Feature from **Environmental Building News**

Passive House Arrives in North America: Could It Revolutionize the Way We Build?

An **Executive Summary** is available for this article.

I'm old enough to remember the passive-solar and superinsulation movements in the late 1970s. In 1976, I was involved with passive solar design while at college, where a group of us studied energy self-sufficiency, and in 1978 I moved to Santa Fe to work with the New Mexico Solar Energy Association, which was leading the charge in advancing passive solar energy.

Dan Whitmore of Blackbird Builders is using a "Larsen truss" detail in this Passive House he is building in Seattle for his family. The 14" wall cavity will be insulated with dense-pack fiberglass to achieve approximately R-55.

Not long after passive solar began picking up steam, along came the competing idea of superinsulation. This movement, I believe, was created largely in response to early solar homes (both passive and active)—which were often complicated, ugly, expensive, and overglazed. Superinsulation proponents sought to create a simpler solution with small window areas, large quantities of insulation, and simple geometries. Proponents included researchers at the University of Illinois who built the demonstration Lo-Cal House in 1976, Canadian builders of the Saskatchewan House in 1977, and Gene Leger in Massachusetts, who built several highly publicized houses during that period. Physicist William Shurcliff helped to publicize this movement with a book and many articles on superinsulation.

While lower oil prices in North America erased much of our interest in these ideas during the 1980s, by then these concepts had migrated to Europe, where high energy taxes were keeping interest in alternatives high. Now the ideas of passive solar and superinsulation are back—in a much smarter way—with the Passive House movement.

Dr. Wolfgang Feist, who wrote his first papers on Passive House in the mid-1980s and founded the Passivhaus Institut in Darmstadt, Germany, in 1996, says that he was inspired to create ultra-low-energy buildings by physicist Amory Lovins of the Rocky Mountain Institute. As recounted by Feist in a paper available on the Passivhaus Institut website, Passive House is based on Lovins' concept of reducing investment through energy-efficient design. "By dramatically increasing the energy efficiency of a building, the HVAC systems can be radically simplified upon reaching a certain level of efficiency," wrote Feist.

Feist determined that when the peak heating load is kept extremely low, "the ventilation system can easily be used for space heating, and a separate heating system is no longer required." From this, Feist derived quantitative performance standards for Passive House that made sense in Germany, based on both total annual heating energy use and total annual combined primary energy use for all applications. By getting the energy loads so small, a Passive House (known as Passivhaus in Europe) can be turned into a net-zero-energy building using a fairly small photovoltaic array.

Passive House construction has been catching on in Germany, Austria, and Scandinavian countries. More than 15,000 buildings—including single-family homes, multifamily apartment buildings, and a wide range of commercial buildings—have now been built to the standard in Europe, according to the Passivhaus Institut, and at least 17% of new homes are being built to the standard in Austria, where market penetration is the greatest.

In the United States, Passive House has been championed by Katrin Klingenberg, a German-trained architect who built the first Passive Houses in the United States with her late husband, Nic Smith, in 2002 and 2003, and later founded the

Passive House Institute U.S. (PHIUS). Today, PHIUS uses a largely unchanged German Passive House standard to certify buildings in the U.S. under license from the Passivhaus Institut in Germany.

What Is Passive House?

The Stanton House in Urbana, Illinois, built in 2008, has 2,200 ft^2 of floor space (as calculated in PHPP), R-64 walls, R-87 roof, R-51 sub-slab insulation, and triple-glazed windows rated at U-0.17 (0.96 W/m^2K).

Passive House is a quantitative, performance-based energy standard for buildings. To meet the standard, whether in Germany or the U.S., a building can use no more than 15 kWh/m^2per year (4,755 Btu/ft^2 /year) for heating and no more than 15 kWh/m^2/yr for cooling. Originally, the metric was based on peak heating load rather than annual usage, with a threshold of 10 W/m^2 (3.2 $Btu/hr{\cdot}ft^2$), but that proved to be unrealistically stringent in more northern regions, such as Scandanavia. The peak heating maximum of 10 W/m^2 is currently considered an optional heating performance path by the Passivhaus Institut.

