Retrofitted Wall Insulation: A State-of-the-Art Review

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ABSTRACT

This paper is a state of the art review of retrofitting of wall insulation in residences. The characteristics of the available insulating materials are summarized. The influence of a variety of factors on the thermal performance of wall insulation, as well as on the overall building's energy use, is assessed. It was found that the addition of wall insulation typically reduces the overall building energy use more than is usually predicted. Numerous potential side effects are also discussed. Other concerns are addressed, including the need for infrared thermographic inspection programs and a possible derating of the R-values of insulations to account for the substantial influence of typical void areas. The fact that some insulating types seem preferable to others is noted. The advisability ofutility-sponsored wall insulation retrofitting programs is discussed. Finally, recommendations for further study are presented.

INTRODUCTION

In a typical existing residence having ceiling insulation and storm windows, about 25% of the energy used is lost through uninsulated walls if the floor is not insulated, and about 45% is lost if the floor is insulated. Since adding conventional blown-in insulation can reduce the rate of heat loss through walls by about 70%, major energy savings can be achieved. Even so, retrofitting wall insulation has been a relatively low-priority conservation measure for both homeowners and utilities. There are a combination of reasons for this, including the relatively poor payback, difficulties with inspection, a variety of concerns over performance and potential problems, and widespread misinformation regarding both insulating materials and many of their advantages and potential disadvantages.

However, given that the cost of retrofitted wall insulation is generally much cheaper than the cost of new power generation, and given the huge potential energy savings possible, it is likely that sooner or later most all residential walls will be insulated unless there are major problems in doing so. Thus, it appeared worthwhile to review the state of the art of the retrofitting of wall insulation in residences and summarize its status as an energy conservation measure. To that end, the characteristics of the various available insulating materials and approaches will be described in this paper, with emphasis on their thermal performance. Side effects that result from retrofitting will also be discussed, as will such topics as quality control and advisability of a major utility-sponsored wall insulation retrofitting program. Finally, recommendations for further needed study will be presented. The material contained in this paper is from a more comprehensive detailed report.[1]

HEAT TRANSFER THROUGH WALLS

Thermal insulation is used in walls to minimize radiative, convective, and gas conductive heat transfer, while contributing only minimally to solid conductive heat transfer. The magnitude of the total heat transfer depends on the temperature difference across the wall,

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the wall surface area, and the thermal characteristics of the wall and the surrounding air films. The resistance to heat transfer is indicated by the so-called R-value of the wall or its insulation.[2] The greater the wall's total R-value, the lower the rate of heat transfer. The total R-value of the wall is the sum of the individual component R-values, including the insulation. One of the best kinds of insulation is simply dead (motionless) air space. The majority of current building insulation materials consist of a solid material, typically in the form of small particles or fiber strands, that creates numerous small air pockets. Those pockets minimize convection heat transfer, whereas the large number of solid particles act to absorb radiation with only a minimal amount of heat transfer in the form of conduction. For materials containing air, the maximum R-value per inch (meter) of thickness must be below about 5.8 $hr \cdot ft^2 \cdot °F/Btu \cdot in.$ (40.2 $m \cdot °C/W$). That is because the thermal resistance to conductive heat transfer (R-value) per inch of thickness, which is sometimes called the resistivity of the material, is given by the reciprocal of the material's thermal conductivity. The thermal conductivity of dead air alone is 0.172 $Btu \cdot in./hr \cdot ft^2 \cdot °F$ (0.0248 $W/m \cdot °C$) at 50°F (10°C).[3] Some closed-cell plastic foams contain a fluorocarbon gas having a lower thermal conductivity than air, and thus can have slightly higher R-values per inch of thickness. One of the highest R-values per inch is 7.04 for aged, foil-faced isocyanurate rigid board, whereas most blown-in wall insulations are about R-3 per inch of thickness.[4]

TYPES OF WALL INSULATION

There are a variety of ways to insulate existing walls. The most common approach is to blow loose-fill or foam insulation into the wall cavity. Another lesser-used technique involves removing the inner or outer wall surface so that conventional batt insulation or, perhaps, reflective foil insulation can be added inside the wall cavity. This is most often done during renovation or remodelling of older buildings or in conjunction with the need for new wallboard or siding. The final major method involves moving one of the wall surfaces inward or outward to make a thicker wall with added insulation; rigid foam insulating board is often used in that situation. The latter two approaches generally have not been used strictly to save energy because they normally involve considerably greater cost than does just filling insulation into an empty wall cavity.

The various types of insulation used to insulate existing walls fall into two broad categories: those that are filled into a wall cavity, typically through holes in the outside surface, and those that are actually installed in the wall cavity or added to the inside or outside of the wall. The specific types in each category are shown in Fig. 1. The types filled into the wall cavity are either loose-filled (typically blown or sometimes poured in) or foamed-in-place. Almost all retrofitting of wall insulation has been done with urea-formaldehyde (U-F) foam (use now banned) or blown-in loose-fill fiberglass, rock wool, or cellulose. In the following sections the general characteristics of each insulation will be briefly described. Greater detail and documentation will be presented in later sections.

Loose-Fill Insulation

Cellulose. Cellulose is generally made from shredded recycled newsprint or other paper stock. Because paper is flammable, the cellulose insulation is treated with a dry fire retardant (usually boric acid, borax, or ammonium sulfate) to reduce the flammability to acceptable levels. However, the most widely used retardents are known to evaporate and are not particularly effective in preventing smoldering combustion. Moreover, some fire retardants, such as ammonium sulfate,can cause corrosion of metals. Although cellulose is generally felt to be one of the best wall retrofit insulations, there are potential hazards associated with its use. Thus, it cannot be recommended.

Fiberglass. Fiberglass is a member of the generic mineral wool family. It is often referred to as glass wool or mineral wool. To make it, glass raw materials are melted and made into small diameter fibers. Thermosetting resin is usually added to bind the fibers together, and then the material is shredded into what is known as blowing wool for retrofit applications. A new unbonded blowing wool has been designed to achieve more effective installation and performance.[5] Nonetheless, while blowing wool is a consistent performer, its use cannot be recommended, except for a few products, because it has one of the lower R-values per inch of thickness and is relatively expensive.

Rock Wool. As the other member of the generic mineral wool family, rock wool is very similar to fiberglass, except that it is normally made from the byproduct slag (a rock-like material) produced in the manufacture of steel and other metals or by melting and fiberizing naturally occurring rock. The properties of rock wool, or slag wool as it is sometimes called, are nearly identical to those of fiberglass, except that the R-value of rock wool is somewhat higher than that of loose fiberglass. The installed cost of rock wool is only slightly greater than that of cellulose.[6] In the author's opinion, blown-in rock wool is currently the best overall insulating material for the retrofitting of existing walls.

Vermiculite and Perlite. These materials can be blown or poured into walls, but the practice is not common. They are used primarily for insulating concrete block or masonry walls by pouring into the block cores or the cavity between exterior and interior walls. Although there is considerable variation in their reported R-values, they are relatively low, and their price per unit R-value is relatively high. Thus, their use is not recommended except where ease of pour-in is a major consideration.

