Environmental Building News™
The Leading Newsletter on Environmentally Responsible Design & Construction
A Publication of BuildingGreen, Inc. **www.BuildingGreen.com** Volume 21, Number 11 · November 2012

The Hidden Science of High-Performance Building Assemblies

Any four walls and a roof make an enclosure, but for efficiency, comfort, and durability, those elements have to be meticulously designed and installed.

by Peter Yost and Paula Melton

FOR CHILDREN, THE DELICATE, fern-like patterns left by Jack Frost on the inside of a windowpane can be magical. But for the owners of a brand new commercial building in the Midwestern U.S., they were more like a nightmare.

"There were 71 punched window openings, all of which had condensation on the inside that turned to frost in the winter," explained a consulting architect who was hired to diagnose the problem and suggest a solution. "They tried lowering the interior relative humidity to get the condensation to stop. That didn't work."

Interior condensation on glazing often indicates a problem with the window itself, but here the culprit was "a poor detail on the architect's part," explained the consultant. "They were trying to do this unique architectural feature where they had a steel element above the window that protruded to the inside." Unfortunately, the steel was a thermal bridge, so no matter how well insulated and airtight the walls and roof might have been, those 71 "unique architectural features" spent the winter relentlessly chilling the rest of the building envelope. In the short term, a problem like this would likely cause major comfort issues and strain the mechanical system; because the condensation was not only on the glass but also on the window frame and the surrounding drywall, the

(continued on p. 8)

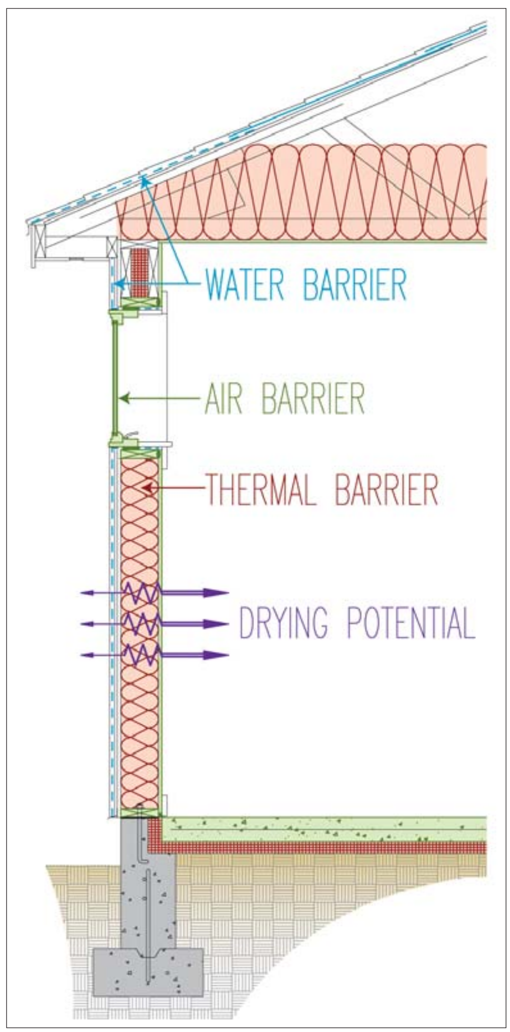

Illustration: Steve Baczek, Architect

Directional drying is designed into high-performance buildings, and all three control layers must continuously manage water, air, and heat. Note how the air barrier is primarily accomplished at the interior and how difficult it is to prevent thermal bridging at structural framing if exterior rigid insulation is not used.

In This Issue

Quote of the month:

"If airtightness and reducing thermal bridging are important, then it becomes increasingly the designer's job to actually show them."

– John Straube, author of *High Performance Enclosures*

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ENVIRONMENTAL BUILDING NEWS (ISSN 1062-3957) is published monthly by BuildingGreen, Inc. *EBN* does not accept advertising. Subscriptions are $99/year. Outside North America add $30. Periodicals postage paid at Brattleboro, Vt. and at additional mailing offices. POSTMASTER: Send address changes to *Environmental Building News,* 122 Birge St., Ste 30, Brattleboro, VT 05301.

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122 Birge St., Suite 30, Brattleboro, VT 05301
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What's Happening

Setting Carbon Footprint Rules for Concrete

"When it comes to building products, reducing the carbon footprint from concrete is one of the most significant actions that the building sector can take," says Ed Mazria, founder and CEO of Architecture 2030. While there are many ways to reduce that footprint, without clear rules defining how to measure the impacts, it's tricky to track progress or provide incentives. Carbon Leadership Forum's new "product category rule" (PCR) for concrete will help.

"There is a real opportunity for improving the carbon footprint of concrete through mix design," says Kate Simonen, AIA, assistant professor in the Architecture Department at the University of Washington and director of the Carbon Leadership Forum. "Concrete is both a material with significant global impact and one that can be customized without retooling a factory," Simonen explains. When environmental performance is called out as a consideration, she notes, suppliers can readily customize mixes to reduce impacts (see "Reducing Environmental Impacts of Cement and Concrete," *EBN* Sept. 2010).

The demand for clear rules to govern environmental product reporting reached critical mass in 2011, with Architecture 2030 calling for the creation of a baseline carbon footprint for building materials and LEED v4 proposing credits that reward environmental product declarations (EPDs). The product category rule (PCR) that Carbon Leadership Forum is developing dictates how to perform a life-cycle assessment and create an EPD with enough specificity that it should be possible to compare EPDs from different suppliers. It also allows for "single-issue reporting" to support the carbon reduction targets of the 2030 Challenge for Products from Architecture 2030. The National Ready-Mixed Concrete Association (NRMCA) has been supporting the effort and intends to become an "EPD program operator" once the PCR is finalized, according to Lionel Lemay, senior vice president for sustainable development. As a program operator, it will provide third-party verification of EPDs.

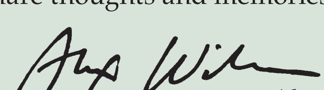
"We're looking to model best practices and address key opportunities and limitations of life-cycle assessments and EPDs," notes Simonen.

Remembering Malcolm Lewis

Malcolm Lewis, Ph.D., the founder of Constructive Technologies Group, a member of the *EBN* Advisory Board, and long a quiet leader in the green building movement, died on October 13 of bladder cancer.

Malcolm was very active with the U.S. Green Building Council, serving on the board of directors in the early years, chairing the Technical and Scientific Advisory Committee, and carrying out extensive work for the Council through his company CTG Energetics. In all those activities, he brought a strong intellect and an unsurpassed ability to build consensus even on contentious issues. He will be sorely missed.

More information about Malcolm can be found at BuildingGreen.com/Malcolm, where we invite you to share thoughts and memories.



Alex Wilson

Photo: Tony Hisgett

A new "product category rule" for concrete outlines how to conduct a life-cycle assessment and develop an environmental product declaration, practices called for by Architecture 2030 and LEED v4.

They chose to work first on a PCR for concrete because of the enormous opportunity for carbon reductions and because creating rules for it is especially challenging, given the variability. "There are literally millions of products; every plant has thousands of mix designs," explains Lemay. So in addition to all the standard issues an EPD has to resolve, this one has to define a streamlined approach that allows for a range of similar mixes to be covered by one EPD.

Building industry support

Phil Williams, vice president of construction company Webcor in San Francisco, has been documenting the carbon footprint of its operations and is excited about how these rules could help bring some consistency to the Wild West of carbon reporting. "If steel, concrete, and wood each had different rules for calculating structural strength, structural engineers would have a very hard time assessing the right material for each application," he notes. Webcor's carbon accounting tracks 99.6% of emissions to its supply chain and only 0.4% to its own operations. "There's nothing wrong with two-sided copying and carbon offsets for airplane flights," he says, "but those aren't where the big impacts are."

Frances Yang, structural engineer with Arup in San Francisco, has been pleased with the results. There was strong interest among engineers and concrete suppliers in taking this step, she notes, because proposed LEED v4 credits create a new opportunity for concrete to contribute to a project's certification. In current versions of LEED (2009), points are available for the use of steel—with its default recycled content value—and wood—if it's local or FSC-certified—that aren't available to concrete. "We think that EPDs are the first step to getting real transparency and real information," Yang says.

The PCR defines how to create an EPD for concrete itself, not the products made from it. Precast suppliers and construction companies that want to compare different construction methods will still have to account for their own processes to compare poured-in-place with precast, for example.

International conflicts

PCRs are supposed to be aligned globally whenever possible, but after this process was already under way, another effort was launched involving cement suppliers from all over the world but none from the U.S. The two groups have been actively working to align their draft PCRs, but some key differences remain.

