Energy Design Update®

The Monthly Newsletter on Energy-Efficient Housing

ASPEN PUBLISHERS Vol. 33, No. 3 March 2013

IN DEPTH

Setting a Foundation for Wall Cavity Moisture Monitoring

In 2009, the NAHB Research Center completed a monitoring program on six homes, located in climate zones 4 and 5, and designed to identify seasonal moisture characteristics in walls (see Figure 1). The collected field data were analyzed both for indicators of potential problems in the cavity, as well as to produce a baseline set of data for comparison to homes constructed with higher performing wall systems.

"High-R Walls for Remodeling: Wall Cavity Moisture Monitoring"

The initial study, "High-R Walls for Remodeling: Wall Cavity Moisture Monitoring," (*http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/high_rwalls_remodeling.pdf*), was led by Joe Wiehagen and Vladimir Kochkin, of the NAHB Research Center (now known as Home Innovation Research Labs, following the NAHB Research Center's February 12, 2013, name change). The objectives of the original study were to document seasonal wall cavity moisture characteristics, oriented strand board (OSB) moisture characteristics, and indoor humidity levels in homes with standard wall construction and substantially lower infiltration rates. Given sufficient data, Wiehagen and Kochkin then isolated variables that could result in the unsatisfactory moisture performance of standard acceptable wall system construction (refer to Figure 2). The study also collected data to characterize indoor humidity levels and seasonal wall cavity moisture performance in these homes.

Data were gathered and homes selected based on the following parameters:

- Identify new homes built in the fall of 2009 that use similar construction methods, and are in the same geographical areas where cases of OSB buckling were previously reported.

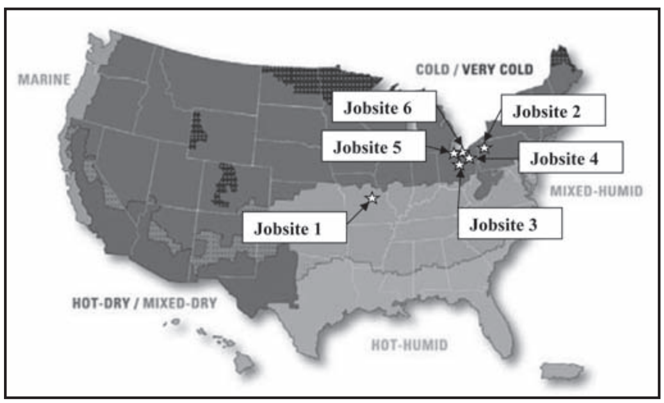


Figure 1. Jobsite geographical locations overlay on the DOE climate and hygrothermal map. Reprinted with permission, Home Innovation Research Labs; from "High-R Walls for Remodeling: Wall Cavity Moisture Monitoring." (*http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/high_rwalls_remodeling.pdf*)

IN THIS ISSUE

IN DEPTH
Setting a Foundation for Wall Cavity Moisture Monitoring 1

IN DEVELOPMENT
Building Energy Efficient and Cost Conscious Homes 5

IN BRIEF 11

IN PRACTICE
A Closer Look at Green Roofs 12

Wolters Kluwer Law & Business

Jobsite Number	City	State	Framed Stories	Framing Size[a,b]	Stud Material/ Grade	Stud MC[c] (%)	Air Sealing	Wall Insulation/ Vapor Retarder	WRB (Perms[d])	Finish
1	Chesterfield	MO	2	2 × 4	SPF/Stud	9-17	Sill, Rim Joist	R-13/ Kraft paper	Brand 1 (46.6)	Brick and Cement Fiber Board
2	Valencia	PA	3	2 × 6	SPF/Stud	11-15	Plates (top, bottom, and sill), Rim Joist	R-19/ Kraft paper	Brand 2 (56)	Brick, Stone, and Vinyl
3	Mansfield	OH	2	2 × 4	SPF/Stud	9-15	Plates (top, bottom, and sill), Rim Joist	R-13/ Kraft paper	Brand 2 (56)	Vinyl
4	Wadsworth	OH	1	2 × 4	SPF/Stud	10	Plates (top, bottom, and sill), Rim Joist	R-15/ Kraft paper	Brand 2 (56)	Vinyl
5	Lorain	OH	2	2 × 4	SPF/2	12-13	Bottom Plate	R-13/ Kraft paper	Brand 3 (63)	Vinyl
6	North Ridgeville	OH	1	2 × 4	SPF/Stud	8-14	Bottom Plate	R-13/ Kraft paper	Brand 3 (63)	Vinyl

a. Spruce-Pine-Fir (SPF) typical wood species for all jobsites
b. Stud spacing of 16 in. on center used for all jobsites
c. Framing MC measured during site visit
d. Perm ratings for WRBs obtained from product specifications physical properties data sheets [Dow, 2010], [DuPont 2007]

Figure 2. Test House Location and Summary Wall Details. Reprinted with permission, Home Innovation Research Labs; from "High-R Walls for Remodeling: Wall Cavity Moisture Monitoring." (*http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/high_rwalls_remodeling.pdf)*

- Observe OSB sheathing installation on each selected home.
- Collect relevant design, construction, and material data for each selected home.
- Install sensors in walls to measure temperature, dew point (DP), and relative humidity (RH) inside the cavity, and the moisture content of OSB sheathing.
- Measure air exchange rates through blower door testing for each selected home.

Of greatest importance from field observations was confirmation of the cyclic, dynamic nature of moisture content in the wall cavity. Among the six homes studied, cavity moisture characteristics tended to be both seasonal and directional, with colder periods, and the east and north walls, showing higher instances of sheathing moisture content. While all wall cavities measured demonstrated a cyclic behavior for the OSB moisture content, there was a wide variation in both the peak moisture content and the duration of higher levels of moisture content measured. Kochkin and Wiehagen isolated several notable data points from this analysis:

- Post-construction sheathing moisture content increase was common in all monitored homes.

Editor: Amanda Voss
Managing Editor: Vicki Dean
Designer: Chris Tankiewicz

Energy Design Update (ISSN 0741-3629) is published monthly by Aspen Publishers, 76 Ninth Avenue, New York, NY 10011. (212) 771-0600. One-year subscription costs $595. *To subscribe, call 1-800-638-8437. For customer service, call 1-800-234-1660. POSTMASTER: Send address changes to* ***Energy Design Update,*** *Aspen Publishers, 7201 McKinney Circle, Frederick, MD 21704.* **Permission requests:** For information on how to obtain permission to reproduce content, please go to the Aspen Publishers website at *www.aspenpublishers.com/permissions.* Printed in the U.S.A.

Purchasing reprints: For customized article reprints, please contact Wright's Media at (877) 652-5295 or go to the Wright's Media website at *www.wrightsmedia.com.*

Editor's Contact Information: Amanda Voss, Energy Design Update, 9019 Hunters Creek Street, Highlands Ranch, CO 80126, 303-663-2009, avitaproverum@gmail.com.

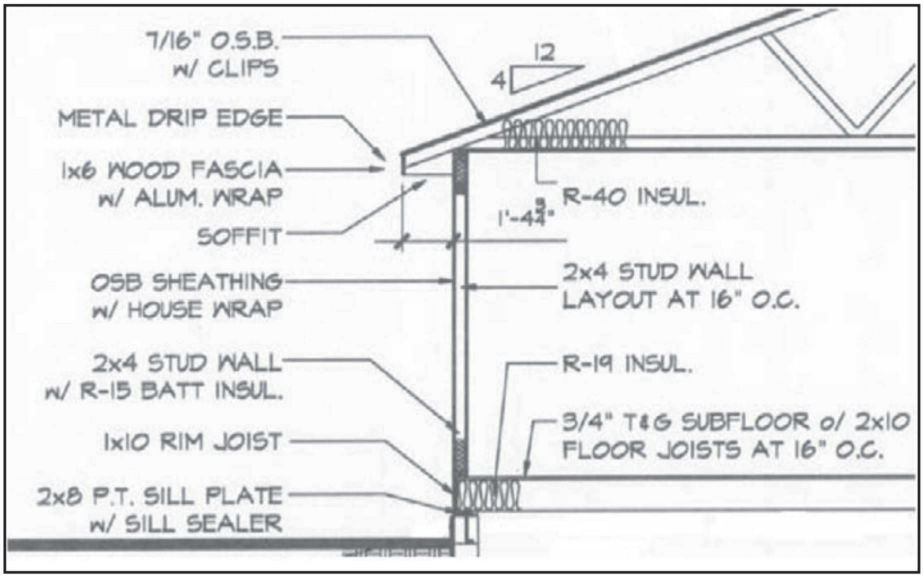


Figure 3. Common wall detail for monitored homes. Reprinted with permission, Home Innovation Research Labs; from "High-R Walls for Remodeling: Wall Cavity Moisture Monitoring." (*http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/high_rwalls_remodeling.pdf*)

- Moisture content levels of OSB sheathing above 20%, and even above 25%, were not uncommon in walls in the initial months following the construction process, and in some cases later in service. This change resulted in a total potential moisture fluctuation of 15% to 20%, relative to the initial starting point of 5%.
- Periods of elevated moisture content (more than 15%) occurred at some time during the year for most of the homes.
- A cyclic nature to sheathing moisture content was common in all homes; however, the level of swing (amplitude) was significantly different among homes in the same climate.
- Colder months had the highest levels of sheathing moisture content, as expected.