Foamed or Formed-in-Place Insulation

Urea-Formaldehyde (U-F) Foam. U-F foam is produced at the site by mixing an aqueous solution of a U-F based resin, an aqueous solution foaming agent that includes a hardening agent, and compressed air in an applicator gun. The foam expands in the gun to a shaving cream-like consistency and then is blown into the wall cavities without further expansion. It hardens within a minute or so. Initially the foam is about 75% water by weight. After the foam is blown into the wall cavities, formaldehyde is then gradually replaced by air in the open-cell structure of the foam over a period of months. Further formaldehyde outgassing can continue at a lower rate for years. Because of substantial shrinkage, U-F foam is subject to considerable degradation of performance. Most importantly, its use in residences has been banned in the United States because of potential health hazards associated with the formaldehyde outgassing. A difficult question for homeowners who have already had U-F foam insulation installed is whether or not they should have it removed.

Polyurethane Foam. Polyurethane foam, or urethane for short, can be foamed in place for retrofitting existing walls, is available as rigid board stock for addition to the inside or outside of a wall, and can be sprayed on when a wall cavity is fully opened up. However, very few contractors pump it through holes into existing residential wall cavities. One reason is because the foam expands within the wall cavity and is difficult to fill without popping nails or busting the wallboard. Furthermore, the installation equipment is relatively expensive, and the installation process is relatively dangerous because the urethane resins are toxic. The major advantage of foamed in place urethane is its relatively high R-value per inch of about 6 after aging.[7] That is offset by its relatively high cost and its potential fire hazard. Although relatively difficult to ignite, once burning it releases a good deal of smoke which contains lethal hydrogen cyanide gas. That is why codes require it and other foams to be covered with a fire barrier material on inside wall surfaces. In curing and aging, it can expand or shrink, and the effect of shrinkage on thermal performance could be substantial.

Polyisocyanurate. Isocyanurate is a relatively new cellular foam that is chemically and physically similar to urethane. Along with urethane, its aged R-value of about 7 per inch is one of the highest yet available for aluminum-faced rigid board used in conventional building applications.[8] For retrofitting of residential sidewalls, one blow-in product claims an R-value of 4.5 per inch. As with urethane, its main application is as a rigid insulating board, rather than as a retrofitting insulation material.

Polystyrene. Polystyrene is available either in the form of rigid board or small (rigid) expanded polystyrene (EPS) beads in loose-fill form. The board material is made either by extrusion or molding of expanded polystyrene beads. The latter molded material is commonly called beadboard, whereas the extruded material is best known by its trade name "Styrofoam". Beadboard tends to shrink or warp more than the denser, stronger extruded polystyrene. Although the extruded version has a somewhat higher R-value, it is also more expensive. As with all other rigid foams, the board type should be covered with a fire barrier. A recent development for retrofitting existing walls involves blowing expanded polystyrene beads mixed with a liquid binder into walls where the mixture solidifies.[9] Nominal R-values are comparable to good loose-fill insulations, but the cost is somewhat higher and long-term performance is as yet unknown.

Polyurea. Polyurea is a new foam[10,11] derived from urethane technology and developed specifically for sidewall applications. It contains no formaldehyde gas. It reportedly does not shrink because the foam catains 85 to 90% open cells.[12] Like Urethane foam, it is flammable and does release cyanide gas when it burns. Its R-value of 3.2 per inch[13] is about the same as the major non-foam blow-in materials. Polyurea foam, like urethane, expands in the wall cavity. Again, long-term performance is as yet undetermined and cost is relatively high. It is not widely used.

Insulation Installed in or Added to Wall Cavity

There are a number of ways of installing insulation in a wall cavity or adding it to a wall cavity that are nonconventional for retrofitting. They include the use of reflective foil, insulating plaster or foamed gypsumboard, added rigid foam board, or conventional batts. Because the wall board or siding must be removed to install these types, they will not be widely used for retrofitting and will not be further discussed here (See Ref 14 for more detail).

THERMAL CHARACTERISTICS OF WALL INSULATION

The nominal R-values per inch of thickness for each of the wall insulation materials discussed are presented in Tab. 1. It should be noted that different, often conflicting, values can be found in different sources. In part, this is because R-values depend somewhat on conditions such as density and temperature and it is not uncommmon to find values for different materials quoted at different conditions. While the nominal R-values quoted in Tab. 1 are of considerable utility, it is important to note that there are a number of factors that influence the actual thermal performance of insulation retrofitted in an existing wall. The actual R-value of an installed insulation material is often different than the nominal value. Each of the major factors influencing thermal performance will be discussed as they relate to the insulation materials described earlier.

Factors Influencing Thermal Performance

Installed Insulation Density. As noted elsewhere[45] and in Tab. 1, the thermal conductivity or the R-value of many insulation materials is dependent on the installed density. For many materials an optimum density exists that maximuzes its thermal resistance. If the installed density is different than that optimum value, either because of improper installation or possibly because an installer wants to save on material costs, then the performance of the insulation material can be adversely affected. In two separate field investigations,[46,47] the density of blown rock wool removed from five sidewalls ranged between 1.7 and 8.8 lbm/ft^3 (27.2 and 141.0 kg/m^3). The R-value at the lower density is about 15% lower than it would have been at the optimum density.[48] For loose-fill fiberglass, the density of three samples removed from existing walls ranged from 1.7 to 2.9 lbm/ft^3 (27.2 and 46.5 kg/m^3).[49] The industry-recommended density for application in wall cavities is 2.0 lbm/ft^3 (32.0 kg.m^3).[50] The ASHRAE Handbook--1981 Fundamentals Volume indicates a range of 0.6 to 2.0 lbm/ft^3 (9.6 to 32.0 kg/m^3) for loose-fill mineral wools.[51] The upper limit applies to wall installation, whereas the lower range applies to attics. Density values for cellulose samples reported in a number of field studies[52,53,54] range from 2.6 to 4.2 lbm/ft^3 (41.6 to 67.3 kg/m^3). Over that range the expected variation in installed R-value would be negligible.[55] The range of densities noted in the ASHRAE Handbook of Fundamentals is 2.3 to 3.2 lbm/ft^3 (36.8 to 51.3 kg/m^3).[56] With cellulose, lower installed densities actually improve performance slightly, although too low a density could lead to settling. Installing materials at their proper recommended densities is clearly important, both to avoid settling and to achieve optimum performance.

Mean Insulation Temperature. The R-value of insulating materials is typically measured in the laboratory and reported at a mean temperature of 75°F (24°C).[57] Yet in winter applications, the insulation's mean temperature is usually considerably lower and, consequently the R-value is higher. For example, that of 1.0 lbm/ft^3 (16.0 kg/m^3) fiberglass is 7% higher at 50°F (10°C) than at 75°F (24°C).[58]

Insulation Moisture Content. If condensation of water vapor occurs in wall insulation, it may increase its thermal conductivity. Unfortunately, there is almost no unequivocal documented evidence showing increased heat loss resulting from moisture in insulation in real building walls exposed to actual weather conditions. The amount of increase in insulation conductivity, if any, probably depends on the type of material and its water content. The moisture content of 50 blown-in mineral wool samples removed from existing walls in Portland, Oregon averaged 0.1% by weight with a 0.4% standard deviation.[59] In no case did the moisture content exceed 2%. Those results are in excellent agreement with other field study results obtained in both colder and milder climates.[60,61] The result is probably attributable to the fact that mineral wool is not hygroscopic, and so the fibers do not absorb moisture. Jespersen[62] has measured the thermal conductivity of moist mineral wool using a special laboratory setup. Based on his results, even if mineral wool had a 2% moisture content by weight, its R-value would be completely unaffected by moisture.

