An Analysis of Floor Modifications to IECC Code Change EC48-03/04

February 23, 2005

This report provides an analysis of several changes made to DOE's comprehensive Residential IECC Code-Change (RICC) proposal (EC48-03/04) that became the basis of the residential requirements in the 2004 Supplement to the 2003 IECC. The changes, proposed "from the floor" at the September, 2003, ICC hearings are hereafter called "floor modifications" or "floor mods." This analysis looks at the energy savings and incremental costs of two of the insulation and glazing floor mods as well as their possible impact on product markets and on the code's usability and enforceability. This report is intended only to serve as background data for DOE in assessing the potential impacts of the mods.

Executive Summary

DOE's "RICC" proposal made sweeping changes to the International Energy Conservation Code (IECC) designed to significantly improve its usability and enforceability. A number of modifications to the proposal raised "from the floor" at the September, 2003, Code Development Hearings of the International Code Council (ICC) changed aspects of the DOE RICC proposal. Many of the floor modifications were successfully inserted into DOE's proposal and subsequently approved by the ICC as part of the 2004 Supplement to the 2003 IECC. This reports analyzes two of the more notable floor modifications.

- **Wall R-values were increased**. In climate zones three through six, prescriptive wall cavity insulation requirements were increased from R-13 to R-15 (normally used in 2x4 walls) and from R-19 to R-21 (normally used in 2x6 walls).

- **Glazing trade-off limits**. Limits were imposed (or strengthened) on the maximum values of U-factor and SHGC permitted for glazing products. Unlike most other energy code requirements, these limits can never be exceeded, even if other compensating improvements (trade-offs) are made. The original RICC prohibited glazing U-factors, even in trade-off contexts, higher than 0.55 Btu/hr-sf-F in zones six through eight; the floor modifications lowered that value to 0.4 Btu/hr-sf-F and extended its application to zones four and five. The floor modifications also added an SHGC trade-off limit of 0.5 in zones one through three.

Wall R-value Increases

The **practical effect** of the wall cavity R-value increase was to increase the overall stringency of the thermal efficiency of the building envelope. While the use of R-15 and R-21 high density batt insulation seems to be the most straightforward prescriptive approach to achieving this increase, there are other methods to meet the R-15 and R-21 requirements. In order to avoid narrowing the list of products capable of meeting the prescriptive requirements, insulating sheathing is needed so that other cavity insulation types, including sprayed cellulose and expanding foams, can achieve the R-15 level (in 2x4 walls) or the R-21 level (in 2x6 walls). Use of these products will consequently require a builder to use a "trade-off" path to demonstrate compliance or will require the use of insulating sheathing in addition to structural sheathing and/or engineered cross bracing.

The **primary cost** associated with this floor modification is the cost difference between standard-density and high-density fiberglass batts or the costs associated using insulating sheathing instead of or in addition to other sheathing methods such as OSB sheathing. The incremental costs for the high density fiberglass products can be high in markets where these products are not commonly used—California data reports these at \$0.42 to \$0.44/ft^2. In Oregon, where the state code requires R-21, the incremental cost of this insulation level is reported at only \$0.10/ft^2. There may be little to no cost increase if insulating sheathing is used to obtain the additional R-2 requirement, but many builders prefer not to use insulating sheathing for reasons other than cost.

DOE calculated the **energy cost savings** resulting from this floor modification when fiberglass batts are used. A 2000-sf house was simulated using the DOE-2 energy simulation program in 239 U.S. locations. The calculated energy costs assume a gas price of \$0.90/therm and an electricity price of \$0.0947/kwh. Overall, the annual energy cost savings from the increased wall R-values average about \$15 per home, which amounts to 2% to 3% of HVAC energy costs.

Combining the increased costs and the energy savings of high density batt insulation allows an analysis of the **economic viability** of this floor modification. The simple payback period assuming the higher insulation data (from California) ranges from about 40 years in the northern affected zones to about 90 years in the southern zones. With the much lower Oregon insulation cost data, the simple payback is reduced to 9 to 21 years. Life-cycle cost (LCC—assuming a 50-year life, a 30-year mortgage with a 6% interest rate, a 6% nominal discount rate (3.3% real discount rate), and a 1% property tax) for the higher insulation levels are reduced if the lower insulation cost is assumed, but increase if insulation cost is at the higher estimate.

It is important to once again note that R-2 insulating sheathing can also be used to achieve the higher insulation requirements. However, as will be discussed later, that option involves additional considerations that complicate a direct cost comparison with the high-density batt option.

Glazing Trade-off Limits

The **primary effect** of the glazing trade-off limits is to set an absolute minimum (or maximum) value that can be used in a compliant home. For example, even if energy consumption is shown to be equal to or better than that resulting from the prescriptive code requirements, glazing products cannot be "traded down" beyond the limits. While this floor modification may ultimately result in energy savings, the trade-off limits clearly affect the market by instantly prohibiting products that would otherwise maintain market share interests and could be compliant within the original DOE RICC code change proposal if other energy efficiency measures within the building exceed code requirements.

The U-factor limit of 0.4 Btu/hr-sf-F has the effect of eliminating almost all types of aluminum windows and almost all windows that do not have low-emissivity coatings. The SHGC upper limit of 0.5 has the effect of eliminating almost all windows not containing low-emissivity coatings, tinting, or reflective glass. Since many homeowners may not want tinted or reflective glass, this is expected to lead to the use of low-E insulating glass virtually everywhere the code is adopted. The biggest impact of this limit will be to effectively eliminate single-pane glass, which is still common in Florida and pockets of the south near the Gulf Coast. In mild Zone 3 locations, most notably coastal California, the forced SHGC limit can actually raise energy costs because higher solar gains are advantageous in these chilly climates.

One tangible benefit of the SHGC trade-off limit is a potential **reduction in peak cooling loads** for homes that are otherwise energy-equivalent to a baseline code home. This could prevent a summer peak load increase of about 1 kW per house for certain trade-offs that increase the SHGC well above 0.50 (for example if the improvement allowing the SHGC trade-off is a high efficiency furnace).

Introduction and Background

This white paper summarizes an analysis of several modifications that were made to DOE's proposed (now accepted) rework of the International Energy Conservation Code (IECC). The modifications, proposed by motion "from the floor" at the 2003 Code Development Hearings of the International Code Council (ICC), were accepted by the IECC development committee.

