Insulation Quality and Compliance Assessments— Field Inspections for Insulation

Bruce Harley
Member ASHRAE

ABSTRACT

The International Energy Conservation Code *(IECC) requires that insulation products be "…installed in accordance with the manufacturer's installation instructions…." In practice, manufacturer's instructions and industry standards are widely ignored; insulation is often installed with substantial defects. Insulation installers and others who have a stake in the work (builders, owners, architects, and code officials) do not understand the performance implications of these defects, so there is little market push to change or improve.*

A mechanism has been introduced into for Home Energy Ratings (HERS) to systematically account for insulation performance degradation. Based on a repeatable and defensible inspection procedure, the inspections provide a tangible reward for good performance. The inspection procedures outlined below are used by energy rating performance analysis, which closely parallels the performance path of the 2004 IECC. Adoption of a similar system by building codes could substantially improve the effectiveness of performance-based codes and improve the performance of new housing stock.

INTRODUCTION

The insulation inspection procedures outlined below were adopted by the accrediting body of the home energy ratings industry in 2006. The procedures were designed to address concerns regarding performance degradation of insulation due to improper installation, in the context of whole-building performance analysis. Gaps in cavity insulation or continuous insulating sheathing that amount to missing insulation over some percentage of the surface of an insulated assembly will have a higher conductance and result in higher overall U-factors for the entire assembly. Compression of insulation material in cavities to less than its rated thickness increases density and R-value per inch, but reduces overall R-value of the material. Missing thickness of blown-in or sprayed-in insulation resulting from irregular installation, attempts to cut material costs, or misunderstanding of application techniques reduces R-value over some or all of a surface area. Stakeholders such as code officials, energy raters, supervising architects, owners and builders don't have an intuitive feel for the consequences of defects. Most parties unfamiliar with parallel-path heat transfer analysis tend to believe that a high percentage of a surface being covered would result in an equally high percentage of rated performance of insulation materials. For example, using the parallel-path flow method, the net R-value of 995 square feet of attic, with perfect blown-in insulation at R-50 $h \cdot ft^2 \cdot {}^\circ F/Btu$, alongside 5 square feet of uninsulated drywall (such as a scuttle access), is approximately R-40 $h \cdot ft^2 \cdot {}^\circ F/Btu$ (ignoring framing)—a 20% degradation resulting from a 0.05% lapse in insulation coverage.

The impact of installation techniques on the thermal performance of insulated assemblies has been established by research. Christian et. al. found that rounded shoulders, air pockets around electrical wires, and cavity voids resulted in a 5% to 11% reduction in whole-wall R-value, when tested with a guarded hot box, concluding that "The seemingly insignificant insulation installation errors and thermal shorts resulting from interface details accumulate to significant impacts."

***Bruce Harley** is technical director for Conservation Services Group, Westboro, MA.*

James and Goss found net R-values of nominal R-19 h·ft^2·°F/Btu ceiling insulation to be below R-5 h·ft^2·°F/Btu (U-0.206 Btu/h·ft^2·°F) when installed with a 3/8 inch gap on each side (almost 5% of the gross surface area) along with a 3/4 inch wood furred air space between the drywall and the faced batt.

All published editions of the *International Energy Conservation Code* (IECC) require that insulation products be "…installed in accordance with the manufacturer's installation instructions…." In addition, the Federal Trade Commission (FTC)'s "Home Insulation Rule" (16 CFR 460), which covers insulation manufacturers, installers, and home builders, requires a statement on products "To get the marked R-value, it is essential that this insulation be installed properly." Using fiber glass batts as an example, proper installation is widely agreed to require that all cavities be filled from side-to-side and top-to-bottom, tucked into corners on all sides, that insulation be fluffed to full loft or thickness, split to fit around wiring, and cut to fit neatly around any obstructions due to services or framing. The likely response to a such a requirement in the building code tends to divide into one of two approaches: inspectors may choose to "look the other way" and qualify buildings based on labeled R-values, or they may insist on proper installation—laudable, but difficult to achieve in practice. The latter approach may be viable for building officials, who have the authority stop a project, but it is rarely enforced by code officials. Enforcement is even more problematic in a competitive market for energy ratings, where raters working in the same marketplace may have differing interpretations of "according to manufacturer's instructions."