"What this field study gave us was an understanding of how typically configured wall systems go through a cyclic process of higher moisture levels and then a period of drying out," Wiehagen emphasized (see Figure 3). The six homes experienced higher moisture in the sheathing during the winter, with dissipation of that moisture through warmer periods. After the winter, into spring and summer, the ability for the sheathing to actually lose moisture is extremely quick in these wall systems, as shown from data curves after peak moisture content is reached.

In all homes, the moisture content started trending down in the spring months as the average daily temperature increased. These observed decreases in OSB moisture content ranged from about 5% to as much as 20%. "This initial field data demonstrated that, in these standard wall designs, wall cavity moisture characteristics and sheathing moisture content is a dynamic, cyclic process. The fact that there is a cyclic process is important to know. This research will help document the change from higher moisture levels to lower levels as it occurs across multiple seasons. Wall systems will not act in a static manner, that is not how they typically work in the field through changing seasons and indoor conditions," Wiehagen

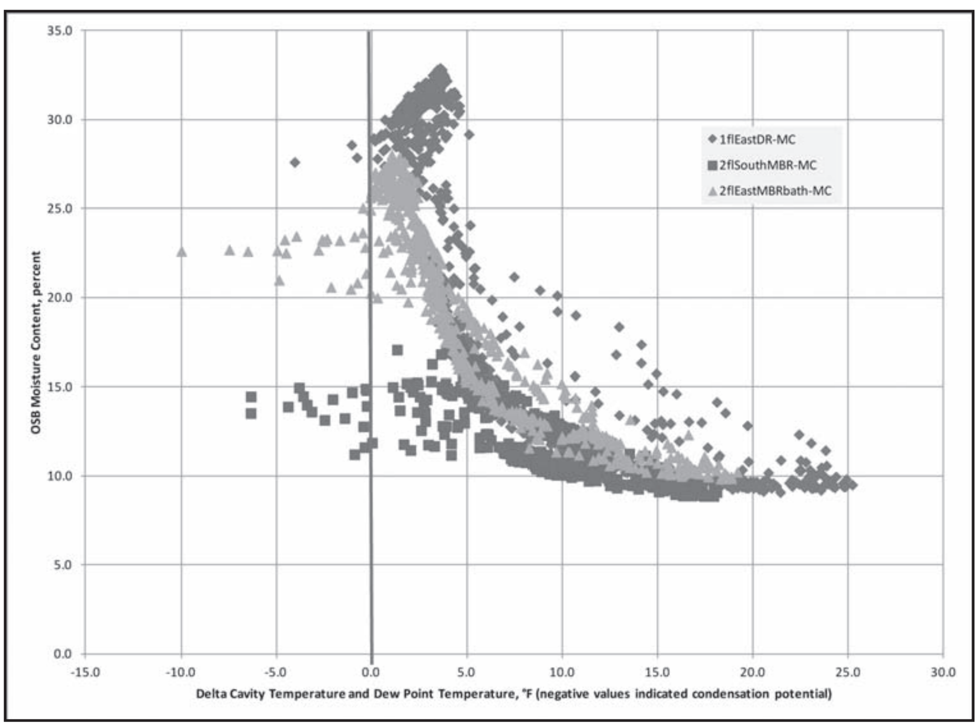


Figure 4. Jobsite 5 comparison of MC and DP. Reprinted with permission, Home Innovation Research Labs; from "High-R Walls for Remodeling: Wall Cavity Moisture Monitoring." (*http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/high_rwalls_remodeling.pdf*)

remarked. "Another notable finding is that the dynamic process is different for different orientations. The observed variation by orientation is important to highlight, to have measured data and show the stark differences between northern and western walls for example, that is something that simulation models have shown."

Beyond monitoring seasonal moisture content, the six-home study also measured relative humidity, seeking any correlations between interior conditions and wall cavity moisture content. Typical annual average interior RH levels in the monitored homes were generally between 45% and 50% RH. While the study site with the lowest interior average RH did correlate with the lowest average sheathing moisture content, as expected, based on the limited data set, interior average relative humidity (RH) appeared not to be a good indicator of increased sheathing moisture content. "Interior conditions, which can drive a lot of these issues, especially in winter when moisture's path is inside to outside, are not at all easy to define," Wiehagen explained. "Most of the modeling assumes indoor conditions, and how they may actually change throughout the seasons is less well known. In simulations, we always presuppose some indoor conditions. This study allowed us to catalog a new set of indoor data, which we found can be quite far from what we model or simulate in any given home."

The lack of predictability in interior moisture conditions, and how these translate to the cavity, was apparent when evaluating the condensation potential at the sheathing (condensation potential is when the DP temperature is greater than the air temperature) and the moisture content in the sheathing. Data graphical results showed that higher levels of sheathing moisture content measured do not coincide directly with the calculated condensation potential (refer to Figure 4). In fact, the wall sections with the higher levels of moisture content appear, in some cases, to have lower overall instances of condensation potential.

"There seems to be a mismatch between sheathing moisture content and condensation potential," noted Wiehagen.

Condensation potential calculations are often used when trying to determine whether there is enough insulation, or the right relative amount of insulation from interior to exterior. Typically, some basic analysis methodologies are used for this calculation. "We are finding that measured data doesn't always correlate with simplified analyses to estimate the condensation potential for a given wall section. It is hard to extrapolate from only six homes studied, but we did note different behavior from that estimated."

"That is the downside of field studies – you don't come up with one answer," Wiehagen explained. "Variability is reality. We did find that variable indoor and outdoor conditions are what causes variable conditions in the cavity, as you would assume. Yet, some of our design of wall systems is based on more static assumed conditions, and we wanted to see how things are matching up. That is why we did some studies the way we did them."

Looking Forward

The data from this six-home study will create a baseline for the next study, currently under way, which focuses on the moisture performance of high R-value wall systems in energy efficient homes throughout multiple climate zones. Wall cavity and sheathing monitoring results gathered from the original six-home study, built using standard construction practices, will provide comparative empirical data on the cyclic moisture characteristics of wall cavities in higher efficiency homes. "With the support of the National Association of Home Builders and public funding, we've been able to instrument homes all over the country, in climate zones 3, 4, 5, and 6, and in moist climate areas primarily," said Wiehagen. "We now have 22 homes instrumented." Qualifying homes had minimum insulation levels meeting the 2012 International Energy Conservation Code (IECC) levels, with air exchange rates less than 4 ACH50. All homes were tested to verify their performance. This ongoing high performance home study seeks to understand higher insulation wall systems and their measured moisture characteristics.

To understand moisture characteristics in high performance homes, the research team will evaluate changes in wall cavity behavior. The location of insulation relative to the cavity (e.g., insulation located to the exterior of the framing versus insulation placed within the cavity) are all variables incorporated in the study. From the 22 different homes, the Home Innovation Research Labs team will monitor 19 different types of wall sections. Several individual homes have various wall systems within the home, so that the team can measure the effect of indoor conditions on different wall types in the same home. Data will then be used to develop a profile of performance for the wall sections. "If there was a point where we see consistent issues with wall system design, or the location of insulation, we are hopeful to isolate and demonstrate that," Wiehagen said. "We also anticipate that the type of ventilation system and its operation in the house can make a significant difference; it can change the dynamic in a house even with higher moisture production."

The Home Innovation Research Labs team hopes these investigations begin filling the gap on moisture data in highly insulated walls. "There is not a lot of field data around," Wiehagen stated. "Having occupied homes, with normal living conditions, is really the advance of this work. Alternatively, lab work is extremely important, to keep interior conditions controlled and quantified, and then measure the effects in the wall cavities. But this field study really shows dynamic processes, and how people are living in homes and how this variability affects the moisture characteristics in the wall cavities."

Data for high performance home wall moisture monitoring will be gathered through 2013, which allows for a full set of winter and summer data for most homes. By early summer 2013, the Home Innovation Research Labs team aims to release the initial results of the winter data. "We are hoping to have sufficient data so that we can give a good profile as walls perform through the winter period, as this tends to be the period where we have the most concerns over the moisture performance," Wiehagen said.

