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CONTENTS

Spreading the WORD

I am thrilled to have the opportunity to step into the role of marketing manager for *Passive House Buildings*.

My introduction to Passive House started a little more than five years ago, when the design-build firm my husband and I co-own in Connecticut was engaged by a local architect to build a Passive House. We anticipated the home's superior energy efficiency performance, but witnessing the additional quality-of-life benefits—vastly improved comfort and superior air quality—was a game changer. With that project as a teaching tool, the buzz about Passive House ignited enough interest to launch the first passive housing designer/consultant training in our state, which ultimately, led to the formation of Connecticut Passive House. Growing the Passive House industry, one state at a time.

In the same spirit, I believe in this publication's purpose and its power to inform and inspire, demonstrating Passive House success stories in a variety of settings and markets. As a trained Climate Reality Leader, I fully appreciate that employing Passive House strategies ensures that our buildings can be part of the solution to meeting reduced emission and decarbonization targets, zero-energy initiatives, and resiliency strategies.

As 2019 unfolds, I invite all of you to consider how you can further spread the word about Passive House. By all means, please do share this magazine—either in hard copy or digitally, by sharing this link: **www.passivehousebuildings.com**.

In the pages of this magazine you will see notifications for a number of events, and I encourage you to look beyond your own silo of expertise and consider attending an event that might not otherwise have been on your radar. Practicing what I preach, I can attest to the benefits of playing in different sandboxes. Last year, I went to a local Health and Wellness in Our Buildings workshop in Hartford. The wealth of data linking health outcomes to buildings was mind blowing and reinforced for me the impact we are making on people's lives when we build to the Passive House standard.

When I look back at the body of work represented on the pages of this publication, what stands out is the impressive diversity and breadth of Passive House projects being built in North America. Bravo. Thank you to all those who shared their project details and photos and to our talented body of writers who contributed their insights and wisdom on climate, policy developments, and building science.

And last but not least, a very special thank you to every company, organization, and individual who has supported this magazine's mission either by advertising or by helping to ensure that our magazine is distributed at all of the major green building, high-performance building, and Passive House events across the country. And of course, at local events, many of them hosted by a Passive House organization in your state.

Through our collective efforts, we are building a movement, and with it, the capacity to meet the growing demand for passive building in North America. Bring it on.

—Alicia Dolce
Marketing Director

Index of SPONSORS

TELL THEM *PASSIVE HOUSE BUILDINGS* SENT YOU!

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Published by **Low Carbon Productions**

Editor and Publisher: Mary James

Senior Editor: Steve Mann

Marketing Director: Alicia Dolce

Art Director: Leanne Maxwell

Production Assistant: Sarah Grierson-Dale

Contributing Writers:
Tad Everhart, Avery Gray, Bill Spohn, Jason Taellious, Richard Yancey, Stas Zakrzewski

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Cover image: The Pennsylvania Housing Finance Agency's new headquarters. Photo courtesy of **Pennsylvania Housing Finance Agency**

EDITORIAL

Welcome to spring and the promise of new growth. Here at *Passive House Buildings* we are elated to have Alicia Dolce as our new marketing manager. She brings a wealth of experience with the Passive House community—and so much more.

Fortunately for us, Tad Everhart is not leaving, but instead is transitioning to the roles of marketing consultant and intrepid product news reporter. See “Prefabricated and Factory Built,” p. 17, for his updated story on the growth in that sector.

On the policy front, the city council in New York City has introduced a bill that should set the stage for a massive wave of energy efficiency retrofits when adopted. See “New York's Path to Scaling Up Passive House,” p. 10, for more on this exciting development. Simultaneously NYSERDA has been working on an initiative to implement and industrialize deep energy retrofits, and we report on one of those projects in “Industrializing Deep Energy Retrofits,” p. 6.

And we continue to see an uptick in the availability of products that are facilitating the construction of Passive House projects. From software updates to prepackaged assemblies, the path from design to move-in dates keeps getting smoother in North America. Even postoccupancy has improved with the proliferation of lower-cost measurement tools, as discussed in “Measuring a Healthy Home,” p. 75.

What hasn't improved—and that's an understatement—is the amount of U.S. greenhouse gas emissions, which jumped up in 2018, increasing by the second-largest amount in the past 20 years, according to the Rhodium Group, an independent economic research firm. The power sector was responsible for most of the increase. However, Rhodium also estimated that direct emissions from residential and commercial buildings increased by 10% in 2018 to their highest level since 2004.

A big thank you goes out to all the members of the Passive House community, who are doing everything possible to reverse that trend—and preserve our future. Enjoy the articles, get inspired to take action, and as always, please thank our sponsors, whose support makes this publication possible.

—Mary James
Editor and Publisher

Industrializing DEEP ENERGY Retrofits

Not all retrofits can be accomplished in one go, as the PHI recognized when it created a certification for phased retrofits, or EnerPHit projects. Deep energy retrofits of existing structures are an absolute must for meeting any reasonable carbon emission reduction goals, but cost-effective retrofits are challenging, to say the least. As reported in previous *Passive House Buildings* issues (“**Scalable, Efficient Retrofit Solutions Under Development**,” Fall 2018, p. 20), NYSERDA is pursuing industrialized approaches to retrofits, building on the Energiesprong program first developed in the Netherlands, and actively working toward market viability of deep energy retrofit solutions.

Tom King, of King + King Architects, is leading one such project, spurred on by his feeling that “it is our responsibility as designers, builders, financiers, and owners to step up and challenge ‘Business as usual.’” His scope of work stands out from others in this NYSERDA initiative for a positive reason: The owner of the five-building, 40-unit, two-story, wood-framed apartment complex in upstate New York has been keeping up with needed maintenance and has even undertaken home performance improvements and weatherization measures. Replacing the building’s entire façade, as is often done in an Energiesprong project, wouldn’t make financial sense up front. Instead, bringing the building to a net zero energy and Passive House level of performance is requiring a long-term phased plan of retrofit measures, some of which are cost-effective now, while others will be cost-effective over the next 30 years of capital improvements.

The all-electric complex currently has an annual site energy use intensity (EUI) of 39.4 kBtu per square foot (/ft^2)and peak heating and cooling loads of 10.7 kBtu/ft^2 and 9.8 kBtu/ft^2 respectively. The proposed retrofits are designed to reduce the heating and cooling loads by almost half.

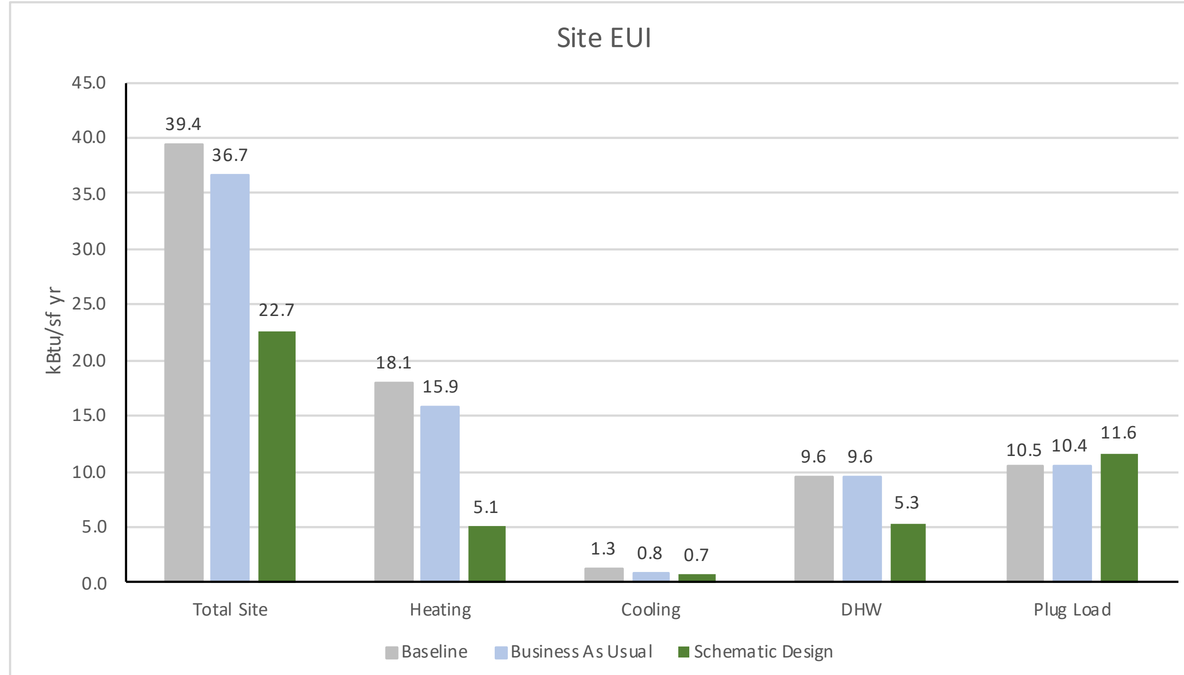
To realize this energy reduction strategy, the planned scope of work includes the development of a mechanical pod housing integrated mechanical systems that can be manufactured off-site, akin to those used in the Dutch Energiesprong projects. Advancements and cost compression in integrated domestic hot water (DHW), heating, cooling, and ventilation systems—similar to the Factory Zero equipment available in the Netherlands—have great potential benefit for deep energy retrofit projects here. Analyses of Dutch projects reveal a 37% cost reduction in façade systems and a 73% cost reduction in mechanical system integrations since 2010.

The planned mechanical pod that King + King, along with Taitem Engineering, a project partner, are developing will include an ERV unit, a DHW tank and outdoor unit, a solar PV inverter, an electric service panel, and a new master meter—all of which will be factory installed and delivered on-site. Each of the five buildings will be served by one system attached to the existing exterior, maximizing tenant storage space within units. Ducts and piping will run through an insulated and air- sealed plenum in the attic, serving units vertically through closets that previously housed electric-resistance DHW tanks. This technique will reduce in-unit construction and tenant disturbances during the retrofit.

The ERVs will be fitted with hot water coils integrated with the DHW system to provide additional and emergency heating as necessary, as well as particulate air filters to remove contaminants prior to supplying air to the apartments. A heat pump water heater using CO_2 refrigerant will supply the DHW with an aquastat to control recirculation, maintaining proper loop temperature while optimizing pump operation. The electric service will include provisions for the DHW system and ERV to be run on emergency power in the event of grid failure, initially provided by temporary generators but with the ability to add battery backup systems in the future.

For the first time, the tenants will be supplied with air-conditioning in all rooms using the smallest-capacity air source heat pumps available fitted with variable-speed compressors to manage the loads. This new equipment will help reduce the humidity of the apartments and prevent mold and mildew, while substantially improving indoor air quality.

Of course, the smaller integrated mechanical systems would not be capable of meeting the conditioning loads were it not for the proposed façade improvements.



Rendering courtesy of King+King Architects; Graph courtesy of Taitem Engineering

Blower door tests performed by Taitem Engineering showed the existing building to be at 4.47 ACH_{50}—definite room for improvement. The team identified areas ripe for air sealing: around electrical boxes, pipe and duct penetrations, and drywall at the sill plate. Any existing window unit air-conditioning sleeves will be removed, insulated, and sealed. Additional reduction in total building air leakage is anticipated from replacing all windows and doors with operable, high-performance triple-glazed units. The team is aiming with these measures to achieve an airtightness of less than 2 ACH_{50}.

Additional façade improvements include enclosing each existing exterior entrance and stair to significantly reduce exterior wall surface area and heat loss from each of the apartment entry doors. The new walls will be insulated with 5.5 inches of mineral wool insulation and R-9.6 continuous exterior sheathing, as will the currently uninsulated walls of the maintenance garage, which abuts one of the buildings.

As designed, the retrofitted building should achieve an annual site EUI of 22.7 kBtu/ft^2 with 89% of its power supplied annually through on-site PV generation. The next major capital improvement cycle, planned sometime before 2050, would include a full envelope upgrade, allowing the complex to further comply with current New York State and global emissions targets, and likely pushing the buildings to net positive power generation, with the ability to act as a resource for adjacent low-income housing properties.

The biggest challenge thus far, says King, has been trying to identify the most cost-effective solutions while still meeting the initiative's EUI requirements. The team is looking for ways to further reduce costs through systems integration and shop-fabricated components, but is not expecting to arrive at a feasible solution without programmatic support—as was the case for early Dutch Energiesprong projects.

King has been much inspired by his participation in this initiative, particularly by the immediate immersion into an intensely focused group exchanging ideas freely between teams, rather than in competition. The goal that is driving his participation in this pilot project is pushing to develop, and most importantly implement, solutions that further align the market for full saturation. European models are showing positive results; continued cost compression through technology innovation and demand aggregation is the path toward feasible deep energy retrofits across North America.

—Mary James

New York's Path to SCALING UP Passive House

Photo by Elizabeth Felicella

The proliferation of Passive House buildings in New York today arose within the context of increasing recognition of the seriousness of climate change—and of adopting new policies or regulations that respond to this serious challenge. The second half of 2018 brought several exciting developments in New York City's drive to transition our buildings toward high performance, the central plank in our fight against climate change. These developments, though, were more than ten years in the making.

In 2007, then-Mayor Michael Bloomberg released PlaNYC, a sustainability plan for New York City. PlaNYC drew up a bold agenda for creating a "greener, greater New York," which included the goal of a 30% reduction in carbon emissions by 2030, compared to 2005 levels. By enumerating the large contributions that buildings make to the city's carbon emissions—they represent nearly 70% of the city's total greenhouse gas emissions—the plan elevated the stature of real estate as an important partner in fighting climate change.

PlaNYC prompted a cascade of legislative changes. In 2009, the mayor signed Local Law 84, which required annual benchmarking and reporting of energy and water use in New York City buildings with more than 50,000 gross square feet—nearly 50% of the city's square footage. In 2016, Local Law 133 expanded the list of covered buildings to include those with more than 25,000 gross square feet, adding another 17,000 buildings. In addition to benchmarking, every ten years these covered buildings must undergo an energy audit and commissioning process to both tune up existing equipment and identify all cost-effective measures to improve their efficiency.

A related law, Local Law 88, requires that all nonresidential covered buildings upgrade their lighting to meet the latest energy code by 2025, triggering the adoption of newer, dramatically more efficient lighting technologies. Still another local law closed an energy code loophole, requiring for the first time that partial renovations—a category that includes most of the city's construction projects—meet the energy code.

This drumbeat of energy-related laws reflects New York's increasing understanding of its vulnerability in the face of climate change. Other shocks to the system have also upped the ante, such as the devastating Superstorm Sandy in 2012, and the People's Climate March, when roughly 400,000 people took to the streets on September 21, 2014, to call for climate action. Shortly afterward, Mayor Bill de Blasio announced New York City's commitment to achieving an 80 x 50 target, reducing carbon emissions by 80% by 2050, with an interim target to reduce emissions 40% by 2030. To lead by example, the mayor committed all new municipal buildings to meeting very aggressive efficiency targets, with Passive House as a compliance path. And in response to the Trump administration's withdrawal from the Paris Climate Agreement, Mayor de Blasio signed an executive order committing New York City to meeting the principles of that historic agreement, most importantly the 1.5°C global warming limit.

Photo by Yetsuh Frank from the report, Pursuing Passive

NYC Time Line

2007 – PlaNYC released; Mayor Bloomberg's master plan includes a 30% reduction in greenhouse gas GHG) emissions by 2030.

2009 – Green Greater Buildings Plan passed, a suite of four new local laws (LLs) for all large buildings:

- LL84 – requires annual benchmarking, reporting, and public disclosure of building energy and water usage.
- LL85 – NYC Energy Conservation Code, closes partial-renovation loophole.
- LL87 – requires energy audit and retro-commissioning, every ten years.
- LL88 – requires lighting upgrades to meet code for all large nonresidential buildings by 2025.

2009 – Incorporation of the Building Energy Exchange (BEEx).

2010 – Creation of New York Passive House organization.

2012 – Superstorm Sandy hits, causing 53 deaths and $42 billion in damage, and destroying 100,000 homes in New York State alone.

2014 – People's Climate March brings 400,000 to NYC streets to fight climate change.

2014 – Mayor de Blasio speaks at UN and releases ten-year plan, *One City Built to Last*.

2015 – Official launch of BEEx's downtown resource center.

2015 – BEEx produces sold-out event, *Passivhaus: Lessons from Europe*, which provides a briefing on fact-finding mission to Brussels. BEEx also provides several high-level briefings to NYC and New York State policy makers.

2015 – Mayor de Blasio announces the creation of the New York City Retrofit Accelerator, a free advisory service to help building owners make energy efficiency improvements to their buildings. Accelerator will include a high-performance track.

2015 – BEEx releases briefing, *Passive New York City: A Snapshot of Low Energy Building Opportunities, Barriers, & Resources*.

2016 – Mayor de Blasio releases *One City Built to Last*, a technical working group report, which sets the stage for:

- Plans to address existing-building GHG reductions.
- Creating whole-building energy performance targets.
- Including midsize buildings (25,000 square feet and up) in benchmarking requirements.
- Creating an exemplary buildings program, similar to Brussels's successful BatEx competition.

2016 – NAPHN16 Conference + Expo, *Decarbonize Our Future Today*, hosted in NYC.

2016 – LL31 passed, establishing aggressive high-performance targets for all new NYC buildings (Passive Standard is a compliance path option).

2017 – In response to the Trump Administration's withdrawal from the Paris Agreement, Mayor de Blasio signs Executive Order 26, committing NYC to the principles of the Paris Agreement and a pathway to limiting global temperature rise to 1.5°C.

2017 – The House at Cornell Tech opens in NYC, the world's first residential high-rise built to Passive House standards.

2017 – Mayor de Blasio proposes new legislation to limit on-site fossil fuel consumption, responsible for 40% of NYC GHG emissions.

2018 – Mayor de Blasio signs two new local laws:

- LL32, Stretch and Performance Codes, mandates aggressive reductions in 2019 and 2022 energy codes, with passive-like performance targets, by 2025.
- LL33, Building Energy Grades, requires publicly posted building energy grades, based on Energy Star scores, starting in 2020.

2018 – BEEx, Brussels Capital Region, NYC Sustainability, and NYPH partner to produce public exhibit, *Icebox Challenge NYC*, located near Times Square.

2018 – BEEx launches its Passive House Primer, a free one-hour seminar on Passive fundamentals delivered in the offices of building owners, managers, and designers.

2018 – Official launch of $1.5 million expansion of BEEx's downtown resource center, including a new connected classroom.

2018 – BEEx opens new exhibit, *CelebrateNYC; Building a Sustainable City*, featuring 60 energy efficiency retrofit projects, ranging from lighting upgrades to Passive House/EnerPHit renovations.

2018 – BEEx becomes the founding hub of the United Nations International Centres of Excellence on High Performance Buildings, a global resource center network created to support development of high-performance buildings, sponsored by United Nations Economic Commission for Europe, with additional centers underway in Vancouver, British Columbia; Wexford, Ireland; Pittsburgh, Pennsylvania; and Brussels, Belgium.

2018 – NYSERDA launches Retrofit NY, a multiyear design-build competition to create new solutions for low-energy renovations for Multifamily Buildings.

2018 – BEEx releases new report, *Pursuing Passive: Strategies for a High Comfort, Low Energy Retrofit in NYC*, a feasibility study of retrofitting a large multifamily building to the EnerPHit standard.

2018 – NYC Council introduces two progressive bills to catalyze energy efficiency improvements, with a high likelihood of being enacted into law in 2019:

- Intro 1253 is landmark legislation that would set strict limits on the carbon emissions of existing large buildings (over 25,000 square feet) starting in 2022, and stepping down in 2024, 2030, and 2050.
- Int. 1252 creates a new form of low-cost financing called PACE (Property Assessed Clean Energy) to ease the up-front cost of making energy-saving improvements.