ENERGY RATING INDUSTRY RESPONSE

The committee that developed these insulation inspection procedures wanted to account for a combination of installation defects. The approach was based on the following criteria:

- It may be applied fairly to all types of insulation materials and applications. There is variability in the completeness of manufacturer's instructions for different products, and that variability should not hinder the creation of a level playing field for all products.
- It is categorical, rather than analytical. This makes the procedure simple enough to implement in a field inspection environment. To implement an inspection process that attempted to account for all the variability in installation practices and generate a precise model based on detailed performance characteristics would be unrealistic. Even if we knew enough about performance of varying installation practices to create an analytical model, it would not be practical for field work by raters and inspectors.
- There are only three categories, to minimize the number of levels where inspectors must make a judgment call.
- Objectivity, to the extent possible, was an important concern. The inspection criteria are intended to be clear enough so that raters/inspectors can justify their choices in a given circumstance.
- The performance characteristics that are assigned to each category for software analysis are based generally on worst-case conditions within each category.
- There is a requirement to use a default value that is equivalent to Grade III, the worst performing of the three categories, for any insulation that is not inspected. This is consistent with other aspects of home energy ratings, and the IECC performance standards (e.g., enclosure air leakage and duct leakage) whereby no credit for performance that is better than the default is allowed without performance testing or inspection to justify it.
- It does allow for analytical treatment of insulation that does not qualify for Grade III, by specifying that uninsulated areas be measured explicitly and treated as separate, uninsulated assemblies in the performance analysis process.

The insulation inspection procedures define three categories of installation quality: "Grade I," "Grade II," and "Grade III." For each level, the protocol defines a threshold, or boundary condition, that the installation must meet to assign that level or Grade: a worst case condition allowed for that Grade. And at each level, the performance values assigned to the software performance analysis correspond generally to the boundary condition of that Grade. This categorical approach is an accepted mechanism for implementation of simplifying assumptions in code compliance. It is analogous to the concept used in the prescriptive compliance paths in MEC 1995 and IECC 2000 (for example). In those codes, if a home has glazing area within a defined range (for example 10%–13% of the wall area) the code requirements for the envelope are based on the worst case within that range, or 13% in the example.

Applicability to Building Codes

Although home energy ratings are widely used for voluntary programs such as ENERGY STAR and energy efficient mortgages (EEMs), the inspection procedure is still relevant to building codes development. Home energy ratings use a virtually identical rule set to the 2004 IECC performance path. Home energy ratings have also been adopted as a performance-based code compliance mechanism in at least 11 states, either as a mechanism for providing analysis and verification of an IECC performance method, or as an alternative compliance path. Further, a nearly identical rule set, including the insulation inspection procedure, has been adopted by the IRS for the certification of the new homes tax credit that was established in the 2005 Energy Policy Act—a certification that is based on 50% heating and cooling energy savings relative to the 2004 IECC performance method.

Insulation Inspection Procedure

During the drafting of these procedures, the committee recognized the need to base inspection criteria on visual cues rather than detailed measurements, which would be impractical in large-scale field operations. The procedures include illustrations of boundary conditions for both gap area and compression area, in order to provide a visual "benchmark" by which an inspector can justify his or her decision to place an installation in a category. These illustrations are reproduced in the following description of the inspection criteria. Note that in addition to the discussion below, there is also a requirement that modeling account for framing depth, thickness and spacing, and interior and exterior sheathing materials, as well as cavity fill and insulating sheathing R-values.