David Shepherd, director of sustainable development for the U.S.-based Portland Cement Association, isn't concerned about the competing standards, however. "There are significant differences in the way that cement and concrete are sold," he explains, which require differences in the PCR. In the U.S., cement and supplemental cementitious materials are combined on a batch-by-batch basis at the ready-mix plant, while in Europe most cement is sold as a pre-blended mix.

Will the PCR get used?

Lemay is pragmatic about the likely reception this PCR will get in the industry. Adoption will take a while, he says, with a few industry leaders diving in right away and others signing on as they see demand from their customers. Williams agrees, noting that Webcor's clients rarely ask for the carbon footprint data the company already collects.

Architecture 2030's Ed Mazria intends to do his part to stir up interest: "We look forward to taking the next steps—calculating the carbon footprint of concrete mixes, setting an industry benchmark, realizing carbon reductions, and engaging architects to specify low-carbon concrete," he said.

– Nadav Malin

For more information:

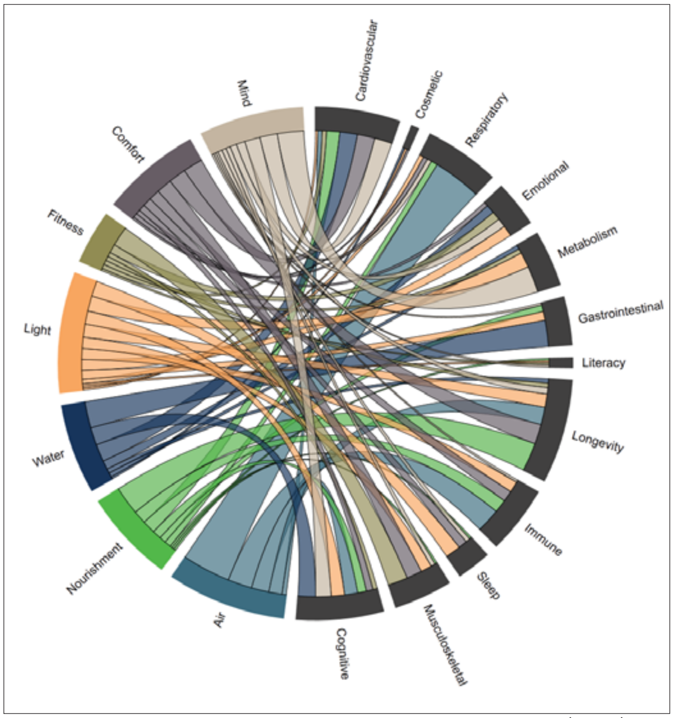
Carbon Leadership Forum
www.carbonleadershipforum.org

Architecture 2030
www.architecture2030.org

National Ready-Mixed Concrete Association (NRMCA)
www.nrmca.org

Make Your Buildings WELL: A New Design Standard for Health

Feeling stressed? Having trouble sleeping? Unable to shed those extra pounds? Maybe your office is to blame—and a new building standard called WELL could help. The standard, now being piloted in homes, offices, and hotel rooms, takes a proprietary set of health-



Source: Delos Real Estate

This diagram—a representation of the Delos Real Estate wellness database—shows the complex interactions between human health and the built environment, according to creators of the WELL Building Standard.

focused design guidelines used by real estate developer Delos and attempts to codify and share them with the world.

When you think of "healthy buildings," indoor air quality and toxic chemicals may be the first things that come to mind, but WELL will take a holistic view, incorporating several alternative-health concepts with the idea of promoting psychological and emotional well-being as well as physical health.

Delos worked with the Cleveland Clinic and the University of Columbia Medical School to develop its original guidelines, and it is now working with a diverse advisory board that includes wellness guru Deepak Chopra, M.D.; former U.S. Representative Dick Gephardt; and Jason McLennan, CEO of both the Cascadia Green Building Council and the International Living Future Institute and co-creator of the stringent Living Building Challenge rating system. Although the standard will not be published until 2013, and stakeholder groups and the public haven't been invited to comment on WELL, McLennan discussed its goals and shared a few details with *EBN*.

"We're looking at health domains or areas where doing the right things within the built environment contributes to better outcomes," McLennan said, citing better sleep as an example. Promoting sleep is seldom a part of the green building conversation, he notes, but "our ability to get really good sleep is essential to our well-being," and the places where we live and work—especially how they are lit—have been shown to affect the amount and quality of our sleep. Although rating systems like LEED already offer incentives for introducing natural daylight, which not only saves energy but in some studies has also been shown to improve both sleep and daytime productivity, WELL takes the connection between lighting and sleep much further—and extends it to residential and hospitality settings as well. "We have requirements for a combination of features that ensure a much better sleep environment," McLennan said, "everything from black-out shades to the proper light spectrum for hallway night lights."

If designing the places where we spend most of our time can help us sleep better, then we should be doing it, McLennan argues. By integrating the science of wellness with sustainable building design and operations, he says, the WELL standard is "beginning to outline and provide guidance about what it means to optimize our environment." Other issues the standard is likely to address include respiratory health, cardiovascular health, and healthy weight and metabolism.

As far as the design guidelines themselves, "there are actually about 48 specific amenities that we're dealing with right now," McLennan told *EBN*, naming mechanical systems, air filtration, cleaning practices, lighting design, acoustics, and electromagnetic fields (or EMFs, a type of radiation we're exposed to routinely in homes and offices) as potential areas of focus for the standard.

The standard will also take into account the potential toxicity of building materials—particularly interior finish materials, furnishings, and other items with which building occupants come into direct contact. McLennan is working to get the Living Building Challenge's Red List of proscribed ingredients included in WELL, at least for interiors.

There are many aspects of sustainability the program will not address, but Delos says WELL is intended to work as a complement to LEED, the Living Building Challenge, and other rating systems. However, the U.S. Green Building Council (USGBC), creator of LEED, was quick to point out that their systems already take health into account.

"We agree that health and well-being are critical, witnessed by thousands of LEED projects that have used strategies to protect indoor environmental quality with daylight, views, supplemental ventilation, and other practices," Chris Pyke, Ph.D., vice president of research at USGBC, told *EBN*. "This has resulted in higher occupant satisfaction and other measures of well-being." He added that "LEED users are also innovators on health-related issues," citing New York City's Active Design Guidelines and USGBC's Center for Green Schools as examples.

McLennan argues that a separate wellness standard is still needed: "If we try to make a single tool do everything, it ends up doing nothing very well. To ram all the things we're thinking about into LEED would be more confusing and less effective."

Delos and its partners announced its creation at the Clinton Global Initiative in September 2012 and committed to piloting the standard in 41 hotel rooms by the end of 2012 and in six homes and 500 office spaces by the end of 2013; the company also committed to implementing the standard in a much larger number of offices, living spaces, and hotel rooms by 2017. An organizational model for implementation, including financial concerns, has not been announced.

– Paula Melton

For more information:

Delos Real Estate
www.delosliving.com

Newsbriefs

Imported Refrigerant Could Be Hot Goods—The ozone-depleting refrigerant HCFC-22 is being phased out in many countries under the Montreal Protocol, but a recent investigation in Florida indicates that illegal quantities are being smuggled into the U.S. and Europe. The U.S. Environmental Protection Agency licenses companies to produce, purchase, or sell limited quantities of HCFC-22 (also known as R-22) for use in air conditioners, but the gas is still produced in large amounts in many countries, including China, India, and Mexico. While new air conditioners in the U.S. have not used HCFC-22 since 2010, large quantities are still needed to refill old equipment, and the limited supply of legal gas has created a black market for imports. The vice president of St. Louis-based Marcone, a manufacturer of appliance parts, was recently sentenced to 13 months in federal prison for importing unlicensed refrigerant, and shipments have been intercepted in eastern Europe. The smuggled gas canisters can be easily disguised by mislabeling, and inspections require expensive testing equipment.

Another Report Questions Feds' Carbon Calculations—The U.S. government is greatly underestimating the costs of carbon pollution, according to a study in the *Journal of Environmental Studies and Sciences.* "The Social Cost of Carbon in U.S. Regulatory Impact Analyses" says the Office of Budget Management (OBM) uses a faulty analytical model, utilizing an unjustifiably high discount rate to translate future costs into present values and ignoring the greater economic impact on poor regions. The model was developed in 2010, when the OBM estimated the "social cost of carbon"—the value to society of reducing carbon emissions—to be $21 per ton of emissions. The new study argues that a more accurate cost is between 2.6 and 12 times higher, but coauthor Laurie Johnson, Ph.D., economist with the Natural Resources Defense Council, points out that even the study's high-end estimate of $266 per ton leaves out worst-case scenarios and damages that couldn't be quantified. As *EBN* noted in 2011, the Economists for Equity and Environment network estimated that the social cost of carbon could be as high as $894 per ton (see "Report: Government Way Off on Cost of Carbon," *EBN* July 2011). These numbers show that a shift to wind and solar power would be more cost-effective than natural gas or coal, says Johnson.