2019 – NYSERDA is expected to launch *Buildings of Excellence*, an annual competition for new construction of high-performance buildings, with substantial financial prizes.

2019 – NAPHN19 Conference + Expo, *Build the World We Want: Implementing Low Carbon Solutions*, to be hosted in NYC.

Photo by Elizabeth Felicella

More recent developments include new energy stretch codes for the city, including a performance-based energy code in 2025 that is expected to have targets similar to those of Passive House. The city will also require buildings covered by the benchmarking law to publicly post letter grades in their lobbies, based on their annual Energy Star score, providing a very public report card for a building's energy performance relative to its peers.

Complementing the energy code changes that will move all new construction toward a Passive House-like standard by 2025, new legislation was introduced last fall that, if enacted, will trigger a wave of high-efficiency upgrades to most large existing New York City buildings. In late November 2018, City Council Member Costa Constantinides proposed Intro 1253, a bill that would set strict limits on the carbon emissions of existing large buildings (more than 25,000 gross square feet) starting in 2022, and stepping down in 2024, 2030, and 2050. With significant penalties for noncompliance, the bill is designed to set our buildings on a path to meet the city's 80 x 50 and interim target goals. This legislation has garnered much support on the council, making it highly likely that a version will become law this year. A companion bill, Intro 1252, creates a new form of low-cost financing, called c-PACE (commercial Property Assessed Clean Energy), to ease the up-front cost of making these energy-saving improvements.

To help envision how to transform a typical existing NYC building into a state-of-the-art low-energy, high-comfort building, the Building Energy Exchange released a comprehensive EnerPHit feasibility study, Pursuing Passive. The report, published in October 2018, lays out the strategies and resources—and the associated benefits—needed to complete a full Passive House renovation of a 15-story, 163-unit apartment building, while keeping the tenants in place, which is critical given NYC's low vacancy rates.

Finally, last summer, the Building Energy Exchange became the founding hub of the United Nations International Centres of Excellence on High Performance Buildings (ICE-HPB), a global resource center network created to support development of high-performance buildings, sponsored by United Nations Economic Commission for Europe. ICE-HPB will be a knowledge-sharing framework among progressive cities to provide on-the-ground implementation assistance for building owners and developers, architects, engineers, contractors, and policy officials. Supporting the Paris Climate Accord and the UN Sustainable Development Goals, additional centers are under way in Vancouver, British Columbia; Wexford, Ireland; Pittsburgh, Pennsylvania; and Brussels, Belgium.

It's exciting to be part of a city and a community that is effecting real change to transform our buildings into comfortable, healthy, and efficient 21st-century climate solutions.

—Richard Yancey

RICHARD YANCEY *is executive director of the* **Building Energy Exchange**.

STRESS TESTING for a *Changing Climate*

Last August, Harding Heights, a Passive House multifamily building designed for seniors, opened its doors in Smithers, British Columbia. Although Smithers is located pretty far north, almost immediately the residents started complaining about overheating, says Monte Paulsen, Passive House specialist at RDH Building Science and the consultant on this project.

The superficial reason was evident—an unusual heat wave. Digging a little deeper, though, several factors had contributed to the summertime discomfort in this multifamily building, including the installation of windows with a solar heat gain coefficient (SHGC) of .61 rather than the specified .36 (see "Cautionary Tales in Overheating"). Another factor that likely came into play is the very real probability that the climate has warmed noticeably compared to the climate files used to model the building in the PHPP.

Each Passive House building is designed for the specific climate where it will be located, and that climate's parameters are averages based on 10 to 30 years of actual weather data. As Jessica Grove-Smith, PHI researcher, says, past data are known quantities. Forecasts have uncertainties. "By designing a Passive House based on reliable past data, you are making a huge improvement compared to not building a Passive House," says Grove-Smith. "Passive House buildings are more resilient when it comes to comfort and energy impacts than conventional buildings are." Still, the climate is changing quickly, and overheating can be the most evident impact in many locales.

For a superinsulated building that already has a heating-and-cooling system, small shifts of up to 5 kWh in cooling loads as temperatures warm aren't crucial, Grove-Smith points out. What is crucial is deciding whether cooling is needed or not. "We are at the point where the focus is on stress testing for summer comfort," she says.

To help with this effort, PHI has created a summer temperature tool to modify existing PHPP climate data for the summer months. This tool, which will be made available to all PHPP users, can be used to test a building's comfort during projected summer conditions and for inner-city locations likely to experience urban heat island effects. Addressing the basic design influences on summer comfort, including shading and night ventilation, is always the best starting strategy, Grove-Smith emphasizes. "Assumptions on user behavior have to be realistic, and the design should allow for some leeway for coping with heat waves and warming temperatures," she adds.

Another strategy would be running a PHPP variant model with yearlong forecasted climate data. Meteonorm sells PHPP-ready future climate files, says Paulsen. Alternatively, free climate data can be obtained from a number of sources, such as the Canadian government or Intergovernmental Panel on Climate Change climate modelers in your region, but the data won't be formatted for easy input into a PHPP model. (See climate-scenarios.canada.ca/?page=download-gcm for example.) To use these sources, you would have to average the generally 30-year series of forecasted monthly data to create one temperature for each month. Then subtract the baseline predicted monthly temperature from the forecasted monthly average to arrive at the difference, or delta, between the two. Finally add that delta to the PHPP's monthly temperatures. This approach will not calculate load data, while Meteonorm does have prepared load data.

Beyond these climate data approaches, Paulsen has started running the buildings he consults on through a series of additional stress tests. The scenarios he has been testing in the PHPP can include removing all horizon shading, eliminating nighttime flushing, lowering ventilation rates, and anticipating possible change orders. Grove-Smith says that PHI is looking at incorporating stress testing into the next version of the PHPP so that designers immediately get feedback on summer comfort risks while fleshing out their models.

For help with the finer points of designing for warming climates, the international Passive House community is a huge asset. The PHI addresses summer comfort issues in more detail at **blog.passivehouse-international.org/summer-comfort-passive-house**. The Passivhaus Trust in the United Kingdom has developed a technical guidance document on summertime comfort, which is available at **www.passivhaustrust.org.uk/guidance_detail.php?gId=35**. And Passive House consultants in such locales as Spain, Greece, and China have plenty of experience that can be accessed via the International Passive House Association. Grove-Smith concurs, saying, "There's an opportunity to feed into the global network, talking to people in hot climates who have been looking at the question of efficient cooling for some time."

—Mary James

Cautionary Tales in Overheating

Summertime comfort at Harding Heights had been designed in, using the usual palette of passive strategies. Unfortunately, many of those strategies were inadvertently thwarted. As we have seen, the installed windows' SHGC was .61, not the specified .36. Further aggravating the summer solar heat gain, the forecasted shading provided by a large deciduous tree on the south-facing façade was eliminated when that tree was cut down during construction. And for a near-perfect storm, none of the residents wanted to open the windows at night to flush the building, because the new bug screens didn't fit properly, and August is a prime season for blackflies.

Although it's impossible to avoid all errors, one often-overlooked technique could have provided some sweet relief—built-in exterior shading. As Monte Paulsen points out, European Passive House buildings include exterior shading to a much greater degree than do North American ones. As screening out sun becomes increasingly important, so does embracing the range of exterior shading options—from fail-safe to flexible.

Another factor that deserves scrutiny is the question of internal heat gains (IHGs) in North American residential units. "In my personal observation, people who live in small suites or apartments plug in nearly as many personal devices per capita as people who live in large houses," says Monte Paulsen. "If this is true, PHPP may be underestimating IHGs significantly in small-suite multiunit buildings." PHI and ZEBx, a Canadian organization that serves as a center of excellence for training about zero emissions building, are studying this question, with results promised for later this spring.

PREFABRICATED and *Factory Built*

Photo courtesy of BC Passive House

With demand for Passive House-quality panels and modules on the rise, the factories producing these goods are expanding in number, capacity, and production. Most are new businesses producing Passive House-performance exterior wall, floor, and roof panels. Yet a strong contingent of existing businesses are also growing their product lines to include higher-performance, thermal-bridge-free Passive House options.

British Columbia and New England remain the anchor regions in the growing community of Passive House factories. (See "Factory Builds Surging," in *Passive House Buildings: North American Highlights*, p. 51, for a previous overview of Passive House factory businesses.) While most still are in Canada, these factories—producing panels or modules—are becoming more geographically dispersed (see Panels or Modules?).

A standout in eastern Canada, Maisons Eléménts in Quebec, focuses on Passive House performance with walls whose R-values range from R-40 to R-60. The firm has been in business since 2013; 2018 marks its first year of exporting walls for a U.S. building. Producing four to eight buildings per year, the firm builds I-joist walls densely packed with cellulose under a fiberboard external sheathing.

Quebec is also home to ConceptMAT, which has produced walls offsite since 1993 and features a vapor-diffusing, open-cell polyurethane stud wall with continuously insulating expanded polystyrene sheathing under strapping.

On Canada's west coast, Passive House factories are humming. New in 2018, Adaptive Homes joins Tree Construction in Revelstoke, British Columbia, in producing high-performance envelopes in a factory setting. In fact, owner Jocoah Sorensen worked at Tree for six years before launching Adaptive. Sorensen is just now producing his first building, a duplex, and he hopes that factory construction will help him meet the affordable housing crisis in Revelstoke. Sorenson's hybrid modular development model consists of modular construction augmented with panels to connect modules. Like many other factory builders, Sorensen favors wood fiberboard exteriors.

Also launching in 2018, Simple Life Homes joins Quantum Passive House and Green Giant Design/Build in Ontario. Simple Life Homes owner Jeremy Clarke explains that he started as a general contractor, building sustainable buildings with a focus on natural materials. He became increasingly interested in such building science topics as indoor air quality and heat and moisture recovery ventilation, eventually taking a Passive House Canada training, and now has left general contracting to focus his energy on supplying Passive House panels to general contractors. Simple Life combines a stud wall with exterior insulated I-joist, but instead of using OSB between them, Clarke sandwiches fiberboard produced in Canada for a vapor-open assembly.

2018 was a growth year for earlier entrants to this growing field. Abby Xerri, at neighboring Quantum Passive House, says that Quantum is "crazy busy in a wonderful way." The growing demand has spurred the company to conduct a hiring spree to bring its own employee count to over 20 and to shift its business model. Rather than mainly delivering turnkey homes—which the firm will still do if required—it is now focusing on creating the superstructures while supporting its general-contractor partners by training their crews to do the installations.

Quantum expected to complete 11 homes in 2018 and is looking at finishing 30 to 45 buildings in 2019. Although most of them are homes, Quantum is supplying for other structure types as well, which is driving innovation. For example, larger panels—such as those required for a 27- to 30-foot wall—must be rigid enough to withstand the stress from lifting, so Quantum has developed systems to stiffen its panels without thermal bridges.

Adam Cronk, at Green Giant, completed a few homes in 2018, but a local labor shortage forces him to turn down projects. Cronk will continue to hone his business toward standardized panels that general contractors can order from a catalog. Although architectural complexity is possible, it is incompatible with his business plan to mass produce affordable Passive Houses. Cronk is currently completing a Passive House that is on track for building certification, and he hopes to eventually obtain PHI Component certification for his building system.

Another well-established business, BC Passive House, reports that virtually all of its customers want Passive House-inspired, performance exceeding code, with roughly 10% specifically asking for Passive House. Like that of BuildSMART in the midwestern United States, much of its production—at least half—is for larger commercial buildings.

Factor Building Panels, located nearby in Squamish, has a goal that many factory businesses echo: producing a high volume of high-performance panels for general contractors throughout the region. Although it occasionally serves as the general contractor, Factor prefers to supply instead. Factor's basic wall combines stud framing from 2 x 6 to 2 x 12, with a wood fiber insulation on the outside of the structural plywood sheathing. It is considering adding wood fiber insulation up to 16 inches thick for roof panels.

Collective Carpentry, located inland in Invermere, continues to increase annual production, and in 2018 started for the first time to export panels to U.S. customers. Another promising development: Its average shipping distance is decreasing as it wins more local business—meaning business within 300 kilometers (186 miles). This company's goal is high-volume repeat business from general contractors within a short distance, where lower shipping cost makes its panels an even better value.

Meanwhile, Ecocor in Searsmont, Maine and G.O. Home by G.O. Logic in nearby Belfast are examples of how New England leads U.S. Passive House factory production. In 2018, pioneering Ecocor owner Chris Corson enlarged his factory to meet increased demand. The firm can ship high-performance building shells to just about any site in North America and also offers predesigned homes, as well as custom design-build services.

G.O. Homes developed out of G.O. Logic's successful design-build business. Although the firm will still produce a turnkey custom home, it will not construct the envelope on-site. Those days are over. Every one of its homes now starts in the factory. As principal Alan Gibson wryly observed, "We've been building homes the same way for 600 years. It's a medieval method, and we didn't make the leap into the factory like so many other products." Now he has!

Making its own panels has allowed G.O. Homes to leave foam behind. While the firm's crews typically used to install structural insulated panels (SIPs) over a stud wall, making their own panels has allowed them to shift to rigid mineral wool panels, typically 6 inches thick, over stud walls.

G.O. Homes has built a fantastic website showing its standard model homes as well as the exterior and interior finish, lighting, appliances, and mechanical equipment options it offers customers. While the firm's standard models are beautifully simple, G.O. Homes will produce panels for all kinds of designs, for outside architects as well as for its own custom design clients. Gibson says

Photo courtesy of Collective Carpentry

Panels or Modules?

Prefabricating a Passive House in a factory before assembling it onsite typically takes one of two paths: construction of panels (wall, roof, and/or floors) or semi-complete modules, which are entire sections of a building (often called boxes with one or more exterior walls plus floor and roof).

Roof and wall panels typically have open-stud cavities on the inside, allowing onsite electrical and plumbing before onsite insulation of the stud cavities and wallboard. Modules are typically finished with all electrical and plumbing installed and connected in the field. Some manufacturers augment modules with a few wall or roof panels as the design and shipping constraints require.

Sizes depend on shipping routes, roads, distances, and regulations, but typically a panel can span up to 30 to 40 feet in length. For a 2,000-ft^2 two-story home, there might be eight to ten wall panels, two or three floor panels, and perhaps four to six roof panels. If constructed using modules, the same home might be delivered in four or six modules, with likely two or three for the ground floor and two or three for the second floor and roof.

Here is a running list of which type of Passive House-quality products are manufactured in various factories.

Adaptive Homes – British Columbia (modular plus panels)
Bensonwood – New Hampshire (panels)
Beracah Homes – Delaware (modular)
Blueprint Robotics – Maryland (panels)
BrightBuilt – Maine (modular plus panels)
BC Passive House – British Columbia (panels)
Build SMART – Kansas (panels)
Collective Carpentry –British Columbia (panels)
ConceptMAT – Quebec (panels)
Ecocor – Maine (panels)
Factor Building Panels – British Columbia (panels)
Foard Panels – New Hampshire (panels)
GO Home – Maine (panels)
Green Giant Design Build – Ontario (panels)
Ironwood Brand/Precraft – Vermont (panels)
Maisons Eléménts – Quebec (panels)
Metric Modular – British Columbia (modular)
MODSpdx – Oregon (modules)
New Energy Works – New York & Oregon (panels)
Phoenix Haus –Colorado (panels)
Preferred Building Systems – New Hampshire (modular)
Quantum Passive House – Ontario (panels)
Simple Life Homes – Ontario (panels)
Tree Construction – British Columbia (panels)

the firm is also looking forward to establishing ongoing business with general contractors who can simplify their own businesses while attaining higher volume by leaving the envelope to experts in a factory.

2018 will also be remembered as the year that Bensonwood put systems in place to propel Passive House from niche to mainstream. First of all, Bensonwood, differentiated into three distinct product lines to distinguish its custom timber frame homes from its Unity Homes (a catalog of customizable factory-built homes uniformly superior to code) and Tektoniks line (Passive House superinsulated envelope panels from R-21 to R-53). Within the Tektoniks brand, Bensonwood offers its PHlex™ – flexible Passive House approach – panels. PHlex™ still takes advantage of Bensonwood's efficient factory manufacturing, because these panels begin with standard designs while allowing for changes in insulation material and thickness for desired thermal resistance.

Sara Kossayda of Bensonwood reports that this is a response to market demand. Bensonwood is seeing steady growth in the customers who ask about Passive House. Although these inquiries are still only about 10% of its overall requests, Bensonwood is banking on these increasing with Tektoniks. Bensonwood's extensive online Tektonik product guide is a wonderfully clear catalog showing exactly what you get in a Tektonik wall or roof panel. And like other high-performance factories, Bensonwood offers a wood-based system featuring cellulose and wood fiber insulation.

In addition, Bensonwood has completed construction of its new 100,000-ft^2 production facility in Keene, New Hampshire, where it can eventually produce homes in three shifts per day. And though 95% of Bensonwood's sales are within New England, it ships throughout the United States and Canada. In short, Bensonwood is poised for Passive House growth.

In New York, New Energy Works, another experienced timber framing company, is expanding and diversifying their 30-year business with the twin benefits of computerized design and CNC (computer numerical control) precision cutting machinery that timber frame companies bring to panelized construction. Currently producing panels for 10 to 15 buildings per year, Eric Fraser promises, "Our focus in 2019 is to push this to the next level." Fraser's most popular panel is a 2 x 8 stud wall with 2 $^3/_8$-inch exterior wood fiber insulation, but New Energy Works plans its next iteration will be to a more complete system, likely with more insulation and windows installed in the factory. New Energy Works operates on both coasts with production in Oregon as well.

Architects and factories work differently. And often speak different languages. Even the software typically used by these parties tends to differ. This inspired a novel factory business model debuted in 2018 by Holzraum ("wood room"), which was cofounded by Passive House architect Ilka Cassidy and factory computerized design and timber frame construction expert Steve Hessler. Holzraum will translate North American Passive House architects' designs to computerized plans and instructions that high-volume factories rely on for return on their tremendous investment in sophisticated, automated machinery. Holzraum is the communication hub, integrating all of the design, engineering, factory production, and assembly teams. Cassidy and Hessler aim to prevent miscommunication and exploit each team members' capabilities.

Cassidy and Hessler are currently working on a few Passive Houses with Blueprint Robotics, one of the largest building component factories in North America with advanced CNC cutting machines and automated fabrication equipment; however, Holzraum envisions working not only with multiple designers, but also with multiple factories.

Although many of these developments are taking place in the eastern half of the United States, in the Midwest BuildSMART continues to build market share, especially in affordable multifamily Passive House development. And it continues its innovation with a proprietary superinsulated slab floor system. In 2018, farther west in Grand Junction, Colorado, Phoenix Passivhaus became the third North American building system to earn PHI's Building System Component certification.

A host of other modular plants have recently introduced Passive House-performance options. Among the modular choices actively marketing to Passive House developers are Metric Modular, in British Columbia, which branched out from its parent BRITCO; BrightBuilt Homes, in Maine; Preferred Building Systems, in New Hampshire; and Beracah Homes, in Delaware, which is currently in planning for multiple Passive row house projects in the Washington, D.C., region for Flywheel Development.

SIP businesses are also taking note of the Passive House market. Foard Panels, in West Chesterfield, New Hampshire, is just one of the SIP plants now selling panels specifically for the Passive House market.

—Tad Everhart

TAD EVERHART *is a marketing consultant for various Passive House-related businesses, including* Passive House Buildings.