Grade I. In order to qualify for a "Grade I" rating, insulation must be installed according to manufacturer's instructions and/or industry standards, where available. Additionally, it must fill each framing cavity side-to-side and top-to-bottom, with no significant gaps or voids around obstructions (such as blocking, bracing, or electrical boxes), and split or fitted tightly around wiring and other services in the cavity. The boundary conditions for "Grade I" as illustrated in the procedures are shown as Figures 1 and 2. In general, no exterior sheathing is visible through gaps in the material, although occasional very small gaps are acceptable for Grade I (Figure 1). Compression or incomplete fill amounting to 2% or less of the total surface area is also accepted for Grade I, as long as all of the insulation is at least 70% of the intended insulation thickness. The gray shading in Figure 2 represents a visual indication of approximately 2%, as a visual benchmark for inspectors.

Note that the condition for compression or incomplete fill is distinct from the requirement to model overall compression. For example, if R-19 batt insulation rated at 6 ¼" thickness is installed in a 2x6 stud bay at 5½", the installed R-value may range from be R-17 to R-18 (depending on the manufacturer's data). In that case, one would begin with the compressed R-value, and then apply the relevant inspection Grade to the result before assigning values to the framing and sheathing materials. If the manufacturer does not provide R-value information for compressed products, the values are calculated using coefficients from ACCA Manual J, 8th Edition, Table A5-1, which are based on the percentage of insulation compression.

Grade II. The "Grade II" rating represents moderate to frequent defects: gaps around wiring, electrical outlets, plumbing, other intrusions; rounded edges or "shoulders," larger gaps and/or more significant compression. The boundary condition for "Grade II" as illustrated in the procedures is shown in Figures 3 and 4. Up to 2% of the gross surface area of insulation may be missing for an installation to qualify for Grade II. The black shading in Figure 3 represents a visual indication of approximately 2% as a visual benchmark for inspectors. Compression or incomplete fill amounting to 10% or less of the total surface area is also accepted for Grade II, as long as all of the insulation is at least 70% of the intended insulation thickness. The gray shading in Figure 2 represents a visual indication of approximately 10%.