Although mineral wool remains quite dry, the water content found in cellulose samples is considerably higher. Cellulose is hygroscopic, and the fibers themselves absorb moisture. In the Portland study,[63] 35 samples of retrofitted cellulose were removed from existing walls. The average moisture content was 13.4% by weight, with a standard deviation of 2.4%. Weidt et al.[64] and Burch et al.[65] found similar results. Because cellulose is basically a wood product, equilibrium moisture contents of 10 to 15% are not unexpected.

Given that cellulose can have such moisture contents, the question is whether or not that moisture degrades the R-value of the cellulose relative to its dry state. If the moisture is absorbed only or mainly in the solid fibers rather than filling the voids, then the effect could be small or even negligible. If moisture fills the voids, then the influence could be more substantial. The question is complicated because of the fact that the nominal R-value can be determined in a laboratory either in a fully or partially dried state or in a state with normal equilibrium moisture content. Seldom is it clear what that state was when the R-value was measured. Thus, what the amount of moisture-induced degradation thatoccurs, if any, is somewhat unclear. The thermal conductivity of cellulose needs to be determined under actual moisture conditions in which a real wall is exposed to typical indoor and outdoor conditions. Unfortunately, most of the available test data has been obtained from laboratory results that may not be indicative of the real behavior of cellulose in walls. Weidt et al.[66] measured the thermal resistivity and moisture content of eight cellulose samples removed from existing sidewalls. No correlation between resistivity and moisture was found. However, it is not clear whether or not the measurementprocess resulted in drying out the sample. Tye and Spinney[67] made laboratory tests to determine the effects of moisture on the thermal conductivity of loose-fill cellulose in a wall. However, their results are somewhat inconclusive, in part because of a lack of measured data on insulation moisture contents, because the outdoor test condition was colder than that typical of many areas of the country, and because in their calculations R-values of air films were neglected and should not be.[68]. It would appear from the Tye and Spinney data that the R-value of the in place cellulose was less than 3 per inch when initially installed with about 11% moisture content; nominal values are typically above 3 per inch.[69] Furthermore, the R-value dropped more than an additional 20% as moisture levels were further increased to fairly high levels. Tye and Spinney state that the latter effect goes away as cyclical drying back to the 11% moisture content occurs. However, it would appear that the R-value was still slightly degraded at even that moisture content.

Careful comparative analysis of data from heat flux meter measurements of cellulose in a sidewall suggests that it performed poorer than expected based on typical ratings, possibly because of the presence of moisture.[70] Kuehn[71] used heat flux meters to assess the 1979 and 1980 winter performance of cellulose in a test house sidewall and found the thermal resistance to be 15 and 11% lower than predicted by ASHRAE. Unfortunately, moisture contents were not determined. Although there are other possible causes, the difference could be due to a combination of moisture in the insulation and a low mean insulation temperature because of the severe outdoor winter conditions. Because lowering the mean temperature below the standard reference of 75°F (24°C) increases the actual R-value, the R-value degradation effect of moisture could be even larger than the 15 and 11% he measured. Burch et al.[72] made laboratory measurements of heat loss through cellulose in a wall exposed to typical winter conditions for 16 weeks. The cellulose moisture content increased from an initial cellulose moisture content increased from an initial value of 8.0% to an average of about 20% at the end of that period. The increase in heat flux due to the increased moisture content was 9%. However, the conditions in these tests may not represent what actually occurs in a real wall.

Although very limited data is available on which to base a conclusion, it would appear that the R-value of cellulose used in sidewalls can be slightly reduced by the presence of moisture in it. The actual amount of performance deterioration relative to dry cellulose, however, still remains to be determined.

Much of the information on moisture effects in foam insulation rigid (board or foamed in place) is for roofing or below grade applications. Yet it would appear that moisture accumulation depends on the specific application. Unfortunately, little information specific to wall foam insulation applications is available. Some information is available on U-F foam, but it will not be discussed in detail because of the ban on its use. It seems important, however, to note that heat flux meter test results[73] from a test house wall containing U-F foam indicated performance considerably poorer than expected. The large discrepancy is probably because of moisture content, and similar effects could possibly occur with some of the other foams considered for retrofit use. Burch et al.[74] have measured the moisture content of extruded polystyrene board used as an exterior retrofit insulating material and found it to be about 1%. Based upon laboratory measurements by Thorsen,[75] there would be no effect of that moisture content on the thermal resistance of extruded polystyrene. More information is clearly needed on the influence of moisture on the performance of foam wall insulation materials.

Finally, questions exist over whether the use of low-permeability insulation board such as extruded polystyrene or faced isocyanurate, as an exterior retrofit system would lead to increased moisture accumulation within the wall cavity insulation and/or the existing sheathing and wood siding. Burch et al.[76] have shown that use of such a system will cause the existing insulation, sheathing, and wood siding to be warmer than otherwise, thereby resulting in less moisture accumulation and less degradation of the R-value of the wall cavity insulation (cellulose in Burch's tests).

Settling. Settling of loose-fill insulation results in a void space at the top of the wall cavity, and such voids can cause a surprisingly large increase in wall heat loss.[77] Settling is most likely to occur if the loose-fill insulation is installed at a density lower than recommended. Obviously, that can occur. It is extremely important, however, to distinguish between settling and incomplete filling of the wall cavity. Although it is often not easy to distinguish between these two causes of a void in the top of a wall cavity, results from a number of field studies[78,79,80,81] strongly suggest that settling of loose-fill materials does not occur in walls to any significant degree when the material is properly installed. What is typically believed to be settling is probably incomplete filling of the wall cavity.

Shrinkage and Voids. Shrinkage is a concern primarily with cellular plastic insulation material, including rigid board types and those foamed into wall cavities. In the latter category, U-F foam has gained notoriety because of its considerable shrinkage (see for example Ref 82). Because shrinkage is known to occur, the U.S. Department of Housing and Urban Development had, before banning itsuse, derated the nominal R-value of U-F foam by 28%,[83] and the Canadian government has derated it by 40%.[84] Vinieratos[85] has reported that a 10% linear shrinkage corresponds to a roughly 70% increase in heat loss with nominal 3-1/2 in. thick insulation; that increase is considerably greater than would be expected based only on the reduced area.

It is well known that other foam insulations lack dimensional stability, especially with changes in temperature. However, no documented field data on shrinkage was found for urethane or isocyanurate foamed into residential wall caviaties. These materials are known, however, to expand or contract in wall cavities. The newer open-celled polyurea is reported to have low shrinkage, based upon undocumented tests by the manufacturer.[86] Rigid board foams are also known to lack dimensional stability. Prior to widespread use of foams, it would appear worthwhile to determine the extent of shrinkage in residential walls, in light of its pronounced effect on thermal performance.