WINDOWS AND DOORS
Schuco AWS75 by
European Architectural Supply, LLC

ARCHITECT
Chris Benedict, RA

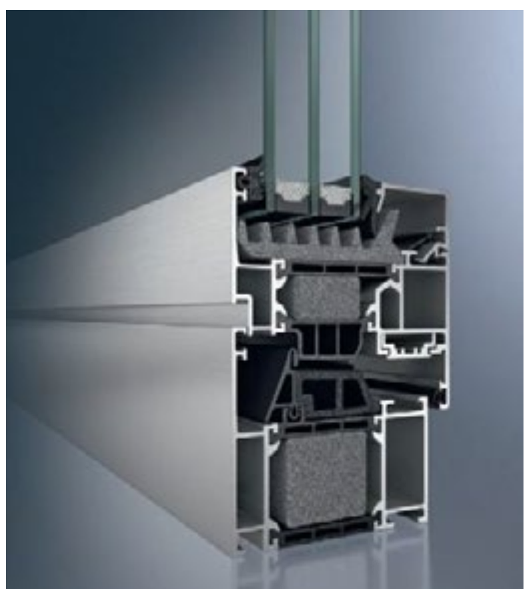
DEVELOPER
Synapse Development Group

Multi-unit Passive House Window Installation

European Architectural Supply, LLC supplied and installed windows for the largest multi-unit Passive House project in Manhattan. The company managed the project from design through manufacturing, delivery and installation.

Completed in 2018, Perch Harlem is among the largest Passive House projects in the US. Chris Benedict, the project architect, brought EAS on board to explore the possibility of using Schuco thermally-broken aluminum windows for this seven story multi-unit PH project. The design called for floor-to-ceiling windows, with the largest reaching 8x8ft. The architect selected Schuco AWS75.SI+ aluminum window system for its thermal performance and cost per square foot.

SCHÜCO
EUROPEAN ARCHITECTURAL SUPPLY
MAKROWIN



Full-Service Passive House Windows Procurement, Delivery and Installation

EAS differentiates itself among window suppliers by offering full service procurement of windows from design through delivery, installation and after-sale service. This project involved 21 tons of triple-pane windows with largest window units weighing 620lbs each. The EAS staff coordinated the delivery and unloading of windows before the building was enclosed to enable easy placement of 6,000lbs pallets on the individual floors. The OSHA-certified EAS installation staff worked with the General Contractor to stage the window installation in a manner to provide maximum weather protection as the building's walls were erected during the winter months.

European Architectural Supply, LLC
sales@eas-usa.com
www.eas-usa.com
(781) 647-4432

Expanding a MISSION

Photos courtesy of the Pennsylvania Housing Finance Agency

The Pennsylvania Housing Finance Agency (PHFA) works to provide housing solutions for seniors, low- and moderate-income families, and people with special needs. Since its inception in 1972, PHFA has managed more than $14.1 billion of funding for more than 175,000 single-family home mortgage loans, helped fund the construction of 134,507 rental units, and saved the homes of more than 49,500 families from foreclosure.

Given the ongoing demand for its affordable housing programs, PHFA has been gradually adding staff to support the expansion of its current services and the potential addition of new housing initiatives. Almost ten years ago, PHFA recognized that it was outgrowing its existing headquarters in Harrisburg and started planning for its own expansion.

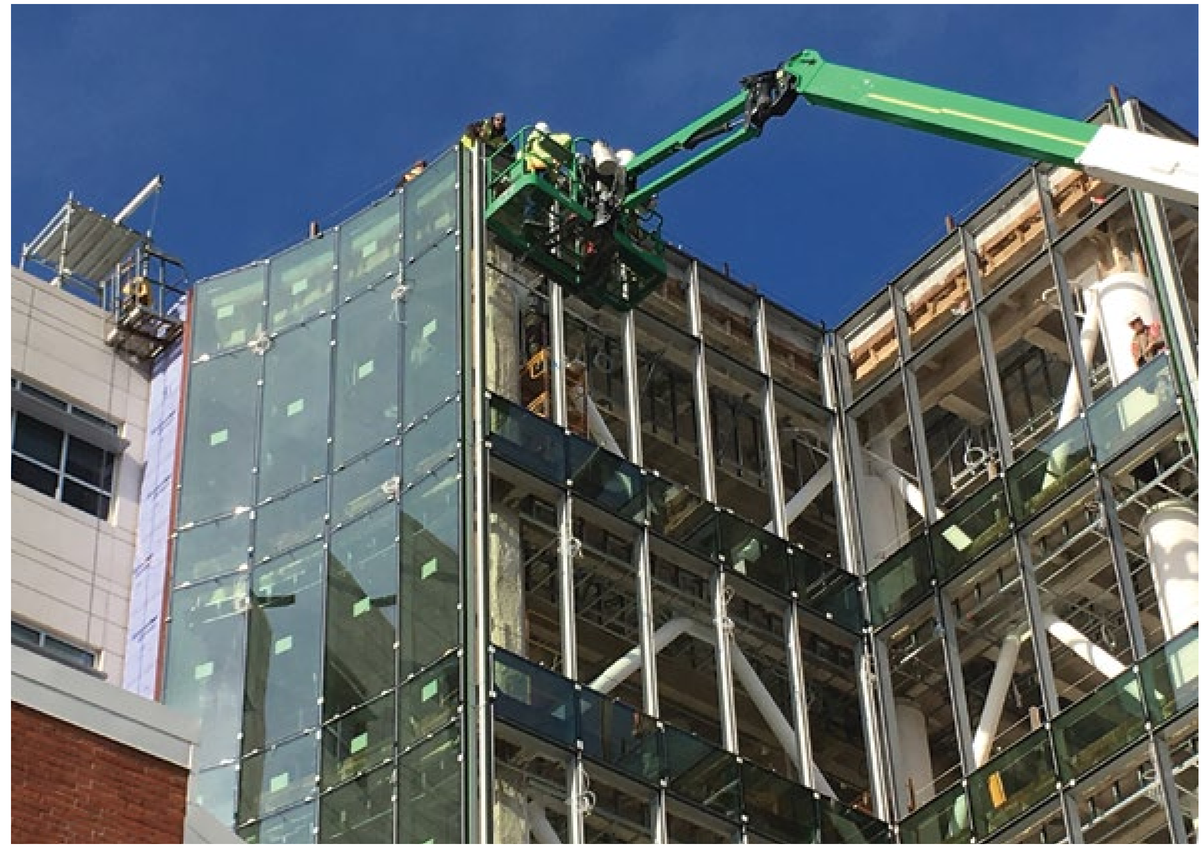
In 2014 its fairly well-developed plans underwent some transformations. That was the year that PHFA first learned about Passive House and was persuaded to include an incentive program for Passive House in its Qualified Allocation Plan or QAP (see "Passive Affordable Housing—In a Growing Number of States," *Passive House Buildings: North American Highlights* 2017, p.11). As Wade Romberger, staff engineer for PHFA recalls, some staff were reviewing plans submitted for the 2015 funding cycle and the question arose, Can we set Passive House as a goal for our new headquarters? The answer, after hashing the idea around and developing new cost estimates, was yes.

"Our executive director, Brian Hudson, felt strongly that if we were asking our multifamily tax credit applicants to consider building to Passive House standards, then we should, too," recalls Mike Kosick, PHFA's director of technical services. "He wanted to make sure we led by example, so really the vision behind the construction of the new building came from him."

The expanded headquarters actually encompass two buildings—a renovated roughly 9,000-ft^2 historically significant structure next door to the existing headquarters and an adjacent new seven-story building. Together the two buildings will provide almost 40,000 square feet of new office space. PHFA is aiming for Passive House performance for both buildings.

The design of the new building was strongly influenced by the desires of the local neighborhood and historic preservation groups. These groups didn't want the new building's massing to dominate the historic residential neighborhood, and in fact wanted the building to be as close to transparent as possible. In a first for Harrisburg, the new office building will be predominately glass, with the top four stories each consisting of at least 75% glazing. The lower levels have much less glazing but are tucked into the surrounding structures.

Extensive curtain walls were a responsive design solution to the neighbors' concerns, but all that glazing presented a stumbling block for Passive House



performance. Fortunately the same week that PHFA was figuring out what to tweak to meet its new and improved performance targets, it learned about two products that ultimately allowed it to marry its design and performance goals: Passive House-certified curtain wall framing and electrochromic glazing. The triple-pane electrochromic glazing lightens and darkens as programmed, optimizing solar gain and visible light to minimize the cooling load while also balancing daylighting needs with indoor-lighting energy use.

Each pane in the curtain wall is separately controllable, with the largest, 5-foot by 10-foot, panes split into three individually programmable segments. This allows occupants to see daylight when they are seated at their desks through the higher subsections, while the lower ones are darkened to restrict glare and solar gain. At night the windows are fully darkened to prevent light pollution.

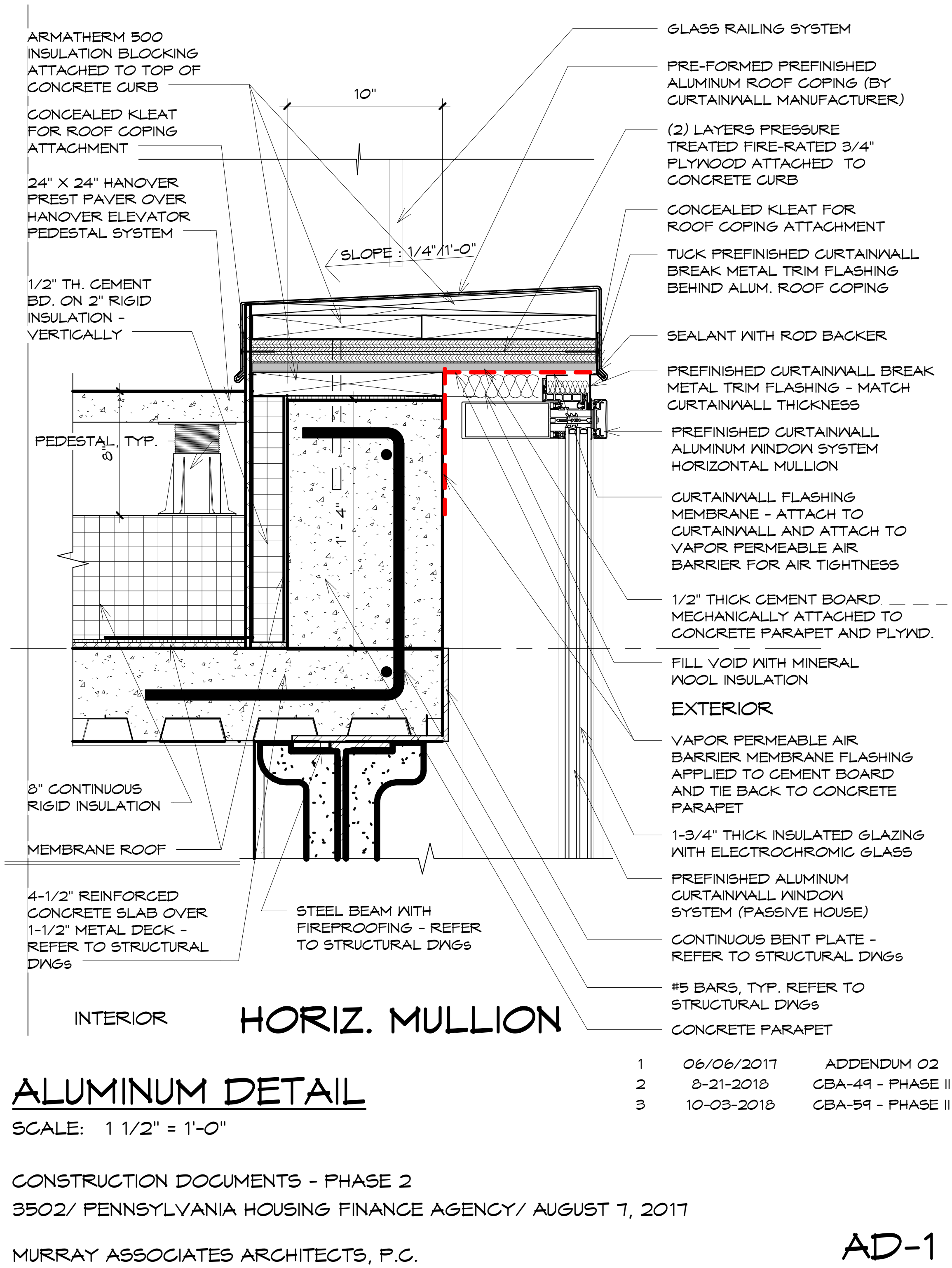
The entire curtain wall and certain main structural building columns are supported using specialized, extremely high-psi structural foam. The foam is used as a thermal bridge barrier and is also load bearing.

The nonglass portion of the façade relies on panels that are insulated on the exterior with 3 inches of polyiso and 6 inches of mineral wool for a total R-value of about 40. These high-R-value walls help compensate for the lower R-value of the curtain walls.

The building's relatively dense occupancy—120 staff members, all with computers and various other electronic equipment—translates into significant internal heat gains that drive down the heating demand but increase cooling and primary energy demand. Romberger and Kosick worked closely with the information technology department to find the most efficient computing solutions, eventually managing to cut the expected load by two-thirds.

A variable refrigerant flow (VRF) system will manage the conditioning loads efficiently, especially when different areas call for simultaneous heating and cooling. A commercial-size ERV will bring in constant fresh air. A 27-kW roof-mounted PV system will help offset the primary energy demand.

The adjacent brick building that is being renovated is a stark contrast to the sleek glass building. In keeping with all retrofits, the project had its series of complications, starting with the stone rubble foundation. That needed extensive underpinning, adding weeks of work to the project, including hammering rock that could not be ripped. Eventually a new concrete bathtub, complete with air barrier membrane, was added within the existing foundation.



The façade's look had to be preserved, including all the double-hung configuration of the windows. Fortunately, the team was able to locate Passive House-certified landmark series windows that simulate the double-hung style. An expanding foam tape was used around the double-hung replica windows, doing double duty as the air barrier and the insulation in that space.

The air sealing had to be done from the inside in order to preserve the exterior look. As the brick walls had deteriorated, the team decided to have what was essentially a second shell built interior to the brick, using two layers of gyp board, resting on structural foam. A liquid-applied air barrier was coated onto the interior of the exterior layer of gyp board, isolating it from potential penetrations. The comprehensive air barrier extends from the edges of the subfloor to the roof underdecking. This very constructible strategy avoided the potential "death by 1,000 cuts" that Romberger has witnessed on other Passive House projects where extensive time has had to be spent chasing small leaks.

Construction started in December 2016, and the move-in date is slated for late spring. Although PHFA doesn't have a handle yet on the project's cost relative to conventional construction, it expects the budget to be in line with grade A commercial office building. There is no question that not that many years ago this project couldn't have been completed at any price, because the Passive House-quality products that helped make this construction feasible weren't available in North America.

Beyond the high-performance products, the other essential contribution to the success of this project was the team effort. The Passive House details were a group collaboration, with Murray Associates, the design architect, taking the lead. "Benedict Dubbs, one of the firm's principals, worked with us for months prior to bidding developing the design. The overall concepts of form and function are his," says Kosick. "Mike Frye, the other principal and their in-field representative, was on-site no fewer than twice a week and was on call anytime we needed him. Last but certainly not least was Murray Associates' Rob Hutchins. He was the actual day-to-day, nuts and bolts architect, who was the design team lead person. I believe we shortened his life expectancy by five years on this job! Between us as owner, our construction manager, Ken Baker with Reynolds Construction, the individual prime contractors—in particular the general contractor—and the entire design group and their consultants, we've been able to hammer the unforeseen situations out as they arise."


The beige color in the column base is 6-inch thick structural thermal break foam. This product's compressive strength is higher than the concrete it sits on.

Thanks to this team effort, the expanded headquarters are allowing PHFA to increase the services it provides, delivering housing solutions to a growing clientele. But the new buildings' benefits don't end there; both the new and the renovated building are shining models of exemplary design and building practices.

—Mary James

Passive House Metrics

Heating energy	Cooling energy	Total source energy	Peak heating load	Peak cooling load	Air leakage
4.0 kBtu/ft²/yr	3.4	36.1	3.6 Btu/hr/ft²	2.2	0.08 CFM_{50}/ft² of envelope area
1.2 kWh/ft²/yr	1.0	10.6	1.1 Watts/ft²	0.6	
12.7 kWh/m²a	10.8	114.0	11.3 Watts/m²	6.8	

Products

Windows — Electrochromic Glazing
SageGlass

Air/Moisture Control
Prosoco from World Class Supply
Hanno from World Class Supply

Ventilation
Swegon

Structural Thermal Solutions
Armatherm from World Class Supply

GLATT GMBH HQ RENOVATED TO INCLUDE 100% SAGEGLASS LIGHTZONE™

THE YARD AT CHICAGO SHAKESPEARE THEATER RENOVATED USING SAGEGLASS

PHFA USES DYNAMIC GLASS TO HELP ACHIEVE PASSIVE HOUSE CERTIFICATION

CUSTOMER: PHFA

ARCHITECT: Murray Associates Architects

GLAZIER: Hershocks

DYNAMIC GLASS SQFT: 12,000

Passive House certification is made easier by dynamic SageGlass®, which changes tint in response to sun conditions. This climate-responsive technology is gaining traction with buildings pursuing targets such as LEED® Gold, LEED® Platinum, Net-Zero and Passive House.

The team at the Pennsylvania Housing Finance Agency (PHFA) had a challenge on its hands. They wanted to achieve Passive House certification, but they also wanted to deliver much more daylight for their employees, which meant a lot of glazing. These dual goals are often incompatible with traditional glazing, which is where dynamic glass came into play. This glass automatically modulates its visible light transmittance, and in turn its solar heat gain, based on climate conditions.

DYNAMIC GLASS ENABLING SUPER-EFFICIENT BUILDINGS

PHFA is not alone. More and more projects with aggressive energy efficiency targets are turning to dynamic glass. Other examples of Net-Zero projects include the American Geophysical Union's new headquarters in Washington, DC, the United Therapeutics "Unisphere" in Silver Spring, MD and the City Gateway project in Raleigh, NC, among others. While dynamic glass helps deliver super-efficient buildings, just as importantly it provides greater comfort for occupants, which leads to better outcomes for the organizations they work for.

SAGEGLASS® DOUBLE PANE

4mm clear w/SR2.0, 0.89mm SentryGlas, 2.2mm SageGlass, 12.2mm air space w/90% Argon fill, 6mm clear

Level of Tint	%Tvis	SHGC	U-factor
Clear State	60	0.41	0.28
Intermediate State 1	18	0.15	0.28
Intermediate State 2	6	0.10	0.28
Fully Tinted	1	0.09	0.28

SAGEGLASS® TRIPLE PANE

6mm Clear HS w/SR2.0, 0.89mm SentryGlas®, 2.2mm SageGlass AN, EC2.0, 12.2mm air space w/90% Argon fill, 6mm clear, 12.2mm air space w/90% Argon fill, 6mm Clear HS LowE180

Level of Tint	%Tvis	SHGC	U-factor
Clear State	52	.35	.14
Intermediate State 1	15	.11	.14
Intermediate State 2	5	.07	.14
Fully Tinted	<1	.05	.14

Optimizing the PREFAB DESIGN Process

Photos by Nils Schlebusch; Drawings courtesy of Barry Price Architecture

A large screened-in porch juts off the south side of this two-story house, providing the perfect venue for relaxation. Extending the slope of the home's roof, the porch's roofline gracefully sweeps west out across the Hudson River valley toward the Catskill Mountains. A carport abuts the north façade, bookending the home and adding visual interest to its massing. On the southern and western corners, overhangs provide shading from summer sun, while also breaking up the scale of the 3,800-ft^2 house.

All of these appendages appear to be seamlessly connected. They're not. They are thermally isolated add-ons to a home designed for and constructed using prefabricated panels. These add-ons distract the eye from the basic boxiness of the underlying structure, which was optimized for panelized construction.

