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Hotel Marcel, New Haven, Connecticut.

Photo by Seamus Payne: courtesy of Becker + Becker

Structural Steel in Passive House Construction

All you really need is a break

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By William B. Millard, PhD

If one asks a building envelope a version of the question Louis Kahn famously posed to a brick—"What do you want to be?"—an energy-conscious envelope might answer, "I'd like to resemble a Thermos bottle." A self-contained system, well-integrated in design and detailing, capable of purposeful opening or enclosure, keeping salubrious contents inside and insalubrious elements out, holding entropy purposefully at bay: that's the type of building the world needs more of, and one that increasing numbers of architects and clients want to build.

"One way to think about Passive House," says Ken Levenson, executive director of the Passive House Network, "is, it's a Thermos. You want to keep the coffee hot and the iced tea cold, and so you've got this airtightness [and] thermal insulation." Reduced energy consumption is only one of the system's many benefits; with well-designed shading to regulate heating, high-performing windows and doors, and a systematic approach to mitigating extremes in both directions, the thermal comfort and air quality in a Passive House building are measurably better than in ordinary buildings. Natural ventilation is an option, not an obligation, Levenson continues: "You open the window because you want to, not because you need to."

Interest in Passive House has been expanding for decades. According to the International Passive House Association's statistics on projects meeting the certification criteria of the Passive House Institute (PHI), over 47,400 units are certified worldwide, with a sharp upward curve in the total floor area included, totaling 4,322,000 square meters as of January 2025 (International Passive House Association). The parallel organization serving North America, Passive House Institute U.S. (PHIUS), reports similar increases in its design-certified projects, with over 3,000 projects including over 2,800,000 square feet (over 260,000 square meters) of total interior conditioned floor area as of 2022 (Klingenberg). (PHIUS maintains two levels of certification, reports Isaac Elnecave, senior policy analyst and a member of the certification team: Design Certification is roughly equivalent to a building permit, indicating the design meets the requireents, while Final Certification, the rough equivalent of a Certification of Occupancy at least with respect to energy requirements, occurs after construction is completed and the building still meets the heating/cooling targets and the source energy target. The total of Final Certified buildings, he says, is 526 projects to date, including 285

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Learning Objectives

After completing this course, you should be able to:

1. Identify aspects of structural steel that create challenges for a building's thermal integrity (particularly thermal bridging) as well as solutions to those challenges.
2. Demonstrate a working familiarity with the Passive House principles and systems.
3. Identify several recent and contemporary construction projects that have used steel structures and met Passive House standards, with or without official certification.
4. Explain how a carefully planned Passive House project using structural steel can have positive long-range environmental effects while generating benefits for clients and occupants.

To receive AIA credit, you are required to read the entire article and pass the quiz. Visit **ce.architecturalrecord.com** for the complete text and to take the quiz for free.

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Photo by James Ewing / JBSA: courtesy of Architecture Research Office

Figure 1. The mixed-use Alloy Block by Architecture Research Office includes New York City's first Passive House public schools: P.S. 456, the Elizabeth Jennings School for Bold Explorers, and the Khalil Gibran International Academy. The building's design strategy relates to two contrasting urban contexts: the major business and cultural thoroughfare of Flatbush Avenue for the high school entrance and the quiet, brownstone-lined State Street for the primary school. From mechanical dunnage posts to the tube-steel play enclosure, all structural elements that penetrated the insulation layer were equipped with polyurethane structural thermal breaks. Thermally broken brick shelf angles were utilized to maintain insulation continuity and avoid the linear thermal bridges typically found in brick-cavity wall construction.

Photo by Pavel Bendov/Archexplorer; courtesy of Dattner Architects

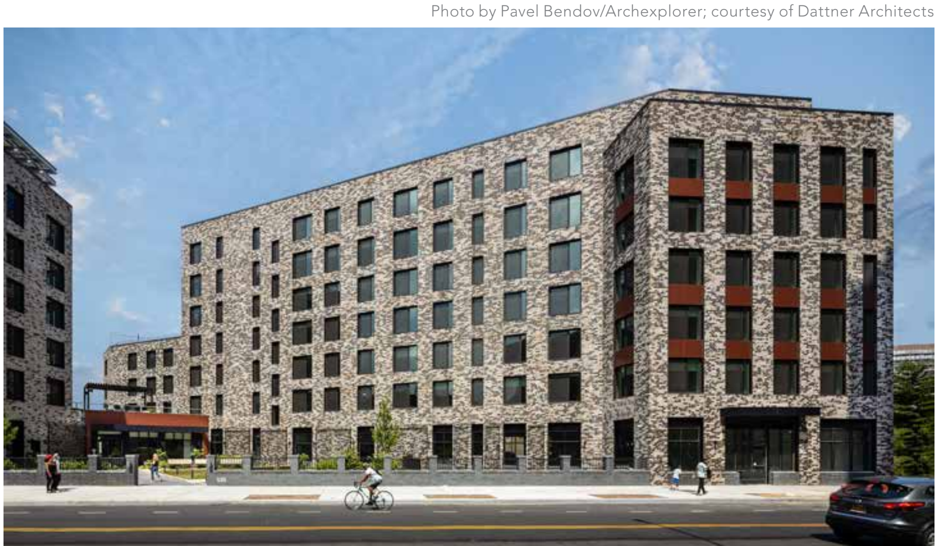

Figure 2. Vital Brookdale, a mixed-use Passive House building with structural steel at the ground floor and cellar, allowing flexible floorplate designs for its non-residential uses, and precast concrete planks and CMU bearing walls in the residential areas; the superstructures meet at the second-floor slab. The entry canopy is thermally broken structural steel, chosen to achieve the desired spans and cantilevered projection.

single-family, 192 multifamily, and 49 non-residential.)