Incomplete Filling of Wall Cavities (Quality Control). In an optimal weatherization demonstration project, 148 low-income homes across the nation were weatherized. Of those, many had wall insulation retrofitted. The installation quality was subsequently assessed in detail using infrared (IR) thermography. Overall, an average void area of about 10% was observed.[87] Hall and Jacobs[88] found the same result when using IR methods to investigate 35 homes in Madison, Wisconsin. Observations made during the Portland study[89] are in general agreement with their results. For a 10% uninsulated area, the increase in heat loss relative to a fully insulated wall is about 40%.[90] Of course, some insulation is still better than none. However, the fact that wall cavities are not all filled reduces the expected performance to a considerable degree. Yet that reduction is seldom accounted for and should be when considering any wall insulation conservation program. Derating the insulation's R-value on the basis of the existence of typical void areas is one possible means. Improved quality control on the part of installers is also needed and certainly possible.

Insulation Age. Aside from possible settling, there would appear to be no known major effect of aging on the thermal performance of loose-fill wall insulation materials. However, the R-value of rigid foam materials foamed with a flourocarbon gas, such as urethane or isocyanurate foam, is known to drop within the first year after manufacture. This occurs because the low conductivity fluorocarbon gas is partially replaced by air as a result of diffusion. Some rigid materials are faced on the two major surfaces with aluminum foil to reduce such gas diffusion and maintain a higher R-value. For example, foil-faced isocyanurate foam board was found to have about a 15% drop in average R per inch from one month after manufacture (8.34) to a time-aged plateau(7.04).[91] Similar characteristics have been measured for foil-faced urethane; removal of the foil facing resulted in a lower R-value.[92] ASHRAE lists the R-value for urethane as 6.25 per inch unfaced and 7.1 per inch with foil facing.[93] Foams containing only air appear to exhibit little or no R-value deterioration with age.

Air Convection Within the Insulation. Natural or forced convection within permeable insulation can degrade its insulating value.[94] This is particularly possible with a porous material such as a fiberglass batt in a well-ventilated attic. Although the effect is hard to quantify, any such air intrusion effects should not be significant in wall cavities retrofitted with relatively high density, loose-fill or foamed-in-place insulation materials. Moreover, addition of retrofitted wall insulation has been found to reduce infiltration and the attendantbuilding heat loss, as noted in a later section.

South Wall Exterior Color/Solar Heating. The results of a combined experimental and computer simulation study[95] show that solar heating of south-facing walls can significantly reduce the net heat loss from them and, thus,influence the economic attractiveness of retrofitting south-facing walls with insulation. The solar gain through a south wall reduces the savings achieved by retrofitting wall insulation in comparison to a north-facing wall by about 25%. This effect depends strongly on the color (or absorptivity) of the exterior surface of the wall. A white or light wall color results in a minimal influence of solar heating; however, changing to a dark color will reduce the net heat loss by about 25%. Thus, using a medium or dark-colored stain or paint on exterior wall surfaces is extremely wise. Given all the characteristics of existing residences, the influence of solar heating cannot be easily determined currently. Overall it is probably not of great significance, but in many cases, it could be. Availability of an alternate building insulation code that takes solar heating into account, like that in New Mexico,[96] would allow easy determination on an individual basis of the influence of solar heating on the economic attractiveness of retrofitted wall insulation.

Effect of Added Wall Insulation on Infiltration Heat Loss. From blower door air leakage tests of 71 older houses in Portland, Oregon, the air leakage rate for reinsulated homes was about 22% lower than that of the uninsulated homes.[97] Thus, it appears that the addition of wall insulation substantially reduces air leakage and its associated energy loss. Yet, that saving is seldom, if ever, accounted for when analyzing conservation options. Of course, these results simply could be the result of differences in the characteristics of the selected homes. Further verification of these results is expected when air leakage tests that are done both before and after insulating walls are completed.[98] The currently available results indicate that a substantial portion of the infiltration loss in an existing home not having a vapor barrier is through the walls. If so, methods for calculating infiltration rates based only on window or door leakage may produce incorrect results.

Effect of Added Wall Insulation on Comfortable Indoor Temperature. As buildings are made more energy efficient by incorporating various building envelope energy conservation measures, the indoor air temperature at which the occupants are comfortable can be reduced. That is because the envelope interior surfaces, such as walls, are warmer and radiation heat loss from occupants to those surfaces is reduced. Adding wall insulation can have a major effect because of the considerable surface area involved, especially if other measures such as ceiling and floor insulation and storm windows have already been incorporated. Although no known quantitive data appears to exist, reductions in the indoor air temperature of 1 to 2°F (0.6 to 1.1°C) seem reasonable. For each degree of lowered temperature, at least about a 3 to 7% energy saving results, depending on the tightness of the house. This is another important effect that is seldom considered when determining the savings and economic attractiveness of wall insulation.

Effect of Added Wall Insulation on Balance Point Temperature. Neglecting effects such as passive solar heating, the annual heating energy use, Q, can be calculated to first approximation from $Q = 24\ UA\ DD$, where UA is the average value for the whole building and its value represents the heat loss (or gain) characteristics of the whole building and its envelope, whereas the DD, the number of degree-days per year, represents the influence of the local weather. When the potential energy savings associated with energy conservation measures such as wall insulation are typically analyzed, the new value of UA is computed and the resultant energy savings determined. One might simplistically assume that if the U-value is reduced by 75% the heating energy would be reduced by 75%. However, that simplified analysis method underestimates the actual savings. That is because adding wall insulation reduces the building's rate of heat loss and makes it possible for the existing internal heat generated from lights, people, and appliances to provide a larger portion of the building's heating needs. Thus, the value of DD is reduced as the value of UA is reduced.[99] In essence, the length (and severity) of the heating season is reduced for the tighter building. Thus, a reduction in the building's UA value has a twofold effect. Oftentimes, the second effect on DD is not accounted for; yet in a well insulated residence, internal heat gains can provide a sizable fraction of the heating requirements. In a thermally tight house (e.g., UA = 250) that utilizes night setback, the required DD can be one-half of what is typically assumed. Thus, the reduction in degree-days can be substantial and should be taken into account.

Overall Influence on Thermal Performance

To evaluate the overall influence of all of the aforementioned factors affecting the thermal performance of insulation on a building's energy use, a best estimate of the individual influences is presented in Tab. 2. These numbers were generated in part by calculating the annual space heating energy use for a single family dwelling using the Balcomb Solar Load Ratio method.[100] The percentage reductions in overall building energy use are relative to a similar building with fully insulated walls.

As can be seen, there are a number of factors that are seldom accounted for that reduce the building's energy use more than would be expected based solely on the reduction in wall heat transmission. However, the influence of these factors is partly negated by the effect of incomplete filling of the wall cavity. Cleraly, incomplete filling is a problem that must be either rectified or properly accounted for when estimating potential energy savings prior to embarking on a wall insulation retrofit program. Nonetheless, addition of wall insulation typically reduces the overall building energy use more than is usually predicted. If the maximum influence occurred for each factor, the overall building energy use could be as much as 50% lower than is usually predicted.

SIDE EFFECTS FROM RETROFITTING WALL INSULATION

Moisture Damage

There has been considerable concern and controversy over the question of whether or not adding insulation to a wall cavity without a vapor barrier would lead to moisture damage. To determine scientifically and objectively if there really is apotential for moisture damage as a result of the addition of wall insulation in existing houses in climates like that of the western region of the Pacific Northwest, a major field study was undertaken in Portland, Oregon.[101] The purpose of the study was to provide anwers regarding the advisability of insulating walls without a vapor barrier.