Energy Design Update sincerely thanks Joe Wiehagen for sitting down with us and opening up his research in this topic. To access "High-R Walls for Remodeling: Wall Cavity Moisture Monitoring," visit *http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/high_rwalls_remodeling.pdf*.

As Senior Research Engineer for Home Innovation Research Labs, Joe Wiehagen performs engineering, testing, analysis, and project management to support the design of new energy efficient homes and energy upgrades of existing homes. His projects range from product development to technology integration and whole-house energy analysis. Projects include design and performance verification of high performance homes, solar thermal and electric system integration, heating and cooling system testing, hot water system design and testing, moisture performance characterization in wall systems, and integration of building shell materials and systems. He is technical lead for many of the technologies and systems used in the Home Innovation Building America Program partnership. His work includes simulation analysis of energy efficiency technologies and low-energy use home designs. He has a wide range of experience in establishing testing protocols and instrumentation of homes to analyze individual component and whole house performance. He supported the product development effort to design, install, monitor, and demonstrate an innovative photovoltaic-metal roofing module integrated with the building roofing. He was project development manager and design engineer for the first solar photovoltaic assisted dc lighting system in a commercial building. Wiehagen is certified as a BPI Building Analyst and Envelope professional. He has published reports and papers relating to numerous aspects of residential energy use, technology performance, and contributed to the development of various design tools and guides. He holds an MS in Energy Engineering from the University of Lowell, and a BS in Electrical Engineering from Gannon University.

As Director of the Applied Engineering Division for the Home Innovation Research Labs, Vladimir Kochkin oversees engineering research programs on the structural, environmental, and energy performance of residential construction. He also manages the ANSI process for the development of the National Green Building Standard (ICC-700). In his tenure at the Home Innovation Research Labs, Vladimir's work has involved analytical and experimental studies on the performance of buildings in natural disasters, with a focus on the development of innovative engineering solutions. Experimental projects have included measuring the performance of various structural systems and materials, including conventional and panelized systems for wood, cold-formed steel, and concrete construction. He has authored multiple research reports and guides for builders and product manufacturers, and has contributed to the development and implementation of product certification programs based on advanced quality management practices. Vladimir also works with product manufacturers on obtaining code acceptance for innovative construction technologies. He participates in the building code development process, and serves on several standard development committees on the structural performance of building systems, including wall bracing. Vladimir holds a masters degree in Timber Engineering from Virginia Tech, and a BS in Civil Engineering from Vyatka State Technical University, Russia.

IN DEVELOPMENT

Building Energy Efficient and Cost Conscious Homes

Residential buildings consume about 19% of all energy in the US, and 32% of generated electricity. Homes contribute significantly to peak electric demand and utility operating cost. As builders committed to energy efficient homes, how can we achieve additional increases in energy efficiency with the highest reliability and homeowner value, at the least incremental cost? The residential construction industry involves many mar-

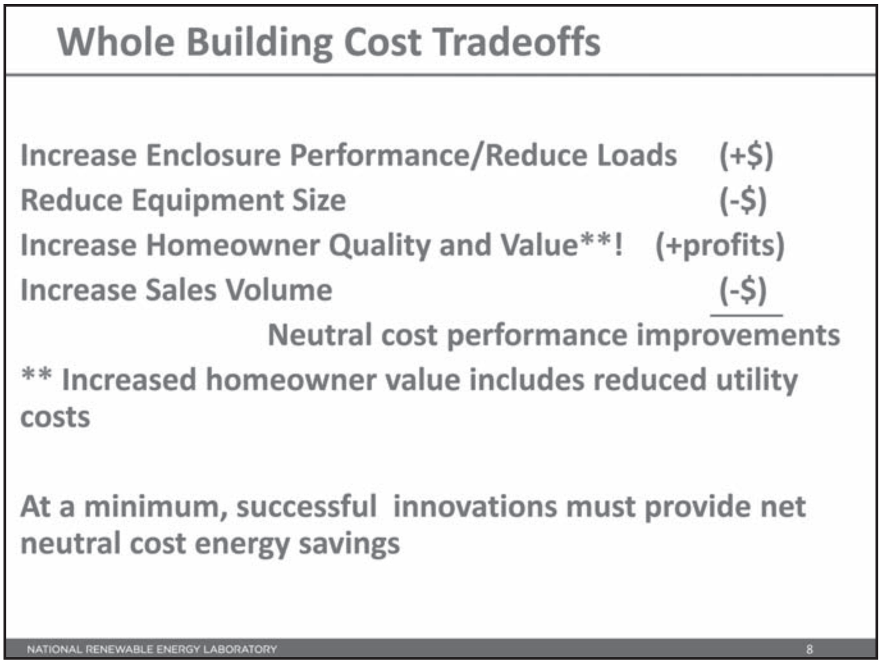


Figure 5. Whole Building Cost Tradeoffs. Figure courtesy Ren Anderson, National Renewable Energy Laboratory (NREL).

ket actors confined by low individual profit margins and low tolerance for risk. Can new levels of energy efficiency be developed and demonstrated as cost effective for average home buyers leading to the broad market adoption and corresponding economies of scale required to produce large reductions in energy use?

While barriers to innovation seem to be substantial, by emphasizing system integration as a key part of new product development, there is a huge potential for cost tradeoffs that maximize benefits and deliver a cost conscious and energy efficient home. While homeowners may not be aware of all opportunities for energy savings, they can appreciate the combined value of improved comfort, reduced maintenance costs, and reduced utility bills that are delivered by a high performance home, emphasized Dr. Ren Anderson, Manager of the National Renewable Energy Laboratory's (NREL's) Residential Buildings Research Group, in a recent conversation with ***Energy Design Update***.

For Anderson, as part of the equation for system cost reduction strategies, a builder should first take advantage of the synergy between increased enclosure performance (increased cost) and the corresponding benefits provided by a reduction in equipment size (cost savings). A better integration between envelope and equipment, when done correctly, directly translates into increased homeowner comfort and value (reduced utility bill cost), and an increase in sales volume (and increased profit) (see Figure 5). Together, this integrated approach can also provide neutral cost performance improvements. At a minimum, successful energy innovations must reach the point where they can provide net neutral cost energy savings in order to achieve broad market acceptance.

"Building high performance homes is the starting point," Anderson stated. "Building quality homes with no callbacks should be the end point goal. Our job is to work with industry partners to integrate energy savings within a quality home construction and remodeling process. The best overall savings are associated with investing in a combination of improvements in envelope R-value, and upgrading equipment efficiency while downsizing equipment components. It's not just investing in the thickest insulation or most efficient equipment alone, it's identifying the best combination of both, that provide the best overall value."

NREL's residential systems research for the Department of Energy (DOE) Building America program encompasses building research and development that focuses on interactions between whole house energy performance, innovation costs, and non-energy benefits validated via comprehensive field studies, all aimed at addressing how best to achieve increases in energy efficiency with the highest reliability, and homeowner value, at the least incremental cost (refer to Figure 6).

"The point is, we need to integrate energy savings into the recognized value of the home," Anderson stressed. "Generally, the biggest single energy saving opportunity in a home is space conditioning, except in the mildest climate zones – followed by lighting and hot water. We are also working hard to evaluate and identify simple, reliable, and cost effective savings from other important energy uses, including home office and home entertainment."

There are lots of choices when it comes to adding performance upgrades to a home. But, what is the best choice? Is there a "best choice?" One way to answer this question is to directly compare the whole

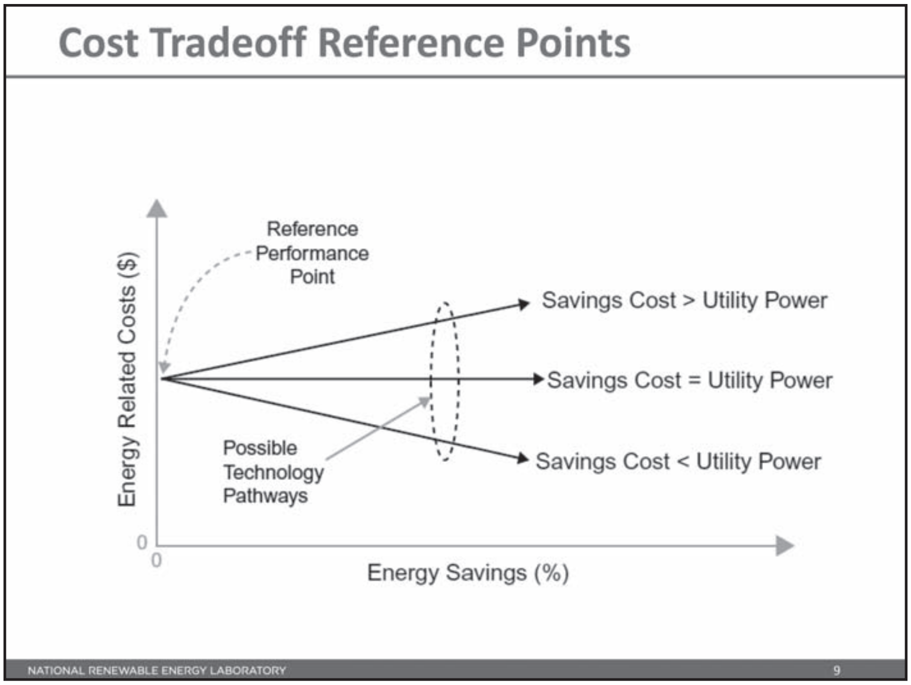


Figure 6. Cost Tradeoff Reference Points. A major question for builders is how best to achieve increases in energy efficiency with the highest reliability, and homeowner value, at the least incremental cost. Figure courtesy Ren Anderson, National Renewable Energy Laboratory (NREL).

house energy savings that are provided by each choice with the net incremental cost associated with each investment in an energy upgrade.