In addition to the heating and cooling energy use limits, the total *primary* (source) energy use of a Passive House can be no greater than 120 kWh/m^2/year (38,000 Btu/ft^2/yr) for all energy needs. This includes water heating, lighting, and plug loads. The Institute uses multipliers to convert site energy (gallons of heating oil, therms of natural gas, kilowatt-hours of electricity, etc.) into the corresponding source energy, thus accounting for the losses in extracting and processing a fuel or in generating and transporting electricity. PHIUS currently relies on multipliers from Germany.

Finally, in a Passive House, the air leakage can be no greater than 0.6 air changes per hour at 50 pascals of pressure difference between the interior and exterior (0.6 ACH_{50}). According to Klingenberg, this air-tightness standard arose as a quality-assurance feature. The German developers of Passive House calculated the amount of moisture that could be introduced into a house from outdoors with different air-exchange rates and picked a low enough exchange rate to ensure that introduced moisture would not cause a problem. "If you build to that standard," said Klingenberg, "you will not have moisture problems."

Unlike other building rating systems, the Passive House standard is entirely performance-based, and it focuses almost exclusively on energy use (though the air-tightness standard may also help to ensure durability). Features like water consumption, indoor air quality, materials selection, and location are not addressed.

In addition to the very specific performance standards, there are a number of recommendations relating to the energy performance of windows, the control of thermal bridging across the building envelope, and the efficiency of heat-recovery ventilators.

Passive House also establishes a recommended floor area of 20–50 m^2/person (215–540 ft^2/person). "We strongly recommend staying within those limits," said Klingenberg, "and almost all projects in pre-certification coming in from consultants are staying within that rule."

A key feature of Passive House is that onsite electricity generation cannot be factored into the energy calculations. Passive solar gain and solar thermal can be accounted for, but not photovoltaic (PV) systems. This is a key difference from "zero-energy" or "net-zero-energy" buildings, which almost always rely on PV systems to achieve net-zero-energy performance goals.

Passive solar gain, however, is a key component of the design of Passive House design, especially in colder climates. "You can't [achieve the 15 kWh/m^2 standard] in these climates without the sun," says Marc Rosenbaum, P.E., a certified Passive House consultant in Meriden, New Hampshire, and a past board member of PHIUS. This is why the recommendation for Passive House windows includes a fairly high solar heat gain coefficient (SHGC) of 0.50, along with a very low U-factor (below 0.14).

To certify a Passive House, its performance has to be modeled using the Passive House Planning Package (PHPP) software. This is a sophisticated, Excel-based spreadsheet developed by Dr. Feist. Rosenbaum says the PHPP spreadsheet is complex and time-consuming to work through, but he likes the fact that you can see exactly what's going on. "A lot of modeling programs are black boxes," he said; with PHPP you can very clearly see the impact of modifying the glazing on the south or reducing thermal bridging through a wall component, and you can see the calculations behind it. "It's a really good educational tool."

An important—and confusing—aspect of PHPP is the way in which floor area is calculated. While most floor area calculations in the U.S. are based on outside dimensions, PHPP subtracts the (fairly thick) exterior walls as well as interior partition walls, stairwells, and certain columns from the area calculation. In addition, secondary spaces, including basements not used as living area, utility rooms, and storage rooms, are calculated at 60% of the actual area.

This difference in calculated area can be fairly significant. For a two-story, 25' x 40' house, for example, conventional practice in the U.S. would be to calculate the area as 2,000 ft^2 (186 m^2). In the Passive House calculation, assuming foot-thick exterior walls, 4.5"-thick interior partition walls, 50 ft^2 of stairwell per floor, and 150 ft^2 of utility and storage area with no basement, the Passive House floor area would be 1,532 ft^2 (142 m^2)—23% lower. Because the Passive House energy benchmark is tied to floor area, this calculation method makes the criteria even more stringent.