FTC Issues Revised "Green Guides"—After two years of public comment and review, the Federal Trade Commission (FTC) has released a revised version of its "Guides for the Use of Environmental Marketing Claims." Also known as the "Green Guides," the publication outlines what the FTC may find to be deceptive marketing; the revised version includes updates and new sections on carbon offsets, certifications, and renewable energy and materials. Most of the revisions proposed in 2010 (see "FTC Cracks Down on Greenwashing," *EBN* Nov. 2010) were accepted, including the warning that broad claims of being environmentally friendly "suggest that the product has specific and far-reaching environmental benefits [that are] nearly impossible to substantiate." Among its revised sections, the guide says marketers should disclose any "material connections" to groups providing certification or seals of approval, and carbon offsets should not be advertised as such if the activity providing them is already required by law. For more information, see www.ftc.gov.

Image: U.S. FTC

Autodesk Increases Simulation Power Through Cloud Computing—Autodesk has released Autodesk Simulation 360, the first simulation software on a "cloud"-based, pay-as-you-go model. The platform offers design and engineering tools for complex simulations, such as designing a building for resilience in the face of cyclic stresses, wind, or earthquakes, or predicting the occupant experience of solar heating. Multiple what-if scenarios may be run in parallel, an operation requiring large amounts of processing power; Autodesk Simulation 360's reliance on off-site servers available through cloud computing should reduce the time needed, as well as upfront investments in hardware, and make complex simulations more widely available.

Product News & Reviews

HOBO Data Loggers: No Longer Just for Researchers

As the saying goes, you can't manage what you don't measure. A world leader in data-collection equipment for environmental conditions in buildings and elsewhere, Onset Computer Corporation in Bourne, Massachusetts, manufactures the popular HOBO line of data loggers to measure temperature, relative humidity, equipment run-time, and other important performance characteristics. Increasingly, these products are finding use among building practitioners.

Founded in 1981, Onset has 120 employees in its solar-powered manufacturing facility on Cape Cod and has shipped more than 2 million data loggers to customers worldwide. The product name, HOBO, came from the founder's interest in all things railroad-related, according to Evan Lubofsky, the director of marketing for the company, and it refers to a person who traveled around the country and did jobs behind the scenes. Later, an after-the-fact acronym was derived for the name: "Honest OBserver by Onset."

What are data loggers?

Data loggers are electronic data-collection instruments that capture and record measurements at set intervals over a period of time. In buildings, data loggers most commonly collect temperature and relative humidity (RH) data, but they can also capture equipment run-time, events like window opening and heating plant cycling, light intensity, carbon dioxide levels, and flow rates. In outdoor applications, they are used to measure such conditions as rainfall, soil moisture, and wind direction and speed. "You're only limited by your imagination," says Gregg Daly, Onset's director of sales, in describing the breadth of their use.

Data loggers are typically compact, battery-powered devices that are equipped with sensors, internal microprocessors, and storage memory. A mechanism is used to transfer stored data to a computer, and software is used to process that data into a useful form for interpretation and display.

Photo: Onset Computer Corp.

The HOBO UX-90 data loggers capture a wide range of conditions, including motor on/off status, kWh, run-time, open windows, lighting use, occupancy, and water flow.

Onset HOBO systems

Onset offers three different families of data loggers that differ by how the information is collected and transmitted.

- Stand-alone data loggers are most common and have the lowest cost. They are deployed to collect measurements, then connected to a computer via a USB port to upload that data, which is processed using Onset's software.
- Wireless data loggers (Onset's HOBO ZW series) transmit real-time data from a few to dozens of locations around a building to a central computer. This eliminates the need to manually retrieve and upload data from each logger. Relays can be used to extend the data transmission range and get around blockages in a building.
- Newer, Web-based data loggers (HOBO U30 system) collect and transmit data over the Internet (using cellular, WiFi, or Ethernet communications). These systems offer the greatest convenience for around-the-clock measurements that can be remotely monitored.

With any of these three platforms, a wide range of data loggers can be used, with more expensive models offering greater accuracy or a larger range of coverage. Most data loggers are battery-powered and come with batteries that should last at least a year.

The HOBOware Pro software is easy to use, according to several users *EBN* interviewed. Both Windows and Mac versions are available. A wide range of data display options is available, and data can be exported to other programs, such as Microsoft Excel. Onset's technical support is highly responsive, according to users we spoke with.

Data loggers for building practitioners

Data loggers have long been used in research—and are critical to gaining deep understanding of everything from building science to moisture profiles in green roof soil. But they're increasingly finding a place in the tool bags of builders, remodelers, and designers.

Photo: Onset Computer Corp.

All of Onset's manufacturing takes place in the company's Cape Cod factory, which produces almost 50% of its annual electrical use from a 225-kW PV array on the roof.

Remodeling contractor Paul Eldrenkamp of Massachusetts-based Byggmeister Design Build and the consulting firm DEAP Energy Group (which specializes in Passive House and building science), has been using Onset HOBOs as well as OmniSense data loggers for more than seven years to capture information in three different areas. To understand occupant comfort, he collects temperature and RH data; to track indoor air quality, he measures RH and carbon dioxide concentrations; and to understand durability issues, he measures the moisture content of building materials. Eldrenkamp uses HOBO data loggers primarily, though for tracking moisture content of building materials, he uses OmniSense equipment.

"If there are moisture problems," Eldrenkamp told *EBN*, "we want to know where the moisture is coming from." At each sensor location, he is able to measure both dew point and grains of moisture per pound. "Comparing those measurements over time from various places around the building, including the exterior, lets you know pretty unequivocally where the sources of moisture are."

Eldrenkamp also notes that with remodeling projects, "We often like to measure the pre-project conditions so we can better evaluate the impact of our work on the dynamics of the house."

Marc Rosenbaum, P.E., of South Mountain Company, is always trying to understand buildings better, and he uses HOBO data loggers for a wide range of purposes, including the following.

- To measure the efficiency of his heat-pump water heater by tracking water temperature in and out along with flow
- For a prototype classroom project to measure room temperature, outdoor temperature, RH, and CO_2 levels using a four-channel logger
- At an affordable housing net-zero-energy project on Martha's Vineyard to measure room-to-room temperature evenness
- At a private boarding school to troubleshoot a large solar hot water system (diagnosis: the solar pumps were running at night)
- In a moldy crawl space to correlate RH with the moisture content of the wood

Most of Rosenbaum's HOBO applications are short-term. He has several four-channel loggers and various probes for collecting measurements as needed. Rosenbaum has so far stuck with the lower-cost units that require picking them up and downloading the data. He sometimes has the data loggers mailed to him after deployment.

A growing use of HOBO data loggers is in hospitals, according to Daly, who explains that patient satisfaction surveys influence how much money hospitals get from Medicare and Medicaid. This drives the need of building operators to independently verify comfort conditions—even if there is an energy management system. "The money they can get from enhanced comfort can outweigh the [financial return of] energy savings," said Daly.

Paying for data collection

Individual HOBO temperature/RH sensors range in price from about $80 to $250, depending on accuracy and whether they are stand-alone or wireless. Multi-channel wireless systems range from $400 to $850, not including the individual sensors.

While these tools aren't cheap, they can make good business sense. "In my experience, it's not hard to sell a client on the benefits of monitoring and to include all or part of the cost as a project budget line item," attests Eldrenkamp. In fact, he believes this monitoring has given him a competitive advantage. "Savvy homeowners appreciate that we take seriously how our projects perform over time."

Mike Duclos, a partner of Eldrenkamp in DEAP Energy Group, cautions that one shouldn't underestimate the time required to effectively *use* the information being collected. Understanding what you want to measure, why you want to measure it, and how you will use that information should be the starting point. "It's easy to collect data; analysis takes more time," he told *EBN*.

