommended in 1938 and required in FHA housing in 1942. It is generally wise to ensure high levels of insulation in the attic or roof system and to ensure that equipment or duct losses are minimized in the unconditioned space of an attic. When frost occurs, it usually occurs on nail points that protrude through the sheathing. Only in the last few decades have roofers stopped taking the precautions that earlier roofers took to make sure nail points did not protrude. Protruding nail points can be snipped off. Widespread frosting in an attic is usually a sign of excessively high humidity in the foundation area or the living space; local frosting is usually a sign of a hole in the ceiling.
7. *Wall insulation*. The theoretical energy savings due to increased thermal resistance in the wall can be easily, if roughly, calculated using a degree-day analysis. As an example, assume 2,000 square feet of opaque wall area, 5,000 degree days, \$0.10 per therm (full efficiency), and an R-6 improvement in the wall. Then the theoretical wintertime conductive heat loss savings amount to \$40.

$$2000\text{sf} \times 5000\text{F}\bullet\text{day} \times \frac{24\text{ hr}}{\text{day}} \times \frac{1\text{ Btu}}{6\text{hr}\bullet\text{sf}\bullet\text{F}}$$

$$\times \frac{1\text{ therm}}{100{,}000\text{Btu}} \times \frac{\$0.10}{\text{therm}} = \$40$$

   Actual energy savings from wall insulation, as from other retrofits, is often lower than the theoretical savings.[16]
8. *Basements*. Interior basement insulation is rarely successful. Water entering from behind or below the walls usually leaves the finish materials damaged. The best approach for energy saving (and for ensuring dry conditions) is to manage rainwater at the exterior so that the soil in contact with the foundation remains dry. Dry soil is a good thermal resistor, and a thick cushion of dry soil surrounding the building provides optimum savings.

From the list above it might appear that wall insulation is a minor contributor to energy-conservation strategies. The potential for savings from insulating attics, for example, is certainly greater because of the reduced cost of installation and the room for higher R-values. A total outfitting of a historic building for cost-effective energy-retrofit performance may be complete with no intervention in the walls at all. However, there are other, often compelling, reasons to consider wall insulation:

- Insulated walls give greater comfort during cold weather.
- Poorly insulated walls in buildings that are humid in cold weather can show signs of discoloration and mold at cold spots (thermal bridges).
- Adding insulation may be part of an overall strategy to reduce air infiltration.

If the decision is made to install insulation in walls, then several concerns apply. Solid masonry walls do not lend themselves easily to the addition of insulation. Insulation is rarely added outside for reasons of appearance. If it is added at the inside, then the interface where the masonry surface meets the insulation surface is maintained at a cold temperature in cold weather. Any discontinuities in the insulation, such as at partitions or floors, show up as cold lines. This is due to the temperature gradient between the inside masonry surface in the uninsulated zone (high temperature) and in the insulated zone (cold temperature). The midpoint of the gradient occurs roughly at the edge of the insulation. So adding insulation creates a cold edge around the insulation that is considerably colder than the inside surface of the uninsulated wall. A cold spot may be a site of condensation or mold growth if the surface-water activity A_w is greater than 0.8 for one month or more.

Wood-frame structures lend themselves more easily to insulation, though with cautions. If the exterior cladding appears equipped to withstand colder temperatures and longer periods of wetting, then cavity insulation is recommended. Several insulation strategies are possible depending on the amount of demolition anticipated. Filling wood cavities blind, without removing either the interior or exterior finishes, is often done, although the completeness of the

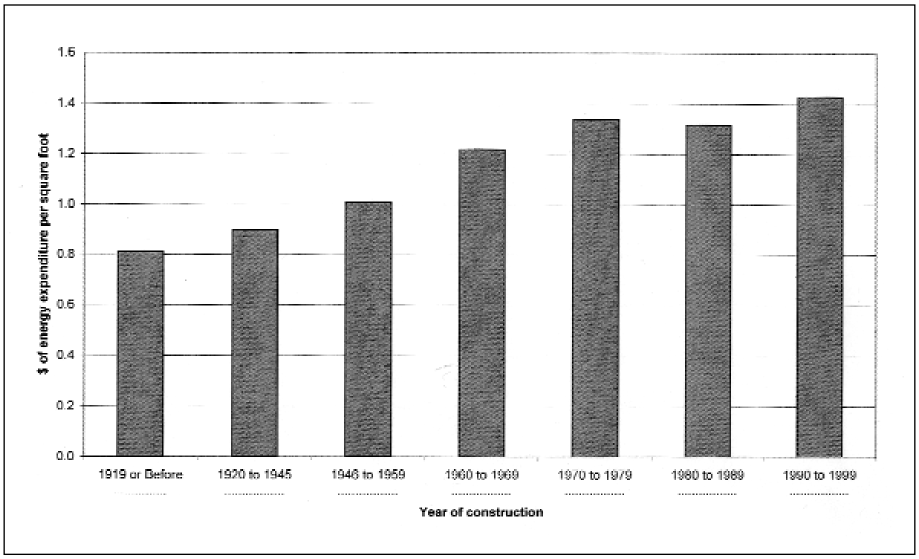

Fig. 8. Energy expenditures in commercial buildings on a square-foot basis depending on age of the building. (Energy expenditures in residential buildings do not follow this trend.)

job is difficult to verify. If the interior or exterior finishes are removed, then the full range of insulation material may be applied: fiberglass batts; fiberglass loose-fill; cellulose (usually applied as wet-spray, which requires drying, with fire-retardant salts that raise a concern for corrosion); urethane foam (blown with HCFCs, raising environmental concerns); "open cell" foams blown with benign gases, such as CO_2; rigid foam; rockwool; and many others. Spray-applied foams attach tightly to building materials and may raise concerns about reversibility. In re-covering the cavity, gypsum wallboard should not be considered the equivalent of plaster in overall performance. In short, doing a verifiably good job of adding insulation in existing buildings typically requires a significant loss of original material.