Passive House is of course not confined to houses, or to any particular scale or typology: the standards have been met by multifamily residential buildings, academic buildings, offices, dormitories, hotels, retrofit projects, and others, soon to be joined by New York's largest Passive House skyscraper, the mixed-use Alloy Block in downtown Brooklyn, including a 700-foot all-electric tower and two public schools (see Figure 1).

A building with any structural system can satisfy the Passive House requirements, and beliefs about materials' suitability can be grounded more in assumptions than in evidence. Minimizing thermal bridging is one of the core principles of the Passive House system, and steel is highly susceptible to thermal bridging. Yet despite a common misconception that structural steel is an unlikely choice for a Passive House project, Levenson and other practitioners find steel buildings entirely compatible with the Passive House concept. "Passive House can be built from any construction system," he says; "it's agnostic" toward steel, concrete, masonry, timber, or hybrid structures. "I like to say you can build a Passive House out of radioactive material and still get certified. You couldn't occupy it, but you could meet the energy targets." With proper attention to thermal bridging, using strategies that are both well-understood and continually evolving, steel and steel-hybrid buildings have already met the Passive House criteria and will continue to do so. Many Passive House projects are on a midrise scale, sometimes using combinations of structural materials; a recent example is Vital Brookdale, a residential and community health center in central Brooklyn (the first project in New York State's Vital Brooklyn Initiative), using both structural steel and concrete (see Figure 2).

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Steel Institute of New York

The Steel Institute of New York is a not-for-profit association created to advance the interests of the steel construction industry by helping architects, engineers, developers, and construction managers develop engineering solutions using structural steel construction.

The global Passive House Database, a free compendium of buildings satisfying the criteria according to the Passive House Planning Package (PHPP) tool provided by the PHI, bears out the hunch that the structural steel/Passive House overlap zone is not yet large. Searches in April 2025 for Passive House buildings with steel construction brought up 29 in total, 23 of which are formally certified; of the latter, the only ones in North America are the Carrick Branch of the Carnegie Library in Pittsburgh, the first library on the continent built with Passive House techniques, and Karen's Place, a four-story supportive-housing building in Ottawa. Yet the database's "mixed construction" category includes hundreds more, including a historically important steel/concrete building recently retrofitted by Becker + Becker of Westport to become the nation's first Passive House hotel, the Hotel Marcel in New Haven, Connecticut (originally Marcel Breuer's Armstrong Rubber headquarters; see Case Studies).

Projects currently in design and under construction are set to expand the world's stock of steel Passive House buildings. The feasibility of controlling thermal bridging through design strategies (particularly the "warm frame" principle, keeping structural steel members inboard of insulation) implies that any dissonances between this material and the Passive House standards are more perception than reality. The challenges differ by site and region, by building scale, and by local availability of experience with the system—Passive House practices pose a learning curve for architects, contractors, and clients alike—yet the advantages are clear in the form of lower energy usage and costs, higher indoor air quality, occupants' comfort, and generally upgraded building details. "Once you deliver one project to this high standard," says Ann-Marie Fallon, associate director and certified *Passivhaus* designer at the Hereford/London/Edinburgh-based firm Architype, "I don't think you can ever go back to your old way of working. You just see things in a different light."

THE ESSENTIALS OF PASSIVE HOUSE

The Passive House concept grew out of conversations between Swedish structural engineer Bo Adamson and building physicist Wolfgang Feist in 1988, leading to construction of the world's first *Passivhaus*, a terrace of four residential units at Darmstadt-Kranichstein, Germany, in 1991 (Feist et al.). Its principles can be distilled in a single sentence: "A Passive House is a building, for which thermal comfort (ISO 7730) can be achieved solely by post-heating or post-cooling of the fresh air mass, which is required to achieve sufficient indoor air quality conditions—without the need for additional recirculation of air" (Passipedia).

The system makes assessing a building's energy performance and indoor air quality straightforward. Instead of the subjective criteria and checklist items that leave some sustainable-design programs open to questions of imprecision or greenwashing, Passive House relies on unambiguous metrics. A building qualifies as a Passive House, according to the PHI, if PHPP verification establishes that:

1. The **Space Heating Energy Demand** is not to exceed 15 kWh per square meter of net living space (treated floor area) per year or 10 W per square meter peak demand. In climates where active cooling is needed, the Space Cooling Energy Demand requirement roughly matches the heat demand requirements above, with an additional allowance for dehumidification.
2. The **Renewable Renewable Primary Energy Demand (PER, according to PHI method)**, the total energy to be used for all domestic applications (heating, hot water, and domestic electricity) must not exceed 60 kWh per square meter of treated floor area per year for Passive House Classic.
3. In terms of **Airtightness**, a maximum of 0.6 air changes per hour at 50 Pascals pressure (ACH50), as verified with an onsite pressure test (in both pressurized and depressurized states).
4. Thermal **comfort** must be met for all living areas during winter as well as in summer, with not more than 10 percent of the hours in a given year over 25 °C. (Source: Passive House Requirements, Passive House Institute.)