"We're finding that an integrated approach that invests in a combination of energy upgrades leads to significantly larger energy savings and non-energy benefits than just investing in one technology. By using this strategy, a builder can nearly double the delivered savings for a fixed increase in first cost. Instead of investing $9,000 in just increased insulation or just the most expensive and efficient equipment, that $9,000 is better spent with smaller improvements in both insulation and equipment performance," said Anderson. "It becomes a trade-off, number crunching analysis." In Figure 7, the energy savings in a hot, dry climate that can result from a $9,000 investment in increased insulation or a $9,000 investment in a residential PV system is compared with the energy savings that can be achieved by choosing a combination of upgrades that provides the largest overall energy savings. In cold climates, the combined approach can provide a 30% increase in performance, relative to a 2009 International Energy Conservation Code (IECC) starting point. In hot, dry climates, savings can approach 50%, relative to an IECC 2009 starting point.

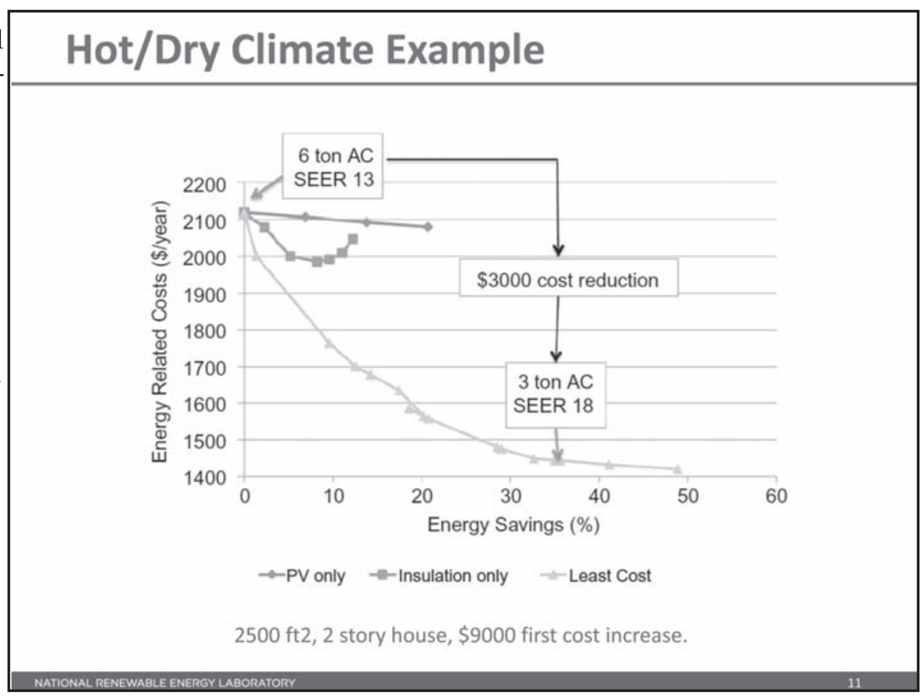


Figure 7. The energy savings in a hot, dry climate that can result from a $9,000 investment in increased insulation or a $9,000 investment in a residential PV system, compared with the energy savings that can be achieved by choosing a combination of upgrades that provides the largest overall energy savings. Figure courtesy Ren Anderson, National Renewable Energy Laboratory (NREL).

"The solutions and innovations that successfully deliver these savings to market are accomplished by our industry partners, industry team leaders, and lab partners in the Building America program. The final market-ready 'sweet spot' for an integrated solution can't be identified by engineering calculations alone. This can only be determined by directly engaging the entire supply chain and measuring success in real homes," emphasized Anderson.

High R Wall Systems: Low Cost Solutions

Evaluation of Three Common High-R-Value Wall Assemblies
(Aldrich et al. 2010)

Wall Type	Cost*	Advantages	Challenges
Double framed walls with blown or sprayed insulation	$1,500 - $2,500	Similar methods to traditional stick construction	Complex designs can double time and cost
2x4 or 2x6 insulated, framed walls with exterior rigid foam insulation	$3,000 - $3,500	Reduced condensation potential, good drying potential	Increased cost for XPS, furring, for finishing doors and windows
Structural insulated panels 8-1/4" SIP 10-1/4" SIP	 $1,500 $2,250	Speed of assembly, inherent air-tightness	Requires special training

Incremental cost when comparing 800 ft² of this wall to 800 ft² of a baseline 2x6 wall

NATIONAL RENEWABLE ENERGY LABORATORY 15

Figure 8. High R Wall Systems Comparison. The relatively low level of individual research investments, combined with the relatively high degree of difficulty – it may be as hard to develop a successful high R wall as it is to develop a new cancer drug – can lead to very interesting policy discussions. Figure courtesy Ren Anderson, National Renewable Energy Laboratory (NREL).

Figures 8–10 summarize some of the opportunities for new solutions for enclosure systems, space conditioning systems, and hot water systems that are being investigated by the program. For more information on project participants, meeting dates, and recent publications, please visit the Building America Web site at *http://www.buildingamerica.gov*.

Energy Design Update also asked Anderson to forecast the evolution of energy efficiency upgrades to standard building practices in the next 5 to 10 years.

What are the gaps in achieving cost conscious energy efficiency?

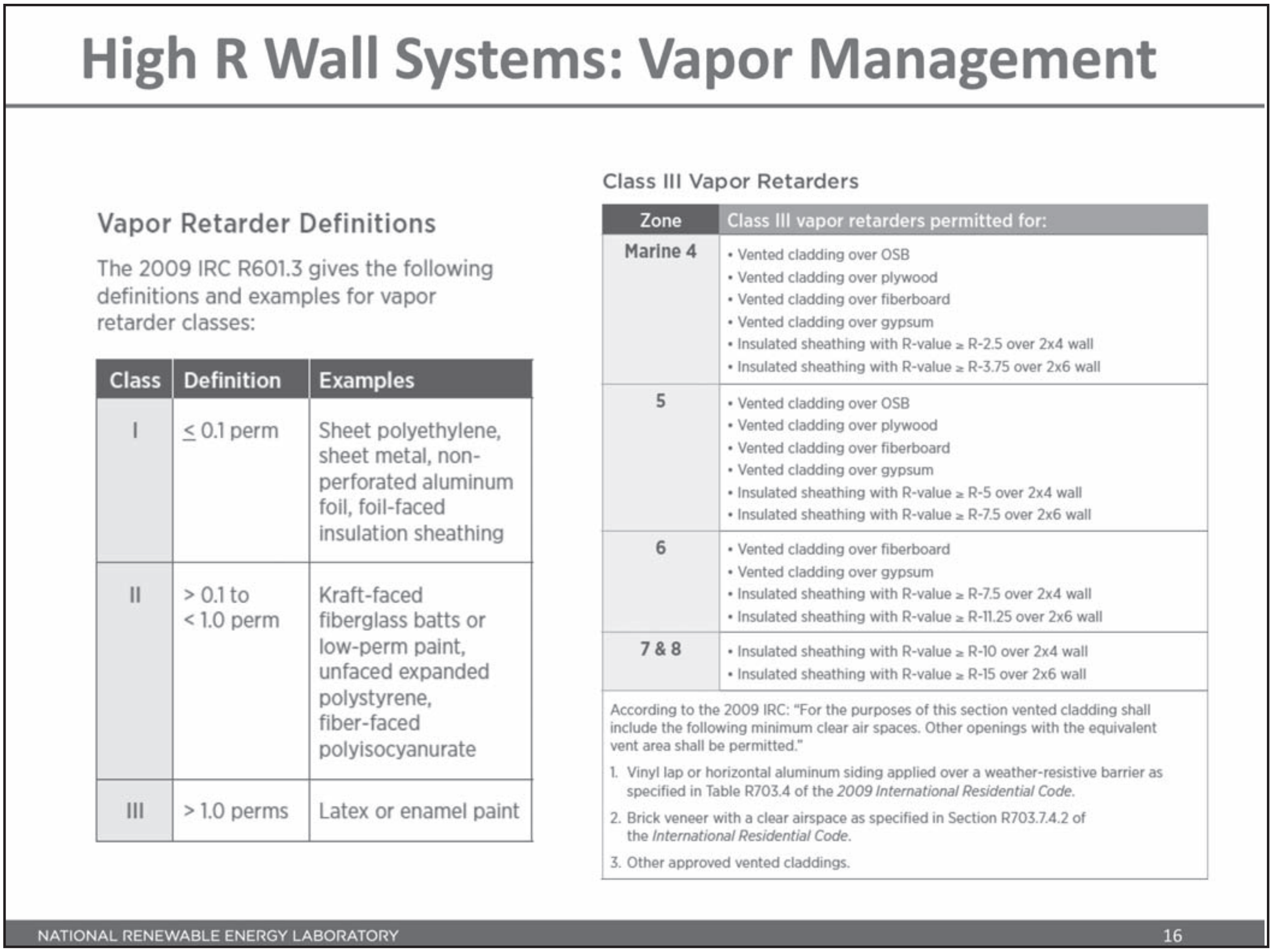
The biggest gap is the low rate of innovation. The relatively low level of individual research investments, combined with the relatively high degree of difficulty – it may be as hard to develop a successful high R wall (Figure 8) as it is to develop a new cancer drug – can lead to very interesting policy discussions. Where are the best opportunities for improvements? How far can you go, within a set practice or method, before you have to come up with better solutions? From an overall economic perspective, it's probably not effective to force people to buy something that is more expensive than it needs to be, or has unintended consequences that have not been fully resolved.