Hereafter we will refer to DOE's change proposal as originally submitted to the ICC as the "original proposal" or, as dubbed during its development, the "RICC" (Residential IECC Code Change). The modifications proposed via floor motion at the Code Development hearings will be called the "floor modifications" or "floor mods." DOE's proposal as modified by the floor modifications will be called the "RICC as modified."

Two of the floor modifications have proven to be most notable among the parties interested in and affected by changes to the IECC. Although the RICC as modified is now officially part of the IECC (the 2004 Supplement), the Department has deemed it necessary to conduct an analysis of the floor modifications to assess the potential impacts of these mods.

A Description of DOE's "RICC" Proposal

The impetus for the original RICC was the frequently-heard comment that the IECC was too complex, hard to understand, and difficult to implement. Having worked for many years on development of energy-efficiency codes and standards, DOE in the mid-1990's added a compliance emphasis to its activities. DOE learned during the last decade of promoting energy codes and developing and deploying code compliance tools is that the energy-saving potential of the IECC was not being fully realized because of the difficulties in understanding, using, and enforcing the code.

A second impetus for the RICC was the common complaint that the IECC was not structured to adequately accommodate the concerns of cooling-dominated climates.

DOE's RICC addressed these two concerns in ways too numerous to discuss here. However, the bulk of the changes can be summarized in two primary characteristics of the RICC:

1. The climate basis for the IECC's requirements was changed from heating degree-days (HDD) to explicit geographic zones designed to align with county boundaries. As shown in Figure 1, there are eight temperature-oriented zones crossed with three moisture regimes (although not all 24 combinations exist in the U.S.).
2. The IECC's envelope requirements were made independent of window area percentage. In all previous versions of the IECC the minimum insulating requirements for walls and windows varied depending on the fraction of the gross wall area comprised of glazing.

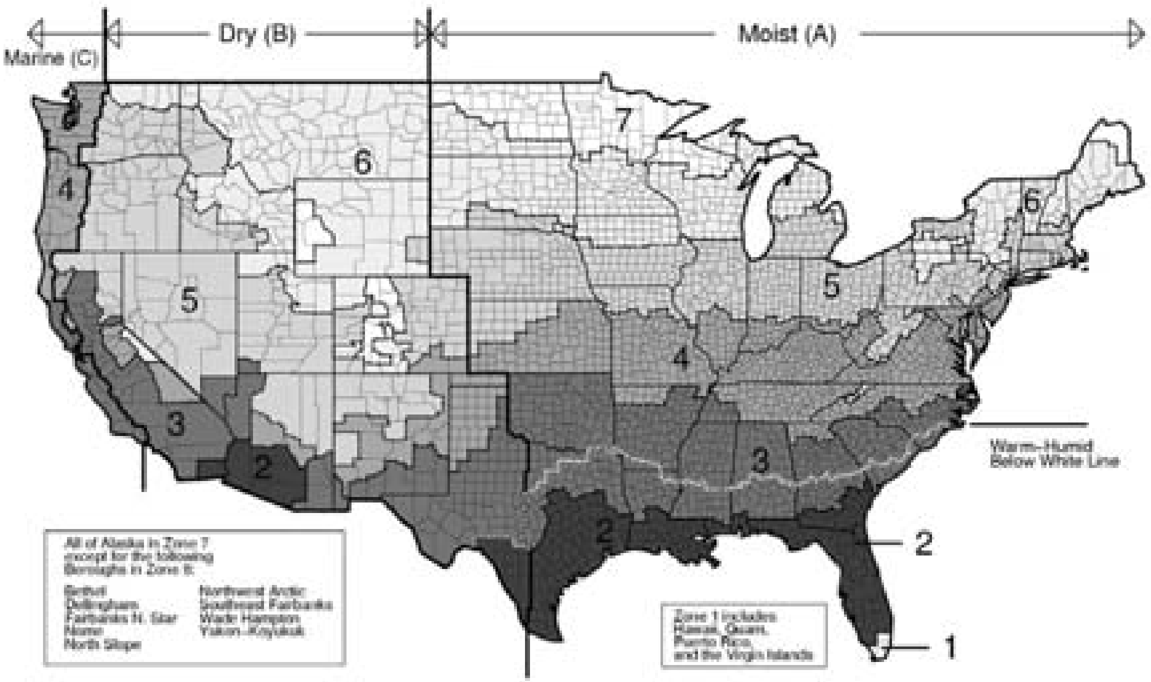

Figure 1 – New Climate Zones in the 2004 Supplement to the 2003 IECC

So that the Department could focus on usability issues without introducing other controversies, the specific envelope requirements of the RICC were designed to result in essentially no change in the code's overall stringency, averaged over all homes. Thus we say the original RICC was "energy neutral" on average. Obviously, some homes (e.g., high window-percentage homes) can be somewhat less efficient under the RICC while others (e.g., low window-percentage homes) will be somewhat more efficient.

The Floor Modifications

In the ICC's Code Development Hearings, minor modifications to submitted change proposals are permitted by motion from the floor. A number of floor motions affecting the RICC were accepted by the IECC committee. Several of those were substantive (as opposed to editorial), technically changing DOE's original proposal. Two floor modifications that noticeably affected stringency or usability are discussed in this paper.

Two primary floor modifications are of interest:

1. The minimum allowable R-values for wall insulation were increased in some zones, and
2. The trade-off limit for glazing U-factors was made more strict and a Solar Heat

Gain Coefficients (SHGC) limit was added

These are discussed in more detail below.

Wall R-value Increases

The floor modifications of interest increased the R-value minimums in climate zones three through six. The RICC's wall R-value requirement in zones three and four (except Marine) was R-13. The floor modifications increased that to R-15. This essentially corresponds to changing a standard fiberglass batt in a 2x4 wall to a high-density batt. Alternately, R-2 insulating sheathing can be added to R-13 framing cavity insulation to meet the requirement.

The RICC's wall requirement in zones four (Marine), five, and six was R-19, with an option of using R-13 between studs plus R-5 sheathing. That nominally allowed a standard fiberglass batt in a 2x6 wall or a standard batt in a 2x4 wall with insulating sheathing. The floor modifications increased those requirements to R-21 in a 2x6 wall or R-15 in a 2x4 wall with R-5 insulating sheathing. Again, the difference is nominally a switch from standard fiberglass batts to high-density batts or the addition of R-2 insulating sheathing.