Barry Price, principal and founder of Barry Price Architecture, is currently working on three panelized Passive House projects. He designed his first one in 2015 for an owner who wanted to maximize the home's performance while minimizing the environmental footprint of the construction process. The soon-to-be owners of the two-story house, who had not heard of Passive House before consulting with Price, chose panelization based on the cost predictability when moving from schematic design to completing the shell. Price's cumulative experience is helping him to perfect the art of the prefab design.

For a variety of reasons, Passive House design and panelization are well-suited partners. Stripping a design to its simplest form facilitates both. "Because every corner is a potential thermal liability, you have to have a good reason to have more than four," Price points out. One of his current projects does have six corners, because an L-shaped building makes better use of the site's topography and features. Still, when he is sharpening his pencil and optimizing his designs, his plans aim for the fewest panels.

Both approaches also require disciplined, engaged clients, notes Price. "A big difference with panelization is that traditional project delivery doesn't apply," he says. "And changes are harder." The prefabrication process requires a heightened emphasis on planning and making binding decisions earlier than would be the case with stick-built construction.

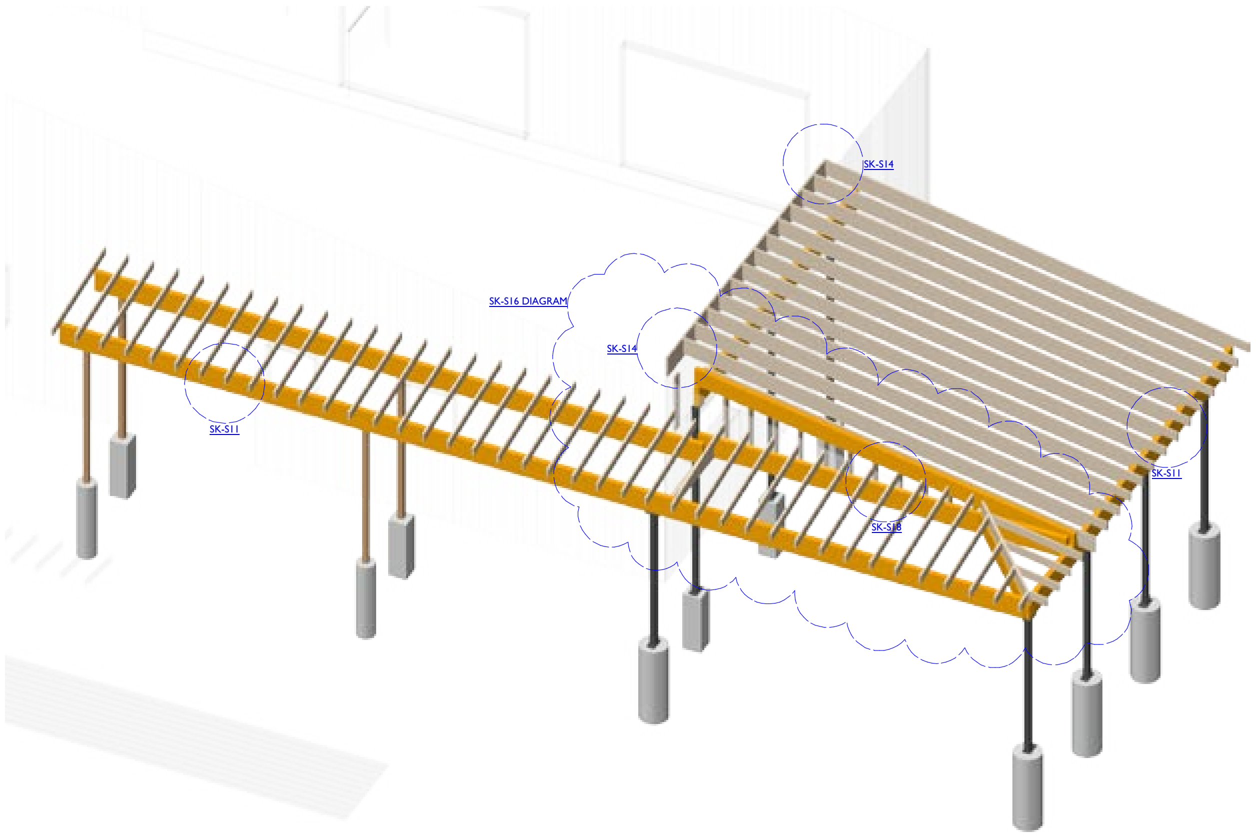
Window choices in particular have to be made early on for Ecocor, the panelization company he has worked with most frequently. Ecocor airtight wall panels come preinsulated with cellulose and generally include installed windows, which take three months on average to be delivered from Poland. You can still be polishing up the floor plans, and the clients are being asked to make window finish decisions—the trim colors both inside and out—when the kitchen design may not even be finished, Price says. And then, to ensure that the exterior trim color won't clash with the siding color, that choice may have to be made as early as five months before construction starts.

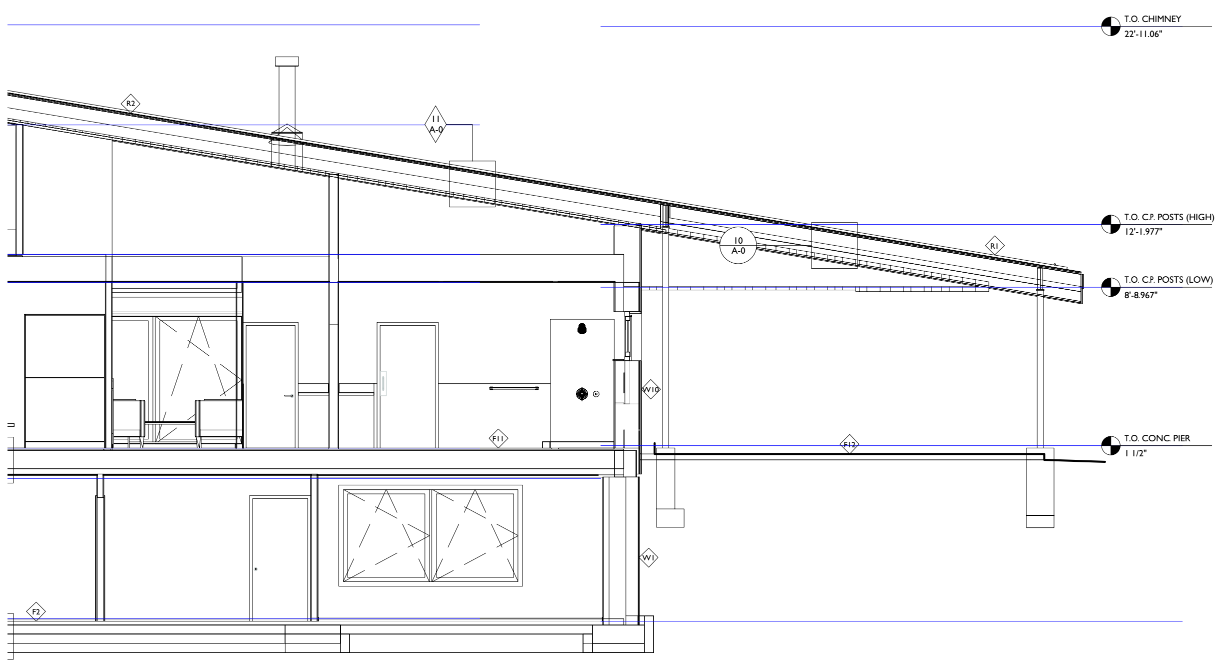
"It comes down to client engagement," Price explains. "You have to have owners that get the process without feeling that their options are being limited." When he first became a Passive House consultant, Price worried that introducing Passive House concepts to clients would be too challenging or risky for his firm. But he found he was wrong. Clients who opt for Passive House performance, he realized, understand that attaining that goal requires a certain amount of discipline. Similarly, owners who want the advantages of both Passive House and prefabrication understand that they will have to reconsider the usual order in which certain decisions are made.

Of course Price also has his own early decisions to make, such as accommodating appendages and all penetrations. Integrating the prefabricated components with those constructed on-site, such as porch overhangs, requires solid planning. The structural details have to accommodate the blanket layer to avoid thermal bridges, which can be achieved either by building a parallel structure or by carefully flashing the ledger framing.

Another decision that has to be made promptly is the location of any appliance that needs a vent hood or exhaust duct, such as a stove or clothes dryer. These penetrations affect the HVAC system calculations.

This family had some particular preferences when it came to cooking; they





wanted a gas-burning stove, which in this location means propane. They also wanted a fireplace for decorative heating. Both the range hood and the fireplace have their own makeup air systems. An ERV supplies the constant fresh air. Heating and cooling are provided by a ducted air source heat pump with three zones to distribute conditioned air upstairs and down.

The four-bedroom home, which is clad in rough-sawn cypress, is intended as a weekend retreat and family gathering spot. The master bedroom suite is located on the ground floor to accommodate the possibility of retiring here. Until then, these owners will be able to enjoy this home's superlative comfort, along with the comfort of knowing that, come freeze and power outage, their home will coast through these conditions just fine.

—Mary James

Passive House Metrics

Heating energy	Cooling energy	Total source energy	Air leakage
8.0 kBtu/ft²/yr	9.1	32.0	$0.6\ ACH_{50}$ (Design)
2.3 kWh/ft²/yr	2.7	9.4	
25.1 kWh/m²a	28.7	101.0	

DELPHI Haus

Universal Design in Washington

Photos by Poppi Photography; Drawings courtesy of Artisans Group

Nestled in the rolling terrain of the Pacific Northwest's Black Hills on the outskirts of Olympia, Washington, Delphi Haus artfully marries Passive House and universal design in a beautiful single-story modern home. Surrounded by mountains and filled with a soft yellow glow that radiates from the top of yellow-painted soffits extending into the living room, the home was designed for the long-term health and well-being of its owners, Kelly and Laura, and the land they love.

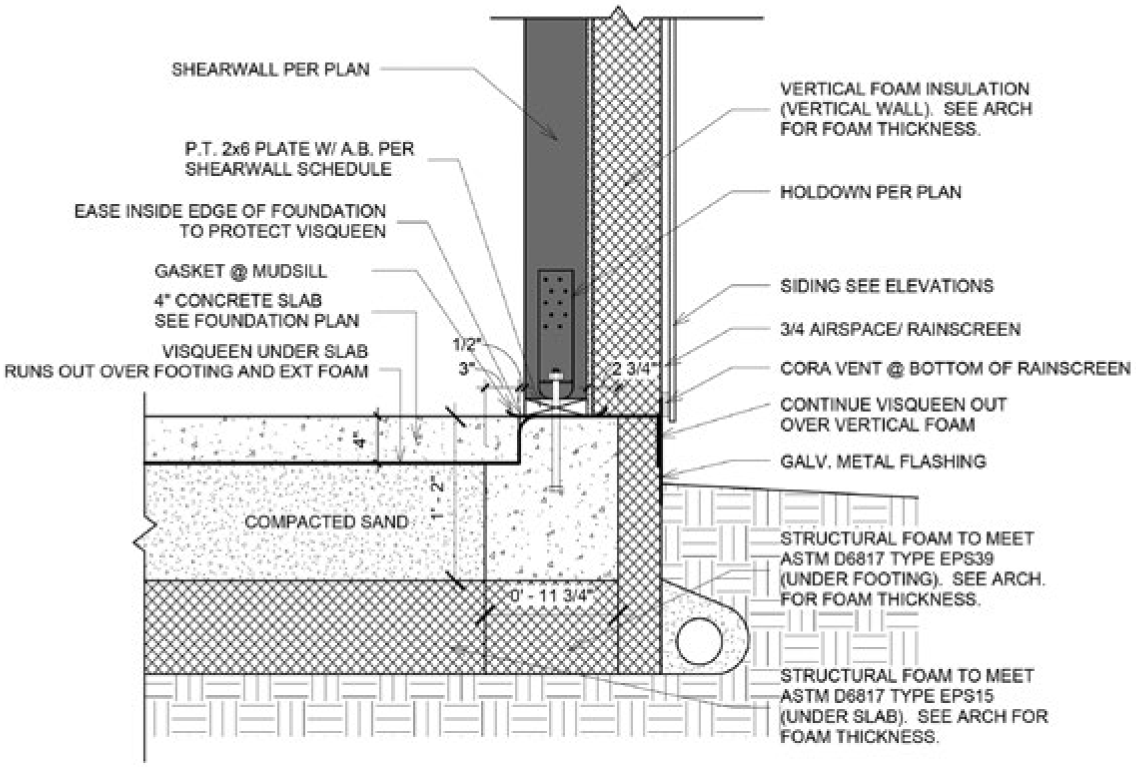
"This house is designed with some very specific medical needs in mind," says Tessa Smith, lead architect on Delphi Haus. "Mobility, fall protection, and an avoidance of direct natural light were critical programmatic needs. They needed healthy indoor air and aging-in-place universal design concepts throughout. It's designed so they can live completely free and independent."

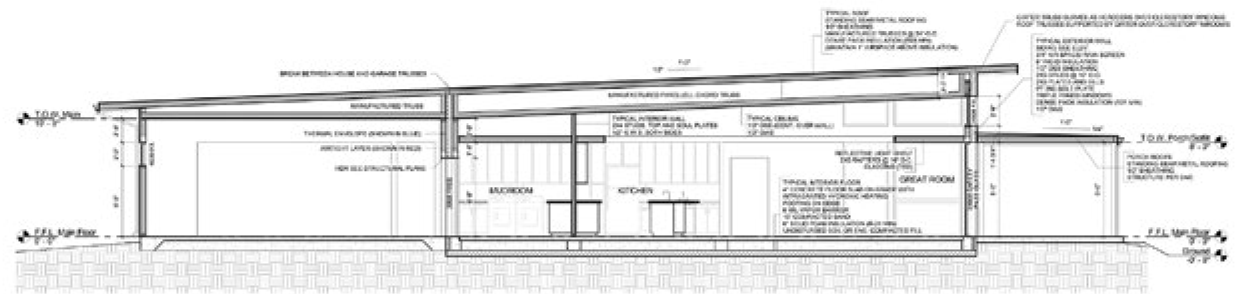
Seeking a home that they could "settle into forever," Kelly and Laura reached out to Artisans Group. Their site, with vast territorial and iconic Pacific Northwest views—Mt. Rainier and Mt. Saint Helens are both visible to the east—called for a beautiful home that could celebrate the area. Yet unless the home would be used only as a brief stopover for them, they needed a home that would work with—not exacerbate—a particular health challenge. Laura has lupus. A chronic autoimmune disease, Laura's diagnosis comes with the knowledge that she is growing increasingly sensitive to direct light while also becoming more prone to falls. Imagine having the property of your dreams with an incredible eastern view, the place where you want to live out your journey, and you have an increasingly uncomfortable sensitivity to natural light.

According to Artisans Group founder Randy Foster, "When Kelly and Laura first approached us, their focus was on custom design, because of Laura's needs. But after talking with them for awhile, Passive House didn't just seem like a good fit, it looked like the best of all worlds. Not only could they get an environment with few temperature swings, but the air would be filtered, and sunlight exposure would be a major design consideration from day one. For their amazing views, we introduced them to the magic that Zola windows offer, and on top of that they both love the environment. So when we could show them the energy savings of a Passive House—well—it made sense for them on every level we analyzed."

As with all Passive Houses, energy modeling on Delphi Haus was used to ensure that sun exposure would meet heating needs throughout the winter—and into the spring and fall as well—without being too extreme during the summer. Clerestory windows admit wintertime solar gain, but instead of the sunlight pouring in, Delphi Haus's design incorporates extended interior soffits that reflect sunlight, allowing the home to heat passively while keeping Laura healthier and more comfortable. Aesthetically, the soffit is seen as a continuous visual plane extending from the exterior eave into the home, but it's a sleight-of-hand architectural move that relies upon supporting posts along the exterior wall. So while the soffit appears continuous, the reality is that the thermal barrier is never bridged and the home's envelope remains sealed.

The behind-the-scenes health and design considerations don't stop at natural lighting. The project's interior designer, Brenda Fritsch, a Certified Aging-in-Place Specialist, wanted to ensure that Kelly and Laura would have not just a beautiful space but a functional one as well, with universal design features woven into the entire home. Bathroom sinks are designed with space for a wheelchair to roll under, and all doorways and halls





have extra room for a chair to travel through. The floor plan, essentially a series of concentric circles with no dead ends, eases wheelchair access and use. The showers are curbless, and the master shower has a gorgeous pull-down teak bench that adds to the atmosphere of a luxury spa. Cork floors overlay the concrete slab foundation because, as Smith points out, "They're warm against sensitive feet, soft on the joints, and much more shock absorbent than hardwood or concrete." Nothing in Delphi Haus makes their home either more functional at the expense of enjoyment, or more enjoyable at the expense of functionality. Even the toilet paper roll dispensers double as grab bars, but you'd never guess it without being told. As Laura says, "We built this so as not to have to modify it—not for doom and gloom, but if we need it."

So what does Delphi House mean for Passive House?

Not many years ago, and coinciding with an increased awareness of excess carbon consumption by first-world nations, Passive House's primary appeal was its sustainability. Yes, the consistent indoor temperature and the constant supply of fresh air were touted as benefits of the standard, but the lion's share of marketing was directed toward clients who sought Passive House for its greater sustainability.

The times, they are a'changin'.

As more data and first-person experiences emerge from researchers, designers, builders, and (especially) the people who live and work in Passive Houses, we in the field are beginning to see a definitive shift in perception of the Passive House standard. Is this because we've been marketing it correctly? More likely than not, it's a beneficial coincidence.

People are increasingly educated about the benefits of healthy indoor air and the long-term implications of living and working in unhealthy buildings. And for those searching for hard truths about Passive House buildings, there are reams of data. Yes, there are data about minimal energy use, but that's just the beginning. There are also data on the comfortable indoor temperatures; data on the consistency of those temperatures; data about the exchange rate of fresh air for stale; data on indoor humidity; data on how quiet these buildings are, even in the middle of a city; and so on. More data keep coming in, and the data consistently point to Passive House being a holistically better experience for building occupants—from environment to health to hygge. Advocates of healthy spaces are beginning to point people toward the standard not just because it's the environmentally responsible thing to do, but because it's the better-quality-of-life thing to do.

As Kelly says of their Passive House, "It's the best house."

That perception is widely shared. Delphi Haus won the award for Best Single-family House in the 2017 Passive House Projects Competition; the 2018 Professional Builder magazine's Gold Award for Green Architecture; and an Honorary Mention in the 2018 Architecture Master Prize for Green Architecture.

—Jason Taellious

JASON TAELLIOUS *is the marketing director and permitting specialist for Artisans Group.*

Passive House Metrics

Heating energy	Cooling energy	Total source energy	Peak heating load	Peak cooling load	Air leakage
5.6 kBtu/ft²/yr	0.1	36.5	2.8 Btu/hr/ft²	0.6	
1.7 kWh/ft²/yr	0.03	10.7	0.8 Watts/ft²	0.2	0.4 ACH_{50}
17.7 kWh/m²a	0.4	115.0	8.7 Watts/m²	1.9	

Historic PHILADELPHIA EnerPHit

Photos by Laura Blau; Drawing courtesy of BluPath

The older a building, the tougher it may be to successfully renovate it to Passive House standards. It's not uncommon to encounter mold, substandard foundations, and failed building materials. Various remodels over the years can complicate intersections between building parts of a building Historical preservation requirements can add a layer of aggravation to an already-daunting task. Architect Laura Blau and partner Paul Thompson encountered all these problems and more when they embarked on a phased EnerPHit remodel of a historic row house in Philadelphia's Rittenhouse-Fitler Historic District.