Good policy should focus on encouraging people to do the right thing, where reliable solutions have been proven to exist. The good news is that there is lots of fertile ground for the formation of private-public partnerships to accelerate the development of new solutions. This approach marries technical expertise with private experience and the market, to find alternative solutions. We really want to develop innovations that will be used on a broad basis without incentives: that's the best way to demonstrate value and save lots of energy. Are gaps in savings also due to lack of information or poor codes? Absolutely, but I also think it is pretty clear that there are huge opportunities for new and better solutions. The investment in better solutions can also improve payback from other strategies. The knowledge developed from our work has also enabled the development of better codes. This is not always easy to accomplish; however, when solutions are proven to be beneficial, cost effective, and low risk, the barriers to improvements in codes are reduced.

What energy efficient measures, practices, or products are becoming standard practice in residential construction? What advancements do you see in the next five years?

In hot climates, an obvious savings is moving ducts inside the conditioned space (see Figure 11, page 10). We are on the cusp of being able to accomplish that in lots of homes, but are not quite there yet. Some builders are starting to offer ducts within the conditioned space as a standard practice. The next step will come when we have improved the envelope to the point that we can downsize ducts enough to integrate them easily into the standard framing in the house. That's the tipping point, and it will happen in the next couple of years.

Another major breakthrough will be to integrate heat pump hot water heaters with the conditioned space in hot climates so that the cooling and dehumidification provided by the water heater can be



High R Wall Systems: Vapor Management

Vapor Retarder Definitions

The 2009 IRC R601.3 gives the following definitions and examples for vapor retarder classes:

Class	Definition	Examples
I	≤ 0.1 perm	Sheet polyethylene, sheet metal, non-perforated aluminum foil, foil-faced insulation sheathing
II	> 0.1 to < 1.0 perm	Kraft-faced fiberglass batts or low-perm paint, unfaced expanded polystyrene, fiber-faced polyisocyanurate
III	> 1.0 perms	Latex or enamel paint

Class III Vapor Retarders

Zone	Class III vapor retarders permitted for:
Marine 4	• Vented cladding over OSB • Vented cladding over plywood • Vented cladding over fiberboard • Vented cladding over gypsum • Insulated sheathing with R-value ≥ R-2.5 over 2x4 wall • Insulated sheathing with R-value ≥ R-3.75 over 2x6 wall
5	• Vented cladding over OSB • Vented cladding over plywood • Vented cladding over fiberboard • Vented cladding over gypsum • Insulated sheathing with R-value ≥ R-5 over 2x4 wall • Insulated sheathing with R-value ≥ R-7.5 over 2x6 wall
6	• Vented cladding over fiberboard • Vented cladding over gypsum • Insulated sheathing with R-value ≥ R-7.5 over 2x4 wall • Insulated sheathing with R-value ≥ R-11.25 over 2x6 wall
7 & 8	• Insulated sheathing with R-value ≥ R-10 over 2x4 wall • Insulated sheathing with R-value ≥ R-15 over 2x6 wall

According to the 2009 IRC: "For the purposes of this section vented cladding shall include the following minimum clear air spaces. Other openings with the equivalent vent area shall be permitted."

1. Vinyl lap or horizontal aluminum siding applied over a weather-resistive barrier as specified in Table R703.4 of the *2009 International Residential Code*.
2. Brick veneer with a clear airspace as specified in Section R703.7.4.2 of the *International Residential Code*.
3. Other approved vented claddings.

NATIONAL RENEWABLE ENERGY LABORATORY 16

Figure 9. Vapor Management in High R Wall Systems. Figure courtesy Ren Anderson, National Renewable Energy Laboratory (NREL).

used to offset home cooling loads. Once this is accomplished, heat pump hot water heaters will really take over the electric water heating market in hot climates.

In cold climates, we're working to come up with cost effective insulation systems that get us past the R-30+ level. We're not quite there yet. Remaining issues include dealing with vapor transport through the wall to ensure bullet proof long-term durability, and reliable integration of insulated sheathing with cladding systems (refer back to Figures 8–10). We are also very close to reaching these goals.

For all climates, we hope to see advancements in appropriately sized space conditioning equipment that more directly match the thermal and moisture loads in high performance homes. The market is not big enough yet. We need more 1.5-ton to 2-ton air conditioning systems, and below 50,000 British thermal unit (Btu) heating systems

How about 10 to 15 years out?

I think the bigger long-term opportunity is to scale up solutions for individual houses so that we can deliver low load remodeling packages and new homes at a community scale, taking advantage of new home performance features to reduce overall infrastructure costs at community scale. Instead of building a home and creating a large additional load on the grid, each future home can potentially provide power and other ancillary benefits back to the grid, including the potential for zero net energy developments. There was a lot of interest and movement toward this before the recession, particularly in California, which has committed as a state to achieve zero energy homes by 2020. To achieve this larger community-level goal, in addition to the innovations in building technologies that we have discussed to this point, we will need to develop an additional set of innovations and business models that enable reliable grid design and operation for low load communities with two-way energy flows.