– Alex Wilson

For more information:

Onset Computer Corporation
www.onsetcomp.com

OmniSense, LLC
www.omnisense.com

Building Assemblies

(article continues on page 10)

Northeast Coastal Passive House

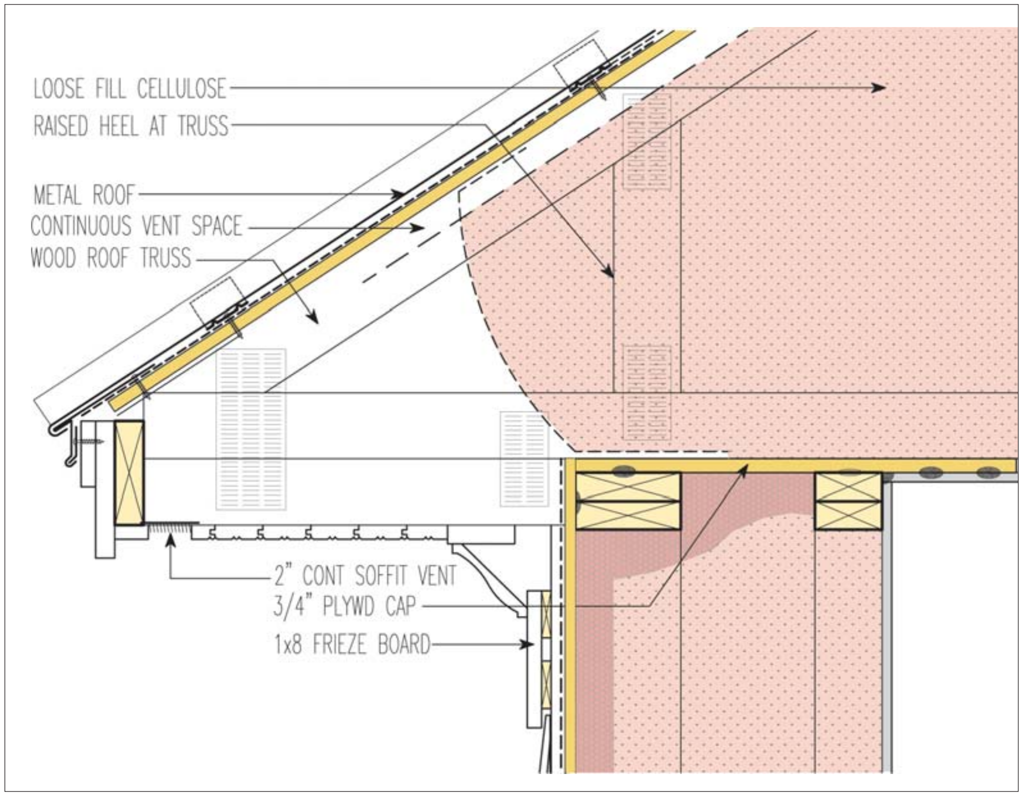
Water barrier: The ZipWall system—OSB with a laminated weather-resistive barrier and taped seams—and free-draining furring strips provide a continuous above-grade water barrier. A closed-cell sill sealer acts as capillary break between the concrete stem wall and the mudsill. A healthy roof overhang handles the transition from the top of the wall to the roof, along with ZipWall up to the bottom chord of the roof truss.

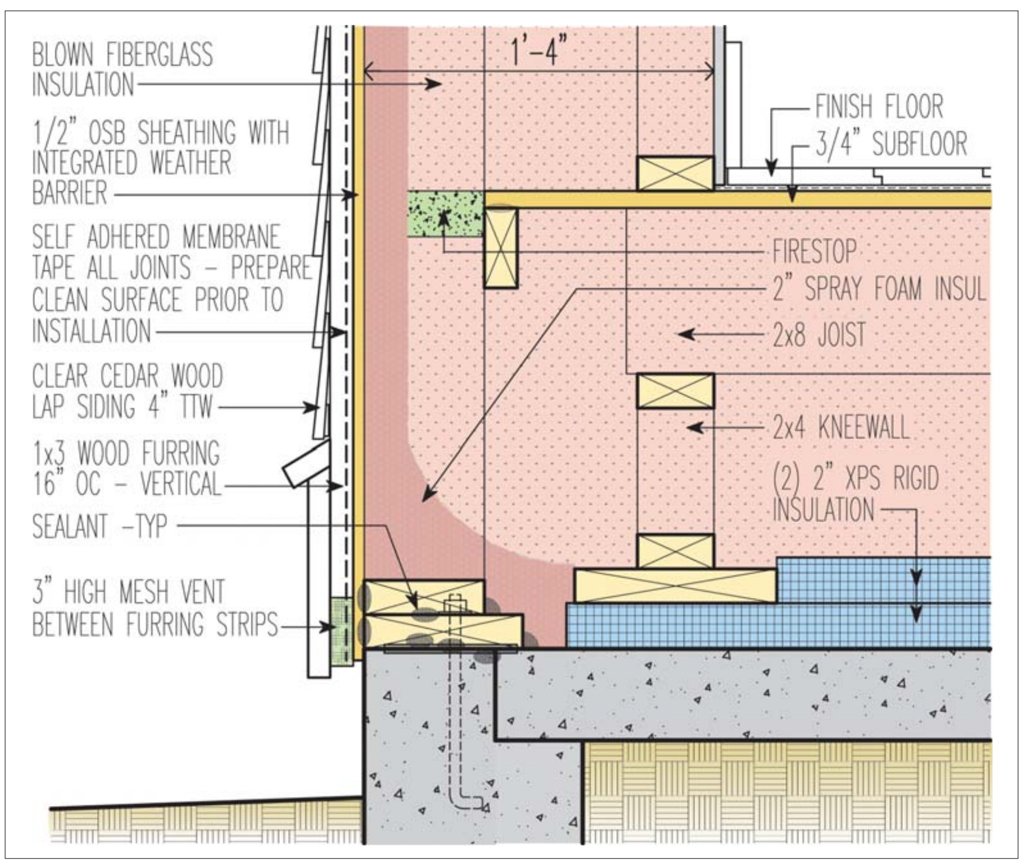
Thermal barrier: The R-60 double-stud wall allows continuous spray foam. Note how the innovative floor insulation system achieves thermal barrier continuity at the slab by connecting the spray foam to the rigid insulation. At the eave, the innovative ¾" plywood cap allows the spray foam to extend all the way to the interior.

Air barrier: The enclosure system has a redundant continuous air barrier—taped ZipWall, spray foam, and sealed gypsum wallboard. The ¾" plywood cap at the eave creates a site-sequenced interior air barrier at this challenging transition.

Vapor profile: The foundation system is designed and specified to dry to the interior. The above-grade wall is designed and specified to dry to both the interior and the exterior. The laminated coating of the ZipWall sheathing is vapor-permeable, and the rainscreen provides excellent drying potential. An interior vapor retarder is unnecessary; the first condensing surface (spray foam) does not get cold enough to support significant wintertime condensation in this particular climate.

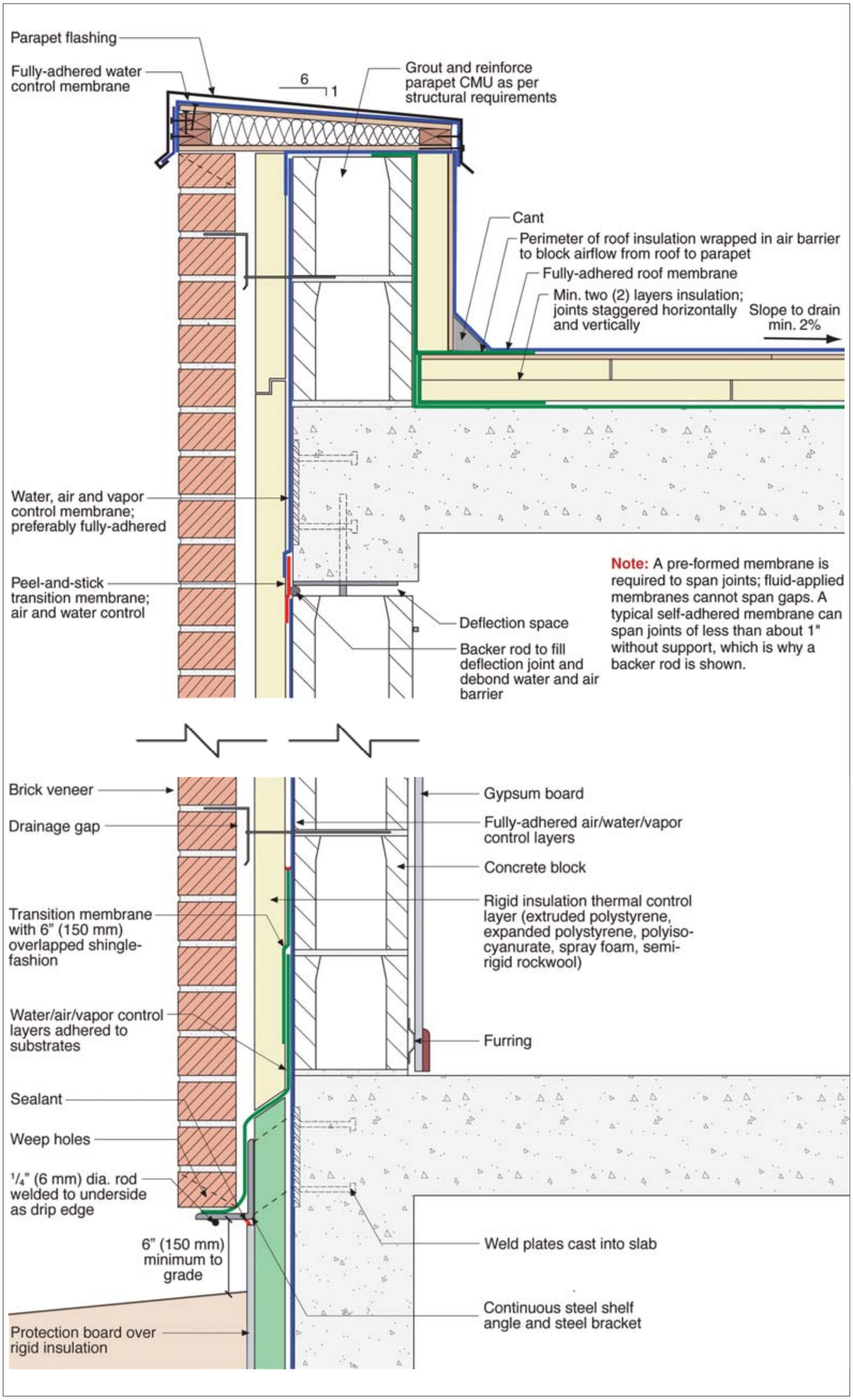
Residential High-Performance Building Assembly – Exemplary Details