These changes are summarized in Table 1.

Table 1 -- Summary of Wall-R Changes Due to Floor Modifications

Climate Zone	*Minimum Wood-Frame Wall R-value*
1	13
2	13
3	~~13~~15
4 except Marine	~~13~~15
Marine 4 and 5	~~19~~21 or ~~13~~15+5
6	~~19~~21 or ~~13~~15+5
7 and 8	21

The floor modifications have the effect of requiring insulating wall sheathing in the prescriptive compliance path if non-fiberglass products are used for the cavity insulation. The two prominent examples are cellulose and expanding foam, both of which can meet the R-13/R-19 requirement in 2x4/2x6 walls, respectively, but cannot achieve the R-15/R-21 levels without increasing the stud thickness.

Glazing Trade-off Limits

The RICC included a trade-off limit on glazing U-factor that disallowed windows with a U-factor exceeding 0.55 Btu/hr-ft^2-F in zones six through eight. This provision was intended to prohibit the use of "very inefficient" glazing products even if the energy losses were made up elsewhere in a home, the intent being to avoid moisture condensation and comfort problems (cold spots) in northern climates. The floor modifications lowered the U-factor limit to 0.4 Btu/hr-ft^2-F and extended its applicability to zones four and five as well.

Additionally, the floor modifications added an SHGC trade-off limit (maximum) of 0.5 for windows in zones one through three. Both the U-factor and SHGC trade-off limits apply to the whole-house average, not to individual windows/skylights/doors.

Approach

This analysis focuses on the floor modifications from two angles. First, we calculate the energy and cost impacts of the changes and estimate the differences in life-cycle costs to consumers. Second, we evaluate any significant factors that might impact the usability or enforceability of the code, thereby impacting the number of states willing to adopt it or the number of homes that will actually comply. The latter viewpoint necessarily involves some subjective assessments. These are deemed important because the original purpose of the RICC was not to increase its stringency but to produce a code that would result in more homes actually achieving compliance. Also, because of DOE's usability focus in preparing the RICC, a number of external reviewers were surprised by the floor modifications and have demanded that DOE publish an analysis of those changes.

Energy impact analyses for the wall R-value increases were conducted with the DOE-2 energy simulation program. Energy impacts for the trade-off limits are, by definition, zero. However, we do present some limited assessments of secondary impacts that may impact energy use, again often using somewhat subjective approaches.

Analysis and Discussion

Wall R-value Increases

Energy Efficiency

The wall R-value increases have a straightforward impact on energy efficiency. The new R-values clearly increase the required insulating properties of walls, which results in an improvement in the overall efficiency of a home. Accounting for this improvement in terms of annual energy costs, the wall R-value floor mods result in an energy savings of between 2% and 3% of HVAC (1% to 2% of total) energy costs.

Energy savings estimates for the wall R-value increases are straightforward to generate. Our wall R-value analysis involved hour-by-hour annual energy simulations of a 2000 ft^2 two-story house on a crawlspace foundation. Simulations were run for each of the 239 available TMY2 weather files (although for many locations there is nothing to analyze because the floor modifications affected only zones three through six). The efficiencies of other house components were set equal to the minimum requirements of the 2004 Supplement. Wall insulation was assumed to be fiberglass batt insulation (no insulating sheathing). The effective insulating value of R-19 insulation was assumed to be R-17.8 because R-19 fiberglass batts must be compressed to fit into the cavity left by 2x6 framing.

The major assumptions used in the energy simulations are shown in Table 2.

Table 2. Assumptions in Simulation Analysis of Floor Modifications

Simulation model	DOE-2.1E
House design and size	2-story, 40x25 ft., 2000 ft^2 conditioned floor area
Wall area (excluding windows and doors)	1878 ft^2
HVAC system type	Natural gas furnace, 78% AFUE; 13 SEER
Fuel prices	$0.90 per therm[a], 9.47 cents per kWh[b]. 2.6% inflation rate[c].
Climate Cities	239 TMY2 weather data locations
Aggregation method	City-by-city results weighted by year-2000 housing starts
Wall Construction	Wood frame, 23% framing by area[d]

a. $0.85/therm is the average long-term “reference case” residential rate for 2005 through 2025 in real 2003 dollars from the 2005 Annual Energy Outlook. This was escalated to $0.90/therm to account for inflation from 2003 to 2005.
http://www.eia.doe.gov/oiaf/aeo/aeoref_tab.html (Table 3)
b. Residential average for August 2004. Source is Electric Power Monthly:
http://tonto.eia.doe.gov/ftproot/electricity/epm/02260411.pdf
c. http://www.eia.doe.gov/oiaf/aeo/pdf/aeotab_19.pdf
d. R-19 is assumed to have an effective R-value of 17.8 because of compression.
http://www.energy.ca.gov/title24/residential_manual/res_manual_chapter2.PDF

The resulting energy cost savings are shown in Figure 2.