The concept has spread institutionally, so that an architect seeking information about it has ample resources from a growing national and global community, with the Passive House Accelerator serving as a centralized resource for information and training. The global PHI, based in Darmstadt (and often rendered as *Passivhaus-Institut*), and the Chicago-based PHIUS operate in parallel, with common principles yet different emphases on regional climate variation and slightly different standards for air sealing; both organizations confer certification on projects, offering basic Passive House certification, Passive House net zero options, and retrofit certification. The two use different digital tools in the certification process: PHI's instrument is PHPP, whereas PHIUS accepts either PHPP or WUFI-Passive (pronounced "woofy," an acronym for *Wärme und Feuchte Instationär*, "heat and moisture transport").

Elnecave notes that PHIUS requires 0.06 cubic feet of air flow per minute, as measured by blower-door testing at a pressure of 50 Pascals (CFM50) per square foot of building envelope (walls, roof, and floor), or 0.08 cubic feet for noncombustible steel or concrete-block buildings above five stories (slightly less stringent, allowing for the greater durability of these materials; see *PHIUS 2024 Certification Guidebook*, Airtightness Limits, p. 28). PHI's ACH50 standard, in contrast, is based on building volume rather than surface area. PHIUS also decided for its 2015 standard to make heating and cooling targets climate-specific, reflecting the temperature extremes across North America. "Our analysis is fairly granular," he says, "in the sense that the targets will change based on a weather station. There'll even be differences, let's say, inside of New York State. A project in Syracuse will have different targets than a project in New York City."

The impression that PHI's evaluations are unresponsive to local climate, however, is out of date or worse, some commentators note. "There was a point in time where the Institute had a very limited climate data set," Fallon says, "and it was very central European-focused. However, the latest data sets that are built into the PHPP software are very extensive. Whilst a region as expansive as North America will have nuanced differences, I do believe that both are on very much the same path. Building physics should be the same anywhere in the world." Bruce R. Becker, FAIA, president of Becker + Becker, board member at the Passive House Network, member of the U.S. Commission of Fine Arts, and a certified Passive House designer, comments that "PHI actually does make adjustments for the local geography; that's not widely known," describing the perception that "PHI does not account for geographically specific standards" as misinformation.

Five general principles guide Passive House practice: thermal-bridge-free design, superior windows, ventilation with heat recovery, high-quality continuous insulation, and airtight construction.

HOTEL MARCEL, NEW HAVEN, CONNECTICUT

Marcel Breuer did not design this building to be a hotel, and he never heard the phrase "Passive House": his death in 1981 came seven years before the concept initially arose. Still, after a succession of uses for his Brutalist masterpiece (as headquarters for Armstrong Rubber and Pirelli Tire, then two decades of vacancy), it is now the nation's first Passive House-certified hotel, retrofitted by Becker + Becker in 2022 and renamed the Hotel Marcel. As a member of the Passive House Network's board and a longtime advocate of sustainable and resilient design, architect Bruce Becker took on Breuer's building as both an act of preservation and an experiment in implementing the principle that "the greenest building is the one that exists now."

Though its high-strength precast concrete panels (known as Mosai or Mo-Sai panels after their 1939 trademark by manufacturer Dextone) give the long-distance impression that its structure is concrete (see Figure 3), the Armstrong Rubber Building/Hotel Marcel has a steel structure, built on over 700 steel piles. "I'm sure there was more steel in the frame of this building than in many highway bridges," Becker says, "because it was designed to suspend the upper section of the building." The Mosai panels are hung directly on the frame; both steel and concrete are thermal bridges, Becker notes, and "there was nothing we could do to isolate the thermal transfer through the concrete or through the steel," but on the inside of the Mosai panels they applied several types of open- and closed-cell foam and aerogel to reduce bridging from the precast (see Figure 4).

"A greater challenge was the steel that was lateral to the exterior, that came in and supported the floors," Becker continues. "We had to remove asbestos fireproofing and replace it with new cementitious fireproofing to protect the steel, but we oversprayed it. Rather than putting an inch on, we put [about] 2½ inches on, so that the fireproofing also served as thermal insulation. We weren't actually able to eliminate the bridging, but we were able to insulate the inside of the building from the steel that was conducting thermal transfers."

Photo by Seamus Payne; courtesy of Becker + Becker

Figure 3. Hotel Marcel, formerly the Armstrong Rubber Building by Marcel Breuer: exterior, north facade.

The hotel's exceptionally quiet acoustics, despite highways nearby, are an additional benefit of Passive House-quality fenestration; Becker notes that thermal energy and sound travel through the same paths. "The window uses nonmetallic materials to hold the glazing in place and also to connect the metal on the outside with the metal on the inside," Becker continues; "it's a classic thermally broken, Passive House-compliant window." The windows by Klar were a multinational collaboration, perhaps possible only in a pre-tariff era: "We actually couldn't find a U.S. manufacturer that could meet the standards for the National Park Service, because this building used historic tax credits and had to go through that review process.... We were able to work with this Polish company, which was based in the U.S. but had their plant in Poland, to use German glazing, assembled and fabricated in Poland, and installed by the Polish window company here on site. They're the first triple-glazed windows ever to be approved by the National Park Service for a certified historic rehabilitation."