Illustrations: Steve Baczek, Architect

Commercial High-Performance Building Assembly – Exemplary Details



Illustrations: Stephanie Finnegan, Building Science Corporation

Building Science Corporation Commercial Details

Air and water barriers: Continuity is achieved by designing and specifying a fully adhered flexible membrane to serve as both barriers and by locating the membrane to the exterior of the structural block wall and concrete roof structure. To reduce thermal stress, this membrane is then kept at room temperature by the exterior rigid insulation.

Thermal barrier: By placing all thermal insulation on the outside of the building enclosure, continuity of this layer is much easier to achieve. Building Science Corporation calls this approach the "perfect wall" because this configuration works well in any climate with any enclosure system. Parapets are notorious for thermal bridges and lapses in bulk water management; this parapet details clear transitions for all three control layers in the wall to the low-slope roof. In the foundation detail, note how the angled cut of the rigid insulation allows the above-grade water barrier to drain away and out while maintaining thermal continuity.

Vapor profile: The least-vapor-permeable layer is the flexible membrane, with all other layers designed and specified to promote drying in both directions. Additionally, many of the materials in the assemblies (concrete block, cast concrete, brick veneer) have considerable *hygric capacity* (they can store significant amounts of water) and low sensitivity to water content (they can *safely* store those amounts).

Used with permission. Source: *High Performance Enclosures*, Building Science Press, Dr. John Straube, 2012. (See book review, page 15.)

thermal bridges also threatened the durability of the building materials. "The only solution was taking out all of the windows, cutting the steel that was the thermal bridge, and installing some additional insulation," the consultant said. Fortunately, no lawsuit was filed. But with more attention to detail, the architecture firm responsible for this building design could have saved itself a great deal of time, expense, and embarrassment.

High-performance buildings begin with a very complex big picture, integrating site-responsive orientation, climate-responsive form, hefty R-values, efficient mechanical systems, healthy indoor air, and glazing that effectively balances daylight and heat gain. But there's more. In a reversal of the usual rule, the whole building can be less rather than more than the sum of these parts if attention isn't also paid to hundreds of hidden components that we don't talk about much. Things like corner joints. Window flashing. Hundreds of beads of sealant and runs of tape. Poorly designed, specified, or installed details in these areas can bring the proudest solar-powered building owners to their knees with moisture and mold problems, façades falling to pieces, and drafty interiors that send tenants packing—and even suing.

Assemblies Put It All Together

The building enclosure manages everything that might get into and out of a building: water, wind, light, sound, air, pests, and people. Assemblies are the foundations, above-grade walls, and roofs that make up the enclosure, and how they're put together makes all the difference to how well the building performs—and for how long.

High performance, says Z Smith, AIA, director of sustainability and building performance at New Orleans-based Eskew+Dumez+Ripple, is all about "using your 100-year glasses" and in the process "thinking in two and three dimensions" about thermal bridges, penetrations, and opportunities for air and water leakage—something he says architects weren't that attuned to 20 years ago.

This goes for residential projects as well, adds Steve Baczek, R.A., a residential architect who has worked on Passive House projects, deep energy retrofits, and high-performance production homes. Baczek says he's seen high-end projects that didn't give a thought to performance: "If the homeowner gave me the house, I couldn't afford to operate it monthly," he said. "As an architect, it's your responsibility to not only do the drawings but to ensure that the building is a responsible effort. What I'm designing is going to be here for 100-plus years."

High-performance buildings aren't just those that offer superior energy performance: we also need them to provide a durable, safe, comfortable, and healthy space in which to live and work. Meticulously designed, specified, and installed assemblies are an integral part of building performance—and because some of the tiniest assembly details can affect all these functions, achieving project goals will require cooperative input and accountability from architects, engineers, building scientists, and contractors.

It's the Heat and the Humidity

For most buildings and most climates, moisture management is key to efficiency, durability, and resilience. This is true because heat flow is inextricably linked to moisture flow.

Hygrothermal focus

In today's energy-efficient, multilayered building assemblies, durability and resilience rely heavily on moisture management to control mold, rot, corrosion, and even many pests

Photo: Dwight Holmes

A quality builder designed and built an energy-efficient, unvented roof assembly with no drying potential in either direction (asphalt shingles on the exterior and foil-faced polyiso board on the interior are both vapor-impermeable) with airtight can lights. But while the cans themselves were tight, gaps between the cans and the gypsum board ceiling meant substantial air leakage and wintertime wetting of the assembly, with disastrous results.

that thrive in humid conditions, such as termites, carpenter ants, and dust mites.

We use the term *hygrothermal* to characterize the inexorable relationship between heat and moisture; the unrelenting nature of hygrothermal pressures requires rigorous continuity of water, air, and thermal barriers in all our assemblies: you should be able to trace the barrier with your finger from footing to ridge or parapet of a building without lifting it off the cross-section even once.

Note that the challenges to continuity for all these barriers happen at the same key places—penetrations, assembly transitions, and assembly margins—and that proper installation is critical.

Continuity Detail – Balcony

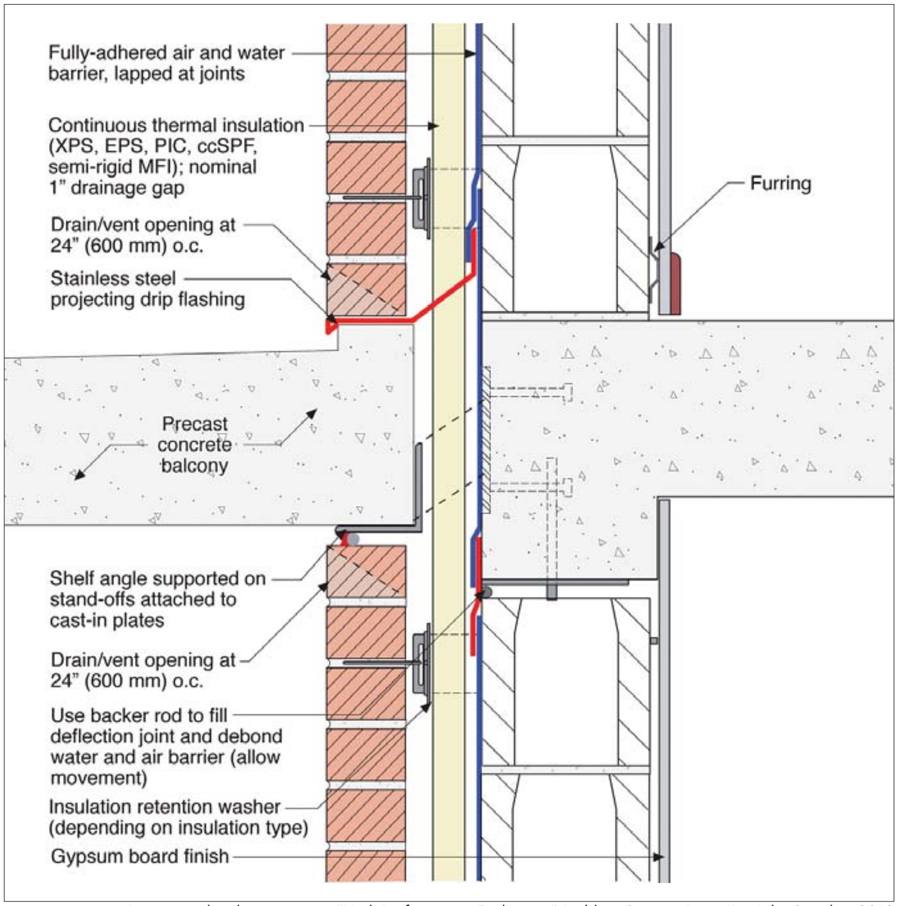


Image used with permission: "High Performance Enclosures" Building Science Press, Dr. John Straube, 2012

Balconies are typically accomplished with cantilevered concrete through-beams that are a control layer nightmare. This detail limits structural support and thermal bridging through the continuous air and thermal barriers to as little as four knife-edge connectors.