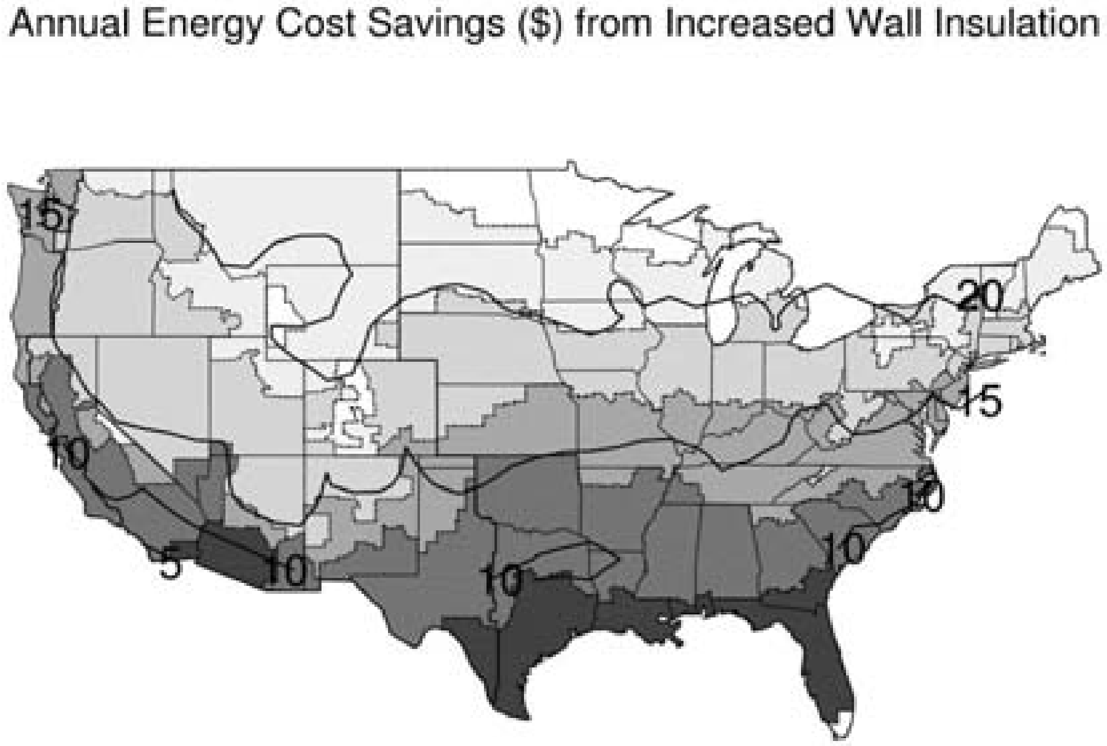
Annual Energy Cost Savings ($) from Increased Wall Insulation

Figure 2 – Annual Energy Cost Savings ($) from Wall-R-Value Increases

Note that annual energy cost savings of the wall R-value increases peak at about $20 in the coldest locations and are between $10 and $15 in most of the U.S. Recall that these savings numbers are for a 2000 ft^2 home. Figure 3 shows the same results as a *percentage* of total annual HVAC costs. For most of the country the energy savings are near 2.5% of HVAC costs.

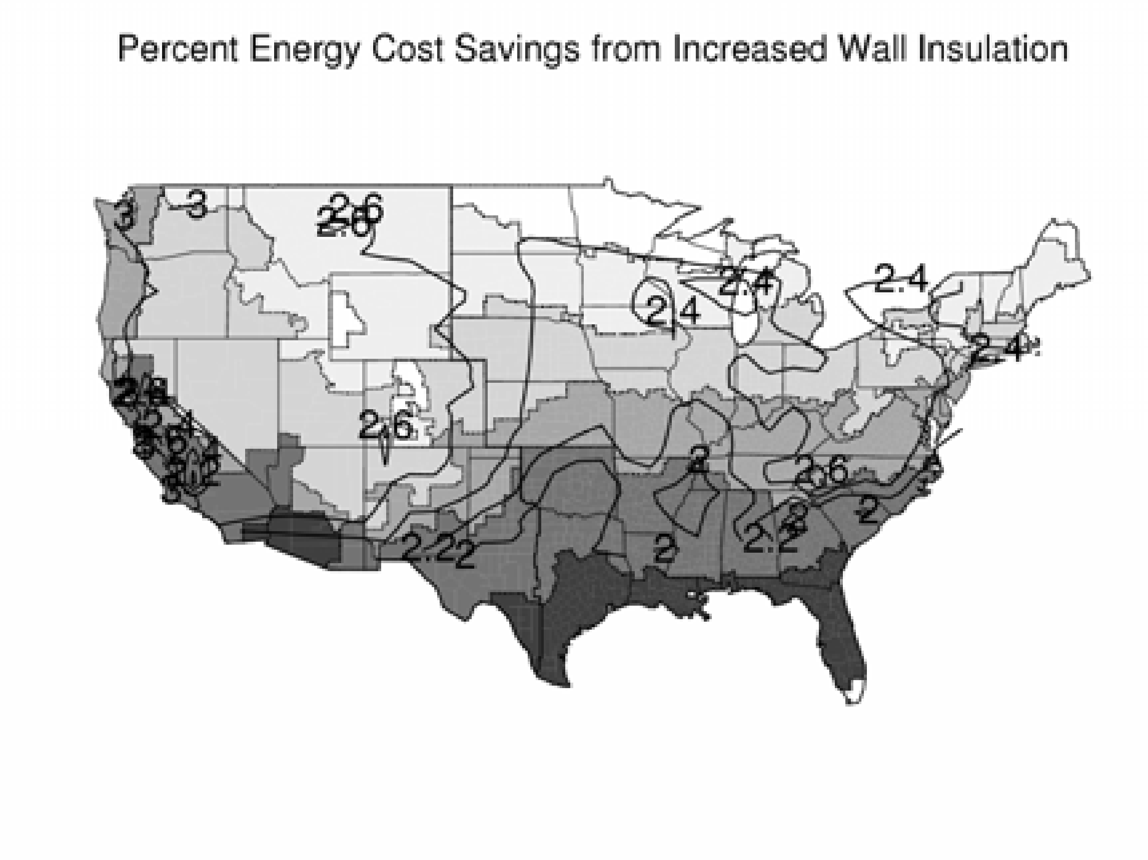

Figure 3 – Annual Energy Cost Savings (as a percentage of HVAC costs) from Wall-R-Value Increases

Measure Costs and Life-Cycle Costs

Addition of R-2 Insulating sheathing

The R-15 and R-21 wall insulation requirements, respectively, can be met with R-13 and R-19 cavity insulation and the addition of R-2 insulating sheathing. Common types of insulating sheathing are polystyrene (either extruded or expanded) and polyisocyanurate. Using extruded polystyrene as an example, insulating sheathing about ½" thick would have to be added to a standard R-13 or R-19 wall to achieve the R15/R21 levels. However, assessing the pros and cons of insulating sheathing as the assumed method of meeting code is complicated because of the variety of factors involved.