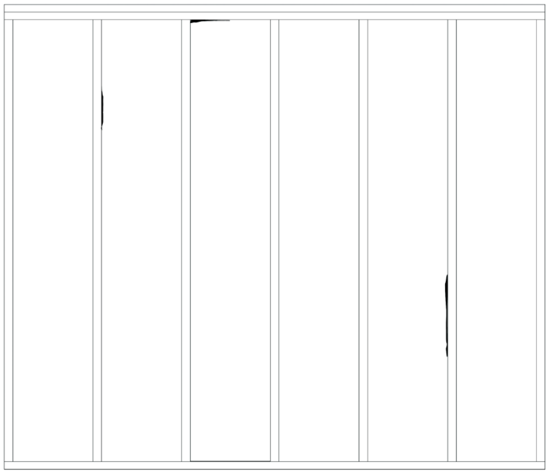

Figure 1 *Grade I boundary condition: minimal gaps.*

Figure 2 *Grade I boundary condition: 2% compressed or incomplete fill area.*

Figure 3 *Grade II boundary condition: 2% gap area.*

Figure 4 *Grade II boundary condition: 10% compressed or incomplete fill area.*

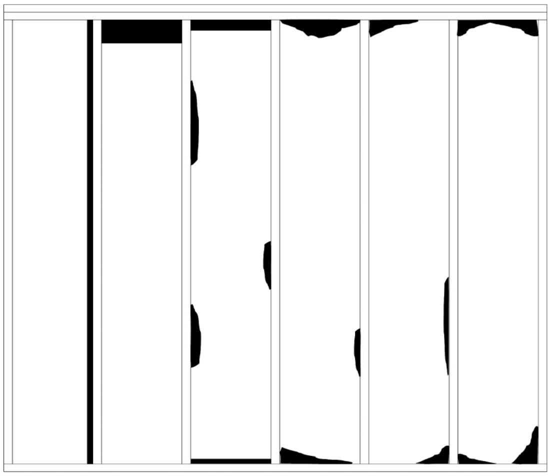

Figure 5 *Grade III boundary condition: 5% gap area.*

Grade III. A Grade III rating applies to any installation that is worse than Grade II: if gaps or missing insulation amount to greater than 2% of the gross surface area, or compression or incomplete fill of up to 30% comprises greater than 10% of the area. However, there is a boundary condition for Grade III, as shown in Figure 5; no more than 5% of gross surface area of missing insulation is acceptable for Grade III. The black shading represents a visual indication of approximately 5%.

If an installation does not meet the qualifications of Grade III, the procedure specifies that the rater/inspector shall measure the uninsulated areas separately, and model them separately in software. For example, if a wall area of 100 square feet had 10 square feet with no insulation, the 10 square feet would be treated in the performance analysis as a separate frame wall area with an uninsulated cavity.

Additional Requirements

In addition to the foregoing, the procedure expressly forbids averaging R-values over area, which is a common misunderstanding that leads to incorrect results. Also, raters/inspectors are explicitly required to properly differentiate how much insulation is in the framing space, and how much may cover the framing. This assessment must be included in the modeling process, with cavity insulation treated separately from continuous insulation that covers the framing. For calculating performance of steel-framed walls, it also specifies the use of "Thermal Design Guide for Exterior Walls, Publication RG-9405, American Iron and Steel Institute; the 'Zone Method' from 2001 ASHRAE Handbook of Fundamentals (P 25.10-11); or equivalent." There are several specific additional conditions and limits for wall, ceiling, and floor insulation, as follows:

Walls. To qualify for Grade I or II, wall insulation must be enclosed on all six sides. Sheathing wrap is acceptable (for example, on the back of unsheathed walls exposed to attic space), but walls that are open on one side to an attic, crawlspace, or other unconditioned or vented area are assigned Grade III. One exception is insulation in joist cavities located between floors, in which the interior surface is not required to be sheathed or enclosed. Also, Grade I or II wall insulation must be in substantial contact with the sheathing material on either the interior or exterior of the cavity; it cannot be installed in the center of an oversized stud cavity. Inset stapling is not prohibited from a Grade I or II designation, but it must meet all the other requirements of the category as outlined above.

Ceilings. To qualify for Grade I, ceiling insulation need not be enclosed on six sides, but it must be in complete contact with the surface it is intended to insulate. For example, faced batt insulation in a flat ceiling that is separated from the drywall by ¾ inch furring cannot be assigned Grade I. Also, to qualify for Grade I, eave baffles must be installed to prevent "wind washing" of the insulation in the eave area.

Floors. To qualify for Grade I, floor insulation must be in complete contact with the surface it is intended to insulate. Floor insulation need not be enclosed on six sides, provided the floor is exposed to an enclosed, unconditioned basement or a vented or unvented crawl space. If the floor is cantilevered or otherwise exposed to outside air, it must be enclosed with sheathing or other suitable material to qualify for Grade I.

Application in Performance Analysis

The general application of the three grades is defined in the standards, based on a parallel UA path with the maximum gap area allowed in each grade. Table 1 shows an example of a specific set of parallel heat path R-values, relative areas, unit UA values, and overall Uo and Ro, for a nominal R-19 h·ft^2·°F/Btu, 2 × 6 wall, framed 16 inches on-center, using the parallel-path flow method. Note that default framing factors for walls,

Table 1. R-Values and U_O of 2 × 6, R-19, Grade I Assembly

Component ($h \cdot ft^2 \cdot °F/Btu$), Unless Otherwise Noted	Framing	Cavity
Inside Air Film	0.68	0.68
0.5 in. Gypsum Wall Board	0.45	0.45
Cavity	6.88	17.7
Sheathing (Typ)	1.00	1.00
Outside Air Film	0.17	0.17
R_1, R_2 (totals)	9.01	19.83
Relative Area	0.22	0.78
UA (Btu/h·°F)	0.024	0.039
U_O ($Btu/h \cdot ft^2 \cdot °F$)	0.064	
R_O	15.7	

ceilings, and floors of various construction types are also specified in the requirements for home energy ratings.