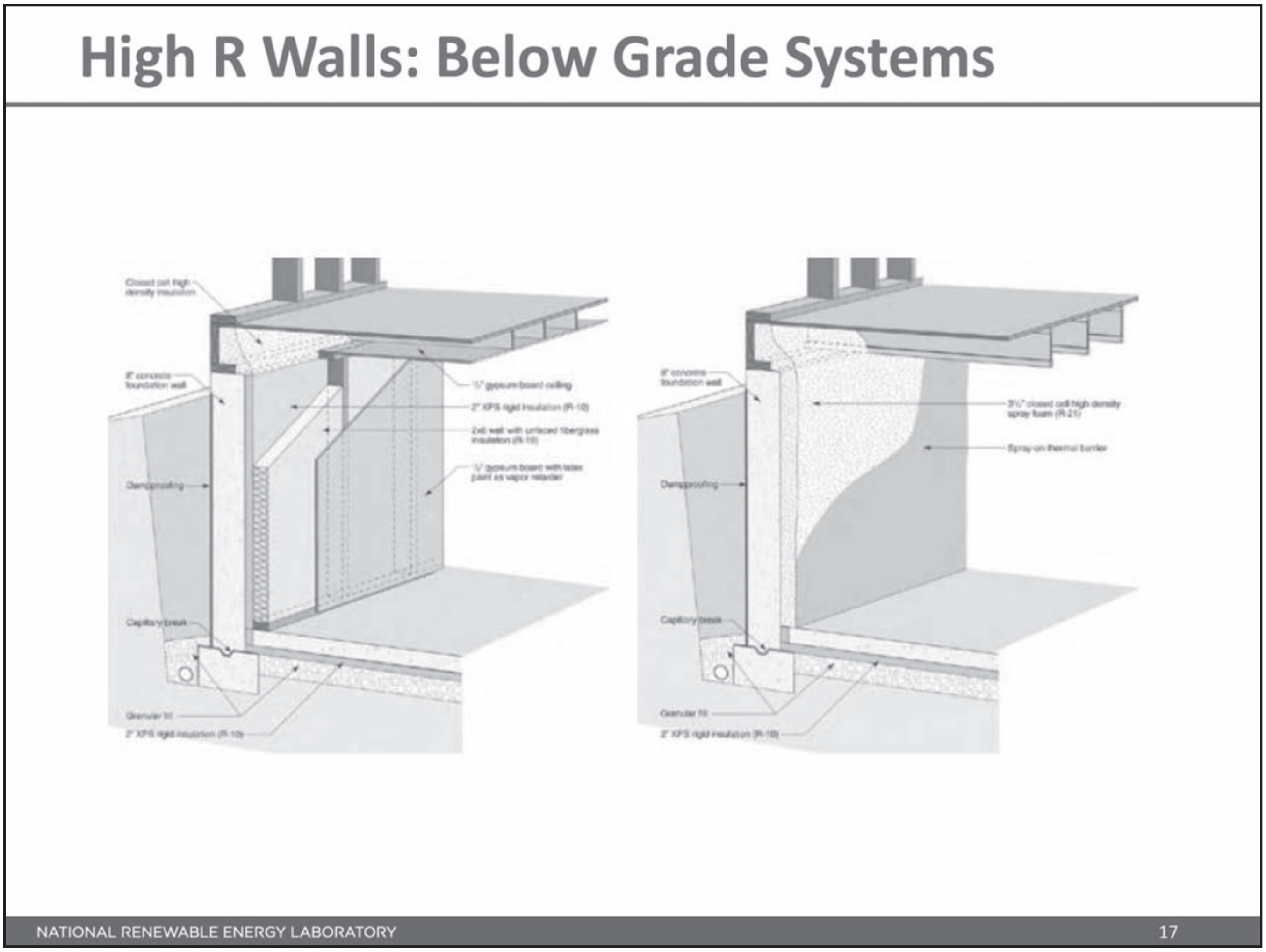


Figure 10. High R Walls Below Grade Systems. Figure courtesy Ren Anderson, National Renewable Energy Laboratory (NREL).

Figure 11. Moving ducts within the conditioned space results in savings for hot climates. Figure courtesy Ren Anderson, National Renewable Energy Laboratory (NREL).

Energy Design Update thanks Dr. Ren Anderson for his time, and for sharing his ongoing work with us.

Dr. Ren Anderson, Manager of NREL's Residential Buildings Research Group, holds an MS and PhD in Mechanical Engineering from the University of Colorado. He has published over 75 reports and papers in peer reviewed and popular literature, is a recipient of patents focusing on advanced heat and mass transfer systems for building and vehicle applications, and has received multiple awards, including the Outstanding Accomplishment Award for the development of NREL's Thermal Test Facility and an NREL Director's and DOE Assistant Secretary's Award for his support of rebuilding efforts in Greensburg, Kansas. The NREL Residential Research Group is a cross cutting team of scientists and engineers that evaluates and optimizes the benefits of innovative residential energy systems.

IN BRIEF

American Taxpayer Relief Act of 2012 Extends Business and Personal Tax Credits for Energy Efficient Residential Properties

On January 1, 2013, the US Congress passed last minute legislation known as the American Taxpayer Relief Act of 2012. This “Fiscal Cliff Bill” included reinstatements of two business and personal tax credits applicable to energy efficient residences and appliances that had expired on December 31, 2011. The Act extended the 25c tax credits through December 31, 2013, and made them retroactive to December 31, 2011, meaning the credits are now available for both 2012 and 2013 projects.

In addition, the bill extended business tax credits of up to $2,000 under 26 USC § 45L Business Tax Credit for New and Renovated Energy Efficient Residences. This Act reinstated and extended the 26 USC § 45L business tax credit of up to $2,000 for contractors or developers that construct or significantly renovate “dwelling units” (apartments, condos, or single-family homes) that meet certain energy efficiency standards. The original law required new and renovated homes to be 50% more energy efficient than those built under the 2003 edition of the International Energy Conservation Code (IECC). The 2013 bill now references the 2006 edition of the IECC as the baseline. The credit is also calculated based on the “dwelling unit,” not the building. Internal Revenue Service (IRS) guidance on the credit defines “dwelling unit” as “a single unit providing complete independent living facilities for one or more persons, including permanent provisions for living, sleeping, eating, cooking, and sanitation, within a building that is not more than three stories above grade in height.” Therefore, contractors and developers of low-rise multi-family properties can claim a credit for each individual unit, and attached town homes each qualify for an independent credit. While the credit had previously applied only to residences acquired before December 31, 2011, the credit is now available for homes built and acquired from December 31, 2011 through December 31, 2013.

The 2006 edition of the IECC contains several structural changes to make the code easier to apply, and adjusted some of the technical requirements. Under determination by the Oak Ridge National Laboratory, the revisions did not change significantly the level of energy efficiency from the 2003 edition. Thus, despite technical changes, properties that would have qualified for the prior version of the § 45L credit may meet the energy efficiency requirements of the new standard.

The American Taxpayer Relief Act of 2012 also addresses 26 USC § 25C Individual Tax Credit for Energy Efficient Residential Improvements and Appliances. The Act reinstated the 26 USC § 25C individual tax credit of 10% (up to $500) of the cost of certain energy efficient existing property improvements, like insulation, windows and doors, and energy efficient heating, cooling, and water heating appliances. A maximum $200 window credit is also included.

As with the §45L credit, the Act extended the availability of the § 25C credit to improvements placed in service between December 31, 2011 and December 31, 2013.

For more, see *http://windowanddoor.com/news-item/government/fiscal-cliff-bill-extends-energy-efficiency-tax-credits* and *http://windowanddoor.com/sites/windowanddoor.com/files/wdfiles_2012/Fiscal-Cliff-Bill.pdf*.

Figure 12. The Esco APS-438 Air Powered Saw and WrapTrack® pipe trolley lets operators rapidly cold cut pipe with ±1/16” accuracy and no HAZ to permit better end prep bevels for welding. Photo courtesy ESCO Tool.

ESCO Introduces Pipe Saw Permitting Better End Preps

In February 2013, ESCO Tool of Holliston, Massachusetts announced the introduction of an air-powered saw and pipe trolley system that cuts all materials and pipe schedules up to 60" diameter to produce perfectly square cuts with no HAZ (heat affected zone) (see Figure 12).

The Esco APS-438 Air Powered Saw and WrapTrack® pipe trolley lets operators rapidly cold cut pipe with ±1/16" accuracy and no HAZ to permit better end prep bevels for welding. Suitable for cutting all pipe schedules of P-91, Super Duplex stainless steel, and other hard materials, the saw comes with fiberglass reinforced abrasive or diamond tipped carbide blades, and the stainless steel band assembly clamps around pipe from 6" to 60" diameter.

Capable of cutting a 10" Sch. 160 pipe in less than 10 minutes, the Esco APS-438 Air Powered Saw has a 3-HP pneumatic motor, and cuts pipe walls up to 4-¾" thick. Featuring four "V" grooved stainless steel roll guides, the saw mounts rigidly on the WrapTrack® pipe trolley, is fully supported to reduce strain on the operator, and glides smoothly around the pipe.

The Esco APS-438 Air Powered Saw sells for $5,195, and the WrapTrack® is priced from $395 up, depending on circumference. For more information, contact: ESCO Tool, A Unit of Esco Technologies, Inc., Matthew Brennan, Marketing Director at 75 October Hill Rd, Holliston, Massachusetts 01746, via telephone at 1-800-343-6926, fax 1-508- 429-281, or e-mail: *matt@escotool.com*.

Drywall Safety Act Efficacy Questioned

The Contaminated Drywall Safety Act of 2012, passed in the first week of January, and signed by the President on January 14, 2013, was intended to prevent the introduction into commerce of unsafe drywall, to ensure the manufacturer of drywall is readily identifiable, and to ensure that problematic drywall removed from homes is not reused, and for other purposes. The measure was originally prompted by problems with drywall used to rebuild homes in the wake of Hurricane Katrina. The drywall, which was mostly imported from China, emitted high amounts of sulfur gas, which triggered respiratory problems in residents and harmed electronic equipment.