Building codes are beginning to downplay the importance once attached to vapor barriers. In general, polyethylene is suited to insulated buildings in Canadian climates, while kraft facings are good for insulated assemblies in the northern third of the U.S., and no interior vapor protection is best for the warmer part of the U.S.[17]

Conclusion

The mandate to conserve energy in all buildings, including historic buildings, does not automatically translate into an imperative for wall insulation. Wall insulation retards conductive heat loss and may retard infiltration heat loss, but its overall contribution to energy performance deserves close study.

Wall insulation makes exterior materials more subject to weathering forces. If the weathering performance in an uninsulated building is marginal, it may become unacceptable with insulation. On the other hand, if the exterior materials are robust, they should withstand the addition of insulation with little change in service life or maintenance costs. It is not easy to estimate the effects of adding insulation, but they may be approached by comparing the performance of assemblies that benefit from waste heat during cold weather with those that do not and judging where between those two bracketing conditions the outcome of adding insulation might lie. Thermography and modeling may provide some professional assistance.

In most historic structures other strategies for energy conservation should be considered to have higher priority than wall insulation. These include (based on the list above), forgoing air-conditioning, reducing infiltration, allowing float in interior temperature and humidity settings, using energy-efficient equipment, and operating windows effectively. Attic insulation is easier to install and contributes more effectively to reducing heat loss than adding wall insulation.

WILLIAM B. ROSE is a research architect with the Building Research Council at the University of Illinois-Urbana.

Notes

1. William Simpson and Anton TenWolde, "Physical Properties and Moisture Relations of Wood," in *Wood Handbook: Wood as an Engineering Material* (Madison, Wisc.: U.S. Dept. of Agriculture, Forest Service, Forest Products Laboratory, 1999), http://www.fpl.fs.fed.us/documnts/fplgtr/fplgtr113/ch03.pdf (accessed September 28, 2005).

2. At room temperature liquid water does not remain completely liquid. Some molecules will leave the water surface and mix with the air. The portion of air pressure contributed by the water molecules (one molecule out of a hundred at normal conditions) is termed the "partial pressure of water". This precise term of thermodynamics is corrupted here to the term "vapor pressure."

3. William B. Rose, "Moisture Control in the Modern Building Envelope: History of the Vapor Barrier in the U.S., 1923-52," *APT Bulletin* 28, no. 4 (1997): 13-19.

4. William B. Rose, *Water in Buildings: An Architect's Guide to Moisture and Mold* (Hoboken, N.J.: John Wiley & Sons, 2005).

5. American Society of Heating, Refrigerating and Air-conditioning Engineers, "Thermal and Moisture Control in Insulated Assemblies: Fundamentals" in *ASHRAE Handbook*, vol. 1, *Fundamentals* (Atlanta: ASHRAE, 2005), 23.1-23.32.

6. This program can be downloaded free at http://www.bfrl.nist.gov/863/moist.html (accessed September 28, 2005).

7. This program can be downloaded at http://www.ornl.gov/sci/btc/apps/moisture/ (accessed September 28, 2005).

8. Energy Conservation in Buildings and Community Systems, Annex 14, *Condensation and Energy: Guidelines and Practice* (Leuven, Belgium: ECBCS, 1990). This guideline sets a threshold of water activity at 0.8 (or 80 percent surface relative humidity) on a monthly mean basis.

9. L. Harriman, G. Bundrette, and R. Kittler, *Humidity Control Design Guide for Commercial and Industrial Buildings* (Atlanta: ASHRAE, 2001).

10. Deterioration not of solid wood but of wood-panel products, which may occur from the combined effects of high interior-moisture load, insulation in the assembly, and outdoor vapor pressure, is not considered in this paper.

11. L. V. Teesdale, *Condensation in Walls and Attics* (Madison, Wisc.: U.S. Dept. of Agriculture, Forest Service, 1937).

12. Some may view energy inefficiency in older buildings as arguing against preservation. Blanchard and Reppe point out that the life-cycle energy consumption of a typical new house is 2,525 barrels of oil, only 6.3 percent of which is embodied energy (http://www.umich.edu/~nppcpub/research/lcahome). A more complete analysis that includes the marginal benefits in energy efficiency between an old and new building usually gives more weight to preservation.

13. Information on residential buildings is available at http://www.eia.doe.gov/emeu/recs/recs2001/ce_pdf/enduse/ce1-2e_construction2001.pdf (accessed September 28, 2005). Information on commercial buildings is available at http://www.eia.doe.gov/emeu/cbecs/pdf/consumption_inten.pdf (accessed September 28, 2005).

14. Thanks to Jim Cavallo for pointing out the data.

15. This charter is available online at http://palimpsest.stanford.edu/bytopic/ethics/neworlea.html (accessed September 28, 2005).

16. M. Blasnik, unpublished report, Illinois Weatherization Energy Evaluation Millennium Project, 2004.

17. See recently adopted revisions to 2005 *International Residential Code*, as yet unpublished.