The derivation of values that are used in the performance analysis for Grades II and III are shown in Tables 2 and 3, respectively. In each case, the third parallel path (“Gap”) is introduced to represent the worst case surface area of missing insulation allowed in the inspection criteria: 2% for Grade II and 5% for Grade III. (Note: The R-value of 1.03 $h \cdot ft^2 \cdot °F/Btu$ for the cavity air space is not specified in the procedures, but is taken from an energy rating software package commonly used in the ratings industry.)

These net R-values are based on the worst-case for gaps in the insulation, and are generally lower than the R-values that would be predicted by the compression or missing insulation thickness alone. The net R-values used for the performance model are based solely on gaps, and the Grade assignment criteria allows for *both* gaps and compression/missing insulation; thus, in the worst case of both maximum gaps and compression the actual performance predicted by the parallel-path flow method may be worse than the assigned performance value based on the performance analysis requirements.

Table 4 shows the differences, for an R-19 $h \cdot ft^2 \cdot °F/Btu$ 2 × 6 stud wall; the first column shows the values used in the performance analysis, which are also the worst-case R-values if the installaition has only gaps and no compression or missing insulation. The overall R-values in Table 4 were calculated using the same parallel-path heat flow method shown in Tables 1-3, with an additional portion of the gross area set aside for compressed or missing insulation. The second column shows the worst-case R-values if there is missing insulation only (missing insulation was used in the table because it yielded lower R-values than compression across the same area); the third shows the worst-case R-values if there are both maximum gaps and missing insulation.

In the case of Grade I, since there is no assumed performance degradation at all, the theoretical performance of the worst-case with missing fill (column 2) is worse than the value used in the performance model, but by less than 1%. In the case of Grade II or III, the impact of missing insulation was less than that of the gaps, by 5% and 6% respectively. In the case of both gaps and missing insulation, there is no value for Grade I (because gaps are essentially eliminated in Grade I); The calculated R-value penalty over the value used in the performance analysis for Grades II and III are 3% and 11% respectively. (Note that ‘missing insulation” was set at 50% of the gross area for the Grade III calculations). This may result in underpredicting the penalty in some individual homes, but only in those assemblies for which both the gaps and the compression or missing insulation are near the limit of the boundary condition for the selected Grade. Overall the two grades represent a reasonable compromise between simplicity and accuracy.

CURRENT STATUS AND FUTURE OUTLOOK

The insulation inspection procedure has been published since its adoption by the accrediting body of the home energy ratings industry on November 7, 2005. (A public comment version was first posted in February 2005.) The procedures are presently required for any new home energy rating initiated on or after July 1, 2006. As of the time of this writing, there is substantial evidence that it has been accepted by major stakeholders. In addition to the IRS adoption of the procedures in the new homes federal tax credit rules, the U.S. Environmental Protection Agency has also adopted the insulation inspection procedure into their new homes labeling program, both implicitly in the performance path (which utilizes the standards by reference as the compliance mechanism), and explicitly in the prescriptive path, by requiring inspection to Grade I for compliance.