Water barriers

"Lack of water control causes much more damage and attracts lawyers much faster" than other types of barrier problems, says John Straube, Ph.D., P.Eng., of Building Science Corporation. Water in liquid form moves about in two ways: as bulk water driven by gravity and wind, and as capillary water driven by the porous nature of so many building materials, such as concrete, brick, wood, and paper.

What we think of as the hidden or concealed continuous water barrier—weather-resistive sheet goods, flashing tapes, and sealants—should actually be the second line of defense, managing only the leftover bulk water that claddings can't handle (see "Tape, Seal, Gasket: A Sticky Search for Better Materials," *EBN* Sept. 2012).

Continuous capillary breaks are achieved in one of two ways: free-draining spaces and non-porous sheet goods or membranes between porous building materials.

Air barriers

Air infiltration and exfiltration make up 25%–40% of total heat loss in a building in a cold climate and 10%–15% of total heat gain in a hot climate. Air barriers manage not only this but also the moisture that leaking air inevitably carries with it.

"Air infiltration is the leading cause of mold, and mold is the leading cause of lawyers" is an oft-repeated chestnut among Z Smith's colleagues. "Wall details are more than the sectional drawings," he told *EBN*. "The air-leakage load of the envelope is dominating all the thermal things we are thinking of doing." Even in his hot-humid climate, where he says dehumidification is the largest operational load, vapor drive is way down the list as a concern, completely overshadowed "by the one little crack near the window."

Air barrier *materials* are pretty easy to come by—gypsum board, concrete, housewraps, some spray-foam insulation, and oriented-strand board (OSB) all meet the definition of an air barrier—but achieving continuity in air barrier *assemblies* requires careful integration. In the end, it's not just each material's air-leakage rating that counts but the performance of the entire building, as measured by a blower-door test.

The dedicated, continuous air barrier in any assembly can be on the exterior, on the interior, or interstitial (in the assembly cavity). The key is connecting the air barrier in the field of the wall or roof to details at penetrations (such as windows) and transitions (such as the eaves and the top of the foundation wall).

Thermal barriers

Thermal barriers, at least in the opaque portions of assemblies, primarily manage heat loss and heat gain by conduction (see "Choosing Windows: Looking Through the Options" *EBN* Feb. 2011, for details on how glazing can manage *radiant* heat transfer). We most often think of thermal barriers as the bulk insulation we install in assembly cavities. But assembly cavities are not necessarily the best place to locate thermal barriers; they are simply the most convenient and least expensive place. In fact, insulating assembly cavities introduces a sometimes very steep temperature gradient across the assembly, risking condensation and the attendant mold, rot, and corrosion.

Leading building scientist Joseph Lstiburek, Ph.D., P.Eng., of Building Science Corporation identifies the "perfect assembly" as one with all thermal insulation (along with continuous air and water barriers) on the exterior, effectively pulling the interstices into conditioned space and avoiding many moisture-related risks.

Managing Moisture in the Air

Water, air, heat … wait, where's the vapor barrier?

If you're like many building professionals, you're probably wondering whether you need one. (And if not, why does the building inspector insist that you do?) The way we deal with vapor diffusion in high-performance assemblies is different from how we deal with bulk water, air, and heat flows:

- When we need one, we probably want a *retarder*, not a barrier.
- A dedicated vapor retarder does not have to be continuous in order to work well.
- We can do more harm than good by trying to block vapor diffusion *into* our assemblies— because that vapor retarder also keeps moisture from getting *out of* our assemblies.
- All building materials—not just the ones we call retarders or barriers—affect vapor movement to some degree; serious moisture problems can occur if the permeability of each and every assembly component is not accounted for in assembly design.

In fact, as mentioned above, the best defense against water vapor in interstitial cavities is often a continuous air barrier. Although codes can be slow to catch up, the design world is moving away from dedicated vapor retarders and toward the concept of a *vapor profile*, assessing the permeance of each material in a building assembly and ensuring that any water leaks or condensation can diffuse readily through at least one side of the assembly. For more on these advancements, see "Using WUFI to Prevent Moisture Problems," page 16.

Continuity Detail – Residential Window

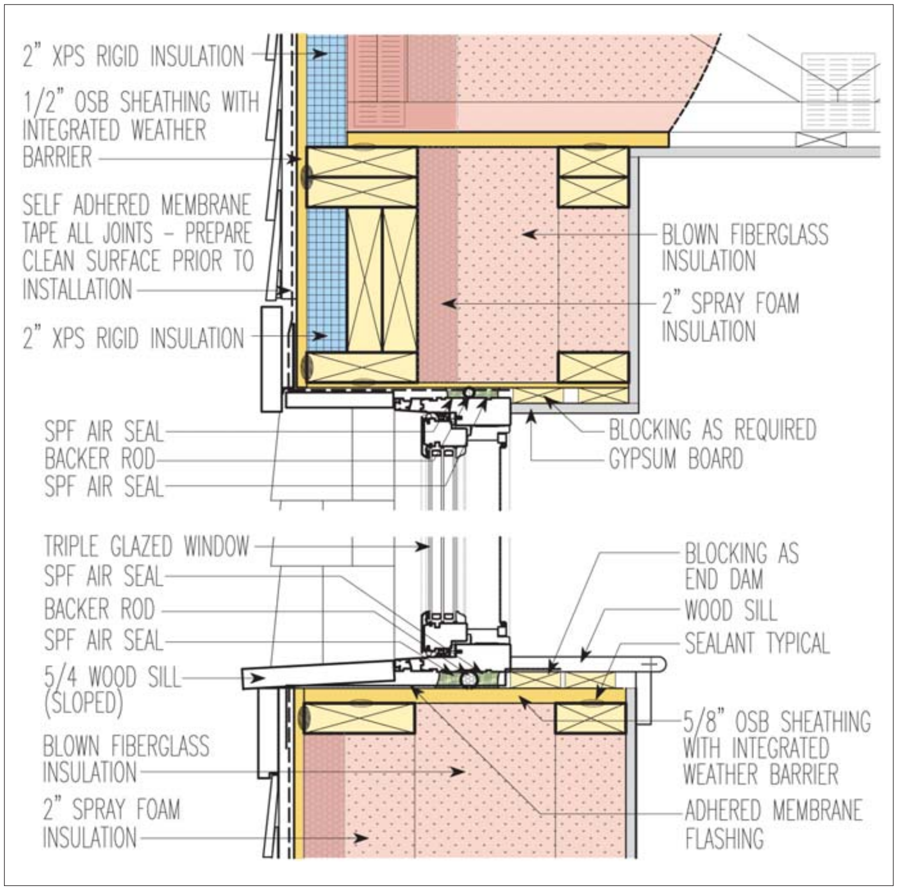


Illustration: Steve Baczek, Architect

Continuous barriers or control layers are challenging at windows, particularly with deeper wall assemblies, which can put windows on a different plane from one or more of the barriers. In this detail, the weather-lapped adhered membrane flashing is dragged back to the plane of the window at the head and sill; the sill pan extends up and over the back dam; and the air barrier is achieved at the sill with exterior and interior foam beads against a central backer rod.

Rubber, Meet Road

The physics behind high performance are constant, but material offerings are changing rapidly—and when it comes to *delivering* high performance, building assembly designs have generally fallen into a gray area—meaning opportunities for better performance have literally fallen through the cracks. Details like corner joints, window flashing, and all those beads of sealant were typically left to the contractor to work out based on manufacturers' instructions.

But that too is changing, says Z Smith. Increasingly, "we are telling a contractor exactly how to do his job," he said. "We certainly show things in 3-D now, and we are showing the sequencing. It almost starts to look like an IKEA construction diagram. We are taking manufacturers' ideas and applying them to our own details." Because of construction management and integrated project delivery, "we work together; we co-design that installation sequence."