Insulating sheathing can often replace other types of sheathing such as OSB or plywood, provided another means of shear bracing is used (this is discussed further below). So a meaningful cost comparison must account for engineered bracing costs, additional skilled labor costs as well as material costs. R.S. Means reports that the total *installed* cost of insulating sheathing is less than that of plywood. Half-inch plywood costs $\$1.15/\text{ft}^2$ while a full inch of extruded polystyrene costs $\$0.83/\text{ft}^2$. A "Toolbase Technote" from the NAHB Research Center reports the *material* cost of insulating sheathing at about half that of OSB or plywood. Neither of these estimates includes the engineering costs or the additional bracing costs. The use of insulating sheathing in lieu of plywood or OSB can sometimes eliminate the need for an air infiltration barrier ("housewrap") if the joints are properly taped and sealed, as has been demonstrated by DOE's Building America program [Home Energy Magazine 1999]. Insulating sheathing may help prevent moisture condensation in walls by raising the temperatures within the walls and providing a drainage plane, depending on climate and other wall construction details.

Though insulating sheathing has some clear advantages over other sheathing materials, there are drawbacks as well, such as the need for bracing. Shear bracing requirements differ depending on the house type (e.g., one- vs two-story), location (e.g., earthquake and high-wind regions), and design details (e.g., locations of windows and doors). We know empirically that most builders choose not to use insulating sheathing [NAHB Builder Practices Reports, www.nahbrc.org]. Other reasons for this may include a perception of less security (from the lack of a "solid" wall barrier) and the absence of a helpful nailing surface for nails that "miss" the studs. Alternative techniques—such as using one-inch foam sheathing except at building corners where half-inch plywood sandwiched with half-inch foam is used—can resolve some of the issues, but the result has a higher R-value than the R15/R21 target, making cost comparisons difficult. (See the article by Paul Frisette in the web link below for an overview of many of these issues.)

Source:

Home Energy Magazine Online. January/February 1999. *Builders Find New Technologies Paying off.*
http://homeenergy.org/archive/hem.dis.anl.gov/eehem/99/990110.html
R.S. Means 2005 Residential Cost Data. Kingston, Massachusetts
National Association of Home Builders, Research Center. 2003. *Alternatives to Structural Plywood and OSB.*
http://www.toolbase.org/tertiaryT.asp?TrackID=&CategoryID=29&DocumentID=3984
Paul Fisette. 2004. *Insulating on the Outside*. University of Massachusetts
http://www.umass.edu/bmatwt/publications/articles/insulating_on_the_outside.html

R-15 and -R21 Fiberglass Batt Insulation

One method of meeting the higher wall R-value requirements is the use of high-density fiberglass batts in lieu of standard batts. However, establishing a confident and universally-applicable estimate of that cost is somewhat difficult. Because high-density batts are relatively uncommon in most areas there is a general lack of good information on marginal costs. The best information available to the Department comes from the California Database for Energy Efficient Resources (DEER) [Xenergy, Inc. 2001]. DOE searched for additional studies and made several requests of interested and affected parties for such information, but none was available at the time of this writing. A few anecdotal suggestions made to the Department were not used because they were unsubstantiated or deemed potentially biased.

California has a long history of tracking efficiency-measure costs and the DEER represents one of the most comprehensive and well-researched databases available. However, the present unpopularity of high-density batts raises the prospect of their costs going down should the national model code result in more widespread use of the high-density material. An example of such a transformed market is the state of Oregon, which has required R-21 in residential walls for some time. A somewhat dated study found the cost difference between R-19 and R-21 in Oregon to be \$0.10/sf [Oikos 1994]. Although prices may have changed in the ten intervening years, it is unlikely that inflation would account for much of the four-fold difference between this estimate and DEER's. The remainder is likely attributable to regional price variations and market transformation effects.

The available cost estimates are summarized in Table 3. Note that the Department did not identify a similar transformed market for R-15 batts.

Table 3. Wall Insulation Cost Estimates

Source	Incremental Cost
R-13 to R-15	
California 2001 Database for Energy Efficient Resources	\$0.42/ft^2
R-19 to R-21	
California 2001 Database for Energy Efficient Resources	\$0.44/ft^2
Oregon 1993 Study (Energy Source Builder #34, August 1994)	\$0.10/ft^2

Sources:

Oikos. 1994. Energy Source Builder. Iris Communications, Inc. Lorane, Oregon. http://oikos.com/esb/34/oregoncode.html

Xenergy. 2001. Database for Energy Efficient Resources Update Study: Final Report. Oakland, California. http://www.energy.ca.gov/deer/2001_DEER_Update_Study.PDF

We examined both the high (the California costs) and low (Oregon's \$0.10 incremental cost) insulation cost scenarios to bracket the cost impacts. Given those cost estimates, Table 4 shows the simple payback periods (years) of the higher wall insulation levels resulting from the floor modifications by climate zone. Zone averages are the averages of the 239 cities weighted by the housing starts in 2000. At the high cost level the modifications are clearly very long-term investments, with paybacks approaching 100 years in the warmest zone and over 40 years in the colder climates. Payback was much faster with the lower insulation cost, ranging from 9 to 23 years.

Table 4. Simple Payback (years) for Increased Wall Insulation R-Values

Zone	Simple Payback in Years	
	High Insulation Cost	Low Insulation Cost
3	89	21
4	52	12
5	49	11
6	40	9

Assuming a 50-year life, a 30-year mortgage with a 6% interest rate, a 6% discount rate, 2.6% inflation, a 30% income tax rate, and a 1% property tax, we computed the change in life-cycle cost resulting from the floor modifications. These are shown in Table 5. The floor mods increase total costs in the high insulation cost scenario but save money in the low insulation cost scenario.

Table 5. Life-Cycle Cost Savings ($) for Increased Fiberglass Batt Wall R-Values

Zone	Life-Cycle Cost ($)	
	High Insulation Cost	Low Insulation Cost
3	-498	32
4	-400	131
5	-424	162
6	-352	233

Other Factors

As mentioned earlier the purpose of the RICC was not to increase the code's stringency but to achieve energy savings by improving the code's usability. It is therefore important to understand the impact of the floor modifications on the palatability of the code, the probability that it will be adopted by states, and the possibility of secondary impacts that might lower expected energy savings.

One issue of interest is the possibility that the R-15 and R-21 wall insulation requirements will result in a market disadvantage for wall insulation systems other than fiberglass batts. In particular, the Department has received data that, for example, wet-blown cellulose and expanding foam products cannot achieve similar R-values to high-density fiberglass batts but have the advantage of better sealing the wall cavity and hence reducing air infiltration. We reviewed several available studies to determine the magnitude of any such effect.