The four-story-plus-basement brick row house was built in 1845. In 1922, it was converted to a three-unit apartment building and first-floor commercial space, with an addition that stretched to the rear property line. Blau and Thompson had the building rezoned to add a three-bedroom, two-bath apartment for themselves. Much of the envelope abuts adjacent buildings; the 1,800-ft^2 lot has only 311 square feet of open space. The basement contains shared storage and mechanical space, plus a portion of Unit A, the owner's unit. The remainder of Unit A is on the first floor. Unit B takes up the second floor. Unit C occupies most of the third floor. Unit D is a bilevel that walks out of the fourth floor onto a large roof deck with great views of the city. A canopy over the deck is structured to receive a future PV array.

The Rittenhouse-Fitler Historic District consists of blocks of brick row houses similar to those found in other East Coast cities developed in the 1800s. The façades and structural walls are high-quality red brick fired in Philadelphia, which at that time was considered some of the best in the country. The brick in the rear from the 1922 addition is poor quality—highly porous and prone to mold and failure. Rittenhouse Historical District guidelines restrict covering any original material seen from a public way.

Blau and Thompson did extensive hygrothermal analyses, using moisture absorption test data, on their planned Passive House assemblies. They learned that the front and rear have vastly different properties and options. The front 1845 brick is of superior quality and low porosity, thus allowing 5 to 7 inches of interior insulation when combined with a smart vapor retarder, with no mold risk. However, the rear brick is extremely porous and presents a significant mold problem, particularly with modern air-conditioning. The only way it could be included in an acceptable Passive House assembly was with a drainage plane covered with 3 inches of exterior insulation and synthetic stucco; a smart vapor retarder; and 5 to 7 inches of interior insulation. This is where they ran into problems with the Philadelphia Historical Commission.

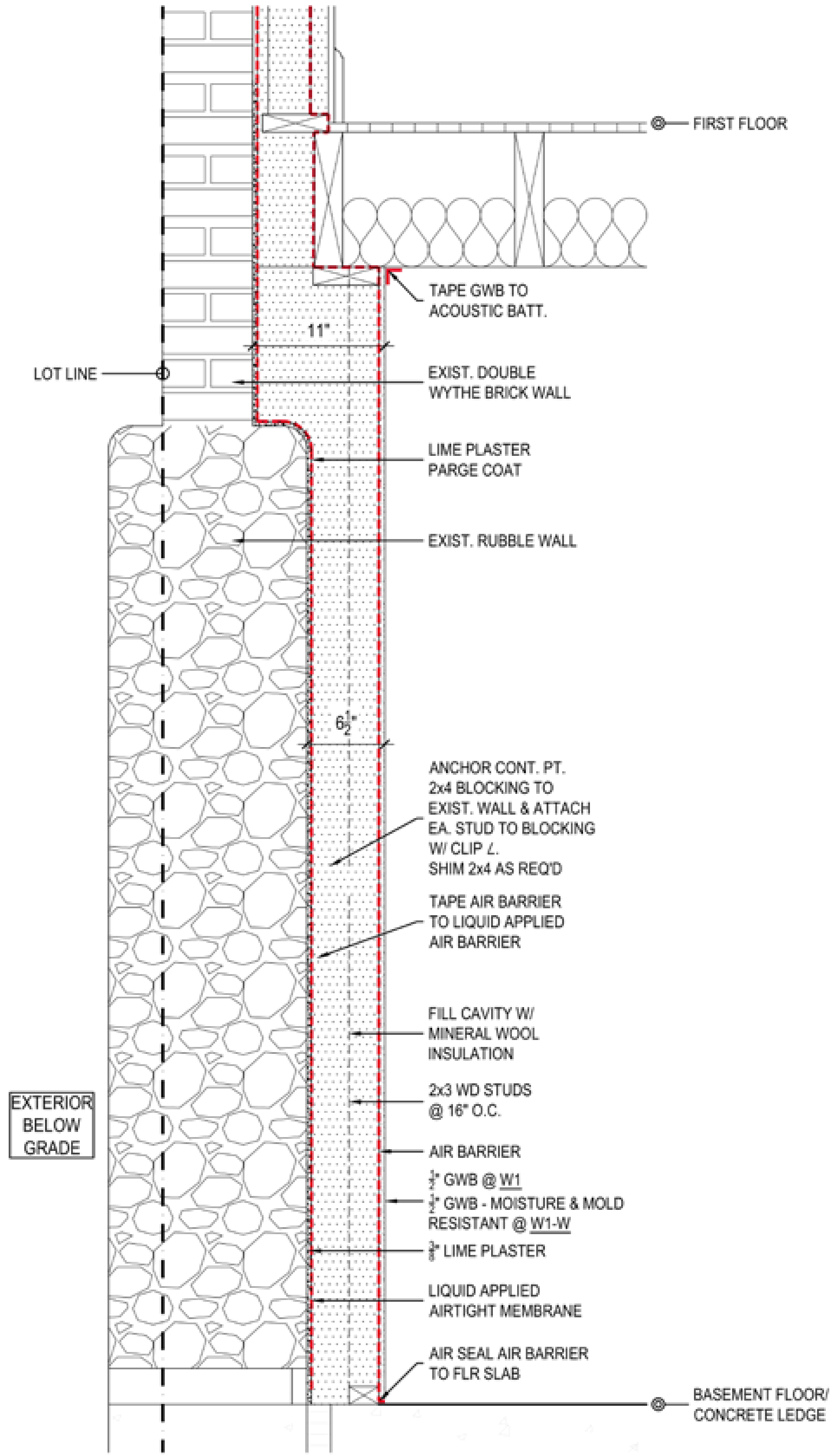
In order to get a building permit, Blau and Thompson had to present their entire project to the commission. They included detailed building science and global-warming information and informed the commission about Passive House basics and their hygrothermal analysis. They pointed out that the unadorned rear façade is on an alley that is used for trash collection and dog walking, and really doesn't contribute to the historical nature of the neighborhood. They showed that approximately 60% of the buildings in the adjacent blocks have stucco on their rear façade. Although the commission approved most of the permit details, it would not approve the exterior EIFS, insisting that the brick in the rear needed to remain visible.

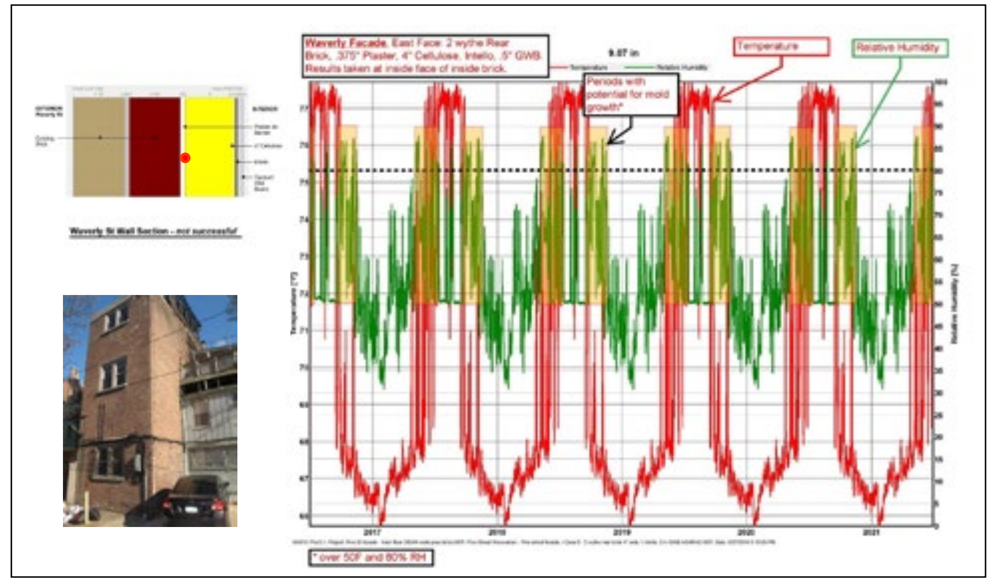
After the hearing, a team of supporters, including lawyers, building science experts, and NAPHN, materialized to craft an appeal of this decision. Their appeal to the Philadelphia Court of Common Pleas cited the 1971 Environmental Rights Amendment to the Pennsylvania Constitution:

The people have a right to clean air, pure water, and to the preservation of the natural, scenic, historic and esthetic values of the environment. Pennsylvania's public natural resources are the common property of all the people, including generations yet to come. As trustee of these resources, the Commonwealth shall conserve and maintain them for the benefit of all the people.

The basis of the appeal was that, while the historical-environmental balance needs to be weighed at all times, because of our climate crisis, we have to favor the environment. The Court of Common Pleas remanded the case back to the Historical Commission. The same project information, supported by various building science experts, was re-presented. This time the commission unanimously approved the project, allowing Blau and Thompson to add EIFS to the rear façade of the building.

Construction finally began in 2017. Not all parts of the building are getting identical attention. The basement and first two floors were gutted, allowing the most control over air sealing. Unit C was upgraded in 2014, including a kitchen and heat pump. Its rear wall and one bathroom were not enhanced, leaving gaps in the air barrier and insulation, as acknowledged in the EnerPHit step-by-step process. Small bathrooms were added to Units B and C. Units B and D have all-new kitchens, and Unit D's





Waverly Street East Facade — WUFI, HygrothermalAnalysis. Option 2: Add interior partition with 4" cellulose with smart vapor retarder. Result: Unacceptable mold risk.

bathroom and laundry were enlarged and reconfigured to open to the common hall. One of the units should be finished this spring, with the remainder completed later this year.

Two-thirds of the basement was excavated to add 18 inches of living space headroom, 8 inches of bathroom headroom, and to accommodate the slope for the plumbing-to-sewer connection. Five inches of rigid insulation was installed under a new slab, and 2 inches were wrapped up the walls. A water barrier was laid under the slab and wrapped up the interior of the walls to mitigate moisture intrusion. In addition, a foundation drain connected to a sump pump was installed at the interior perimeter of the basement. The foundation footers had to be underpinned in 3-foot sections, with adequate setting time between pours and special inspections for each section, a time-consuming task.

All the windows were upgraded with Passive House-certified components. Blau and Thompson won a precedent-setting approval from the Historical Commission to use divided-light triple-pane simulated double-hung windows on the front historical façade. Most of the remaining windows in the rear are triple-pane casement products. Windows that required fire-rated glass were paired with a fixed-interior Energy Star product. The house was converted to an all-electric building, eliminating gas-fired boilers and water heaters. Heating and cooling will be provided by a combination of ducted and ductless heat pumps. Hot water is provided by three devices: an 80-gallon heat pump water heater with a smart sensor-controlled circulation loop for the upper units, supplemented by an on-demand unit to serve the remote rear kitchens on the second and third floors. A 50-gallon heat pump water heater serves Unit A. Individual ERVs provide fresh air to each unit.

The air barrier presented some challenges. The original finish on most of the interiors was plaster, which is an excellent air barrier. Where accessible, the plaster was repaired. Intersections between walls and interior materials like floor joists were sealed with a liquid-applied air barrier. Because of the complexity of the building,

and lackluster work by an air-sealing specialist who is no longer associated with the project, the initial infiltration testing did not go well.

The building is divided into two envelopes—Unit A (plus common storage in the basement) and the rest of the building. The initial Unit A testing revealed an infiltration rate of 3.7 ACH_{50}, far above the required 1.0 ACH_{50}. Blau and Thompson were able to become a local test case for a new air-sealing technology. Much like a similar forced-air duct-sealing technique, this approach involves blowing an air-sealing agent into a pressurized space while measuring the infiltration rate. The agent finds and fills penetrations of up to ¼ inch in the air barrier. In the space of about one hour, the infiltration rate dropped from 3.7 ACH_{50} to 0.63 ACH_{50}, using a single 5-gallon bucket of the air-sealing agent.

A large percentage of existing buildings will be rebuilt in the coming years. A self-described environmental activist, Blau asserts that it's necessary to maintain a balance between historical preservation and mitigating the effects of climate change. As in her case, that may require challenging, enlightening, and changing existing institutions and their practices. This retrofit is proof that existing housing stock can be smartly revitalized to last for another 100 to 200 years while maintaining its historical character. This is a win for preserving our history and ensuring our future.

—Steve Mann

Passive House Metrics (Preliminary)

Heating energy	Cooling energy	Total source energy	Peak heating load	Peak cooling load	Air leakage
5.3 kBtu/ft²/yr	4.9	22.5	5.0 Btu/hr/ft²	4.4	
1.6 kWh/ft²/yr	1.4	6.6	1.5 Watts/ft²	1.3	1.0 ACH_{50}
16.7 kWh/m²a	15.5	71.1	15.7 Watts/m²	13.8	

Washington Heights MULTIFAMILY Passive Building

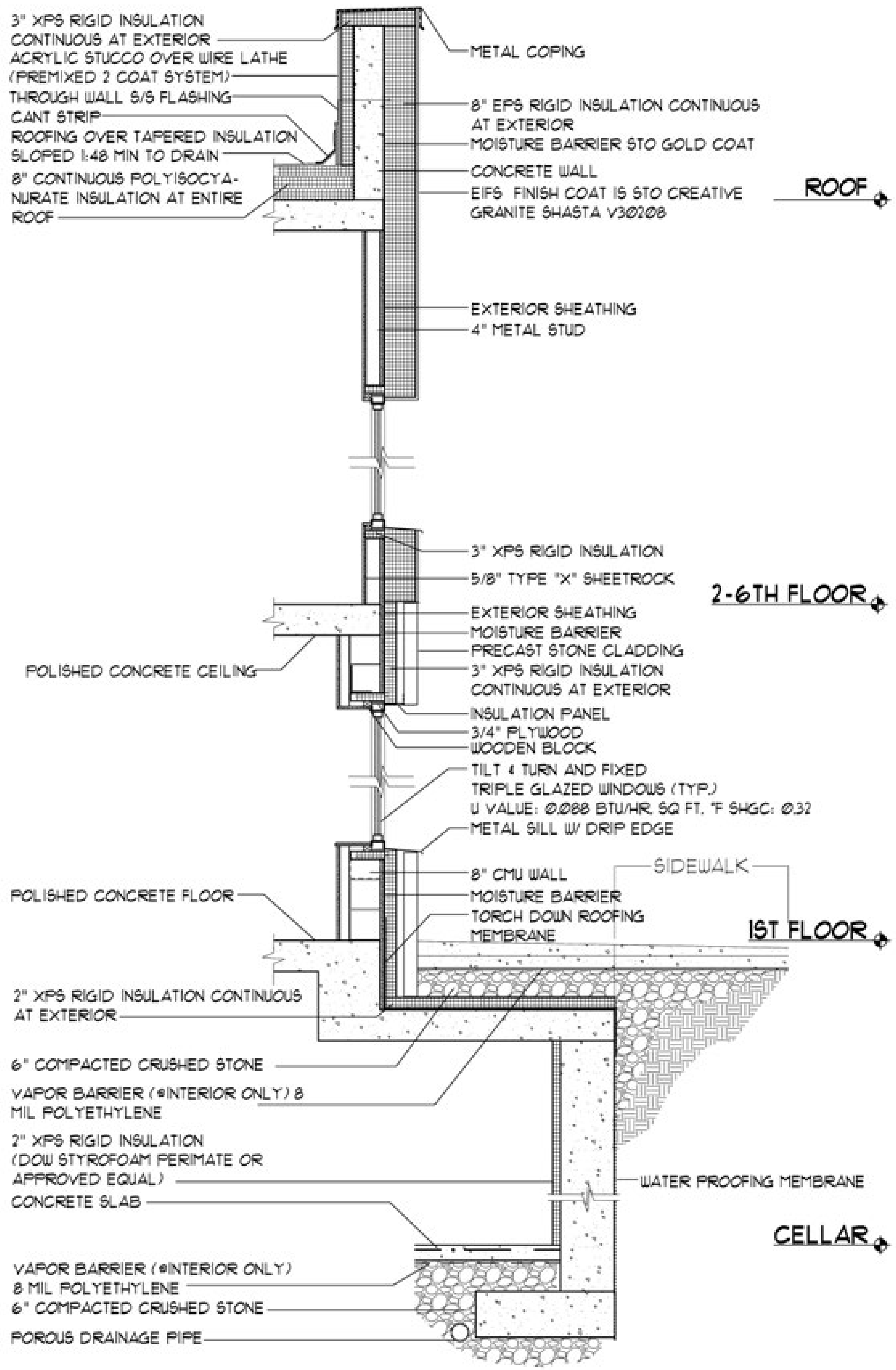
Photos by Iklyl Sari; Drawing courtesy of PM Architecture

It is said that there are no coincidences. Such is the case with 577 West 161st Street in Washington Heights, New York. The initial six-story project, which was originally permitted by a physician, consisted of multiple medical offices. However, shortly after excavation began, the initial development team abandoned the project. Sensing an opportunity, PM Architecture PC stepped in as architect, developer, and builder.

The first order of business was to redesign the project, placing the medical offices on the cellar and ground floors and introducing five upper floors of apartments. These units are primarily market rate, ranging in size from approximately 375 to 525 square feet. These sizes fit the neighborhood perfectly. The building has been occupied since October 2018. Its tenant mix consists predominantly of college students and young professionals working at the local hospital and tech companies. Many have said they are drawn to the building's unique and modern elements, such as the polished concrete floors and the unusual façade, which features graphic diagonal lines in the exterior insulation and finish system (EIFS).

Assuming the role of developer was an easy decision, as Parag Mehta, PM Architecture's principal, and other family members jointly own Technocraft, a construction company. PM Architecture maintains close ties with this company; it is the architect of record for most of the construction firm's projects. Construction on the new structure started in 2016.

Having completed several LEED projects in the past, the nine-person firm is strongly grounded in



energy-efficient and sustainable design. Once Parag Mehta was exposed to Passive House principles, he was inspired to take PHIUS's consultant training. Other staff members are educated in environmental science and have attended Passive House seminars. Even so, the firm had never tackled a Passive House building. However, being able to act as architect, developer, and builder, PM Architecture could control costs. It decided to pursue PHIUS certification.

The Passive House walls consist of metal studs covered with sheathing. The roof is concrete. The building is completely coated on the outside with a liquid-applied air-and-water barrier. To minimize thermal bridging, the shell is wrapped with 3 to 8 inches of foam insulation. The windows are a mix of triple-pane tilt-and-turn and fixed units with a .088 U-factor (R-11) and a .32 solar heat gain coefficient. Heating and cooling are provided by individual heat pumps with the compressors mounted on the roof. Ventilation is provided by a single whole-building HRV ducted to each unit.

Many strategic design decisions were made in keeping with the firm's desire for sustainability. The building incorporates low-flow water fixtures and Energy Star appliances. The exposed concrete floors were a smart material choice that requires little maintenance and produces minimal volatile organic compounds, limiting off-gassing and improving indoor air quality. PM Architecture also strove to reduce its carbon footprint by utilizing fly ash, a recycled component, in its concrete, and installing reclaimed tiles wherever possible.

Although this was the firm's first Passive House, it successfully completed the project with no significant difficulties. According to Mehta, this was due to the firm's construction experience. Technocraft often produces mock-ups of challenging details, such as window and door assemblies, the building's EIFS skin, and moments of transition from, for instance, the EIFS front to the insulated roof. These mock-ups provide unique insight into how to successfully construct the details, eliminating a lot of guesswork and resulting in efficient production. Furthermore, the building's massing was thoughtfully streamlined. There are no balconies or overhangs that might create unfavorable thermal bridging. The team was easily able to air seal and wrap the whole building with insulation.

This Washington Heights multifamily Passive House building is a testament to the success possible with integrated project team delivery. When all parties work closely together, striving toward a common goal, an elegantly simple and yet highly functional design can be achieved.