The results strongly suggest that the addition of wall insulation without a vapor barrier does not cause moisture damage in existing homes in the western portion of the Pacific Northwest. Although moisture damage was found in both insulated and uninsulated walls, it was always caused by a leak. There was some moisture damage outside the wall cavities, but it could not be attributed to the addition of wall insulation. In fact, just the opposite may be true. Comparison between results from insulated homes and uninsulated homes indicates that evidence of moisture in the attic, blistering paint, and previous moisture problems were found less frequently in the homes with insulation than in those without. Although it is not obvious that the results of this study can be extended to colder climates, it is interesting to note that no evidence of moisture accumulation and condensation or damage was found in homes in cold climates during two other field studies.[102,103] To settle the question for the rest of the Pacific Northwest and similar colder climates, a followup moisture study was planned for Spokane, Washington (6835 degree-days) during 1982 to 1983. It should also be noted that the Portland study test results suggest that it is not necessary to add a vapor barrier when insulating the walls of existing homes in the western portion of the Pacific Northwest. Yet, a recommendation often made when retrofitting sidewalls is to add a vapor barrier paint or possibly vent the exterior surface to allow moisture to escape. Although paints can reduce vapor transport by diffusion,[104] most of the vapor transport is usually via leakage (convection), such as through electrical outlets. Thus, vapor barrier paint is both relatively ineffective and, more importantly, unnecessary. In addition, vents are unnecessary and even increase heat loss.

Fire Hazards

A major concern involves the installation of wall insulation in contact with or near heat-producing devices, such as fireplaces or exhaust flues of wood stoves. Of special concern here is the potentially hazardous use of cellulose insulation because overheating can lead to smoldering with generation of toxic gases and eventual ignition of the insulation. Unfortunately, the fire retardants currently used in cellulose have little effect in inhibiting smoldering, and more effective retardants are needed. In tests of samples of cellulose commercially available nationwide in 1978, only about half passed combustion tests.[105,106] Cellulose blown into sidewalls can also fill electrical outlet boxes and create potentially dangerous overheating around wire connections.[107] Electrical wires surrounded by insulation can also be overheated and cause fires, especially in overloaded circuits.[108,109] As part of a nationwide low-income housing test program, about 90% of the homes had overloaded circuits.[110] It would be wise to inspect for such circuit deficiencies befpre installing wall insulation. Another serious concern involves the permanency of combustion retardants in cellulose. It is known that commonly used retardants such as boric acid and sodium borate are water soluble and can be lost by evaporation.[111] Whether they are lost in walls, and, if so, at what rate, are unanswered questions.

Corrosion

There is a possibility that insulating materials, especially when moist, will corrode metals or other materials within the wall cavity, including pipes, wiring, electrical outlet and switch boxes, and heating ducts. However, because published field data on the corrosiveness of wall insulation materials is almost nonexistent, it is difficult to assess the problem. In a number of field studies,[112,113,114] no significant corrosion was found, but the sample size is small. Obviously, it would be unwise to generalize from those results. However, a 1978 report of a U.S. House of Representatives Subcommittee noted several cases in which cellulose fire retardent additives had produced severe corrosion of metal building components.[115] Moreover, numerous research reports indicate that cellulose insulation definitely corrodes metals such as steel. Moreover, corrosion is more significant with retardant compounds containing sulphates.[116,117] It is possible that cellulose that has additives that do not contain sulphates may not pose a serious corrosion problem. In addition, laboratory tests show U-F foam can be corrosive,[118] and different mineral wool tests indicate conflicting results.[119] Rigid polyurethane foam in a warm and humid climate was also found to be corrosive to steel, but not to aluminum or copper.[120] Thus the limited field data and test results are somewhat in conflict. Clearly, this is an area where more field data is needed.

Health Hazards

Potential health hazards from various wall insulating materials fall into two main areas: those associated with handling during installation and those associated with long term inhalation of particles or gases released from the insulation after installation. It is well known that mineral wool can cause skin and eye irritation during handling, and even transitory respiratory tract irritation.[121] However, results to date indicate that man-made mineral wool insulation fibers do not appear to produce any chronic adverse health effects in humans.[122] Cellulose fiber appears to present no significant health problems, although borate salts used as flame retardents can be toxic if ingested or if enough is absorbed through the skin. Whether or not the borate salts get into a house if they evaporate from wall cavity insulation, at what rate, and what, if any, health risk is involved are unanswered questions. There are no known health hazards associated with the use of perlite or vermiculite insulation.

As noted earlier, the use of U-F foam insulation has been banned in residences and schools because of the health hazards associated with the release of formaldehyde gas. Thus, the major questions for those whose homes already have it in their walls are whether there is a dangerous level of formaldehyde gas inside their house and, if so, what can be done about it. Determining what is safe is exceedingly difficult, although a Canadian report[123] recommended the free formaldehyde concentration in UFF-treated homes be less than 0.1 ppm.

There are many possible sources of formaldehyde, and determining concentrations is difficult. If high concentrations are found, the wall insulation may have to be removed. Since the release of formaldehyde from U-F foam wall insulation gradually decreases with time, no dangerous level may in fact exist in many houses. A handy brochure that may help homeowners decide what to do can be obtained from the Consumer Product Safety Commission (CPSC).[124]

In addition to U-F foam, there are a number of other foam insulations whose use may pose health hazards, especially during installation. According to the CPSC, finished rigid foams such as polystyrene generally do not pose adverse health effects. The major hazard with urethane foam appears to exist during handling and installation. Isocyanurate is toxic, and extreme caution should be excercised during handling and application. Since polyurea is so new, any health hazards associated with its use are not well known. However, because it is somewhat similar to urethane and isocyanurate, it also should be handled with caution. The final health hazard to be considered when using foam insulation materials (other than U-F) is associated with the outgassing of the chlorofluorocarbon gas that occurs. It could potentially get into the house air. However, those gases, such as Freon, are generally inert and stable, and there are no known health hazards associated with breathing them.[125]

Indoor Air Pollution

There is now widespread concern that implementation of energy conservation measures that reduce air leakage in existing homes may create an indoor air pollution problem. This is largely based on the fact that high levels of moisture and indoor air pollutants have been found in some newly constructed homes that were designed to be extremely air-tight. Of greater importance is the fact that indoor air pollution is not always a problem, even in tight houses.[126] It is alleged that tightening up an existing home may cause a significant buildup of indoor air pollutants. However, there is little experimental field evidence to verify the generality of that allegation. If fact, it is extremely difficult to tighten up a typical "loose" existing home so as to produce air change rates that are low enough to create a problem. Even "House Doctor" weatherization approaches that are specifically aimed at reducing air infiltration typically only reduce infiltration by about 10 to 15%.[127,128]

It is believed that indoor air pollution can be a health problem only when natural infiltration rates are reduced to below about 0.4 to 0.5 ach.[129,130] However, based on the author's experience, average air change rates for the winter heating season in weatherized conventional housing seldom get below those values. Usually, the infiltration rates are much higher, as suggested by results of blower door tests[131] and tracer gas tests.[132] Even considering the few low levels found in those studies, there is no certainty that an air pollution problem exists. Although this potential problem clearly needs more attention, including field measurements of indoor air pollutant concentrations in existing weatherized homes, the severity of the problem may have been overestimated. Until further information is obtained, it would be wise to at least warn smokers that smoking seriously affects the indoor air environment. Moreover, because several studies have shown that gas stoves can cause high indoor air pollutant concentrations when weatherization is substantial,[133] it would also be wise to recommend that homeowners having gas stoves operate a kitchen fan during stove operation. Finally, it should be stressed that retrofitting an air-to-air heat exchanger into existing homes withair change rates greater than 0.5 ach will generally be of no value except to provide needed ventilation with minimal heat loss for homes having smokers, gas stoves, or known high levels of a particular air contaminant.