"So where there's a will, there's a way," Becker says. "Even with metallic materials, if you follow all the principles for Passive House, it's all about the detailing. It isn't so much about the inherent property of the materials that you're working with.... There's a misconception that a steel building cannot be easily turned into a Passive House-certified building, and I think we've disproved that myth."

Photo courtesy of Becker + Becker

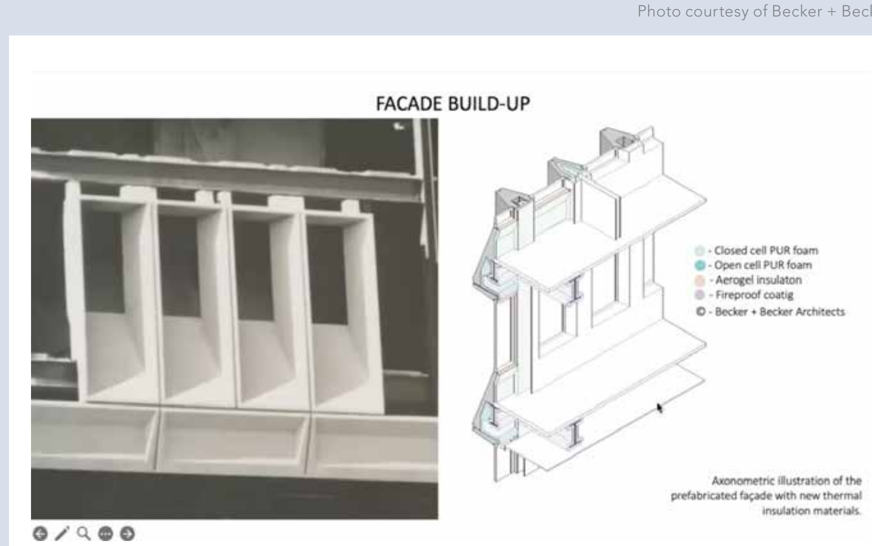

Figure 4. Photo and axonometric illustration of Hotel Marcel's facade with new thermal insulation materials.

The first of these is of greatest concern in steel-framed buildings, either avoiding or minimizing heat transfer through careful detailing of edges, corners, connections, and penetrations. These strategies all occur in a context of close attention to all aspects of a building, from its location and orientation to material selections and small-scale construction details such as bolts and taping. Although a detailed consideration of all five Passive House strategies is beyond the scope of this article, the existence of successful projects with steel or steel-hybrid structures and the available strategies for thermal-bridging reduction and appropriate insulation support the contention that steel's compatibility with the Passive House approach is congruent with its other environmentally sound qualities such as durability, recycled content, and advanced, low-carbon production methods.

STEEL IN *PASSIVLAND*: ALWAYS WELCOME, NOT ALWAYS SIMPLE

Charles J. Carter, SE, PE, PhD, president of the American Institute of Steel Construction, recalls that steel has had a prominent role in the history of Passive House: "If you look at all the original designs, they're usually a steel perimeter and some kind of stone masonry or concrete interior, because the idea of Passive is you're using the sun, but you're using it in a controlled manner." Fenestration and overhangs are essential to control solar gain. "That's really the lure of steel: you can get the least blockage of sunlight with a steel-framed wall." To avoid thermal bridging, "either put the steel on the inside of your perimeter or insulate at the steel and have the fenestration abut the insulation. The reason steel is so good for this is you get the smallest profile of vertical support and the greatest flexibility for the overhangs that you're going to need, so you get it when you want it and you shade it when you don't." Ventilation design in warm climates, Carter adds, puts a premium on certain properties of steel: "If you're going true Passive, you're not doing air conditioning either, so you're looking for ways to get air flow through the building. That's also a place that steel can be an advantage, because you have the maximum flexibility to put ventilation where you want it or where you need it."

Expansion of technical options can overcome some perceptions of incompatibility, Carter suggests. "The fundamental thing that's different today is ability to deal with thermal bridging, and that really didn't exist a long time ago. If you were going to attach to steel, you were going to create a thermal bridge. And today that that might not be the case. There's a lot of products and a lot of success with using those products." Minimizing the size of the pieces connected will also reduce thermal conductivity. "Maybe a close second would be the quality of the window systems," he adds; "it's really common today to have a pretty stringent air-infiltration resistance in the systems." Cantilevered balconies remain a trouble spot, requiring support structures to pass through walls; "you could bring the barrier on the outside of the steel at that point, but you still have some transmission through it.... The challenge is to detail the wall system, the window system, even the joint between the roof and the wall, or the roof and the fenestration, and make it function as a unit. I've seen a lot of different approaches, sometimes bringing the air barrier to the inside, actually right behind the drywall. That one freaked me out a little bit; you're putting everything on the outside of the air barrier."