In addition to going through the PHPP software and producing a compliance report that demonstrates modeled energy consumption that complies with the Passive House requirement, certification also requires a blower-door test to verify that the house meets the 0.6 ACH_{50} air tightness standard. This is an extraordinarily tight standard. By comparison, the energy code component of the International Residential Code (IRC) establishes a maximum air leakage of 7 ACH_{50}—more than ten times as leaky.

PHPP results and the blower-door test results are submitted to PHIUS, along with a fee of $700–$800 (assuming a certified Passive House consultant is used) to achieve Passive House certification. The certification cost goes up somewhat, according to Klingenberg, if the house exceeds the recommended floor area per person. When a submission is not provided by a certified Passive House consultant, the certification cost often goes up two- to threefold, says Klingenberg, because of consulting support needed to complete the PHPP submission, assist with HVC system sizing, etc. Whenever possible, PHIUS likes to be brought in early in the design phase of a building that will go through Passive House certification.

Passive House Projects in North America

To date, according to Klingenberg, ten buildings in the U.S. have been certified by her organization (and one directly by Passivhaus Institut in Germany), with several dozen in various stages of development or review. These projects span a wide range of climate zones: from Minnesota and Vermont on the cold side to Louisiana, North Carolina, and Berkeley, California in warmer climates (see map).

While most of these projects are single-family houses, the list includes several larger projects, among them multifamily housing, schools, a university building, and a senior housing facility. A few of the certified projects, as well as a number of the projects underway, are existing buildings being retrofit to Passive House standards.

Passive House Projects in North America

What Works Well About Passive House?

Many of the experts *EBN* contacted for this article are attracted to Passive House because of its simplicity and its focus on performance. "I like the fact that it has an actual energy standard," noted Rosenbaum, who is disappointed that most American certifications don't have specific energy performance requirements. "It has a target, and it's a tough one."

The inclusion of a limit for *total* energy use (not just heating and cooling but also water heating, lighting, and other electricity uses) and expressing that as the *primary* energy use are very important features for Rosenbaum. In highly energy-efficient homes, water heating and various electrical loads become more and more significant, and the Passive House standards address these energy uses.

John Straube, Ph.D., P.Eng., of Building Science Corporation, who has criticized certain Passive House requirements in articles and blog posts, likes key aspects of the system. "It is, in most respects, a very good new-house standard," he told *EBN*. "Almost everything the low-energy community has been preaching for 20 years is there," he said. (Some of his concerns with Passive House are described later in this article.)

Jamie Wolf, a remodeling contractor and Passive House consultant with the firm Wolfworks in Hartford, Connecticut, noted a more psychological benefit of Passive House. "It captivated my attention and has captivated the attention of a lot of people who realized that their understanding of energy was coming up short," he told *EBN*. Recognizing the immense challenges we're facing as we try to reduce greenhouse gas emissions, Wolf realized that the level of energy improvements he was making to houses weren't enough and that Passive House offered an answer. "It moved the goalpost down the field in understanding what's possible and how to think about it."

Finally, Passive House is spurring product innovation. Rosenbaum, who has been designing and consulting on low-energy homes in the U.S. for 30 years, is often constrained by what's available. He says that Passive House has spurred product innovation in Europe, and he expects to see that happen here. You can't achieve Passive House performance without top-performing windows that do an exceptional job at controlling thermal bridging through the frames, for example, so some Passive House builders are bringing in European products to satisfy that need. A few U.S. manufacturers are stepping up to the plate and introducing such products, but more are needed, says Rosenbaum.

What Are the Challenges with Passive House?

Whitmore's 2,600 ft^2 (1,895 ft^2 based on PHPP calculations) Passive House in Seattle will use windows with a SHGC of 0.57 and a U-factor (NFRC) of 0.18 for fixed-glass and 0.20 for tilt-turn.