Draw, But Verify

This new, more collaborative way of doing things invites other opportunities as well, says Luke Leung, P.E., director of sustainable engineering at SOM. "The world as a whole is moving more toward the actual performance of the wall," looking at "how that wall is actually performing in the actual condition," he says. This is not just true for light construction anymore: he's seen blower-door testing on 30- and 40-story buildings and has worked on contracts for the U.S. General Services Administration and the U.S. Army Corps of Engineers that required it.

Testing sometimes doesn't go as well as expected, in which case things could potentially get less collegial rather quickly. "Depending on where [the leaks] are, it could be as simple as people forgetting to seal up a certain part of the building," Leung explained. "Those are easy to fix, but if you have a wholesale problem, it requires a much deeper discussion on how to remediate that." Still, the prospect of testing tends to keep everyone on their toes. "It's a different attitude if you know the building will get tested in the future. You're going to be a little bit more careful because you know Big Brother is watching," Leung jokes.

Smith is seeing the same trend toward more field-testing of assemblies and the building envelope in the commercial building world. There used to be an assumption that commercial buildings were inherently airtight, he says, and commercial architects used to view residential building as "kind of simple, something craftsmen threw together." But in fact, he claims, not only do conventional commercial buildings (and particularly curtainwalls) turn out to be pretty leaky, but also "I think the people trying to build net-zero and Passive House are pushing the boundary in a way that is rebounding to commercial [projects]." At the same time, the lessons of high-performance commercial buildings are being applied even in production homes. "It's like a badminton game between the commercial and residential worlds—and the net keeps being raised."

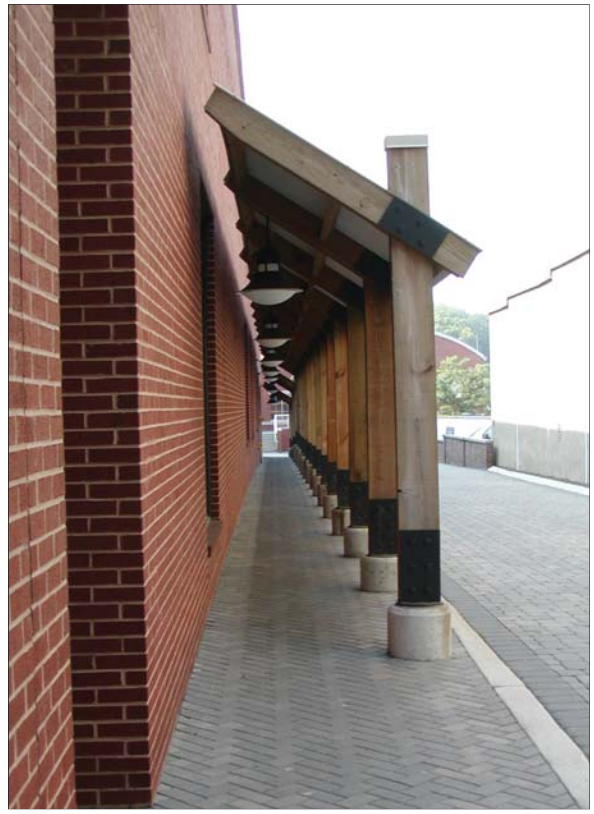


Photo: Peter Yost

During a major renovation of the Frederick, Maryland, town library, the main entrance was moved from the town's main street to a courtyard near the back of the library. The architect designed a covered walkway completely detached from the original building; it was simpler and faster to build, honored the continuity of the existing wall's water management, and was less expensive than any attached walkway would have been.

On the residential side, Steve Baczek has hosted a "trade day" on his projects to help with follow-through from design through construction. The team met with all the trades and asked, "What do you think of these details?" and received valuable insights, he said. This practice also "gets them to buy into the project. If you offer insight, you're going to feel emotionally tied to the project."

Teamwork Is Key

The lives of buildings and building professionals used to be a lot simpler, Baczek points out. "Even 50 to 75 years ago, all residential wall systems were the same, and performance expectations were the same," he says. Designs were less complex, there were not many material choices, and interior environments came with fewer health concerns and wider comfort tolerances. "You didn't care that the house was an energy pig. Now people care."

But caring has consequences. "Ten years ago, there was the code," Baczek said, and now we have a whole buffet of building and testing standards and product certifications to choose from. Not only has the number of ways of doing things "right" proliferated, but there are also "new materials [that] come online almost weekly" that may look similar to the materials we're used to working with but can have fundamentally different hygrothermal

No Clean Slate: The Special Challenges of Retrofits

The challenge with moving existing building assemblies to high performance is that they have a built-in hygrothermal balance that any retrofit is likely to disrupt. For example, older building assemblies may not be well insulated, but they usually dry readily: when we add insulation, our energy-efficiency improvements have often-ignored consequences for moisture flows. In order to optimize the performance of existing building assemblies, we need to:

- assess their current hygrothermal status;
- evaluate and recommend changes to that balance;
- and monitor the new balance.

Assessment

Hygrothermal assessment of an existing building is an integrated combination of visual inspection, moisture and temperature measurements, and testing (using a standardized building assessment checklist to help with objective data collection). It yields a complete profile, benchmarking what is and is not working in the building assemblies, identifying what additional information you may need, and prioritizing your efforts to manage both energy and moisture to meet performance goals.

An important source of information for the assessment can be the building manager or owner. On the other hand, care must be taken to prevent their preconceived notions of the building's performance from biasing the assessment. This is the key to the checklist nature of an assessment form as a quality assurance mechanism. Checklists enforce a regimen while not excluding the perspective that someone long associated with the building has to offer.

Evaluation and recommendations

The assessment benchmarks the current hygrothermal performance of the building and its assemblies, informing what moisture phenomena need to be addressed as part of the energy-efficiency improvements. The evaluation and recommendations honor approaches such as air, water, and thermal barrier continuity and vapor profile analysis for dedicated drying; they also indicate whether detailed hygrothermal modeling is necessary (such as WUFI—see page 16).

Monitoring

At some point in the work of every professional involved in retrofits, there comes a project whose long-term hygrothermal results no one can predict with complete confidence. At this point, you should consider long-term monitoring of the project as a way of protecting the customer, your business, and your reputation.

Continuous monitoring of indoor and outdoor temperatures and indoor and outdoor relative humidity—and even spot-monitoring of moisture content—used to be expensive and difficult. Now both Omni-Sense and Onset monitoring systems give 12–15-channel capabilities that include data logging and real-time Internet assessment for well below $1,000 in equipment (see "HOBO Data Loggers: No Longer Just for Researchers," page 6). Unheard of just years ago, this sort of hygrothermal field research is moving from publicly funded programs like Building America to private-sector companies.

Photo: Peter Yost

In snow country, managing roof load with gutters typically turns into an annual replacement cost. No gutters + backyard deck = a recipe for failed patio doors and the first three courses of lapped siding. Here, the deck board that lines up with the roof eave's drip line was replaced with a free-draining grate. No splashback, no built-in assembly failures.

properties. Staying on top of it all isn't easy: "As an industry, I see us wanting to turn the corner, thinking we should turn the corner, talking about turning the corner. But I don't think we've turned the corner yet."

Today's high-performance building assemblies demand a lot more from everyone on the project team and require building assemblies that purposefully manage all the flows on and through the building. "Things have gotten too complicated," Baczek concludes. "You cannot approach any of these projects as anything less than a good team."

Turning the Corner

To move our residential and commercial building assemblies to high performance, a lot is needed.

- Clients have to see the value.
- Architects, specifiers, and builders need to get the details right.
- Manufacturers need to provide the full slate of hygrothermal

properties for how their products perform in terms of all heat and moisture transfer.

We will turn the corner when clients demand durability and energy efficiency right along with curb appeal; when building practitioners use products only from manufacturers supplying all hygrothermal data and indicating how their products integrate within assembly systems; and when codes, standards, and programs fully recognize sustained performance right along with more conventional metrics for our better and our best buildings.