However, several groups have questioned the actual effectiveness of the Act in preventing future contaminated drywall incidents, while accusing builder group and industry lobbyists of watering down the final bill. The final Act does not include any preventative standards, an alteration from the first version of the bill, which stipulated criminal and civil penalties for those who use or sell contaminated drywall. The final version asks an association committee composed of drywall manufacturers and builders to develop voluntary sulfur limits.

In October, UL Environment released standard requirements for environmentally preferable gypsum wallboard and panels. The ULE ISR 100 standard evaluates products based on several factors, including materials management, energy use, water use, manufacturing and operations, health and environment, product performance, product stewardship, and innovative practices.

On December 17, 2012, the National Association of Home Builders® (NAHB) released a letter in support of the bill, particularly the Vitter/Warner/Nelson amendment for its significant improvement to HR 4212 "by clarifying that the authority granted to the Consumer Product Safety Commission is narrowly tailored and that the voluntary standard adopted by the Commission will be consensus-based, having the full support of business stakeholders."

For more, go to *http://www.propublica.org/article/home-builders-lobby-weakens-drywall-legislation*, *http://www.govtrack.us/congress/bills/112/hr4212/text/ih*, and *http://www.nahb.org/fileUpload_details.aspx?contentTypeID=6&contentID=15665*.

IN PRACTICE

A Closer Look at Green Roofs

With green building certification programs and policy increasingly aimed at promoting green roofs, what actual data exist on their performance? Researchers and communities are beginning to perform detailed, life-cycle analyses to determine the potential net benefits of green roofs.

As of June 2008, 8.5 million square feet of green roofs were installed, or in progress, in the US (see *http://www.greenroofs.com/projects/plist.php*). Green roofs – stable, living ecosystems formed by placing thin layers of living plants in specialized growing media on a building's roof – may be built up, or formed through modular systems, and are generally classified as extensive, semi-intensive, or intensive, based on soil depth and plant complexity (see Figure 13). Depending on the region and building type, the estimated costs of installing a green roof start at $10 per square foot for simple, extensive roofing, and $25 per square foot for intensive roofs. Annual maintenance costs for either type of roof may range from $0.75 – $1.50 per square foot (Peck, S. and M. Kuhn. 2003. Design Guidelines for Green Roofs. *http://www.cmhc.ca/en/inpr/bude/himu/coedar/loader.cfm?url=/commonspot/security/getfile.cfm&PageID=70146*).

A University of Michigan study compared the expected costs of conventional roofs with the cost of a 21,000-square-foot (1,950 m^2) green roof. The green roof cost $464,000 to install versus $335,000 for a conventional roof, in 2006 dollars. However, over its lifetime, the green roof was expected to save about $200,000, with nearly two-thirds of these savings from reduced energy needs for the building with the green roof (Clark, C., P. Adriaens, and F.B. Talbot. 2008. Green roof valuation: a probabilistic economic analysis of environmental benefits. Environmental Science and Technology 42(6):2155–2161.).

The United States Environmental Protection Agency (EPA) undertook a multi-year green roof study in Denver, Colorado, comparing its own green roof against a neighboring conventional roof. EPA's green roof, built for its Region 8 headquarters, was constructed on a newer 10-story, 250,000+ square foot (23,000 m^2) building completed in November 2006. The vegetated portion of the green roof covers 20,000 square feet (1,858 m^2) of the 33,000 total square ft (3,066 m^2) roof. The conventional roof, used as a control, is a flat gravel ballasted roof. Both buildings are US Green Building Council® (USGBC) Leadership in Energy and Environmental Design (LEED) Gold certified.

The report, "Thermal characteristics of an extensive green roof and a gravel ballasted roof in high elevation, semi-arid, temperate Denver, Colorado, USA," by Thomas J. Slabe, Region 8 Laboratory Office of Technical and Management Services, was drafted in December 2011.

The researchers found that temperature variation is the greatest on exposed control roof surfaces, whereas it is lowest beneath the substrate surface on the green roof. Based on data collected, the cumulative effect over the course of the growing season is predicted to be that green roof temperatures are

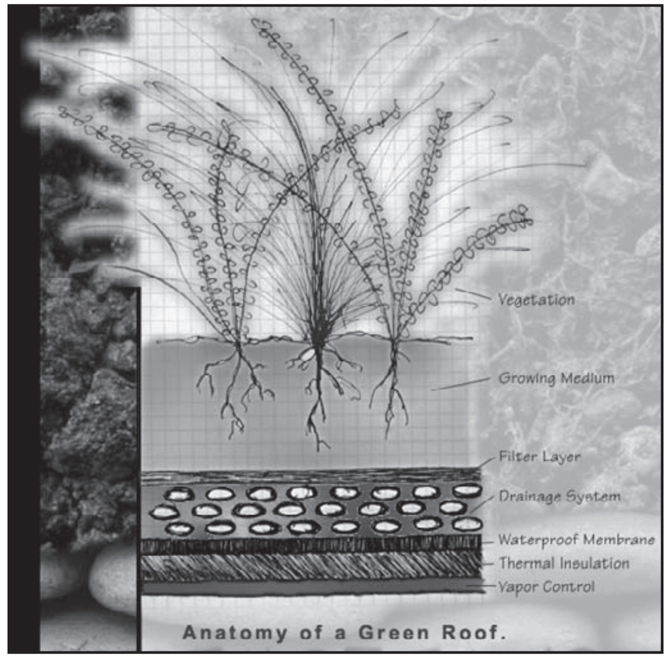


Figure 13. A typical green roof cross section. Image courtesy Green Roofs of Colorado (*http://www.greenroofsco.com/*).

lower than those of the control roof surface. Due to this characteristic of green roof thermal properties, the net thermal radiation emitted from the green roof into the atmosphere is lower than that of the control roof, as calculated by the Stefan-Boltzmann equation for net radiated power.

To launch our series of articles exploring green roof research and data, ***Energy Design Update*** spoke with Andy Creath, LEED AP, of Green Roofs of Colorado, to gain a basic foundation on both the technology and industry. Creath's first piece of advice? "The first thing to know about a green roof is that it is not always the best or least expensive single source solution for getting to benefits such as energy efficiency. However, the overall benefits of a green roof can offer multiple advantages. A green roof can yield benefits throughout the roof's life."

Alright, let's kick it off. How about a brief history of green roofs?

Really, when you walk into a situation with green roofs, the builder is thinking why would I want to grow plants on a roof membrane? Why put my building in jeopardy? Why should I deal with additional weight, maintenance, and cost? But then you start thinking about what's been in literature for a long time. Why do cultures dating as far back as the Hanging Gardens of Babylon create green roofs in hot, arid climates? Why did Scandinavian cultures embrace sod roofs?

In the early 1970s, the Germans started to ask these questions and pick up on green roofs; a lot of research went on. The modern green roof can trace its heritage to them. Green roofs have been done in Europe for 30 to 50 years now. The technology has been around for a while, and we use most of the same overall technology today. Materials have changed, the weight has lightened, but the overall design of a green roof has stayed the same.

Expand on that. What are some typical elements of design?

A typical green roof begins with a membrane base layer, a root barrier, the drainage layer, the soil (referred to as media), and plants. A green roof needs to be designed to hold enough water for the plants and to direct excess water off the roof as fast as possible. We want the media to store water and lose any excess via the drainage layer and roofs drainage system. Media can be as thin as 2–3″ in depth in an extensive roof plan, and up to 2′ to 3′ deep intensive plans featuring trees. A whole scope of designs come under the green roof label.

There are multiple different membranes you can use as a base: EPDM, PVC, TPO, rubberized asphalt, which is hot applied as a singular membrane, or polyurea foam that forms an impenetrable layer, and can be especially good for a remodel. The root barrier is simply a sheet of material that stops root growth from penetrating the membrane below. In design phase, you also need to pick particular plant systems that do not have roots like aspen trees or bamboo that are prone to penetrate materials. After the root barrier we have a drainage layer. This can be as simple as a clean aggregate, such as ¾″ rock or pea gravel, that allows water to flow in or out. You may also incorporate a cover of filter fabric that stops particulates; this filter goes on top of the aggregate or other drainage material. On top of that, depending on the situation, you might have a water retention mat or cups to hold water and address stormwater issues by slowing down the flow of water off of the roof. Finally, within your green roof media, most designs incorporate either a drip irrigation or spray, which is especially vital in the first two years for establishing plants and times of drought.

Other design elements should include a vegetation-free zone, so you can maintain access to wall areas, such as the transition between horizontal and vertical planes. These can be guarded off with aluminum edging, and covered with rock, and can even be used to frame the interior.

For the process of choosing plants, always take advantage of local knowledge and local plants (see Figure 14).