While Passive House is making tremendous strides in advancing low-energy building in Europe, some argue that widespread implementation in the U.S. and Canada will be very hard if not impossible. Some, such as Straube, argue that certain provisions should be modified if significant market share is to be achieved here. A few of these issues are covered below.

Applicability to North America's climate

Passive House was developed in a moderate heating climate with neither extremely cold nor hot conditions. Northern U.S. and Canadian climates are much colder than those found in central Europe, and the southern U.S. has cooling loads that are far greater than those in Europe. Some parts of the Upper Midwest and the Canadian Prairie Provinces have both high and low extremes that exceed either found in central Europe. "They picked these numbers where it doesn't matter whether you're in northern Minnesota or central Tennessee," complains Straube.

The German standard has already been modified by the Passivhaus Institut to allow it to work in Scandinavian countries with heating loads comparable to those found in North America. (As noted above, the original 10 W/m^2 maximum heating load was replaced with a standard that could be met by either that heating load or an annual heating budget of 15 $kWh/m^2/yr$.)

As for how well Passive House works in a hot climate, the jury is still out. A small number of Passive House projects have now been completed in these climates, but there is little actual operating experience. The maximum energy use allowed for cooling is 15 $kWh/m^2/year$ (the same as the heating requirement), though the optional cooling load maximum is lower, at 0.8 W/m^2 (2.7 $Btu/hr{\cdot}ft^2$), according to Klingenberg. She has modeled houses in various U.S. climates with high cooling loads. "Phoenix is really difficult," she said. *EBN* is not aware of any completed Passive Houses in extremely hot climates, though some projects are underway.

While getting the total energy requirement for cooling that low will be a challenge in some climates, providing cooling *solely with the ventilation system* will be even harder, according to Rosenbaum. (Delivering heat and air conditioning solely with a ventilation system is a goal of Passive House but not a requirement.) In delivering heat, it's possible to deliver air with a greater delta-T—the difference between the temperature of the room air and the delivered air—than is possible when delivering chilled air, says Rosenbaum. In other words, ventilation supply air can contain more heating energy than cooling energy, given the delivery air temperatures that people find acceptable.

Too much focus on heating?

The Passive House movement is heavily focused on heating. While there is a total energy use requirement, that tends to take a back seat in discussions about the standard. Some experts suggest that the larger focus should be on the total primary energy use. "If you get the total number down," asks Straube, "why harp on the heating energy?"

And if the focus shifted more to total primary energy, why not accept site-generated PV? With net-zero-energy buildings, which are being championed by the U.S. Department of Energy and others, the total energy consumption (either site energy or primary energy, depending on the definition) drops to zero. Paul Torcellini, Ph.D, P.E., of the National Renewable Energy Laboratory, who has worked actively on DOE's zero-energy initiative, thinks that net-zero-energy should be as good as Passive House. "I like the idea of a number, and zero is the best number," he told *EBN*. "The beauty of net-zero is that it's really hard to game the system if you follow the established definitions." Adds Straube: "How can you tell me that a net-zero house is worse than a Passive House?"

Passive House proponents are well aware of the benefits of net-zero-energy buildings, but they also recognize the reality that if you don't get the energy loads way down, generating enough renewable electricity onsite to satisfy that demand will be prohibitively expensive. By focusing on the envelope, the loads can be reduced enough that onsite PV can satisfy those needs.

Existing buildings

Many experts have pointed out how difficult it is to dramatically cut energy use in existing buildings (see "The Challenge of Existing Homes: Retrofitting for Dramatic Energy Savings" in *EBN* July 2007). At least in colder climates, meeting the standard is very hard and very expensive. "There's no way we're going to get most of our buildings in the Northeast to be Passive House," says Rosenbaum.