From the Library

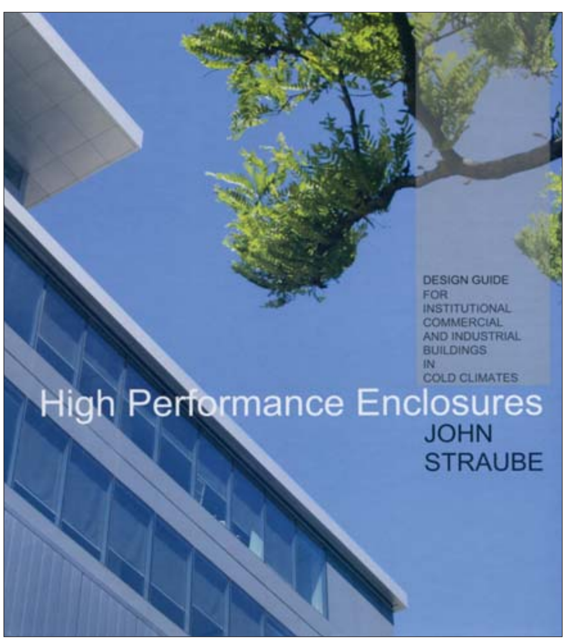
High Performance Enclosures

Design Guide for Institutional, Commercial, and Industrial Buildings in Cold Climates

(John Straube, Ph.D., P.Eng.; Building Science Press, 2012; 336 pages, $65)

Envelope failures are the most common cause of missed energy targets, durability issues, and health and comfort problems—and hence the most common cause of lawsuits—points out author John Straube. Making multilayered, high-performance building envelopes function as they should will require a new way of thinking that has not yet become second nature in the industry.

While the modern building envelope may be complex, the book lays out this new way of thinking in the systematic, easy-to-follow terms Building Science Corporation is well known for. Although it does not cover the "the quantitative part of the work," as Straube puts it, the book provides a deep and detailed introduction to the topic of high-performance building envelopes and is intended for both architects and engineers who work in North American climate zones 4 through 8. "The emphasis starts to change, and we're less concerned about thermal bridges and condensation when going from zone 4 to zone 3," Straube explained. "After that, it's a different building style that deals with things like hurricanes and long-term humidity." (There are currently no plans for a hot-climate sequel.)



The heart of the book is a set of enclosure details illustrating everything from skylight penetrations to curtainwall-to-opaque-wall transitions and basement walls that are continuous with above-grade walls. Some details are merely conceptual rather than "buildable," Straube warns—but when designing for high performance, a designer's details always should be buildable, he claims. Flashing and air sealing details are part of the design now, not "means and methods" that you leave to the contractor, he told *EBN*. "If airtightness and reducing thermal bridging are important, then it becomes increasingly the designer's job to actually show them." He adds, "Juries and judges are also agreeing with me."

In addition to the extensive library of details, the book also looks at the big picture throughout, and it concludes with several key appendices that supplement the preceding chapters. These look at issues like "the perfect HVAC" and how to use curtainwall wisely.

Environmental Building News | 1062-3957 | 9/28/12

4. Issue Frequency: Monthly | 5. Number of Issues Published Annually: 12 | 6. Annual Subscription Price: $99.00

7. Complete Mailing Address of Known Office of Publication (Not printer) (Street, city, county, state, and ZIP+4®): 122 Birge St - Suite 30, Brattleboro, Windham, VT 05301 | Contact Person: Charlotte Snyder | Telephone (Include area code): 802-257-7300

8. Complete Mailing Address of Headquarters or General Business Office of Publisher (Not printer): Same as above

9. Full Names and Complete Mailing Addresses of Publisher, Editor, and Managing Editor (Do not leave blank)

Publisher (Name and complete mailing address): Publisher not named

Editor (Name and complete mailing address): Alex Wilson, Executive Editor, 122 Birge St Suite 30, Brattleboro, VT 05301

Managing Editor (Name and complete mailing address): Paula Melton, Managing Editor, 122 Birge St Suite 30, Brattleboro VT 05301

10. Owner (Do not leave blank. If the publication is owned by a corporation, give the name and address of the corporation immediately followed by the names and addresses of all stockholders owning or holding 1 percent or more of the total amount of stock. If not owned by a corporation, give the names and addresses of the individual owners. If owned by a partnership or other unincorporated firm, give its name and address as well as those of each individual owner. If the publication is published by a nonprofit organization, give its name and address.)

Full Name	Complete Mailing Address
BuildingGreen, Inc.	122 Birge St - Ste 30, Brattleboro, VT 05301
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11. Known Bondholders, Mortgagees, and Other Security Holders Owning or Holding 1 Percent or More of Total Amount of Bonds, Mortgages, or Other Securities. If none, check box → [X] None

12. Tax Status (For completion by nonprofit organizations authorized to mail at nonprofit rates) (Check one)
The purpose, function, and nonprofit status of this organization and the exempt status for federal income tax purposes:
☐ Has Not Changed During Preceding 12 Months
☐ Has Changed During Preceding 12 Months (Publisher must submit explanation of change with this statement)

13. Publication Title: Environmental Building News | 14. Issue Date for Circulation Data Below: Sept 2012 (Vol 21 No.

15. Extent and Nature of Circulation: Monthly / 12 issues per year	Average No. Copies Each Issue During Preceding 12 Months	No. Copies of Single Issue Published Nearest to Filing Date
a. Total Number of Copies (Net press run)	2888	2500
b. Paid Circulation (By Mail and Outside the Mail) (1) Mailed Outside-County Paid Subscriptions Stated on PS Form 3541 (Include paid distribution above nominal rate, advertiser's proof copies, and exchange copies)	2194	1976
(2) Mailed In-County Paid Subscriptions Stated on PS Form 3541 (Include paid distribution above nominal rate, advertiser's proof copies, and exchange copies)	13	12
(3) Paid Distribution Outside the Mails Including Sales Through Dealers and Carriers, Street Vendors, Counter Sales, and Other Paid Distribution Outside USPS®	Ø	Ø
(4) Paid Distribution by Other Classes of Mail Through the USPS (e.g., First-Class Mail®)	226	181
c. Total Paid Distribution (Sum of 15b (1), (2), (3), and (4))	2433	2169
d. Free or Nominal Rate Distribution (By Mail and Outside the Mail) (1) Free or Nominal Rate Outside-County Copies included on PS Form 3541	75	71
(2) Free or Nominal Rate In-County Copies Included on PS Form 3541	5	5
(3) Free or Nominal Rate Copies Mailed at Other Classes Through the USPS (e.g., First-Class Mail)	1	0
(4) Free or Nominal Rate Distribution Outside the Mail (Carriers or other means)	124	30
e. Total Free or Nominal Rate Distribution (Sum of 15d (1), (2), (3) and (4))	205	106
f. Total Distribution (Sum of 15c and 15e)	2639	2275
g. Copies not Distributed (See Instructions to Publishers #4 (page #3))	249	225
h. Total (Sum of 15f and g)	2888	2500
i. Percent Paid (15c divided by 15f times 100)	92%	95%

16. [X] Total circulation includes electronic copies. Report circulation on PS Form 3526-X worksheet.

17. Publication of Statement of Ownership
[X] If the publication is a general publication, publication of this statement is required. Will be printed in the November 2012 issue of this publication. ☐ Publication not required.

18. Signature and Title of Editor, Publisher, Business Manager, or Owner: President | Date: 9/28/12

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Environmental Building News
122 Birge St., Suite 30 · Brattleboro, VT 05301

A publication of BuildingGreen, Inc. · www.BuildingGreen.com

BackPage Primer

Using WUFI to Prevent Moisture Problems

"Do I need a vapor barrier?" It's a perennial question, but there's no simple answer: heat and moisture interact with each other and with building assemblies in complicated ways, so the first thing you need is a *vapor profile* of the building assembly. This means looking at the vapor permeance of each material and ensuring it can dry should leaks or condensation occur.

You can take vapor profiling to a much more sophisticated level with a modeling tool known as WUFI—short for *Wärme und Feuchte Instationär*, or "Transient Heat and Moisture." WUFI looks at both drying potential *and* wetting risk by predicting dynamic heat and moisture flows based on the site, climate, building materials, mechanical systems, and more. Although we've gotten by without such tools in the past, modeling hygrothermal performance (the interplay of heat and moisture) has become increasingly urgent as energy flows have radically decreased.

Originally developed by the Fraunhofer Institute for Building Physics for use in central Europe, WUFI was later adapted by the Oak Ridge National Laboratory for North American climates and construction practices. The software simulates the movement of moisture and heat on, into, and through complex building assemblies that you "build" by choosing components from an internal data library.

WUFI also incorporates historical weather data to simulate hygrothermal performance over several years. The software accounts for a wide variety of material properties and how these materials are likely to respond to typical weather events—for example, when wind-driven rain is followed by intense sunlight.

WUFI Pro has all these capabilities and is designed for use by any building professional (with some training). WUFI 2D includes a number of features focused on moisture consequences at joints, corners, and other thermal bridges; users typically have an engineering background. A third version, WUFI Plus, models whole-building hygrothermal performance. For example, it can help assess mold risk based on which type of HVAC system is chosen, determine how interior finish materials affect comfort, or guide decisions about ventilation to handle moisture loads from rare weather events. WUFI Passive models hygrothermal performance specifically for Passive House projects.

Although a free WUFI download is available (WUFI–ORNL), the free version lacks key features and capabilities that serious users will require.