OTHER CONCERNS

As noted earlier, incomplete filling of wall cavities has the greatest adverse impact on the thermal performance of insulated walls of any of the factors considered. Although some areas are unquestionably hard to insulate well, the amount of the wall cavity that is typically left uninsulated can and should be reduced. Clearly, some form of improved quality control that will reduce the void area is essential if wall insulation is to be more cost-effective. Unfortunately, this problem has been created by insufficient quality control on the part of insulation installers. Some sort of onsite inspection program would appear to be one of the best ways to assure improved quality. Providing improved quality control is obviously in the best interest of insulation installers, and many are in favor of onsite inspection. If contractors knew that there was a good chance of their work being inspected, they would be more careful because it would cost them more to go back and fix a bad job than to do it right in the first place. Those contractors repeatedly performing poorly could be dropped from the weatherization program. Because one of the major problems involved in inspecting is the fact that it is usually impossible to visually locate voids inside the wall cavity, selective testing using infrared thermography to locate any voids seems prudent. During any infrared thermography inspection it would be important to check to see if sufficient clearances exist between insulation and any heat sources. Although thermographic inspection is relatively expensive (a full scan might cost $50 or so per house), it is cheap in comparison to the cost of installing the insulation or in comparison to the full life cycle dollar value of the energy savings from installing wall insulation or even from reducing voids.

CONCLUSIONS

Retrofitting of wall insulation in existing residences has been a relatively low priority conservation measure for both homeowners and utilities. Many utilities, including such large power marketing agencies as the Tennessee Valley Authority and the Bonneville Power Administration, have not included retrofit wall insulation as part of their conservation programs. There are a combination of reasons, including the relatively high cost and relatively poor payback when retrofitting sidewalls, inspection difficulties, a variety of concerns over performance and potential problems, and widespread misinformation regarding both insulating materials and many of their advantages and potential disadvantages as well. Thus, it appeared worthwhile to review the state of the art of retrofitting wall insulation in residences and to summarize its status as an energy conservation measure.

To that end, the characteristics of almost all available wall insulating materials and approaches have been summarized. The types of wall insulation considered include loose-fill and foamed-in-place insulation as well as other insulation installed in or added to the wall cavity. The influence of a variety of factors on the thermal performance of wall insulation as well as on the building's overall energy use has been assessed. The factors considered include: insulation density, mean temperature, and moisture content; settling and shrinkage; incomplete filling of wall cavities; air convection within the insulation; south wall solar heating; and effects of added wall insulation on infiltration heat loss, on use of lowered temperatures, and on decreased overall building energy use as a result of the reduction of the outdoor balance point temperature (i.e., length of the heating season). Many of those factors influence the actual thermal performance of insulated walls or the overall building's energy use, yet few are actually accounted for when analyzing the effectiveness of added wall insulation. Quite often the heat loss through an insulated wall is considerably lower or greater than would be expected based on the nominal R-values quoted in the literature. In effect, the actual R-value of an installed insulation material is often different than the nominal value, and in some cases considerably so. Thus, each of the effects should be accounted for.

Some of the factors would appear to have little or no effect on the thermal performance of wall insulation, including settling, insulation age, and air convection within wall insulation. Although shrinkage in urea-formaldehyde foam does markedly influence its effective R-value, this will not be a problem in the United States and Canada in the future because its use in residences has been banned. Some of the factors influencing thermal performance improve the effective R-value of the wall insulation or their influence results in reduced overall building energy use. For example, in addition to the usual reduction in wall heat loss, added wall insulation can result in reduced infiltration heat loss, lowered thermostat settings for adequate comfort, and a lower building balance point temperature. Moreover, solar heating of south walls can reduce the net heat loss from walls. Each of those effects can reduce the overall building energy use by between 0 and 15%. Although the influence of each is relatively small, their cumulative effect can be substantial. On the negative side, the incomplete filling of wall cavities that typically occurs results in about 40% more wall heat loss than for a fully insulated wall; that translates to about 10% greater building energy use relative to what would be expected if the wall cavities were completely filled. A derating of the R-values of insulations to account for the substantial influence of typical void areas is therefore recommended (as was done with U-F foam because of its shrinkage). Finally, it would appear that moisture in cellulose can slightly degrade its thermal performance, but the actual reduction in R-value is not well known and needs to be determined. The thermal performance of other conventional loose-fill insulations such as rock wool and fiberglass is not affected by their normal moisture content.

Overall, it appears that addition of wall insulation results in a greater reduction in building energy use for space heating than is typically predicted based only on reduced wall heat transmission and nominal insulation R-values. Properly accounting for all the various factors makes it more cost effective than is usually assumed. The overall building energy use could be as much as 50% lower than is usually predicted if the maximum influence of all the above-noted factors occurred.

There are of course a number of potentially adverse side effects that may result when retrofitting, including moisture damage, fire hazards, corrosion, health hazards, and indoor air pollution. There appears to be no possible moisture damage, either inside or outside the wall cavity, associated with the addition of wall insulation in existing homes, at least in the western regions of the Pacific Northwest or in simlar climates. The same appears to be true for homes in colder regions, but a detailed field investigation of that problem presently underway should further clarify this issue.

A variety of potential fire hazards are associated with the retrofitting of wall insulation. Of special concern is the potentially hazardous use of cellulose insulation (such as when insulation is improperly installed too close to heat sources like exhaust flues of wood stoves or fireplaces or around wire connections) because overheating can lead to smoldering combustion and possible evental ignition of the cellulose. Unfortunately, the fire retardants that have been used in cellulose have little effect in inhibiting smoldering, and more effective retardants are needed. Moreover, serious concern exists that commonly usedcellulose fire retardants can be lost by evaporation. Whether they are lost in walls and, if so, at what rate, are questions that need to be answered. Some cellulose fire retardant additives may also cause corrosion of metal building components, although this too needs further study.

A major concern regarding potential health hazards involves long-term inhalation of particles or gases released from the insulation after installation. Results to date indicate that man-made mineral wool or cellulose insulation fibers, as well as Freon gas from foam insulations, do not appear to produce any chronic adverse health effects in humans. There is, however, a potential health hazard associated with the release of formaldehyde gas from retrofitted urea-formaldehyde foam. Because the use of U-F foam is now banned, the remaining difficult question is whether or not it should be removed from walls where it has been added. No easy answers exist.