—Steve Mann

Products

Ventilation
Ventacity

Passive House Metrics

Heating energy	Cooling energy	Total source energy	Peak heating load	Peak cooling load	Air leakage
0.4 kBtu/ft²/yr	7.0	67.0	2.6 Btu/hr/ft²	3.4	0.08 CFM$_{50}$/ft² of envelope area
0.1 kWh/ft²/yr	2.1	19.6	0.8 Watts/ft²	1.0	
1.2 kWh/m²a	22.1	211.4	8.1 Watts/m²	10.8	

ARTISTS' RESIDENCE in Stonington

Photos and drawing by Wyeth Architects llc

Passive House was an unknown concept to the two visual artists who approached Leonard Wyeth, principal of Wyeth Architects LLC, seeking a new house with a pair of studios for their property in Stonington, Connecticut. Once he explained its many benefits, 'That fits the bill" was their response.

The clients' new 1,850-ft^2 house overlooks a tidal salt marsh and includes two detached studios located to the north of the house, outside the Passive House envelope. It's in an area near Long Island Sound that is prone to hurricanes, so this single-story house is constructed to withstand the elements, while also opening up to expansive views of the surrounding marshland.

"The biggest design challenge was the orientation of the site. It is narrow—runs north to south—with views to the east and the southern edge of the property. The land to the south belongs to the state and is a protected forest," says Wyeth.

To capitalize on the light and views, openings on the east and west sides were increased using glass with a solar heat gain coefficient of .51 to mitigate solar gain. Morning light floods the structure, just as the clients wanted, while deep overhangs block direct heat in summer. A tinted-glass overhang protects the west elevation, while the views to the east are washed in afternoon sunlight reflecting off the marsh.

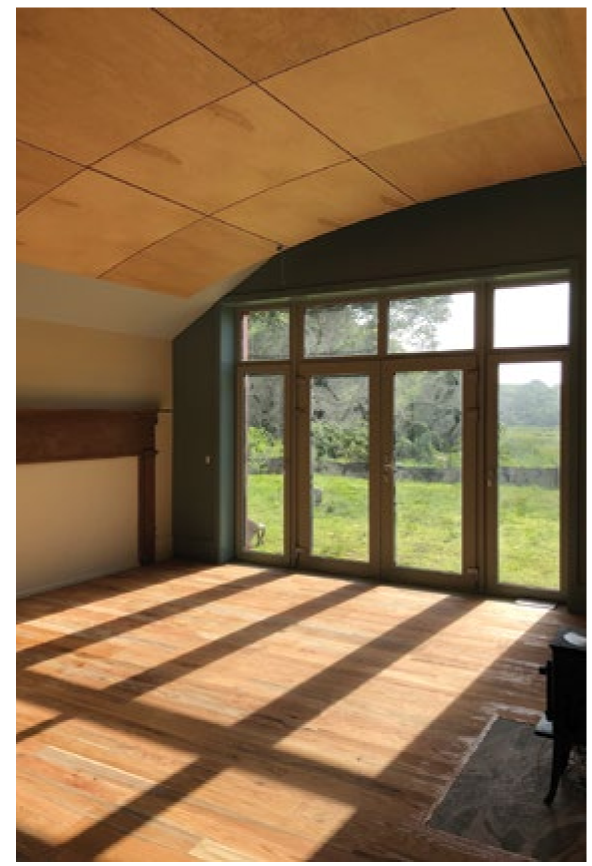
Combining hurricane resistance and Passive House superinsulated assemblies required the Wyeth team to develop some innovative solutions. They started with a double-wall assembly whose outer wall is bolted tightly to the concrete foundation and slab. The windows are fitted for fabric hurricane shades for extreme weather events.

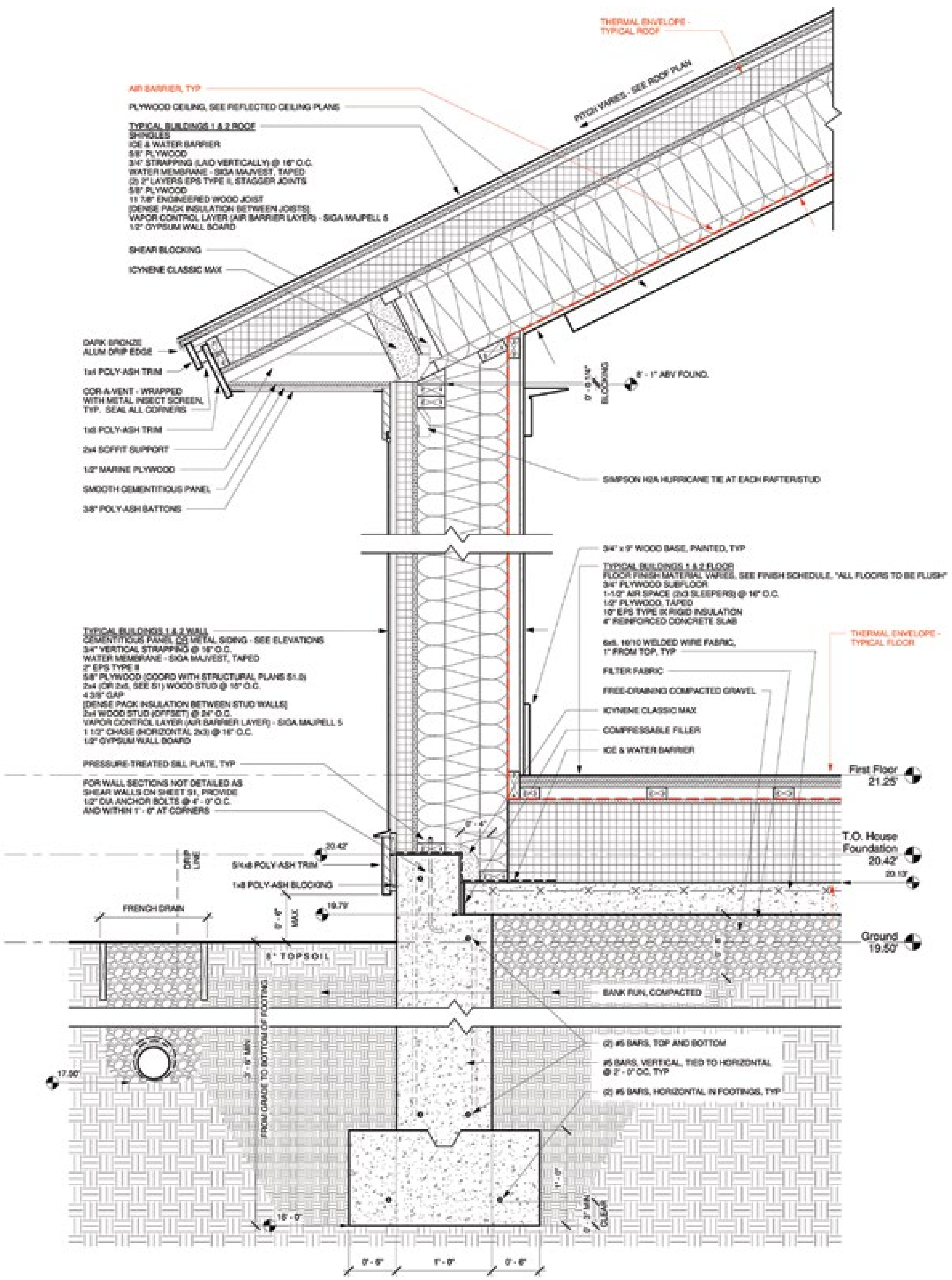
The thick double walls are filled with dense-packed cellulose. Two inches of EPS insulate the exterior of the outer wall, and 10 inches of EPS were installed on top of the slab, creating a wall-to-floor connection that is thermal-bridge-free. An air barrier was installed to the interior of the insulation, followed by a 1.5-inch service cavity to allow wire to travel everywhere while eliminating penetrations of the air barrier. The palette of materials used throughout the exterior was selected for minimal long-term maintenance, including weathering-steel siding, cement board siding, poly-ash trim, and composite decking.

The expanse of glass to the east and west (for views) required special tints and films to control heat gain and loss. Layers of safety plate were included in the windows, both for strength and for their ability to filter out ultraviolet light—protecting the works of art within.

The interior material selections reflect the artist clients' personal visions. Combinations of industrial and natural appear throughout. Discarded framing and doors from the clients' former farmhouse were reused or reimagined as counters or shelving. Boulders dug up during site excavation were cut for flooring tiles and paving slabs for exterior walkways.

Working closely with Passive House consultant David White at Right Environments and mechanical engineer Russell Knuth at Consulting Engineering Services yielded a whole-building approach to the systems. Heating and cooling are provided by an air-to-air heat pump with separate controls so that each resident artist can control their individual comfort level. Another heat pump delivers hot water. An independently ducted ERV system brings fresh air into the building.





G1 PHPP TYPICAL HOUSE WALL
1 1/2" = 1'-0"

The 24-panel PV, roughly 6-kW, array is projected to bring the three buildings to net zero. It is generously sized to compensate for the energy-intensive equipment in the artists' studios. The studios are designed to a high level of insulation, but not to Passive House. They operate independently on their own air-to-air heat pump system.

The all-electric building includes indusction cooking and a very efficient heat pump dryer, along with a decorative closed-system gas fireplace. Despite the innovative Passive House approach, the building preserves a New England aesthetic, with a pitched roof covered in fiberglass shingles and a cozy screened-in porch.

The owners have discovered a new level of comfort that they had not expected. Their past lives had involved wonderful old drafty farmhouses and tiny cottages by the sea. Their initial reaction to their new Passive House was a deep appreciation of the comfort level of the uniform heat in the winter and cooling in the summer. The absence of dust, allergens, and stale air was another pleasant surprise. The mechanical systems are essentially silent. The sound of the Amtrak rail line in the distance was gone; in fact, the silence itself was also a welcome surprise.

There are always lessons learned in each new project. Wyeth notes that the design team has been amazed by the number of basic assumptions about building and comfort that had to be completely reexamined after the team's experience with Passive House. "So many aspects of our experience have been reimagined for the better. I suppose that's why they call this the practice of architecture," Wyeth says. "Practice just makes it better!"

—Mary James

Passive House Metrics

Heating energy	Cooling energy	Total source energy	Air leakage
3.9 kBtu/ft^2/yr	4.5	38.0	
1.2 kWh/ft^2/yr	1.3	11.1	0.60 ACH_{50} (Design)
12.3 kWh/m^{2}a	14.2	119.9	

Products

Ventilation
Zehnder America

zehnder always the best climate

ECOLOGICAL Home in Dorval

Rendering by Andre Bazinet; Drawing courtesy of Alias Architecture

The right tools can make such a difference. Lucie Langlois, principal of Alias Architecture in Quebec, is finding that SketchUp and DesignPH are helping to streamline the design process for her second certified single-family Passive House. Because she can see immediately the impact of her choices on the home's efficiency, she can more quickly find the solutions she needs. Working with an experienced builder, the greater availability of Passive House-quality products, and the PHI's reconfigured primary energy renewable (PER) factors are also advantages.

Langlois designed the first certified Passive House in Quebec in 2014—a project with many challenges, starting with the relatively small volume of that single-family house and the tough wintertime climate. That experience was invaluable, giving her a practiced understanding of creating a Passive House in her climate, where wintertime temperatures average −9°C.

One takeaway from that project was that the two-story house she had originally planned did not result in sufficient volume to allow for meeting the heating requirement; only the addition of a basement, which enlarged the treated floor area and improved the volume-surface area ratio, made hitting the target feasible. The family who live in the home have made great use of the added space, turning it into a generous play and workshop area.

Other hurdles included the primary energy penalty the PHI then gave to all electricity used in a building, regardless of how the electricity had been generated. All that has changed. The PHI's PER factors recognize hydropower—the source for Quebec's electricity—as a renewable energy, making it more practical for an all-electric house in Quebec to meet the primary energy performance target.

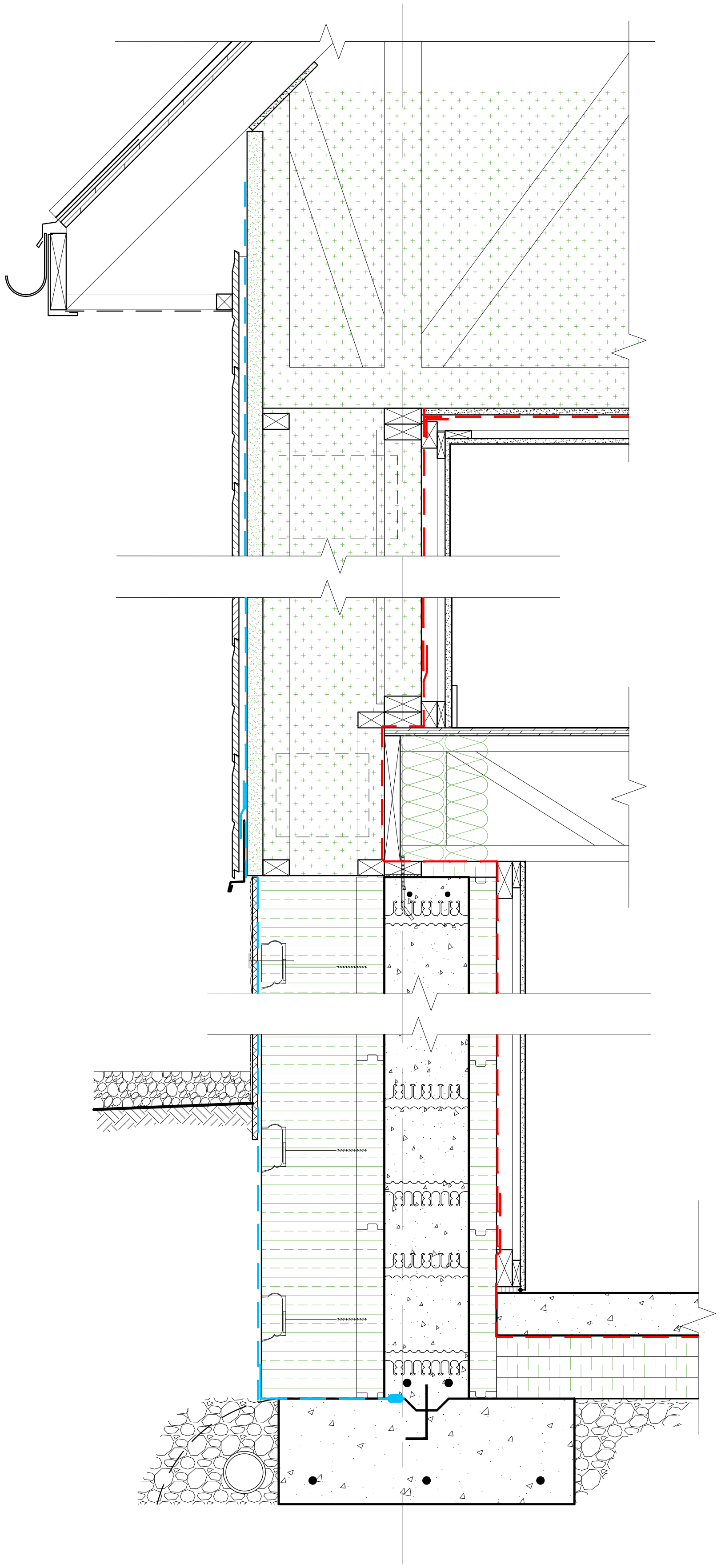
Langlois's current project, a 222-m^2 house in Dorval, a suburb of Montréal, has two floors plus a basement, designed in from the start. The basement, says Langlois, is a good solution in their climate, because it cost-effectively produces useful space and also elevates the ground floor above the snow level. The foundation walls have to be set deep enough to avoid freezing the footings, so extending their height enough to create a full basement is not a large cost premium. For this house the basement walls are using an ICF system with an additional 9 inches of exterior polystyrene. The kitchen and great room occupy the ground floor, with three bedrooms and a bath on the second floor.

The whole structure hugs the north end of the lot in order to give the south-facing façade greater exposure to wintertime sun. The front of the house faces east, while an attached garage buffers the house on its northern end. On the western façade, a large sliding door in the dining room affords access to the backyard. A 3-foot overhang shades this door, along with deciduous trees. The overhang continues around to the southern façade to screen the windows there. It also breaks up the fairly uniform building shape.

In order to use DesignPH, Langlois had to learn SketchUp, which was very simple and akin to drawing by hand, she says. The preliminary drawings were easily imported into DesignPH, allowing her to check to see if she could reasonably hit her Passive House performance goals. For Langlois, the one big drawback of DesignPH is that it doesn't adequately simulate the risk of overheating. Potential fixes to any overheating problems, such as window size and shading, can have large consequences for the home's overall design. However, the newest iteration of DesignPH will address this issue. Her ultimate PHPP model was finalized with the help of Maxime Thillaye Du Boullay, a French engineer and Passive House consultant.

While working out the construction details, Langlois had the advantage of collaborating from an early stage with Richard Price, the builder who constructed her first certified Passive House. They are both familiar with the challenges ahead and conversant with the potential solutions, simplifying the entire process. The exterior walls will be a double-wall construction with 14-inch trusses filled with cellulose wrapping the home. The clients opted for aluminum cladding for its easy maintenance.

The mechanical system choices have improved substantially since Langlois's first go-around. Heating,



cooling, and ventilation are being provided by a relatively new, locally produced conditioning ERV. Heat pump water heater options have become more readily available, and that combined with their relatively high coefficient of performance has made this type of water heater an obvious choice, as its contribution to the total primary energy use is small.

The vent hood in the kitchen, required by local building codes, is another hurdle that Langlois and Price have addressed before, so it's one more problem that isn't. This nexus of better software, more product choices, and previous experience is a sweet spot for Passive House building in Quebec.

—Mary James

Products

Ventilation
Minotair

Passive House Metrics

Heating energy	Cooling energy	Total source energy	Peak heating load	Peak cooling load	Air leakage
4.2 kBtu/ft²/yr	0.6	18.5	3.8 Btu/hr/ft²	2.5	
1.2 kWh/ft²/yr	0.2	5.4	1.1 Watts/ft²	0.8	0.6 ACH_{50} (design)
13.2 kWh/m²a	2.0	58.4	12.0 Watts/m²	8.6	

BERKELEY Passive Houses

Photos and drawing by Ian MacLeod

Certified Passive House buildings are not yet a trend in the San Francisco Bay, despite the region's tendency to embrace techy innovations. This slow uptake is partly due to the mild climate: Passive House certification seems superfluous to many high-performance builders. Ian MacLeod of MacLeod Design & Construction is ahead of the curve, having built and certified two Passive Houses in Berkeley within the past three years.

The impetus for both projects was the clients; they each wanted significant performance. In the case of the Berkeley Way two-story accessory dwelling unit (ADU), a 1,000-ft^2 cottage designed for an elderly parent, the clients were easily convinced that certification made sense. In the case of the larger, 3,324-ft^2, three-story gut remodel located on Los Angeles Avenue, the engineer-trained client knew from the beginning that he wanted a Passive House.

MacLeod was introduced to Passive House basics by his colleague Nabih Tahan, one of the earliest Passive House pioneers in the Bay Area. Tahan was the architect and builder for the first Passive House retrofit in California. As a builder and architect, Passive House construction made sense to MacLeod. He just had to wait for a suitable project.

Berkeley Way

The Berkeley Way project is located in the relatively flat area of Berkeley close to the Bay Area Rapid Transit system, perfect for the elderly occupant of the house. It was originally designed and had zoning approval by another architect as traditional housing. MacLeod took over the project to do the building permit plans and eventual construction. Once the Passive House goal was set, he redesigned aspects of the house, in consultation with consulting firm Beyond Efficiency, to clarify air and water barrier and insulation details and optimize the glazing.