Carter has not found a consensus on placement of vapor barriers. "We used to say, 'Put them on the warm side.' Well, in Chicago, the warm side during the summer is the outside, and the warm side during the winter is the inside." Moisture can be problematic as buildings become tighter; he is beginning to see temperature-dependent barriers as one solution. "The permeability of the barrier varies with temperature, which is pretty slick. The vapor barrier lets the moisture pass through but won't let the gas pass through. It's all based on the location, and you have to figure that out project by project."

As experience with steel components in Passive House buildings has accumulated, best practices have developed. Michael Lynch, PE, SE, director of modular design at Murray Engineering in New York, reports that his firm has had good results and learning experiences with modular steel construction on several projects in Brooklyn, including the Bethany Terraces senior residence (see Case Studies). "Passive House was an integral part of the design right from the start," he says of these projects. "The steel that's inside the building isn't the problem," he comments; "it's when you have to extend through the facade to the exterior and make sure that that is thermally broken." Strategies for protecting a structure from thermal transfer have evolved from a period when "we went from four- to six-inch steel stud walls, thinking we were increasing the insulation value, but the steel stud walls ended up being thermal bridges through the insulation and were actually more detrimental than the additional insulation we were putting in. Now we're back to the four-inch studs and putting two inches of insulation outboard of the whole structure to improve the performance."

Lynch finds that New York City's rigorous codes for energy and fire rating (limiting multifamily buildings to noncombustible materials) drive clients toward long-range thinking. "In New York City, the drive for Passive House is not a big stretch," he says, and "there is more value for the Passive House in the long term." Bearing in mind the use and maintenance of a building, for "homeowners and developers who are going to rent out and maintain the whole building over time, Passive House has value to them, because the long-term costs are going to drop pretty significantly." Though payback time for up-front investments in Passive House features may be longer, and third-party evaluations for certification add an expense, in New York "the cost impact is not huge... The Passive House actually is so tight that it actually helps reduce the cost of mechanical systems over regular non-Passive House products." His firm has several Passive House affordable-housing projects in the pipeline, using a combination of precast plans, precast panels or CMUs for walls; for canopies and similar components, "when we transfer from the inside to the outside of the building, we're using steel."

The decision to pursue the Passive House standard, commentators agree, should be as early as possible in the planning of a project, because the system requires integrated thinking about variables that optimize performance: shading, the form factor, the complexity or simplicity of surfaces, the use of novel ventilation systems, the amounts of insulation, and the overall quality of construction. "You want to make the decision for Passive House on Day One," Levenson says. "This is one of the biggest distinguishing characteristics between cost-effective and not cost-effective. The worst thing that could happen is you're halfway through DD [design development] and somebody discovers Passive House – or, worse yet, they're in CDs [construction documents] and they [say], 'Oh, we want to make this building Passive House.'" His advice in such cases is, "'No, don't do it. Do

BETHANY TERRACES, BROOKLYN

Photo courtesy of Murray Engineering

Figure 5. Bethany Terraces, eastern facade.

Paul Castrucci Architects, Murray Engineering, and RiseBoro Community Partnership won a blue ribbon in the Buildings of Excellence competition sponsored by the New York State Energy Research and Development Authority (NYSERDA) for a steel-framed senior housing project that meets environmental benchmarks, including Passive House, while optimizing both material efficiencies and affordability (see Figure 5). This team's answer to New York's housing shortage involves apartment modules built offsite, solar energy generated onsite, Passive House insulation and ventilation technologies, and a phenomenally fast construction schedule: delivery of the modules from the Whitley Manufacturing plant in Leola, Pa., to East Flatbush and installation by New York-based Metropolitan Walters took less than three weeks.

This five-story, 58-unit residential building, required to meet Passive House standards from the outset, blended 75 percent modular construction (a welded steel frame with cold-formed steel infill panels forming volumetric modules) and 25 percent site-built work (largely concrete foundations and foundation walls at cellar level, plus a first-floor greenhouse and terraces on floors 2-4). Structural steel components were built offsite, recalls Michael Lynch of Murray Engineering, and assembled inboard of the waterproofing membrane. The design included a solar canopy on the fourth-floor terrace, a steel structure sitting atop a steel structure, with a thermal break on each post (see Figure 6); he describes this component as "a giant section of insulation that is structural and has compressive capacity, installed inside the insulating layer, in this case the roof." Similar structures appear in other designs, he adds, where exterior balconies have set of bolted plates separated by thermal material. Bolts in such an assembly have "a lot less area than if we had the steel touching steel" and are made of a less thermally conductive material, either stainless steel or an alloy with a lower coefficient of thermal transfer. Lynch comments that the point connections with a steel frame and any structures attached to it have a thermal advantage over concrete buildings: although a balcony or parapet connected to concrete requires a continuous thermal break, "with steel, the isolation locations are smaller, because we don't have to do that continuous piece."

Image courtesy of Murray Engineering

Figure 6. Thermal break pad (pink) used on canopy at Bethany Terrace.