The idea of a different Passive House standard for existing buildings is being considered. According to Klingenberg, the Passivhaus Institut in Germany will release a retrofit standard this year, though she's not sure how it will differ from the current standard. The expectation is that the standard will be relaxed somewhat for existing buildings to make it easier to comply.

One of the challenges with existing buildings, notes Rosenbaum, is access to sunlight. In northern climates, passive solar gain is critical to Passive House performance, and that's a huge challenge with existing buildings. "We're not going to have clear solar access for every house," he says.

Small-house penalty

Because Passive House performance standards are based on floor area, and the airtightness requirements are based on house volume (instead of being based on cfm of air leakage), there's an inherent advantage for larger buildings. "It's harder to get small buildings to comply," argues Rosenbaum. He described a compact home he was modeling in the PHPP software, and the easiest, lowest-cost way he could achieve the standard was by eliminating an open area in the living room by extending the second floor over that space (increasing the measured floor area).

One response to the concern about the difficulty of meeting the Passive House standard with small buildings is to do what is done in Europe: aggregate dwelling units into larger apartment buildings. By doing so, the surface-to-volume ratio drops, and it's much easier to achieve low energy use per unit of floor area.

Extreme airtightness in moderate climates

Some people suggest that in a very "easy" climate for heating and cooling, such as coastal California, it should be possible to build a house that meets Passive House standards with a less-stringent airtightness requirement. In the San Francisco Bay Area, for example, the 15 kWh/m^2/year heating and cooling limits can probably be achieved with relatively standard insulation levels (2x6 with dense-pack cellulose) and double-glazed, low-e, argon-filled windows. But to achieve the 0.6 ACH50 standard requires much more expensive components to control air leakage.

Though Klingenberg stands by the Passive House standards, she notes that "it's entirely valid to argue that in that climate it doesn't make sense to have to achieve that [airtightness] standard."

"Relax that? Sorry, no," said Berthold Kaufmann, Ph.D., of the Passivhaus Institut in Germany. "Airtightness is the most simple, most cost-effective, and therefore most energy-efficient thing of all," he told

Whitmore used high-perm-rating Homosote wall sheathing to provide a breathable wall exterior; a ¾" rainscreen will be provided

EBN. He argues that the heat-recovery ventilation system relies on a very tight envelope; without airtight construction, bypass airflow would occur. He also says it's really not that difficult. "Our experience is that even 0.3 ACH50 is easy with some experience."

behind the siding. Roof trusses provide for 19" of dense-pack fiberglass providing R-68.

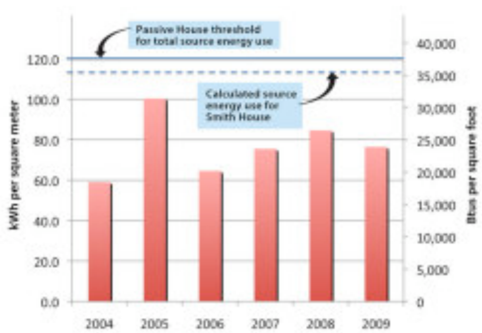
Lack of cutting-edge, low-energy products

Some complain that the products needed to achieve Passive House compliance aren't available or have to be imported from Germany and are prohibitively expensive. Indeed, that has been a problem in the U.S. (less so in Canada), but at the same time, it is programs like Passive House that drive innovation.

Kaufmann noted that people in Sweden (which is significantly colder than Germany) have complained that to meet the Passive House standard they need exceptional windows with U-factors as low as 0.8 W/m^2K (U-0.14 in North America) that aren't available. Kaufmann counters, "Well, if we had just complained about the lack of products 20 years ago, Passivhaus would never have been realized at all."

Clearly, innovation is happening, from Serious Windows (see *EBN* Nov. 2008) to the Zehnder ComfoSystems ultra-high-efficiency heat-recovery and energy-recovery ventilation systems that are now being imported into North America from Switzerland (see the March 18, 2009, "product of the week" blog post on BuildingGreen.com). It is likely that a slew of advanced, low-energy products will be introduced from Europe in the next few years.