Limitations

The problem of thermal defects due to improper installation had previously been ignored by home energy ratings and performance-based codes alike. Although these procedures are an important first step, they do not address every shortcoming or pitfall in the insulation field. Some of the limita-

Table 2. R-Values and U_o of 2 × 6, R-19, Grade II Assembly

Component ($h \cdot ft^2 \cdot °F/Btu$), Unless Otherwise Noted	Framing	Cavity	Gap
Inside Air Film	0.68	0.68	0.68
0.5 Gypsum Wall Board	0.45	0.45	0.45
Cavity	6.88	17.7	1.03
Sheathing (Typ)	1.00	1.00	1.00
Outside Air Film	0.17	0.17	0.17
R_1, R_2 (totals)	9.01	19.83	3.16
Relative Area	0.22	0.76	0.02
UA (Btu/h·°F)	0.024	0.038	0.006
U_O ($Btu/h \cdot ft^2 \cdot °F$)		0.069	
R_O		14.5	

Table 3. R-Values and U_o of 2 × 6, R-19, Grade III Assembly

Component ($h \cdot ft^2 \cdot °F/Btu$), Unless Otherwise Noted	Framing	Cavity	Gap
Inside Air Film	0.68	0.68	0.68
0.5 in. Gypsum wall board	0.45	0.45	0.45
Cavity	6.88	17.7	1.03
Sheathing (Typ)	1.00	1.00	1.00
Outside Air Film	0.17	0.17	0.17
R_1, R_2 (totals)	9.01	19.83	3.16
Relative Area	0.22	0.73	0.05
UA (Btu/h·°F)	0.024	0.037	0.016
U_O ($Btu/h \cdot ft^2 \cdot °F$)		0.077	
R_O		13.0	

Table 4. Worst-Case R-Values

	Gaps Only	Missing Insulation Only	Worst-Case: Both
Grade I	15.7	15.6	n/a
Grade II	14.5	15.2	14.1
Grade III	13.0	13.7	11.6

tions of the procedure and the associated performance analysis include:

- It is only applicable “when it is possible to inspect insulation as installed (i.e., new construction).” It is not feasible to use when insulation is blown in to closed wall, floor or ceiling cavities. (Scheduling problems in new construction do not qualify as an exemption.) This is typically only a problem when applying the procedures to existing home retrofit work rather than to new construction. Although closed cavity installations are occasionally used in new home construction, it should not be a large barrier to implementation of such a procedure in new construction codes.
- The R-value of blown-in cavity fill and attic loose-fill insulation are dependent on installed density, and some commentators have suggested that the inspection procedures should incorporate a density test. At the present time, no procedure has been written to implement a field measurement of installed insulation density in the context of home energy ratings. In the absence of such a field measurement, a rater/inspector may depend on the installers’ receipt or invoice (as required by the FTC Home Insulation Rule, Section 460.17) in combination with the manufacturer’s labels (as required by the FTC Home Insulation Rule, Section 460.12) to verify installed R-value.

- The assessment remains a subjective exercise, despite efforts to create clear guidelines for visual assessment and to make the criteria for each category as objective as possible. It is particularly subjective when an installation is near the boundary condition that defines the distinction between categories—a "judgment call."

To date, there has not been any field research on compliance with the inspection criteria, or on correlation of the performance analysis to actual energy performance. Both would be potential areas for useful research. Development of viable field sampling for installed density of loose-fill insulation could improve the standard significantly, and reduce dependence on installers' claims. Additionally, several commenters have suggested development of criteria for verification using thermal imaging, which could be useful for situations (1) where insulation has been covered before the inspector can see it, and (2) where insulation is installed in closed cavity (such as dry-installed cellulose).

POTENTIAL IMPACT

In an attempt to quantify the potential impact of this inspection requirement in terms of energy saved, modeling was conducted on a single home design in five locations, representing IECC climate zones 2-6. These climate zones cover a large majority of the continental United States. Table 5 shows the impact of changing the building insulation from Grade III to Grade I, along with the estimated dollar impact of those savings. The home was 2700 square feet, and in each climate zone the assumed insulation values were set at the prescriptive requirements of the 2006 IECC (Table 402.1.1). The energy consumption for heating and cooling were calculated using accredited home energy rating software, and the values for insulation grade were changed from III to I for all walls, ceilings and floors in the home. The estimated heating savings varied from 8% to 13%, averaging 11% of the consumption for all climates; cooling savings were less than 1.5% of the consumption in all climates. The price of fuel was set at $1.50/Therm of natural gas, and $0.10/kWh electricity, which is close to the national average for the year 2006.