Thermal bridging prevention is only one of the features contributing to the building's performance. A rooftop +/-130 kW solar system provides 80 percent of the entire building's energy and 100 percent of its common-area electricity. Energy recovery ventilation (ERV) simultaneously draws in fresh outdoor air and expels stale indoor air, performing heat and moisture transfer inside the ERV, "a key item in the Passive House system," says Lynch. Blower-door testing performed both at the factory and after installation ensured that each residential unit met Passive House airflow standards. Bethany Terraces opened in September 2024 and provides a tangible refutation of assumptions that amenities, environmental performance, and affordability are impossible to combine in New York's residential environment.

the *next* building Passive House. It's going to be painful and expensive and awful, and you'll never want to do one again.' On Day One, if you have it in the programming as a goal, and you can optimize to that, along with everything else, in the bigger buildings the cost premium should be within a few percentage points."

When the Passive House philosophy is embedded in a project, the structural material choice follows. "It makes sense to use steel construction in Passive House to the extent that it makes sense to use steel construction, period," Levenson comments. When economic and supply-chain considerations, environmental performance (often including full assessments of embodied and operational carbon), contractors' familiarity with materials, design considerations, and the other customary variables point to steel, the challenges of thermal bridging are readily managed and need not determine the choice. Nate Thomas, AIA, CPHC, director of sustainability at The Architectural Team (TAT) in Boston, comments that, "Passive House might have a slight influence on your structural method, but most of the time, your structural framing method is going to be determined by building type, height, use, and cost. Above the eight-story mark, you're down to steel, concrete, or mass timber, and in certain regions of the country mass timber is not probably going to be cost-effective, so you're between steel and concrete. Your approach to Passive House is not drastically different, particularly if you go with a thermally broken envelope completely outbound of the structure, hung with thermally broken clips."

In Massachusetts, New York, and other locations, Thomas adds, codes now call for Passive House or near-Passive House metrics and other sustainable standards. TAT is currently designing a Passive House housing project at Boston's West End Public Library site and has opted for a steel and cross-laminated timber (CLT) hybrid frame, after analyzing five structural options, to balance code-driven embodied-carbon requirements, constructability, and cost. "Boston this year is adopting new zoning codes that require you to provide life-cycle analysis, embodied carbon analysis, for your envelope and structure," he notes. "Those decisions can influence your structure, because now a high-recycled-content steel or hybrid structure, like we're doing at the Library, which is a steel frame but a CLT floor-slab assembly, will have a much lower embodied carbon than an all-concrete building."

Clients and architects who opt for Passive House are likely to have other green priorities as well—LEED ratings, renewable energy from photovoltaics or geothermal, the Global Warming Potential of other materials, and healthy-building programs like WELL—and will choose structural systems accordingly. "When you're trying to have that wider impact," says Levenson, "and you're doing the life-cycle analysis and all of these things, so many variables, so many things to speak to, Passive House is nice in that it's not trying to solve *every* problem. It's saying, 'OK, here are some performance goals. We're going to focus on the drivers of those performance goals.'"

STRUCTURAL THERMAL BREAKS AND INSULATION: HUMBLE YET PIVOTAL

Julie Torres Moskovitz, AIA, LEED AP, CPHC/CPHT, founding principal of Fete Nature Architecture and author of *The Greenest Home: Superinsulated and Passive House Design* (Princeton Architectural Press, 2013), points to technical innovations over the past 10 to 12 years affecting the frequent trouble spots for thermal bridging: balconies and rainscreens. Hard plastic structural thermal breaks between a building's structural members and the steel supports of a balcony or metal fasteners for a rainscreen have allayed, or at least reduced, concerns about thermal bridging at these points. "Back in 2010-2011," Torres Moskovitz says, "when I was doing the first certified Passive House in New York City [23 Park Place in Brooklyn; see Case Studies], it took a lot of research to figure out the rainscreen... that could hold [about] four inches of insulation on the back facade, but also have a thermal break at the fasteners. At that point, there were fewer products on the market"; architects and structural engineers "might not have trusted the thermal-break product, this really dense plastic product, as being safe enough or reliable enough."

Today, however, with load-bearing thermal-break products available from Schöck, TekTherm, Armatherm, Marmox, and other providers, and with "increased energy code requiring things like thermal breaks to get a permit," Torres Moskovitz finds that test data adequately support their use and structural engineers have confidence in them. "A lot of architects and certainly clients wouldn't necessarily know that there are thermal breaks that you can use just about everywhere to mitigate your use of steel, so that the thermal bridge is controlled. I think that structural engineers are all fine reading that spec and agreeing to find some product that works in that way.... There's more than one way to do a balcony or work on a rainscreen where you can mitigate thermal bridges." An online store dedicated to Passive House products, she adds, Source 2050, has appeared to address problems that some architects have raised about difficulties obtaining thermal breaks, insulation, and other high-quality parts in North America (Alter).

Levenson finds steel stud walls containing insulation common but unsatisfactory. "Why not just leave the steel cavity empty and run all your insulation outboard? Use that cavity; use the sheathing. That's the point of your air barrier, so it's uninterrupted, and use the steel framing as a service cavity. That's the perfect wall built up, and then the whole question is, 'How am I supporting that rainscreen facade back to the steel framing?' That's pretty common at this point; there are more and more certified systems. We're getting rid of the continuous Z girts." When a horizontal metal flange runs "around the building like a girdle, that flange is undermining the insulation completely."