The Cellulose Insulation Manufacturer's Association website summarizes a 1989-90 study comparing fiberglass and cellulose in two otherwise identical test buildings. The study, which looked at both ceiling and wall insulation, concluded that cellulose can indeed result in a tighter house (36% to 38% tighter in the test buildings). A comparison of overall heat loss values showed improvements of about 26% for cellulose over fiberglass. DOE was not able to obtain a copy of the report on this study, however.

Source:

http://www.cellulose.org/cellulose_benefits.html

In contrast, the North American Insulation Manufacturers Association cites several studies that suggest a smaller infiltration reduction benefit or no benefit for wet-blown cellulose or expanding foam products, based chiefly on the observation that an otherwise well-sealed wall will see little or no benefit from different types of cavity insulation.

Sources:

Field Demonstration of Alternative Wall Insulation Products. Prepared for the U.S. Environmental Protection Agency by NAHB Research Center, Inc., November 1997.

A Field Study of the Effect of Insulation Types on the Air Tightness of Houses. G.K. Yuill, Ph.D., Pennsylvania State University Department of Architectural Engineering, 1996.

Research and Development Project, "Maple Acres," Union Electric, St. Louis, MO. William Conroy, Division Marketing Supervisor, 1995.

This review of available studies suggests that the insulation products may indeed affect infiltration through the wall but the magnitude of the benefit depends on how well-sealed the remainder of the wall is. In other words, if the interior and/or exterior finish is well sealed to framing, and penetrations are well-caulked or gasketed, the marginal benefit of an air-impervious insulation layer is small. Given the often-reported lack of quality control in air-sealing techniques, these insulation types may have some impact on air sealing. However, the available data for infiltration testing in actual houses is not extensive enough to verify or quantify the impacts of different wall insulation types.

Glazing Trade-off Limits

DOE's original RICC proposal included a hard upper bound on glazing U-factor—a limit beyond which no windows would be allowed, even in the context of a compliance trade-off against better features elsewhere in a house. This type of restriction differs from the minimums and maximums typical of most codes' provisions in that it effectively prohibits certain types of products without recourse—in the relevant region, those products are basically illegal.[1]

Energy Savings

By definition, a compliance trade-off is energy-neutral. Therefore, the direct energy impacts of the U-factor and SHGC trade-off limits imposed by the floor modifications are zero.

One indirect exception to this line of thinking relates to SHGC benefits (or lack thereof) in some mild climates. Our energy simulations suggest that in some relatively cool zone-three locations the prohibition of higher SHGC values can actually force a higher annual energy consumption because of increased heating loads. Although the number of locations and magnitudes involved are small, it is philosophically problematic for a code to mandate the higher-energy option.

There are other indirect or secondary impacts that may influence energy consumption. These impacts, which are uncertain and difficult to quantify, are discussed later.

Measure Costs and Life-Cycle Costs

As there is no direct increase in code stringency, the costs of measures related to these floor modifications are likewise zero. These measures may prevent trade-offs that could

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[1] Actually, as structured in the 2004 Supplement, the "prohibited" products *can* be used as long as the area-weighted average U-factor (or SHGC) is not beyond the trade-off limit. This permits minor trade-offs to allow, for example, a decorative sidelite or a few small windows that are outside the trade-off bounds. It also permits, for example, half the windows to be worse than the trade-off limit if the other half are sufficiently better.

lower construction costs, however, preventing a builder from finding less costly ways to achieve equivalent energy consumption. But even in this context the costs are difficult or impossible to specify since many trade-offs are done to take advantage of local and/or short-term cost structures.

Secondary Energy Impacts and Other Considerations

Code-imposed trade-off limits require a stronger basis than do simple minimum/maximums that can be circumvented via trade-off. Strictly speaking, a trade-off limit saves no energy, so absent another compelling reason (safety, durability, etc.) it is difficult to justify such restrictions in an energy code.

DOE's intent for the fenestration U-factor trade-off limit in its original RICC proposal was two-fold.

First, placing an upper limit on the U-factor can prevent certain kinds of moisture failures. Specifically, windows with a too-high U-factor in northern locations can experience moisture condensation and even ice formation on the glazing and/or frame. Condensed moisture can find its way into walls where it lessens the effectiveness of insulation or compromises the integrity of the wall itself.

Moisture condensation on windows is a complex function of the indoor temperature and humidity and the outdoor temperature. A summary of the conditions under which condensation can be expected can be viewed at http://www.efficientwindows.org/condensation.cfm.

Second, limiting the installation of high-U-factor glazing can prevent comfort problems. Even if the overall UA of a house is maintained (thereby making a trade-off theoretically energy-neutral), "cold spots" on the exterior walls can make occupants uncomfortably cool because of radiative heat exchange. In the worst case, a too-low "mean radiant temperature" can influence occupants to raise thermostat setpoints, having a deleterious effect on energy consumption. However, there is insufficient research and data to permit reasonable estimation of either the average occurrence of discomfort due to high-U windows or the frequency of thermostat manipulation as a result. Given this lack of hard data, a U-factor of 0.55 was deemed by many parties consulted as a reasonable, but not overly stringent, limit.

Although DOE's original RICC proposal included no SHGC trade-off limits, DOE recognizes the potential rationale for such limits. First, limiting the installation of very-high SHGC windows in southern climates can prevent occupant discomfort from hot spots in the home, even when overall energy consumption is theoretically unaffected. When occupants experience too-warm rooms or radiant heat from solar-heated floors and walls, they may lower thermostat setpoints. However, DOE is unaware of research or data that would quantify this energy impact with sufficient confidence to justify a code restriction. Additionally, the trade-off limit does not credit alternative methods of solar heat control such as roof overhangs in lieu of low-SHGC glazing[2].

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[2] Overhangs are credited in the performance approach but the 0.5 SHGC glazing limit applies regardless of how much solar heat is blocked by the overhang.

Second, limiting the worst-case SHGC of homes in cooling climates can have a beneficial effect on peak loads. Even if a trade-off is energy-neutral, raising SHGC in trade for other improvements can result in higher peak loads in some cases. This can require larger air-conditioning units that will operate at lower part-load ratios for much of the year, indirectly raising energy consumption. Also, high peak loads are increasingly problematic for electric utilities. Although few residential electric customers pay directly for their impacts on peak loads, recent blackouts and brownouts in California and the Northeast have focused much attention on the possibility of billing residential customers for their impacts on system peak.