The present value of the savings is shown in the last row of Table 5. Present value was calculated using a 6% discount rate and 20-year life of the investment; because this calculation assumes constant energy prices, it is likely to be conservative; at the same time, the estimates assume that the Grade III insulation assemblies actually perform as badly as the modeled performance, which is likely to be untrue in many cases. In all but the warmest climates, the present value of the annual savings is significant for the consumer, ranging between $1000-3000 for most of the continental United States. Upgrading the insulation quality would typically increase the labor cost for installation, and should be cost-effective. The prototype home used in this example has 6438 square feet of insulated wall, floor and ceiling. At a price of $0.10-0.20 per square foot for the labor to detail the insulation properly, the total price tag would be in the range of $644 to $1,288, which would certainly be cost effective in most climates.

Improving insulation, however, may not be the most likely compliance option. Although current codes widely require proper installation, anecdotes from the field consistently suggest that proper installation is rare. Given the choice between upgrading the quality of insulation and performing other building upgrades, many builders may choose to take routes that are easier to accomplish, less expensive, or both. If energy codes were structured such that the assumed baseline was a Grade III installation, then users of the code could choose to take credit for improved installation practices, or for other measures that would yield equivalent improvement in energy performance.

AN ALTERNATIVE EXAMPLE

One western state has code requirements for residential buildings using a somewhat different system to allow credit for proper insulation installation techniques. As with the national home energy rating procedures, these state rules require that a home meet specific insulation criteria in order to take full credit for rated performance; if an inspection is not done to confirm compliance with a detailed checklist, then a penalty is assigned to the assumed performance of the insulation. The penalty is on a percentage basis for walls, and on an additive basis for ceilings (U-value adder). Table 6 compares the net U-values for two common wall and attic assemblies in that state energy code with those of Grades I and III, for four assemblies. The state system may be somewhat easier to implement than the home energy rating procedures because it is a binary system: all items on the checklist must be verified to receive the "improved performance" credit. However, the assignment of penalties may not be adequate, particularly when addressing higher R-values. Based on the parallel-path heat transfer method, the same sized gap in insulation coverage should have a larger percentage impact on the overall U-value as the intended R-value increases. Comparing the state code ratios (standard/improved) to the Grade III/Grade I ratios, the state code penalties are much more conservative, especially with more heavily insulated walls and attics, and probably do not adequately derate the performance.

The home energy rating procedures, like the IECC codes, use Uo values in the standard design building (or "reference home") that assume insulation is correctly installed to meet the general requirements of the code. Unlike the IECC, the state code performance method assumes a "standard" insulation quality in the standard design building, which makes it much easier for a building design to comply by reducing modeled energy consumption relative to that of the standard design building. In this way, the state energy code does not require the same potential for energy performance that the IECC codes do.

CONCLUSIONS

Because of the embedded assumption that all insulation materials are installed correctly, the IECC energy codes currently fall short of realizing assumed levels of energy efficiency. One way to improve compliance and save energy

Table 5. Savings Value for Grade III Versus Grade I

	Orlando, FL	Dallas, TX	Topeka, KS	Boston, MA	Minneapolis, MN
IECC Climate Zone	2	3	4	5	6
Annual Gas Savings—(Therms)	10	52	133	142	182
Annual Electricity Savings—(kWh)	87	90	negligible	negligible	negligible
Net Annual Energy Cost Savings	$23.70	$87.00	$199.50	$213.00	$273.00
Present Value of Energy Savings	$272	$998	$2288	$2443	$3131

Table 6. Comparison of Insulation Penalties Between National Home Energy Ratings and a State Building Code

	R-13 Wall	R-19 Wall	R-30 Attic	R-49 Attic
State Code "Improved" U_O	0.107	0.078	0.042	0.030
State Code "Standard" U_O	0.121	0.088	0.052	0.040
State Code Ratio	1.13	1.13	1.24	1.33
Grade I U_O	0.084	0.064	0.046	0.036
Grade III U_O	0.096	0.077	0.075	0.065
Energy Ratings Ratio	1.14	1.21	1.63	1.81

would be to focus on ensuring correct insulation practices. The current system of "requiring" correct installation is not working; adoption of a system similar to that used by the home energy rating industry could effectively increase the level of compliance with the levels of energy efficiency anticipated by the code.