Todd Kimmel, US senior manager of sustainable solutions at Rockwool, a certified Passive House designer, and a co-founder and chair of the Rainscreen Association in North America (RAINA), emphasizes how today's codes specifically require continuous insulation, usually outside a steel frame. "There are multiple ways to address the insulation," he says. "You could put all of your thermal insulation outside of the framed wall, or you could do what's called split insulation, where you might put some low-density insulation inside the studs and then additional continuous insulation outside the studs. By doing that, you start to limit the impact of the thermal bridging created by the stud framing. The more insulation you put continuously outside the studs, the lower the impact that metal framing has on the conductivity through the enclosure, so you start to not only add thermal resistance through the continuous insulation but make the batt insulation more optimized in the process." Calculations to identify that performance within the holistic Passive House system, he adds, can lead to design choices that compensate for thermal loss at some points through more high-performance fenestration or doors.

"In New York City," Kimmel continues, "where we have a lot of Passive House high-rise buildings and a number of them have metal frame construction, you can run hygrothermal analysis and effective R-value calculations to identify the impact of that thermal bridging," both for certification and to meet code. The Department of Buildings is "cracking down on thermal bridging; whether you're trying to hit Passive House or not, you have to run U-value calculations for any systems that are penetrating the insulation." As wind loads vary with height, he continues, connections may be simpler in a single-family townhouse, where "the only thing penetrating the thermal insulation would be a fastener," than in larger buildings with more connections, and hence more thermal bridging.

Working with RAINA on training, standards development, and terminologic consistency around products related to the envelope, Kimmel has observed some confusion among different manufacturers;

TIGHTHOUSE, 23 PARK PLACE, BROOKLYN

The house that earned New York City's first Passive House certification from PHI in 2013, explains architect Julie Torres Moskovitz (then principal designer at the firm Fabrica 718), was a retrofit of an 1899 residence, a "brownstone-faced veneer with brick," with a modern extension. Her team added a third floor with a steel structure and an angled roof with solar thermal and photovoltaic panels; added a new facade (see Figure 7) built of CMU block with steel columns; and improved the storm drainage from the site. "We were working within a brick shell of a building," she recalls, and "we did have to knock down the back facade and build back with CMU rebar and steel, and then add with steel on the top for the new third floor."

The project faced structural difficulties, Torres Moskovitz notes, and took place while she and others were working their way up the Passive House system's learning curve. "At that point in that environment, there were 10 to 12 other architects and builders working on Passive House," she says. "No one had certified yet, but [they were working] mostly the scale of brownstones and private residences, so I was learning from others. They were visiting my site, and we were all figuring it out from talking to people in Europe that had already gone through this with retrofitting to just learning from each other, learning from builders."

At the same time, she was working on a book of 18 Passive House case studies, *The Greenest Home*, bolstering the American examples the publisher had primarily wanted with projects from Europe and Japan, both of which were ahead of the U.S. in adopting Passive House practices. Conversations for the book with clients and specialists informed her work on the house, as did participation in an overseas Passive House training program; "at the time, there were no tradesmen trainings in the US, so they sent 14 of us to Dublin to do a building-envelope tradesmen training," learning local techniques and materials for insulating windows of masonry buildings. "I got off the plane from that training and practically went right to the job site to help show my contractor how to use the tape and membranes that we had purchased." With 90 percent savings on heat energy and 75 percent on total energy (see Figure 8), the building, renamed Tighthouse, was named winner of the 2014 International Passive House Design Award.

Photos by Hai Zhang; courtesy of Fete Nature Architecture

Figure 7. Tighthouse, front facade (left) and new rear facade (right).

Image by Sam McAfee, courtesy of Fete Nature Architecture

Figure 8. Thermal image showing external temperature of Tighthouse (fourth facade from left) and its adjoining neighbors.

his organization's aims include "develop[ing] specific testing requirements around rain screens from a moisture-management perspective" and providing hands-on training for contractors, trade-union members, and design professionals.

One concern he hears colleagues raising is that Passive House buildings might be too airtight to be safe; he emphasizes that their energy-recovery ventilation and heat-recovery ventilation systems (ERVs and HRVs, respectively) provide not a sealed Petri-dish condition but much better interior air quality than non-Passive House buildings. "The intent is to prevent air from passing through the envelope in the areas where air is not intended to pass through the envelope," he says, areas where it brings moisture and condenses, admitting contaminants and toxins. Colleagues should understand that "Passive House buildings are very intentional about stopping that, making sure that we can quantify the air that is coming through either the mechanical systems or the doors and windows," he says, and that "airtightness is the bedrock for designing mechanical systems."

A SYSTEMATIC APPROACH TO CLOSE THE PERFORMANCE GAP

Fallon, who has worked on retrofits and decarbonization of multi-building estates, and who led the team that produced an influential technical position paper on steel construction—particularly detailed on thermal bridging, its calculation, and its remedies—for the Passivhaus Trust in 2023 (Fallon et al.), points out the common "performance gap" between what is expected when a building is designed to code and its metrics once in use. "The Zero Carbon Hub in the UK has done reports on this way back in 2014," she notes; "typically we're seeing performance gaps of anything from 30 to 50 or even 60 percent more energy being used in buildings than what we're declaring and committing to at the design stage" (Zero Carbon Hub). Another relevant resource is the Passivhaus Trust's comprehensive 2022 review of research on thermal bypass (Siddall). Preventing such a performance gap through foresight is more effective, if not always easier, than recognizing it belatedly and correcting it; as her Passivhaus Trust paper put it, "Generally, the approach with *Passivhaus* is to try to design problems out, rather than having to compensate with additional insulation."