Measured Performance of Passive Houses



Measured annual primary (source) energy consumption of the Smith House in Urbana, Illinois, 2004 - 2009. Also shown is the PHPP-calculated energy consumption of the house (113 $kWh/m^2/yr$) and the threshold for Passive House certification of 120 $kWh/m^2/yr$.

Some energy experts have complained that Passive House-certified homes aren't living up to their modeled performance. There is still relatively little actual performance data in the U.S., though the Smith House in Urbana (owned by Klingenberg) is a notable exception—see graph.

A report showing detailed energy performance of 14 Passive House projects in Europe has been widely publicized and is available in English (the CEPHEUS Report, published in 2001 by the Passivhaus Institut). The report, which was supported by the European Union, shows a close correlation between predicted and actual performance. Unfortunately, that report is now quite dated, and little new, English-language data is available.

As more performance data becomes available, we should be aware that with very tiny heating and cooling loads, relatively small variations in actual energy use (due to vagaries of climate or occupant behavior) have huge percentage impacts on energy consumption. So, before criticizing the results, one should look at the magnitudes involved: 50% higher heating energy use may still represent a very small amount of energy.

Adapting Passive House for North America?

A lot of smart people, led by Dr. Feist, have put a lot of thought into what an ultra-low-energy building standard should look like. The Passive House certification system they created does a great deal to push the envelope and demonstrate that the energy demand of buildings really can be reduced so far that it can easily be satisfied by onsite PV. "We should be using these great houses as clubs," quips Straube, "to show that it is possible."

That said, there are a few tweaks that might make Passive House even better, at least for the North American climate and market. A few suggestions are provided below. (BuildingGreen.com will host an online discussion on whether these or other modifications might make sense; look for this in the Blogs area of the website.)

• Eliminate the bias against small houses. Perhaps the energy performance requirements could be pegged to the number of bedrooms, or a two-tiered system could be implemented to allow higher per-area energy consumption for very small houses—for example, adding 2 kWh/m^2/year to the allowable energy consumption for heating and cooling for houses under 100 m^2 (1,076 ft^2).

• Tie performance requirements to climate in some way—so that designers and builders in extremely cold or extremely hot climates can create viable Passive Houses. For example, perhaps it should be possible in a very cold, heating-only climate to allow some of the cooling energy cap to be applied to heating—and vice-versa for very hot climates—while maintaining the overall cap of 120 $kWh/m^2/yr$ of primary energy consumption.

• Relax the Passive House requirements for retrofits. Consideration should be given to reducing both the energy-use and airtightness requirements based on recommendations from a panel of leading experts. Doubling the heating and cooling limits to 30 $kWh/m^2/yr$ (9,500 $Btu/ft^2/yr$) and adjusting the airtightness limit to 1.5 ACH50 might be more reasonable. Perhaps a relaxation of the energy performance requirements should be somehow tied to access to sun with existing houses—which will be a limiting factor in many situations.

Final Thoughts

For those of us who have been struggling to advance low-energy buildings for a long time, Passive House is one of the most exciting things to come along in decades. It is a specific energy-consumption standard for buildings—residential and commercial—that necessitates both creating extremely well-insulated, airtight building envelopes and controlling the other energy uses in a building, such as water heating, appliances, and lighting. Further, Passive House is almost alone in addressing primary energy use of buildings, instead of simply site energy.

Passive House standards are hard to achieve, but that isn't a bad thing. Passive House will drive innovation, provide a firm target for leading-edge designers and builders to aim for, and force other building rating systems and codes to tighten their own standards. I don't think Passive House is expected to achieve extremely high market penetration (though it would be great if it did); it is intended to be a leading-edge standard that will demonstrate what is possible—and make it a lot easier to create true net-zero-energy buildings, which should be our ultimate goal.

– Alex Wilson

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April 1, 2010
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