In addition, there is now widespread concern that implementaion of energy conservation measures that reduce air leakage in existing homes may create an indoor air pollution problem. However, there is little experimental field evidence to verify that allegation. In fact, it is extremely difficult to sufficiently tighten up a typical "loose" existing house by using conventional conservation measures such that air change rates become low enough to create a problem. Moreover, even if low levels occur, there is no certainty that an air pollution problem exists. Although this potential problem clearly needs more attention, including field measurements of indoor air pollutant concentrations in existing weatherized homes, it appears, based on currently available information, that the problem has been overestimated. However, three situations may merit special consideration. Until further information is obtained, it may be wise to warn smokers that smoking seriously affects the indoor air environment and suggest to homeowners with gas stoves that they operate a kitchen fan during stove operation. Homeowners in areas of a known high source strength of a contaminant such as radon should avoid tightening up their homes or add an air-to-air heat exchanger.

Other concerns have also been addressed, such as quality control. To protect consumers and improve quality control and thermal performance, an onsite inspection program is needed. One that provides a check for uninsulated areas by using infrared thermography scans appears cost effective and in the best interest of installers and utilities; it is recommended.

Because this study has shown that the thermal performance of a residence with added wall insulation is better than typically expected, the cost effectiveness of a utility retrofit wall insulation program should be better than it has been in the past. Most of the potential problems that have kept utilities from embarking on a retrofit wall insulation program are not significant or can be readily handled by proper program design, such as to provide onsite inspection to improve quality control.

A major policy decision must be made with regard to selection of acceptable insulation types because it is clear that some insulation types are preferable to others. Blown mineral wool (rock wool or fiberglass) appears to be the best all-around retrofit wall insulation because it performs as expected, or possibly better, without any significant side effects or hazards. Unfortunately, cellulose has a number of potentially hazardous side effects, including possible fire hazards due to evaporation of fire retardants and ease of initiating smoldering combustion even when fire retardants are present, as well as possible corrosion. Thus, although the use of cellulose provides a number of advantages, including slightly lower cost than other conventional wall insulations, it appears prudent to delay the acceptance of cellulose until further study or testing resolves some of the concerns associated with its use. Although such a policy will not be popular and elimination of competition from cellulose may drive up the cost of other insulating materials, it seems wisest to accept materials such as mineral wool that perform about as well as cellulose but have no major potential side effects. In that regard, it also seems reasonable not to allow the use of blown-in or pour-in foam insulations, such as urethane, isocyanurate, polyurea, or polystyrene beads, until questions about potential hazards or thermal performance (e.g., possible shrinkage) are better resolved. Currently, there is a lack of well-documented scientific information addressing these questions. Fortunately, these materials are not widely used for retrofitting walls of residences.

As a policy recommendation, it seems appropriate to suggest that retrofitted wall insulation continue to be viewed as it is currently - as a relatively low-priority conservation technique. Nonetheless, it would appear that energy costs will continue to inflate rapidly so that even with its current relatively long payback, wall insulation will sooner or later be added to all residential walls where possible. In that sense it would seem best to initiate a major wall insulation retrofit program so that the savings could begin sooner rather than later.

RECOMMENDATIONS FOR FURTHER STUDY OR ACTION

A field study of possible moisture damage in walls retrofitted with insulation in climates like that of the eastern region of the Pacific Northwest is needed and planned for the 1982-1983 winter in Spokane, Washington. The scope of that study has been expanded because it will provide a unique opportunity to jointly study and resolve a number of other questions regarding wall insulation, including poor installation quality and its effect on thermal performance, onsite inspection, and potential fire hazards associated with improper installation of insulation near or in contact with heat sources such as wood stove flues.

Because major concerns exist over the potential for smoldering in cellulose and over the permanency of cellulose fire retardents in walls, both problems should be further studied before allowing the use of cellulose in any wall insulation program. Furthermore, field testing is needed in existing homes exposed to actual weather conditions to see if the moisture that normally exists in insulation really does increase heat transfer as expected for some materials. This information is especially vital in the case of cellulose. In addition, because of the unlikely possibility that adding wall insulation may tighten up houses enough to create an indoor air pollution problem, it is suggested that a field test program be initiated to determine if that can happen. Moreover, this study has shown that there are a number of factors that influence the energy used for residential space heating that are seldom accounted for. Because the cumulative effect of these factors can be substantial, methods for properly taking the effects of each of them into account should be developed or incorporated when available.

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TABLE I

Insulation R-values

	R per inch (meter) thickness hr•ft²• °F/Btu•in.(m•°C/W)		Reference Source
Still air (conduction only)	5.8	40.2	15
Freon 11 (in urethane foam, conduction only)	20.8	144.2	16
Cellulose			
Loose-fill, 2.3-3.2 pcf (36.8-51.3)[a]	3.13-3.70	21.70-25.65	17
Spray-on	4.0	27.7	18
Fiberglass			
Batts	3.16	21.91	19
Loose-fill			
Conventional	2.2	15.3	20
Insul-Safe II	3.86	26.76	21
High density rigid	4.0	27.7	22
Rock wool (slag wool)			
Batts	3.4	23.6	23
Loose-foil			
1.5 pcf (24.0)	2.1	14.6	24
2.5 pcf (40.0)	3.4	23.6	25
3.5 pcf (56.1)	3.9	27.0	26
Vermiculite, 4.0-6.0 pcf (64.1-96.1)	2.27	15.74	27
Perlite			
2 pcf (32.0)	3.6	25.0	28
5 pcf (80.1)	3.1	21.5	29
10 pcf (160.2)	2.4	16.6	30
Urea-formaldehyde foam	4.2	29.1	31
Polyurethane			
Aged, aluminum-faced board stock	7.1	49.2	32
Aged, unfaced board stock	6.25	43.33	33
Modified for pouring or spray-on	3.8	26.3	34
Isocyanurate			
Aged, aluminum-faced board stock	7.04	48.81	35
Modified for pouring, 1 pfc (16.0)	4.5	31.2	36
Polystyrene (EPS)			
Molded (beadboard)			
1.0 pcf (16.0)	5.0	34.7	37
1.5 pcf (24.0)	4.2	29.1	38
2.0 pcf (32.0)	4.3	29.8	39
Extruded (Styrofoam)			
1.75 pcf (28.0)	4.4	30.5	40
2-2.4 pcf (32.0-38.4)	5.5	38.1	41
Loose-fill beads in binder, 1 pcf (16.0)	3.6-3.8	25.0-26.3	42
Polyurea, 0.5-0.75 pcf (8.0-12.0)	3.2	22.2	43
Wall cavity air space	1.01[b]	0.178	44

[a] Pounds per cubic foot (kg/m³)

[b] Total R for 3-1/2 in. (0.089 m) total thickness

TABLE 2

Factors that influence the thermal performance of common types of retrofitted wall insulation (cellulose, mineral wool)