To evaluate the potential peak-load benefit of restricting SHGC trade-offs, DOE conducted energy simulations using the DOE-2 computer program for each of the available 239 TMY2 weather locations. The worst-case trade-off for peak loads is to reduce cooling-oriented envelope efficiency (i.e., increase SHGC) in trade for better heating performance (e.g., increased AFUE) in climates that have substantial heating. DOE evaluated the peak load impacts of trading the code-mandated 0.4 SHGC up to a hypothetical value of 0.65 and making up the difference with non-cooling-oriented changes. The results, shown in Figure 4, reveal a fairly consistent peak cooling load "potential" of about 1.5 kW resulting from this hypothetical SHGC trade-off. Specific load impacts will depend, of course, on actual window area and orientation (our simulations assume windows equally distributed in the four cardinal directions). Also, though we analyzed the impact of raising SHGC only to 0.65, it is conceivable that higher values could be attained using single-pane glass.

The floor modifications cap the SHGC at 0.5, eliminating a sizable fraction of the SHGC-induced peak load potential.

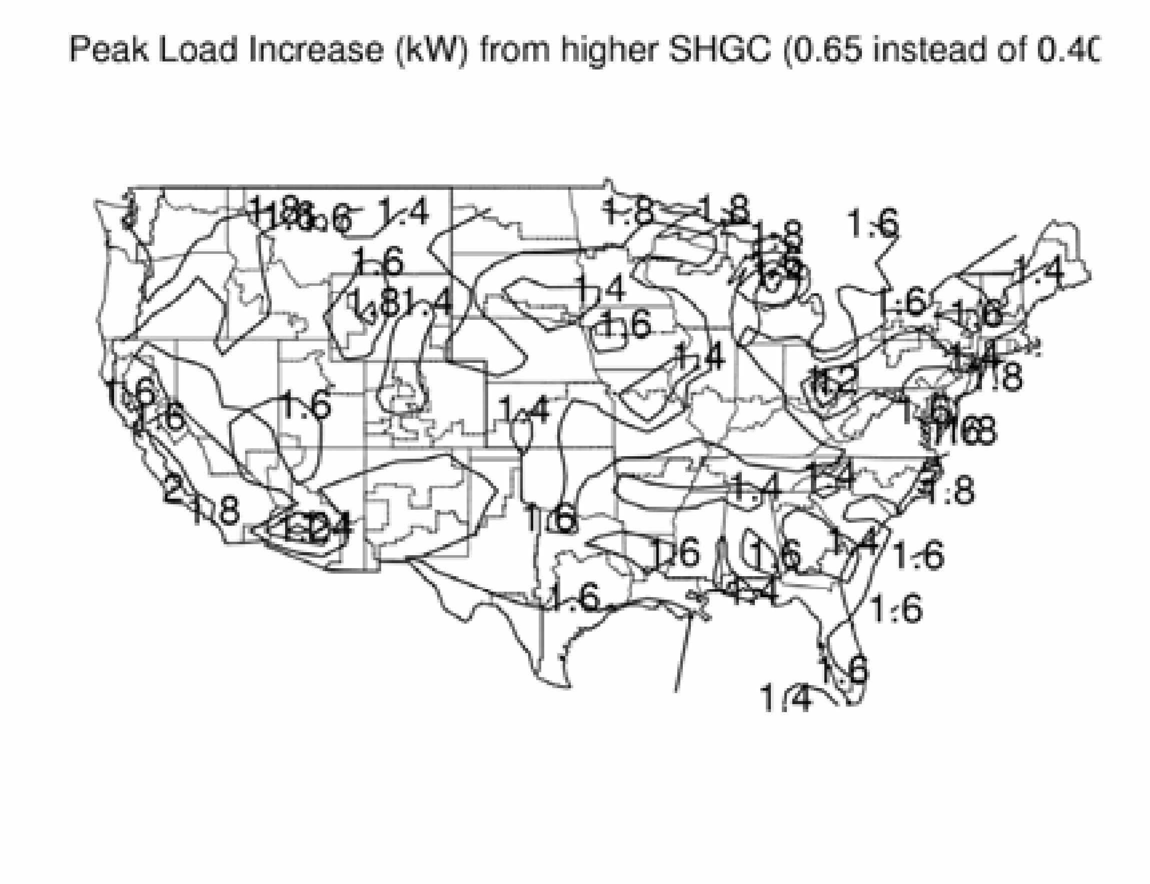

Figure 4 – Peak Load Increase (kW) from Raising SHGC from 0.4 to 0.65.

Market Influences

To assess the effect of the mods or product choices and options, the relatively simple trade-off limits imposed by the floor mods were evaluated against the range of window options available in the 2001 NFRC database (an electronic version of a more current database could not be obtained from NFRC).

Figure 5 shows the distribution of U-factor options in the NFRC database. Only double-pane options are included because single-pane options are rarely used in the northern tier states. The histogram clearly shows the bi-modal distribution of double-pane U-factors, the leftmost mode representing low-E glazing options and the right mode representing non-low-E options.