The modern, angular design is a model of two-story efficiency designed for primarily one occupant, with a second bedroom for visitors. The building shell is typical for a Bay Area building that meets Passive House criteria: 2x6 dense-packed walls with 2 inches of exterior insulation, and 2x12 TJI dense-packed roof rafters, also with 2 inches of exterior insulation above. Current local building practices favor insulated slabs. Location in an earthquake liquefaction zone calls for thicker slabs, generally on the order of at least 8 inches. Berkeley Way only required a 5-inch reinforced slab with 2 inches of EPS underneath, and 1 inch around the perimeter.

The building sheathing is covered with a liquid-applied air and water barrier. To help maintain the integrity of this barrier, a second layer of roof framing was laid over the roof sheathing, with the exterior insulation laid in between the framing. This strategy made it easy to provide overhangs for rain protection and shading where needed without compromising the air and water barrier.

The original plan was to cover the walls with one and one-half inches of foam coated with stucco. During construction, the clients opted for cork instead, because of its sustainability compared to extruded polystyrene (EPS) foam. MacLeod realized that the cork could actually be used as the exterior finish. The additional cost of the cork was basically offset by the savings from not having to apply the stucco finish. Everyone involved with the project is quite pleased with the result.

The mechanicals are standard fare for small, high-performance Bay Area buildings—a mini-split heat pump for heating and cooling, a heat pump water heater for domestic hot water, and an HRV for ventilation. According to MacLeod, due to the advance consideration of the details, there were no significant challenges while building the house.

The only real hiccup was figuring out the dampering on the kitchen range hood. There was quite a bit of debate prior to construction about installing an electronically-activated in-line damper. The winning solution was to install a magnetic damper on the outside that only opens at pressures above 60 Pascals. This configuration stayed closed during the required blower door testing, but opens when the range hood fan is turned on. Initially this didn't work as expected—the damper opened at lower pressures. A few small magnets were added to solve the problem.

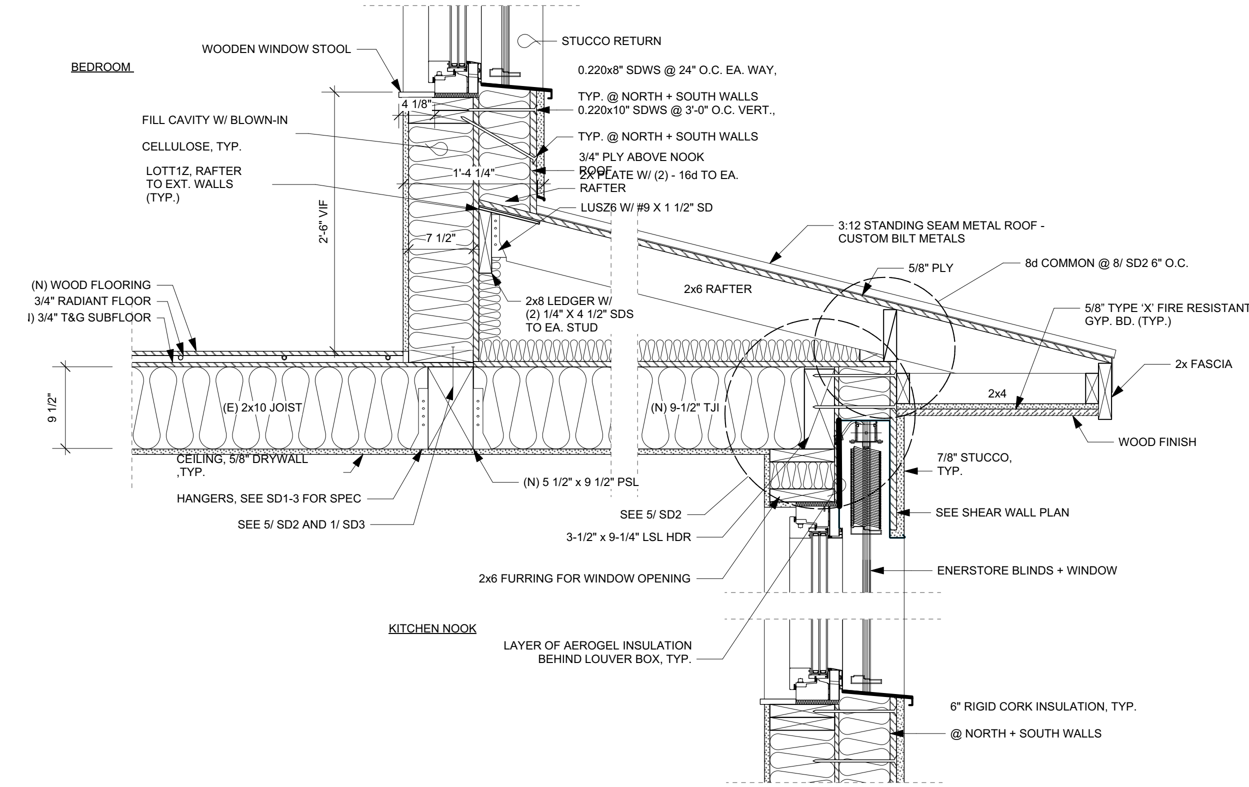
Products

Ventilation
Zehnder America

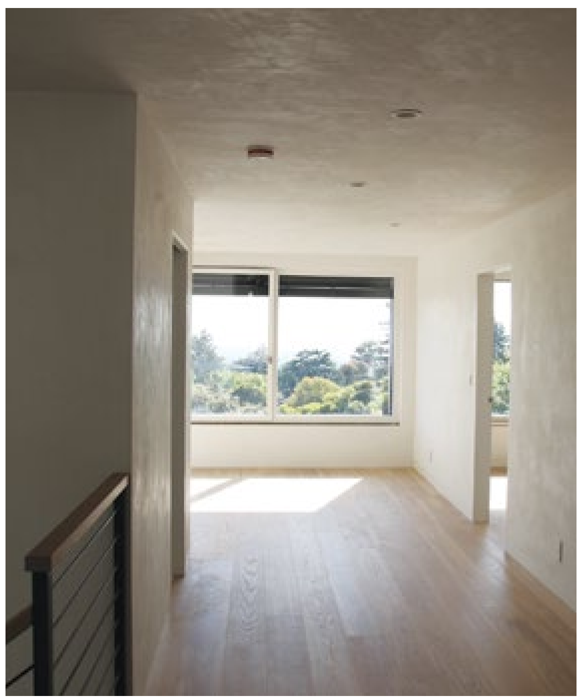
Insulation
Rockwool

Passive House Metrics

Heating energy	Cooling energy	Total source energy	Peak heating load	Peak cooling load	Air leakage
5.1 kBtu/ft^2/yr	3.8	34.9	2.9 Btu/hr/ft^2	1.6	
1.5 kWh/ft^2/yr	1.1	2.1	0.9 Watts/ft^2	0.5	0.4 ACH_{50}
16.0 kWh/m^2a	12.0	110.0	9.2 Watts/m^2	5.0	



4 / S1.2 NOOK ROOF + UPPER NORTH WALL @ BEDROOM DETAIL
Scale: 1" = 1'-0"



Los Angeles Avenue

The Los Angeles Avenue project was much more challenging for a variety of reasons. It was an existing house in the Berkeley Hills that was essentially gutted. The top floor and roof were removed and rebuilt. All interior and exterior finishes were removed. Window sizes and locations were all changed, many taking advantage of views across the San Francisco Bay to the Golden Gate Bridge. Floor plans were redesigned to accommodate a family of four with open, workable spaces. The ground floor includes a second kitchen and fully outfitted apartment for visitors.

Although this project could have been modeled and certified as an EnerPHIT project, MacLeod and his client decided to pursue full Passive House Plus certification. The biggest difference between these two certifications is the infiltration rate. EnerPHIT projects can be certified at 1.0 Air Changes per Hour (ACH_{50}). Classic Passive Houses have a lower infiltration threshold of 0.6 ACH_{50}.

This ambitious goal translated to some significant challenges during air sealing. There were a variety of situations where new framing components were married to old framing (all exterior sheathing was removed), and access to some of the old components was limited. Several weeks of air sealing work, with multiple rounds of blower door testing, ensued, and some very creative approaches were required. For instance, the first-floor subfloor and framing cavities had to be fully coated with a liquid air barrier product to seal the intersection with the existing unconditioned mechanical room below. The project team eventually reached an admirable infiltration rate of 0.4 ACH_{50}.

There are quite a few very large windows on the resulting structure (the window-to-square footage ratio is over 31%). Just getting the windows to the upper floors required lots of elbow grease. Many of these windows are on the western elevation to take advantage of the views. Unfortunately, that can lead to overheating. To mitigate the siting, electronically controlled exterior blinds were installed on the western windows.

The wall assemblies are a complex mix of new and existing walls with additional interior framing and insulation. Existing walls were built out from 2x6 to as much as 2x10 depth; 90% of the walls are 2x8. All insulation is blown-in cellulose. For exterior insulation, MacLeod once again used cork. The rear southwest and front northeast-facing walls have 6 inches to accommodate the depth of the exterior shades. The

side walls have 1 inch of cork. The roof structure is similar to the dual roof assembly that MacLeod used on the Berkeley Way project—dense-packed 2x12 TJI rafters topped with sheathing, then a secondary vented roof structure insulated with 2 inches of mineral wool between the framing.

Ventilation is provided by a large HRV in the basement mechanical room. All floors have radiant heat powered by a heat pump water heater that also provides domestic hot water. The radiant heat system is rarely used. A detailed analysis was done to determine electricity consumption and properly size the 10.8-kWh PV system that was installed to make the home a net zero energy dwelling, including an electric car charging station. In a nod to the owner's sensitivity about harmful environmental characteristics, the bedrooms are EMF shielded.

Both of MacLeod's projects demonstrate that the most successful residential Passive House projects tend to have a tightly integrated team. This is easy to achieve when the architect is also a hands-on builder.

— Steve Mann

Passive House Metrics

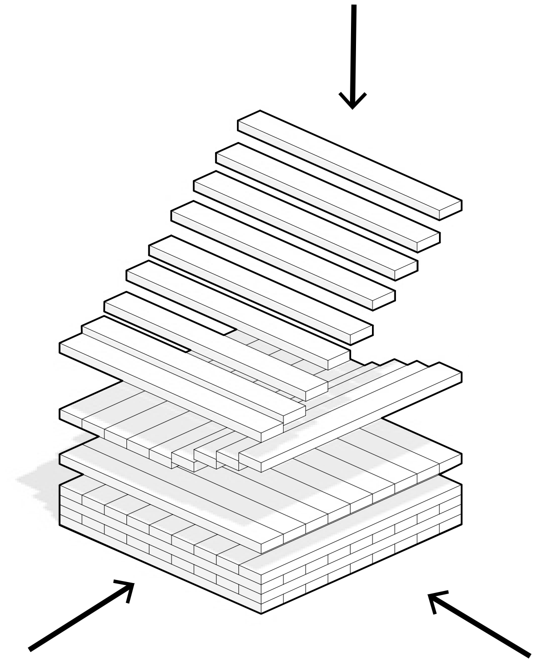
Heating energy	Total source energy (PER)	Peak heating load	Air leakage
4.9 kBtu/ft²/yr	6.7	2.5 Btu/hr/ft²	
1.4 kWh/ft²/yr	2.0	0.7 Watts/ft²	0.4 ACH_{50}
15.5 kWh/m²a	21.0	8.0 Watts/m²	

Products

Ventilation
Zehnder America

Insulation
Rockwool

Addressing Embodied Energy with MASS TIMBER



Figures by ZH Architects

The team at ZH Architects has been exploring sustainable building strategies for 18 years, and over that time we have intensively examined many different facets of sustainability. We began with investigating low-volatile-organic-compound (VOC) materials to improve air quality and occupant health in the buildings we designed. Later, we became interested in Passive House construction and how to detail and insulate our projects to make them airtight, well insulated, and energy efficient.

Passive House design and energy modeling with the PHPP allows architects to focus very specifically on a building's operational energy use. Whether it is the windows and components, installation details and thermal bridges, or the efficiency of ERVs and other mechanical systems, every aspect of operational energy is addressed and reduced with Passive House design. Over the life span of a building, this lowered operational energy use can create a substantial financial payoff for the owner and significantly reduce a building's carbon footprint—by more than 70% over the building's lifetime. The precision and focus afforded by the PHPP is very effective and hugely important. Yet its intensity perhaps obscures another possible route to savings in emissions that could help further cut our buildings' carbon footprint—specifically, embodied energy.

In 2015 we began exploring the impact of embodied energy in a new midrise Passive House residential building we were designing in New York City. We decided to use this building as a pilot project to analyze how much of the building's embodied energy contributed to its overall emissions over a 75-year building life span. Interestingly, after some research we were surprised to find that Wolfgang Feist had already done a similar study of the embodied energy of the first Passive House in Darmstadt (see Figure 1). For the Darmstadt project, the embodied energy accounted for roughly 20% of the building's total emissions—a significant amount! The structure alone constituted 51% of the total embodied energy.

At the same time that we were discovering that embodied energy is not an insignificant portion of a building's lifetime emissions, we also discovered a class of products that allow designers to significantly impact the embodied energy of a building: mass timber. Mass timber is a group of products made by laminating small sections of wood to create large structural sections; the technology was invented in Austria in the early 1990s. Mass timber can be used for beams (glulam), panels (cross-laminated timber, or CLT), and many other systems. A critical sustainable attribute of mass timber is that it can be used as a structural component, and structure is typically the largest portion of a building's embodied energy (see Figures 2 and 3).

Mass timber is such a sustainable product because it requires much less energy to produce than comparable materials, it sequesters carbon in its fibers, and it has low conductivity compared to other structural materials. If it is harvested properly, it is also renewable and does

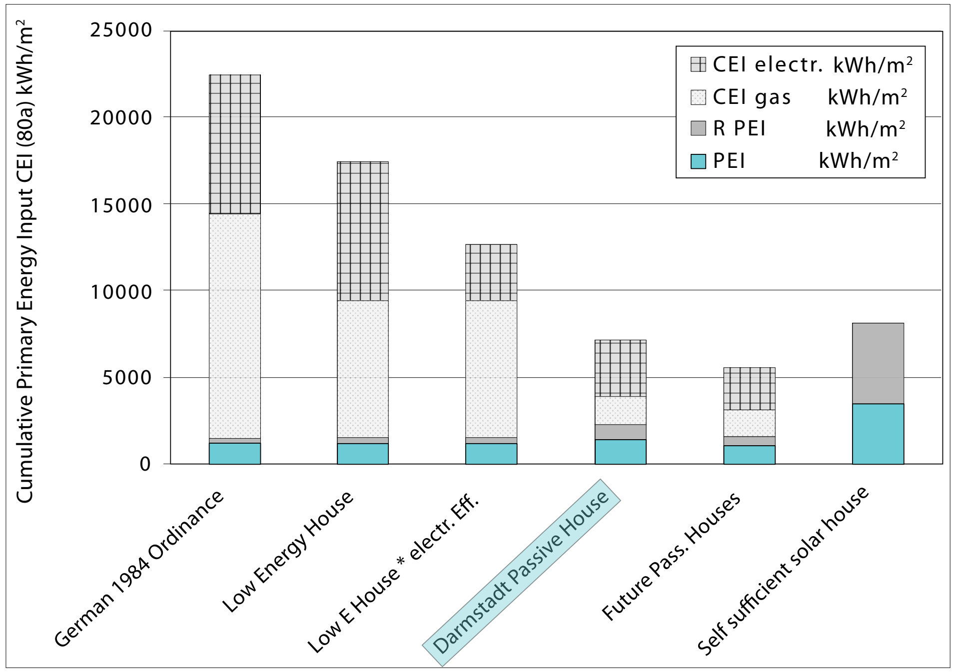


Figure 1. Darmstadt Passive House. Source: Passive House Institute

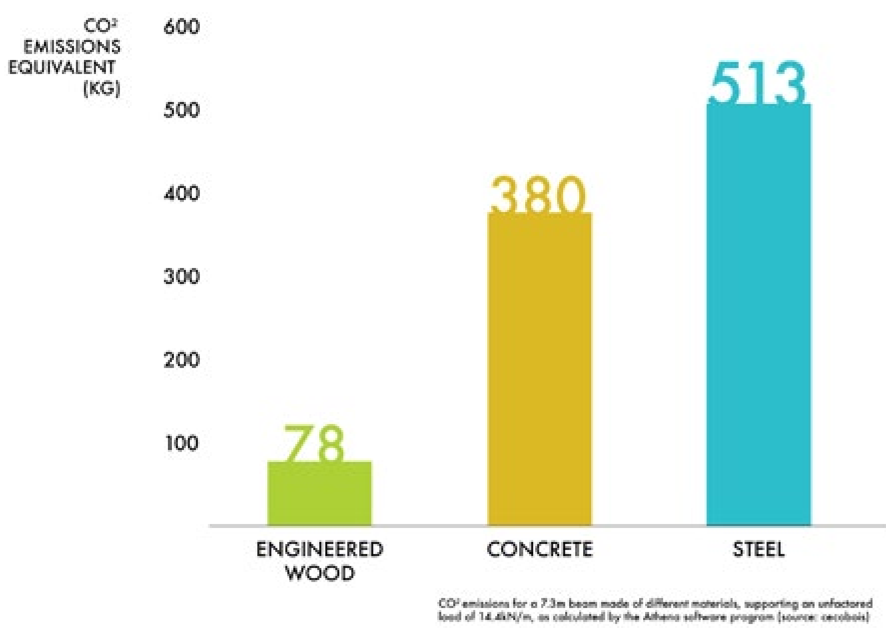


Figure 2.

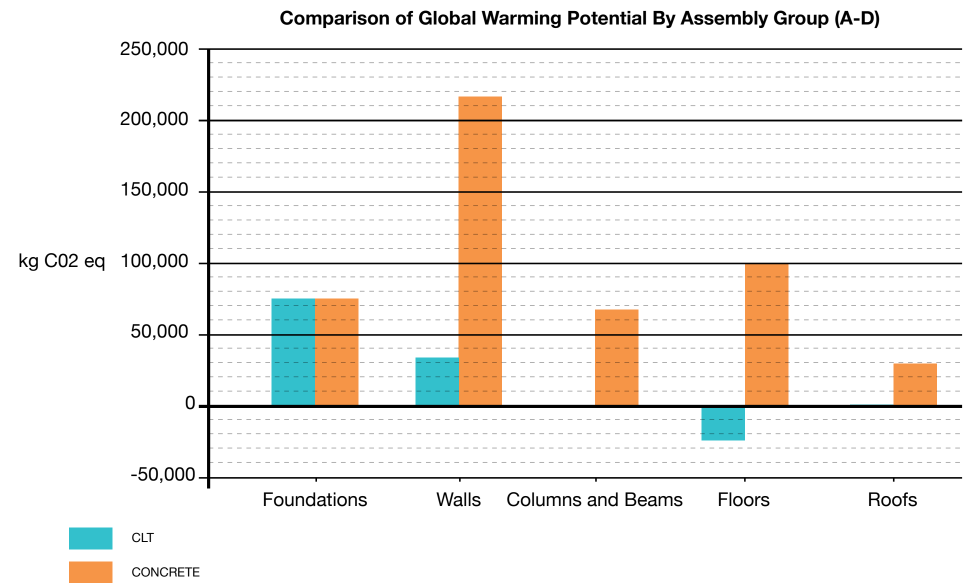


Figure 3.

not degrade forest ecosystems. Beyond its sustainability benefits, it is also dimensionally stable and allows for precise manufacturing, prefabrication, and quick construction. Many people are surprised to learn that mass timber is safe in tall buildings and actually performs well in a fire, unlike small-dimensional lumber. In a fire, the exterior of large wood sections chars and forms a protective barrier that insulates the interior of the member from fire, allowing the mass timber product to retain its structural capability as long as or longer than steel or other conventional materials.