Item	Change in Insulation R-value (%)	Reduction in overall building energy use (%)
Installed insulation density	± 0-10	± 0-2
Mean insulation temperature (50°F(10°c))	5-10	1-2
Insulation moisture content	a	a
Settling	0	0
Shrinkage	0	0
Incomplete filling of wall cavity		-10
Insulation age	0	0
Air convection within insulation	0	0
South wall exterior color/solar heating	10-35	0-2
Effect of added insulation on infiltration heat loss		10-15
Effect of added insulation on indoor air temperature		0-15
Effect of added insulation on balance point temperature		10-25

a Unknown

LIST OF FIGURES

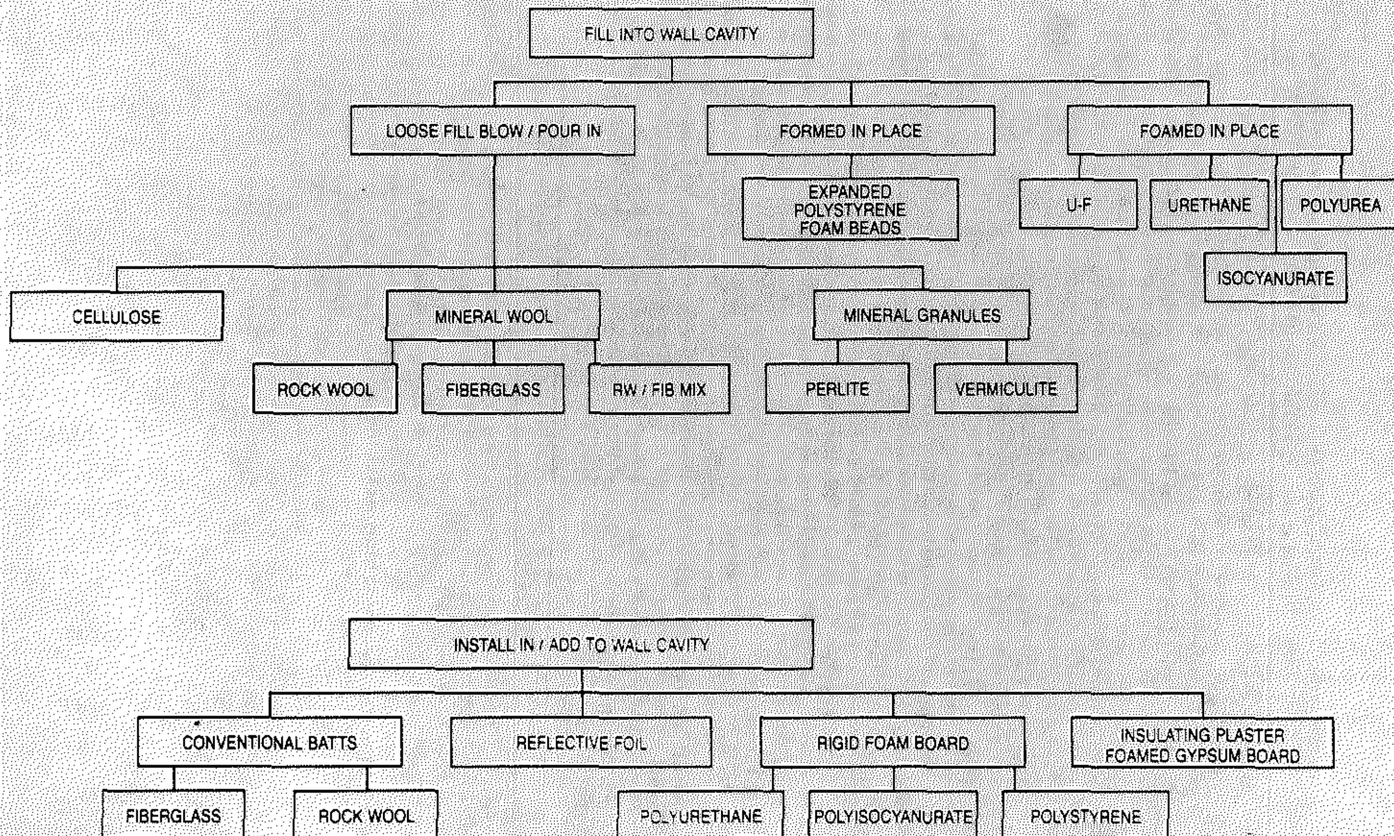

Figure 1. Types of insulation for retrofitting existing walls

Discussion

A.W. Johnson, NAHB Research Foundation, Rockville, MD: Work done at Pennsylvania State in the early 1960s supports the conclusion that moisture accumulation in sidewall insulation does not significantly increase heat flow. Over the entire year, the moisture content increases (maximum in March) and is essentially in equilibrium with framing (or Less) by September (6500 degree-day climate).

G.A. Tsongas: The question of the effect of moisture on the thermal performance of wall insulation is complicated and, as yet, not entirely resolved. What needs to be known is whether or not there is any effect of moisture on the R-value of the insulation as it actually exists in a wall where moisture is continuously migrating through it. Any such influence must be considered relative to the nominal R-value typically listed in handbooks. Those values are most often determined by laboratory testing, but unfortunately the baseline moisture content is seldom known or documented.

Sometimes the samples to be tested are oven-dried, sometimes they have a moisture content in equilibrium with that of the laboratory air, and sometimes the test procedure itself results in drying of the sample. Furthermore, the moisture content of hygroscopic insulations such as cellulose is strongly dependent on the relative humidity of the air in the room where it is stored and tested. In addition, it now appears that the conventional oven-drying procedure for determining the moisture content of cellulose can result in considerable error, so that reported values of moisture contents of either laboratory of field samples are in question.

Unfortunately, there is relatively little suitable field or laboratory data from which to conclusively decide whether or not the normal accumulation of moisture in sidewall insulations degrades their thermal performance. However, evidence to date indicates that mineral wool insulations in actual walls have extremely low normal moisture contents. Thus, this strongly suggests that there is essentially no increase in heat flow relative to the dry state. However, the situation may be quite different with cellulose. While it is well known from numerous field investigations that the normal moisture content of cellulose in walls in considerably higher than for mineral wools, the values of moisture content reported for cellulose may be in correct.

Nonetheless, examination of the test results from a number of studies suggests that the normal presence of moisture in cellulose may result in effective R-values that are substantially lower than nominal handbook values, i.e., greater heat loss than typically predicted. Unfortunately, the currently available data are not sufficient to be sure. What is needed to conclusively determine the influence of moisture on the thermal effectiveness of cellulose insulation are carefully designed field measurements of the performance of cellulose in actual walls exposed to real (dynamic) weather and moisture migration conditions, in combination with proper laboratory determinations of the moisture content and R-value of cellulose.

D. Burch, Natl. Bureau of Standards, Washington, D.C.: Please comment on your concerns for using cellulose as a retrofit wall insulation.

Tsongas: As noted in detail in the paper, there ar a number of potential hazards associated with the use of cellulose. These include possible fire hazards, because tests have shown that the currently-used fire retardants are relatively ineffective in inhibiting smoldering combustion, and also because fire retardants may possible be lost over time because of evaporation. Moreover, corrosion of metals has been associated with the use of cellulose. Finally, there is the possibility that the thermal effectiveness (R-value) of cellulose insulation is degraded due to the presence of normal moisture in it. Given all these porential problems, it seems most prudent to substitute the use of other conventional blow-in insulations, such as mineral wool, that perform thermally about the same, generally cost only slightly more, and do not have any serious hazards associated with their use. The application of cellulose could easily be reinstated once the potential hazards associated with its use are further studied and better resolved.