Figure 14. A green roof located in Steamboat Springs, Colorado, taking advantage of native plants in its design. Designed by Lisa Lee Benjamin and Andy Creath, built by Green Roofs of Colorado. Photo courtesy Lisa Lee Benjamin.

For the more arid west, the Denver Botanic Gardens is a great resource; they offer monitored growth areas featuring native plants in a xeriscape setting. Just do your research. In a broad sense, Sedums tend to do well across the country, until certain species are faced with very high temperatures. There is a group of plants already vetted for green roofs. Good strategies are finding plants that adjust, and tweaking technology to fit your climate. Maybe adding more moisture retention, or tweaking the soil composition to hold more water; that's been the transition to bring green roofs to the dry west. Ask your client if they would allow several test plants to be planted on their roof.

When looking at residential applications, we are almost always looking at extensive or semi-intensive design, with media at 3″ to 12″ deep. That will encompass 98% of residential roofs. Several overarching themes have allowed the recent rise of green roofs. First, modern architecture has fallen back in love with flat roofs, so green roofs are more easily allowed within that design. Flat roofs also mean finding ways for aesthetic appeal, and green roofs can help. Surprisingly, a lot of motivation for green roofs is from the aesthetic. Unknowingly, the homeowner is getting multiple other benefits as well.

Any other design considerations for builders?

The biggest thing is how much weight do you have available for a green roof? In new construction, this question is not that big of a deal, especially in design phase with structural engineers – you can plan for it without major financial implications. With an exten-

Figure 15. A green roof in Denver, Colorado, designed by Mark Fusco and Andy Creath, and built by Green Roofs of Colorado. Photo Courtesy Lisa Lee Benjamin.

sive system, typically 30 to 40 pounds a square foot, saturated, could be your maximum weight. Where you see this question become crucial is within a renovation or remodeling situation. In cold climates, you already have a snow load you have to cover, and a green roof load is then calculated on top of the snow load. ASTM testing and saturated media weight testing is vital. This is what the engineers need. As with many energy efficiency elements, the first and foremost question is what to do in pre-planning. Structurally, a green roof always comes back to weight. You can design to fit parameters.

Pre-planning questions need to address what you want to use the space for. How will you make it accessible? Does there need to be irrigation, especially for the establishment period? What type of irrigation? Maintenance of a green roof is just like garden maintenance, it can be as simple as trimming the surface back twice yearly, or as complex as weekly upkeep. We always caution that no living thing is "no maintenance." Especially if the homeowner values aesthetics, what elements would they like to see?

Some excellent resources for green roofs include the FLL, German Research Society for Landscape Development and Landscape Design (*http://www.fll.de/* and *http://www.epa.gov/region8/greenroof/pdf/IntroductiontotheGermanFLL2.pdf*), ASTM Standards E2396-E2399 (*http://www.astm.org/*), and Green Roofs for Healthy Cities (*http://www.greenroofs.org*).

The decision process really looks like asking the following questions: why put a green roof on my house? Then, you have the policy side, the potential benefits to the entire city, and the possibility to address multiple issues.

What can we expect, generally, as benefits from a green roof?

From the residential side, roof life is one of the biggest factors; anytime you have a membrane down on a rooftop, UV radiation, and a high disparity between the high and low temperatures of the day means that membrane is constantly stretching, contracting, and shifting. That movement breaks down the membrane and dramatically impacts its lifespan. A rooftop in the summertime is getting up to 150°, and down to close to freezing at night. It could be a 100-degree swing in a 24-hour period. With that type of temperature gradient, we could have major issues. A conventional roof life could be 15 to 20 years. However, a green roof could be 35 to 40 years, with some climates seeing 90-year life spans from a green roof. How is this possible? The green roof provides protection, offering a break to the roof membrane in terms of temperature and impact. As Thomas Slabe pointed out in his observations and research at the EPA green roof, this is an important observation because the extent of variation in temperature seen is the likely reason for differences in the serviceable lifespan of a roof, which may be 2 ½ times longer for a green roof than that of a conventional roof. Slabe's results indicated that the temperature variation at the control roof membrane they studied was 205% greater than that at the green roof membrane. A great amount of material expansion and contraction, along with material fatigue and failure, accompany temperature variations.

Not only does this mean a longer lifespan and monetary benefit to the homeowner, green roof applications also mean less waste. Using figures from a US EPA OSWER report (EPA. OSWER, 2003) on solid construction wastes for the year 2003, it is likely that 70,000 tons of solid waste can be avoided annually for every 1% of existing conventional roof surface area in the U.S. that is converted to a green roof.

In a single residential scale, you get small, individual benefits. Yet, in several areas, a green roof becomes an important efficiency driver in the overall city development scale.

Green roofs can also promote biodiversity by attracting birds, bees, and other fauna that may be displaced by development. A series of green roofs grants the ability to have greenways all the way through urban corridors. That also leads into increased area for food production, especially in cities.

There are several energy efficiency benefits that green roofs can yield to their structure. While actual efficiency savings are hard to calculate, given the fluctuating R-value of the roof, most literature estimates 5% to 20% savings. In the summer, with water evaporation, a green roof can act similarly to an evaporative cooler, as water comes out of the green roof, ambient temperatures go down on the rooftop, and heats up the building less (Figure 15). This allows air conditioning to work significantly less for the space just below. On a larger scale, this combats the urban heat island effect, which works on bringing down the overall temperatures across the urban zone, leading to a wider local benefit.

Green roofs allow you to work in tangent on multiple, overall goals, which is why we're seeing promotion of green roofs in wider design, in policy, and support for their deployment in mass scale. EPA research in Denver also recorded potential winter benefits as well, as the roof remained at 32° longer than a conventional roof, which could mean the building stays warmer and allows heating systems to work less. There's an overall case that needs to be further researched: what can I downsize to take advantage of the benefits of the green roof? Heating, ventilation, and air conditioning systems (HVAC)? Maybe.

Done right, they offer a multiplication of benefits. Green roofs offer a cooler, more long-lived roof, cooler buildings, and a viable stormwater plan. Buildings pay for stormwater permits, based on how much water comes off the site. The question becomes how do you keep water on your site by slowing it down, so contaminated water doesn't flow in rivers, or create overflows at a wastewater facility. This has been one of the biggest benefits of green roofs: they absorb the first 1" of moisture from a storm, allowing everything to slow down. Slowing down the water exiting from your roof and running it through plants, soil, and the drainage layer also means any water that does leave is much cleaner than runoff from a conventional roof. For a good beginning guide to the principles of green roofs and stormwater, see Urban Drainage and Flood Control District's Best Management Practices for green roofs (*http://www.udfcd.org/downloads/down_crit-manual_volIII.htm*). LEED recognizes this effect, and offers stormwater quality and quantity points to green roofs (refer to Sidebar 1). This goes back to the large-scale process – green roofs constructed over a large area are very efficient at controlling and conditioning water. The cities of Chicago and Toronto actually feel it's cheaper to give out money to promote green roofs, rather than update and expand their treatment plants. In research, the Denver Botanic Garden installed a 14,000-square-foot green roof on their new parking structure, and will be taking stormwater numbers there. The EPA has also been taking stormwater and temperature gradient data on their green roof for last the five years, versus monitored data from a control roof.

Sidebar 1

LEED Points for Green Roofs

- Site Development, Protect or Restore Open Space and Maximize Open Space: SS 5.1, SS 5.2
- Stormwater Design-Quantity and Quality Control: SS 6.1, SS 6.2
- Urban Heat Island Effect, Roof : SS 7.2
- Water Efficient Landscaping: WE 1.1
- Innovative Wastewater Technologies: WE 2
- Optimize Energy Efficiency: EA 1
- Regional Materials: MR 5.1
- Recycled Materials: MR 4.1
- Innovation in Design

What are your thoughts on combining a green roof with solar systems?

Despite the purported controversy, that's another reason to look at a green roof, as we're seeing a lot of growth in solar. These technologies can combine; solar panels work better at lower temperatures, so you get higher performance on a green roof. Some plants can grow better underneath the panels, as the panels offer shade during parts of the day.

Energy Design Update thanks Andy Creath for sharing his insights and experience with us. Our next article in the series will look into current research and data development on green roofs. Visit Green Roofs of Colorado online at *http://www.greenroofsco.com/*.

Andy Creath is an entrepreneur in the environment and sustainability fields. He founded Green Roofs of Colorado, a green roof design, installation, maintenance, and consulting company, based in Boulder, Colorado. He currently serves on the Board of the Green Infrastructure Foundation, which was founded in 2007 to respond to the need for greater awareness and resources to promote green infrastructure in local communities, and is a course developer and instructor for Green Roofs for Healthy Cities. Creath is recognized as an Accredited Professional in Leadership in Energy and Environmental Design (LEED AP) by the USGBC.