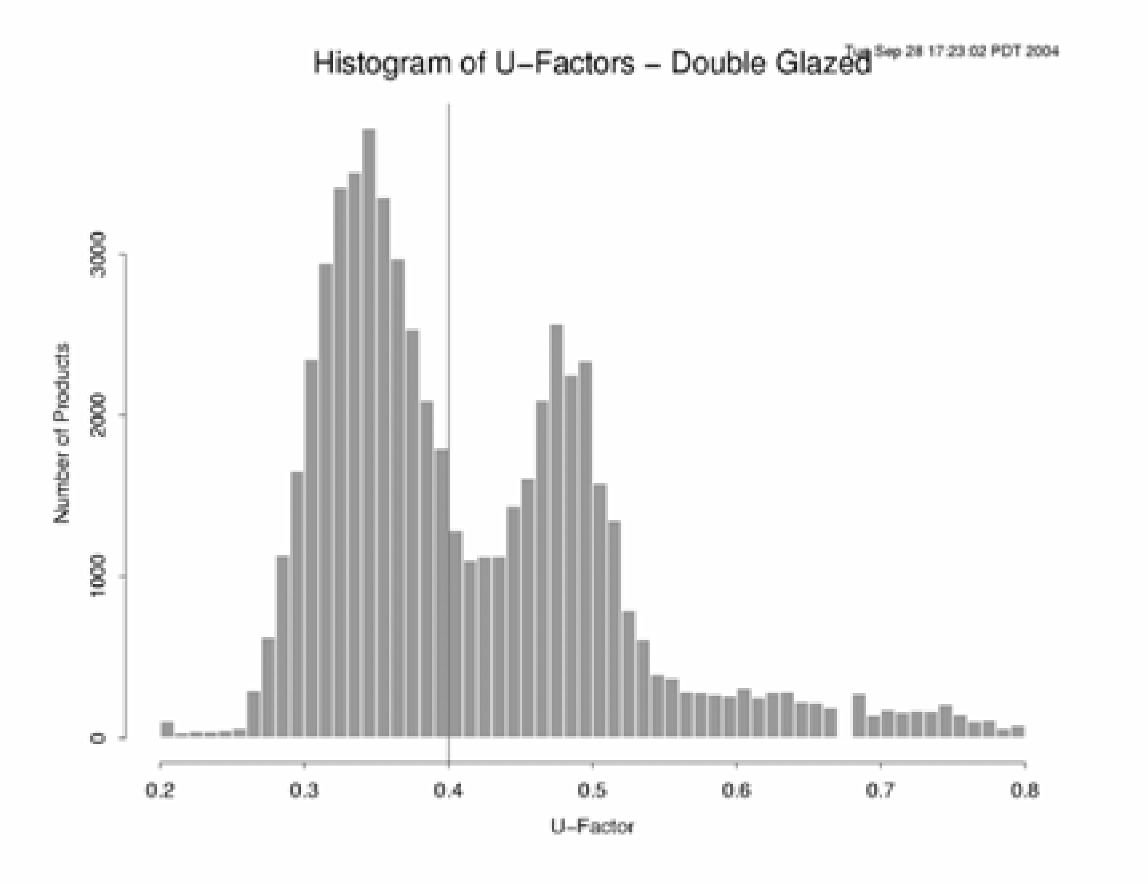

Figure 5 – Distribution of Rated U-Factors of Double-Pane Windows

Figure 6 shows the distribution of SHGC values among window options available in the NFRC database. This graphic includes both single- and double-pane units. Unlike the U-factor distribution, the SHGC distribution is single-mode, indicating no clear performance distinctions resulting from technology differences. What is not evident from the graphic, however, is that most of the windows to the left of the 0.5-SHGC cutoff achieve a low SHGC by either a low-E coating or some form of tinted or reflective coating. Low-E windows are expected to be the predominant method of meeting the 0.5 SHGC requirement in zones one through three. This would practically eliminate the single-pane window market.

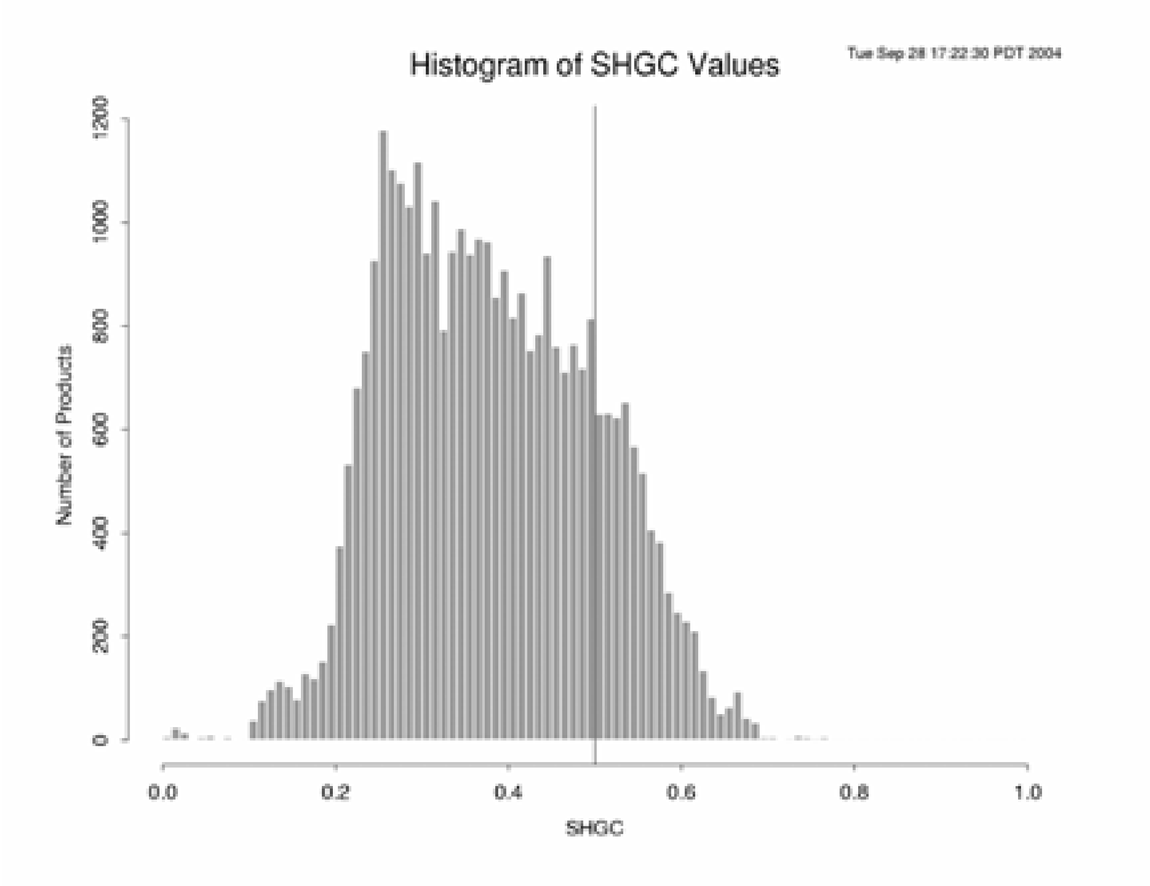

Figure 6 – Distribution of Rated SHGCs