Because of the close alignment between the analysis process in home energy ratings with the performance analysis method in the 2004 and 2006 IECC, this method could be adopted easily, with few modifications, into the performance path of future editions of the IECC. Inasmuch as some state and municipal governments have adopted home energy ratings as a code compliance option, these procedures are already adopted by reference into building codes in those jurisdictions, using a performance path or using a home energy rating as an equivalent performance path. Implementation of these procedures in the prescriptive compliance path of the IECC would be more complex, and would require recognition that standard practice in construction falls short of correct installation. If the default assumptions for developing prescriptive code paths were modified to include an assumption of downgraded insulation performance, two options seem likely: first, to simply assume incorrect installation, and develop prescriptive paths that are more stringent in order to recover the difference. The increased stringency could be in the form of higher R-values of insulation, in other building component specifications, or in a combination of the two. Second, and more likely, would be to simply require an inspection to the Grade I criteria, explicitly spelled out in the code, rather than relying solely on a brief statement of conformance to "manufacturer's instructions." Although the latter system would likely not be enforced universally, it would certainly be more visible than the current requirements, and would likely get more attention. A third, less likely option would be to indicate specific trade-offs that would be available (for example, wall insulation could be required to be R-15, without verifying correct installation, or R-13 with verification). Any of these mechanisms would put better installation practices on a more even footing with simply increasing R-values, and provide a cost incentive to improve installation practices. An equal or equivalent provision could also be adopted into the International Residential Code (IRC), which parallels the IECC prescriptive path.

Adopting such an approach would not likely immediately change installation practices in the field, considering that the current code requirements are often ignored. However, it would likely increase awareness of the performance trade-offs by effectively making the code more stringent to make up the difference. Designers would be faced with anticipating the incremental construction cost for a number of options: specifying verifiable installation practices for standard products; specifying alternative products, such as sprayed- or blown-in insulation that may meet the required criteria more easily; or specifying alternative upgrades that make up the shortfall in performance for the building. Designers and builders would be more aware of the impact of installation defects in building performance, as they would see more directly what the equivalent trade-offs were. Insulation subcontractors would have a market push to do a better job for a competitive price, because there would presumably be an increase in funds available to pay them. However, code officials would then be responsible for learning and enforcing the new code provisions. Although such a provision would certainly make the requirements more obvious than they are now, it may not raise the issue of installation quality much higher on the priority list of code officials with limited time and resources.

In addition to residential codes, these procedures could also be considered for adoption into codes and/or voluntary programs for commercial buildings. Although the home energy ratings industry only addresses low-rise residential buildings, insulation inspection procedures could be equally applied to commercial and/or high rise residential buildings. The thermal transfer implications may not have as high an impact in proportion to total energy use in some of these building types, but the absolute Btu losses (and gains), and consequent carbon emissions, in a given climate are much larger in large buildings.

Overall, these insulation inspection procedures provide a sound and viable means to address a range of insulation conditions commonly found in the field, and apply them to performance analysis used in code compliance. These provisions could be useful to consider for adoption into the IECC codes, for both the performance and prescriptive compliance paths, and the energy portion of the IRC. However, there remain limitations based on (1) subjectivity, (2) lack of verification of installed density of loose-fill insulation, and (3) the limitation of inspection to exposed building cavities only. Additional research on real-world performance impacts and enforceability would be useful.

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