These materials were interesting to us not only for their sustainability features, but also for their design and aesthetic potential. We at ZH—and we are certainly not alone in this—have used wood for its aesthetic beauty for years. It is a material that has a multitude of colors, grains, textures, and luster and can be used in its raw form or be highly crafted. Many would argue that people have a natural inclination to biophilic design, which incorporates elements that tie us to nature, such as natural light, ventilation, and materials; for this reason wood is a logical design tool. The development of mass timber allows the use of wood on a much larger scale, and the benefits of wood scale with the quantities used.

Our initial findings on mass timber were exciting enough that we continued to pursue the potential of incorporating mass timber into our Passive House project. We decided to compare the embodied energy of our project if built with a concrete structure or CLT. We compiled a life cycle assessment (LCA) model of the entire building using the Athena Impact Estimator LCA software. The Athena program provides a detailed analysis by construction phase—from harvesting to end of life—as well as by building component, from walls to columns, and so on.

We combined our modeling and data from the PHPP and the Athena model to estimate the greenhouse gas (GHG) emissions over the life of the building for several variations: a conventional building in both concrete and CLT, a Passive House building in concrete and CLT, and a Passive House Plus building in concrete and CLT. The results were impressive. The Passive House Plus CLT building reduced life cycle GHG emissions by 93% compared to a conventional building in concrete (see Figure 4). Building with mass timber reduced the project's embodied energy by 83% and the building's lifetime GHG emissions by nearly 10%.

Our next question was how the building code addresses mass timber. We found that many countries are already using mass timber successfully, and in the western United States a growing number of projects were receiving variances to build with mass timber. We wanted to understand exactly what was permissible with the current codes and the viability of proposing mass timber construction in both NYC (where we are based) and other parts of the state and country.

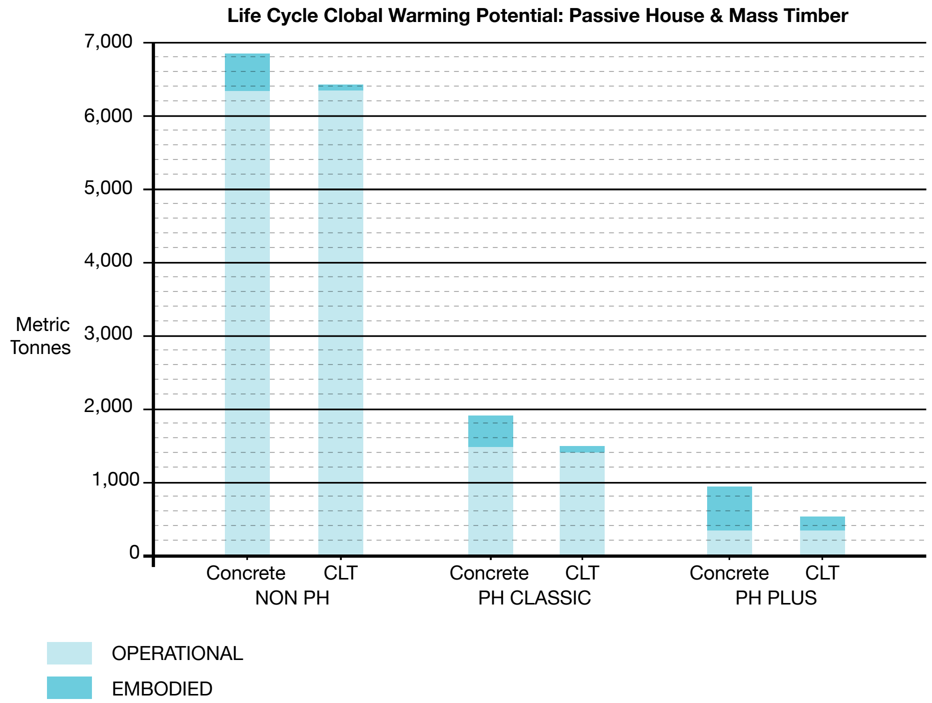


Figure 4.

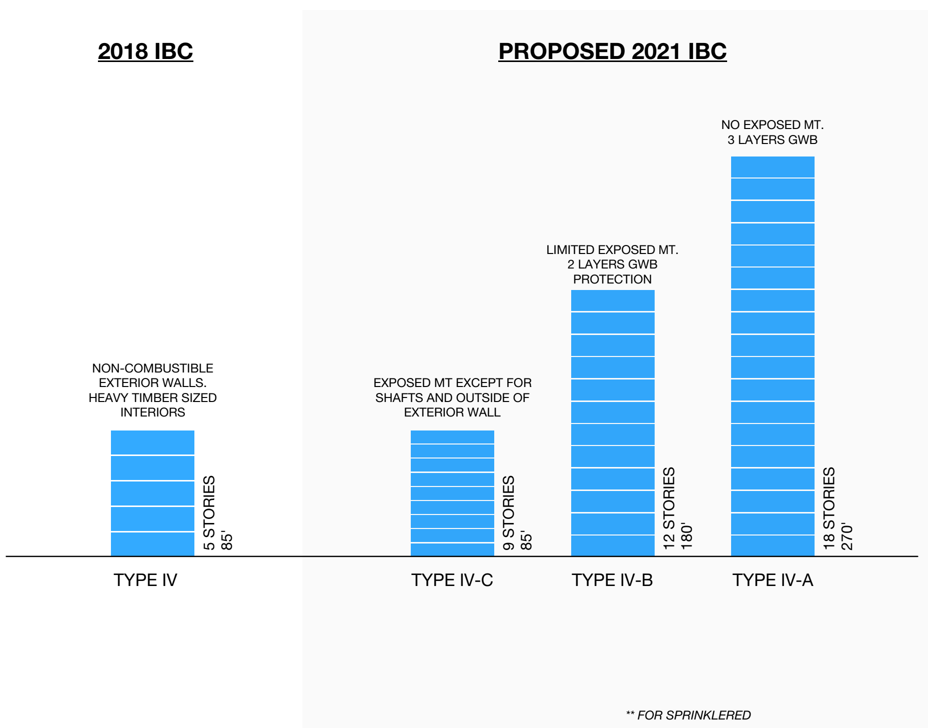


Figure 5.

To do this we tapped into a movement consisting of a group of dedicated professionals—architects, firefighters, engineers, and fire experts—who have been heavily involved with mass timber construction and its application in the building codes. We found that the process of advocating for mass timber to be added to the codes has been ongoing for many years, and we were joining the group at an exciting time. In 2016 the International Building Code (IBC) created an ad hoc committee to formally investigate mass timber and the model codes. Interested stakeholders also coordinated a series of large-scale fire tests to prove the performance of mass timber. These tests had impressive results and showed how resilient mass timber is in a fire and how consistently it performs.

As a result of the many years of advocacy work and testing, proposed code changes for mass timber were approved by the IBC in the fall of 2018 (see Figure 5). These changes will be included in the next version of the IBC in 2021. Three new construction classes are being added allowing mass timber buildings at high-rise scale. The three types will be Type IV-C (9 stories), Type IV-B (12 stories), and Type IV-A (18 stories). This is an important milestone, because this approval serves as a guideline so interested code officials can model their approvals off the IBC's recommendations. Starting in 2021 this new code will also supersede the previous code cycles in jurisdictions across the United States and the world.

Central to the idea of Passive House is that it is critical to address operational energy, because doing so results in greater emissions reductions from the building sector than any other strategy. This is as true now as ever, but we have a unique opportunity to go further by also addressing embodied energy. The predictions of the effects of climate change are becoming increasingly urgent, and we cannot afford to ignore the roughly 20% of building emissions from embodied energy. With mass timber and Passive House, we can simply and easily design buildings that radically reduce our carbon footprint and also create a higher-quality built environment.

—Stas Zakrzewski and Avery Gray

Stas Zakrzewski is a principal and Avery Gray is a project manager at Zakrzewski and Hyde Architects in New York City.

Figure 1. Low-cost IAQ monitors. Photo by Bill Spohn.

Measuring a HEALTHY HOME

I'm trained in engineering and have worked either developing or selling test and measurement (T&M) equipment for the last 30 years. Not just any T&M products—only those associated with building performance and heating, ventilation, air-conditioning, and refrigeration equipment produced by such fine companies as Bacharach and Testo. Throughout this whole time, and only until very recently, all indoor air quality (IAQ) meant to the broader market was monitoring temperature and humidity, and in a few cases CO_2. A wave of new air quality measurement devices available at increasingly lower price points has more and more people testing. What is the value or purpose of these products in a high-performance or Passive House building?

A HEALTHY HOME

Nate Adams, home performance professional and author of *The Home Comfort Book*, describes a healthy home this way:

> A healthy home is in balance. It's comfortable, healthy, and easy to control. Part of what makes it healthy are that moisture levels aren't too high or too low, dust particles are being filtered out, chemical and pollutant levels are under control, and the air just feels fresh. In other words, indoor air quality (IAQ) is continuously managed all year.

A decade ago, personal health monitoring was mostly limited to the bathroom scale. Now millions of people closely monitor their Fitbits, weather data, steps taken, visitors, and stock market and Twitter feeds from their watches, doorbell video cameras, and smartphones. Soon the Apple Watch will allow something that approximates a real-time EKG. Personal health is on the public's mind. Now more than ever, health-related information (of varying quality) can be seen in social media posts. It's easy to "research" and self-diagnose on the Web.

"We're on the cusp of a trend," Nate Adams says. "Homes are gaining more and more sensors like cars did a decade ago. People are looking for their houses and systems to talk to them. The IAQ sensors are the first bridge."

We breathe about 3,000 gallons of air per day, and many of us spend 90% of our time indoors. We "eat" a lot of air. Sensitive populations, like the elderly and infirm, may spend 100% of their time indoors. Children eat even more air—about 40% more air per pound of body weight than adults.

AN UNHEALTHY HOME

IAQ can vary widely, because it is largely related to occupant behavior. Using chemical cleaners, hobby materials and solvents, personal beauty items, and other vapor-emitting products can contribute to poor IAQ. Recent studies underscore that cooking is a major contributor to poor IAQ, irrespective of the type of cooking appliance, since the majority of the emissions come from the food.

It is generally recognized that smoking and burning incense increases particulate and volatile organic compound (VOC) levels. Showering, clothes washing, and bathing increase humidity levels, which can lead to mold growth. All the creature comforts we have become used to can contribute to poor air quality. Vented and unvented combustion appliances, and electric appliances with dirty coils can all produce unhealthy particulate levels.

Many people have systems in their homes to filter the air, but filter replacements are often neglected. We also see installed exhaust systems that are not used, are improperly installed, or operate ineffectively, sometimes merely due to lack of maintenance. People are reluctant to use noisy range hoods, and often these do a poor job capturing what they should.

Seasons change, the weather changes, the humidity and temperature change, even the amount of moisture in the soil changes (affecting radon propagation into a structure). Occupant behavior changes. Equipment breaks down. These constantly changing factors make the case for constant, albeit imperfect, measurements.

Finally, there's the shell game: If the enclosure is leaky, the nasties get in from the attic, the basement, the crawl space, or outside. If the enclosure is robust, but ventilation and filtration are weak, indoor air pollutants accumulate.

With all these competing factors at play, how do we get to Nate's Zen condition of balance?

MEASURING IAQ

Earlier in my career, I believed that the perfect measurement, taken with expensive test gear, was the only measurement worth taking. Time and experience have softened me on that stance for two reasons. First, it's beneficial to get users measuring IAQ parameters, even if they are not exact. Second, there are benefits to taking measurements over an extended period of time. A monitor that can constantly analyze and provide feedback helps increase awareness of these changing IAQ factors.

Fortunately, there are now inexpensive monitoring products of reasonable quality that can be broadly installed and remain in place for long periods. In this way, they are like security cameras with motion detection (I recently bought such a camera for $29)—always monitoring the environs and reporting on out-of-character values. Timely reporting can help occupants modify their behavior in real time or command active ventilation or filtration equipment to kick into gear. In many cases, these devices can increase occupants' curiosity on the topic, leading to better measurements as they come to understand more about their air quality.

Figure 1 shows six low-cost monitors. From left to right, they are (1) LL6070 low-level carbon monoxide (CO) alarm (**www.defenderdetectors.com**); (2) PG-2017 low-level CO alarm (**www.coexperts.ca**); (3) Corentium home radon monitor with display (**www.airthings.com**); (4) Wave Bluetooth radon, temperature, and humidity monitor (**www.airthings.com**); (5) uHoo WiFi IAQ monitor with nine parameters—temperature, humidity, VOCs, particulates, CO_2, CO, nitrogen dioxide, ozone, and barometric pressure (**www.uhooair.com**); and (6) Fooboot WiFi IAQ monitor with four parameters—temperature, humidity, VOCs, and particulates (**www.foobot.io**). Prices range from $99 to over $300.

Independent lab testing shows that devices like the Fooboot ($199) correlate reasonably well to more-scientific monitors, especially in the particulate values. The uHoo ($329) measures CO2, a surrogate indication of air freshness and a pollutant in its own right, as well as barometric pressure, and noise in decibels. Presently Airthings Wave ($199) and Corentium ($179) are the only devices that provide radon measurements. More-precise CO measurements come from the Defender LL6070 ($160) and CO EXPERTS PG 2027 ($189) alarms with displays.

Most of these devices are app based and Cloud connected, so notifications are available whether you are present or not. Data are logged and plotted with consumer-friendly graphics as well as engineering-type reports and tables. Trend tracking of multiple values can often unravel the complexities of a situation.

Several models send automatic reports and alerts that warn of changing values in real time. This capability allows for event tagging of what the occupants were doing or sensing or feeling at that time, to help understand how their behaviors relate to and impact air quality. Some apps even provide general recommendations on what an occupant can do to alleviate these out-of-bounds values.

QUALITY

Researchers from Lawrence Berkeley National Laboratory (LBNL) note that these sensors and monitors are unregulated, and there is limited third-party evaluation information. While they caution people on using these monitors and assuming that the measurements are accurate and the advice relevant, they are also working to make that a reality.

While sensors are getting better, it is important to remember that reliability is not necessarily robust; some units measure certain, but not all, parameters accurately. Figures 2 and 3 show the results of an LBNL evaluation of several low-cost consumer-grade monitors. This evaluation, titled "Consumer IAQ Monitor Responses to Residential Sources of Fine Particulate Matter," can be found online at **onlinelibrary.wiley.com/doi/abs/10.1111/ina.12463**.

As this evaluation shows, some devices indicate IAQ issues related to particles, but none of them senses ultrafine particles, many which have serious health implications. The researchers feel that although these devices are getting better, there are no devices that are good enough to control a filtration system. There is also a lack of long-term performance evaluation.

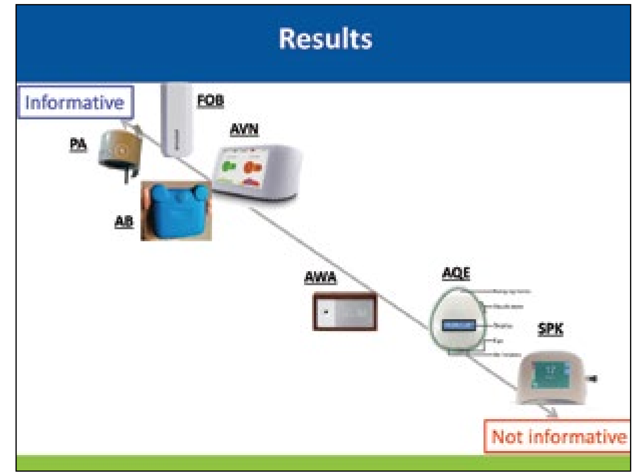
LBNL researchers also believe that total VOC readings are almost useless, due to false positives from activities such as drinking alcohol or peeling oranges, for instance. However, the inexpensive CO_2 sensors are acceptable, especially when used with drift correction software that functions by assuming that sometime in the past few days there was a "fresh-air incident." This correction can be error prone when installed in homes where people rarely leave the premises, such as households with the elderly, home offices, or preschool-age children.

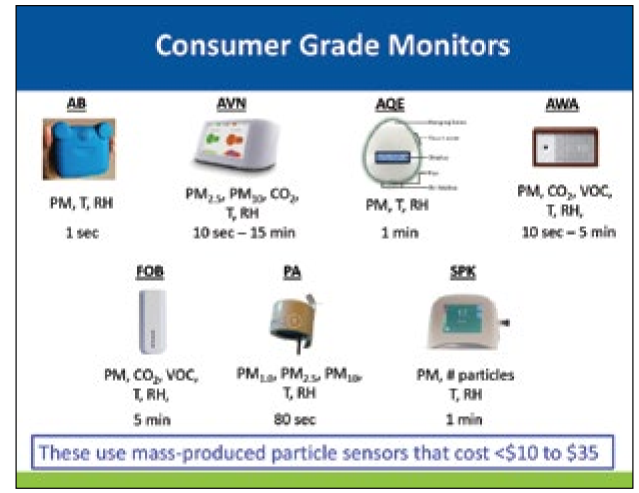
There are strong signals that a market for low-cost IAQ-monitoring devices is growing. The Building Performance Institute has developed the Healthy Home Evaluator trade certification for professionals. Bill Hayward, founder and owner of Hayward Lumber, has developed the Hayward Score (www.HaywardScore.com), a national consumer scoring test for self-evaluation of aspects of a healthy home, along with advice on how to improve one's own home, or how to connect with contractors.

In conclusion, I believe there is good value for these products with prudent use, especially in high-performance and Passive House buildings.

—Bill Spohn

Bill Spohn *is president and owner of TruTechTools.com.*





Figures 2 and 3. Graphs courtesy of Brett Singer, Lawrence Berkeley National Laboratory

Resources

HOMEChem YouTube channel: House Observations of Microbial and Environmental Chemistry. Twenty-two research scientists study indoor air chemistry in a manufactured home in Austin, Texas, during the months of May and June 2018. See **www.bit.ly/HOMEchem**.

Watch real home performance and IAQ problems get solved on Grace and Corbett Lunsford's PBS TV show *Home Diagnosis*. Go to **www.HomeDiagnosis.tv**.

Adams, Nate. *The Home Comfort Book*, 1st ed. CreateSpace Independent Publishing Platform, November 8, 2017. This is a great communication tool to educate consumers and even pros on building science and IAQ in an engaging manner. **www.NateTheHouseWhisperer.com**.

IAQRadio has years of quality audio content in IAQ research and practice. To learn more, go to **www.IAQradio.com**.

The Indoor Air Quality Association focuses on engaging and educating industry professionals and the general public about indoor air quality. See **www.IAQA.org**.

Healthy Indoors magazine delivers timely and credible resources for indoor environmental and sustainability topics, connecting professionals to consumers, and vice versa, via print and digital publications, live and virtual events, video, and social media. Online at **www.HealthyIndoors.com**.

Delp, W. W. and Singer, B. C. "Response of Consumer and Research Grade Indoor Air Quality Monitors to Residential Sources of Fine Particles." *Indoor Air Journal* 28, no. 4 (2018). Online at **onlinelibrary.wiley.com/doi/abs/10.1111/ina.12463**.

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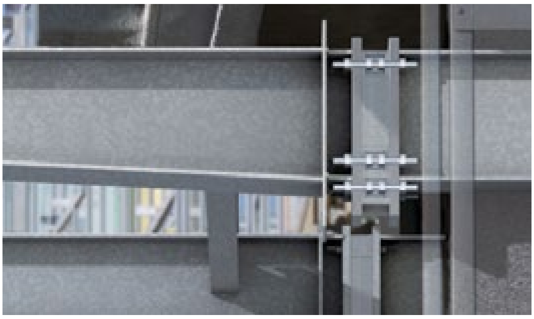

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