She describes a set of key requirements to consider from the outset of a project: "The first issue for us to consider is the position and nature of the insulation layer. Where is the thermal boundary, and where does that structure sit in the context of that thermal boundary?" In an extreme climate where low U values (high R values) are a priority, or in "a building that has a poor efficiency or form factor, so we're using more insulation, two to four inches, to compensate," the location of the insulation and the structure's interaction with it are critical. The *warm frame* (a term used more in the UK than in North America), with the structure inside the insulation, is preferable to the *blended frame*, where the superstructure and insulation are within the same layer or layers and "we're calculating the thermal bridging effect of that steel to a greater extent through the insulation layer, and maybe having to add more insulation to compensate."

Secondly, she says, the design of the steel *connections and junctions* affects the position of the insulation; the positions and deflection of plates and beams can be complex, with difficulties introducing insulation to ensure that there are no gaps and that U values are optimized. "If we're able to keep all the insulation on the outside of that steel frame," she continues, "which is possible with prefabricated construction and larger buildings that maybe don't need such low U values, we reduce that risk enormously, and that's where the success of steel frame comes at scale." Preventing thermal bridges through the envelope not only reduces heat loss but controls "condensation and dew-point risk within that buildup as well." Not all building scales need the same level of caution: "When we get into super-skyscraper territory, we could be a bit braver, because the sheer scale and volume of the building and its compact form can allow us to be slightly more relaxed about that relationship between insulation, position, and thermal bridging."

The third factor Fallon stresses is the *continuity* of the airtightness layer. In steel-frame construction, the airtightness layer may be on the inside or outside of the structure; it may double as the vapor-control layer, or the envelope may include a separate vapor-control layer. "The easiest way to keep those layers continuous is to ensure that they're on a flat, smooth substrate as much as possible," she says, "rather than trying to duck and dive under all the joints and connections and rivets and components of a steel frame superstructure. You could say that's just good logical detailing, but when we start bringing in airtightness [and] high volumes of insulation, any thermal bypass, any insulationgaps, any poor-quality installation, or poor design work is made worse because we're dealing with more specific temperature differentials and vapor differentials, because we're introducing such a good-quality envelope." With flawed envelopes, warm, cold, or humid air could infiltrate or exfiltrate the building fabric, reducing energy performance and comfort but not affecting the structure; if there is thermal bypass, allowing air behind insulation or through gaps that allow moisture or vapor to condense, structural problems can be worse than with other frame materials.

Another consideration Fallon emphasizes is *windtightness*, separate from airtightness; the latter term describes "an encapsulation of insulation on the warm side of the insulation," while windtightness refers to the outer (usually) cold side, and membranes in both places can reduce moisture and heat-loss risk. She points to a finding by building physicist Hugo Hens two decades ago, based on masonry buildings but applicable to other structures, that "suggested through monitoring that U values could be out by as much as 500 percent because of thermal bypass, and wind washing of insulation is associated with that" (Hens and Carmeliet).

Outer surfaces, including rainscreen cladding and its connecting components, can best improve windtightness when tailored to the local climate. "In our typical cool, temperate climate scenario, which is only a small proportion of climate in America, we would look to have a very diffusion-open membrane for windtightness or weather tightness on the outside, and a much more either diffusion-closed or intelligent diffusion membrane on the inside." (An intelligent diffusion membrane allows a degree of moisture or vapor diffusion, balancing moisture control and breathability.) A hotter site like Mexico City has reverse diffusion in summer, "where there's actually more humidity outside than inside, and your windtightness layer can become almost the vapor layer or the airtightness layer, because it's trying to keep moisture out."

These are "traditional building concepts," Fallon says; "it's not new concepts here. It's how we apply them and execute them now, at a much higher level of quality than perhaps we have in the past to ensure robust building performance and reducing that performance gap." In addition, climate change and natural disasters raise the stakes: increasing humidity with flooding, combined with increasing heat intensity reducing nocturnal temperature decreases (a diurnal fluctuation that naturally helps wick away moisture built up during the day), poses risks of "many buildups having failure on that outside facade."

Relatively modest investments in design consultancies or structural thermal breaks, Fallon and others find, bring substantial returns for Passive House clients. Cost premiums for meeting Passive House standards are lower than expected, particularly for clients who hold onto a building long enough for energy savings to offset and outweigh the up-front investment. In Massachusetts, where opt-in stretch codes since 2023 have required Passive House certification for residential buildings over 12,000 square feet in 45 municipalities (with the Mass Save incentive program lowering the barrier), Thomas reports, "the average premium, going from the robust Massachusetts codes to Passive House, was only about an average 3 percent."

Fallon recalls an even more encouraging assessment of St. Sidwell's Point Leisure Centre in Exeter, UK (the first Passive House project in the normally warm, humid, energy-hungry typology of recreation centers with pools), finding in "the overall cost to the client," Fallon says, "including the construction costs for the project, that Passive House, including certification, only came to half a percent of an increase on the overall project fees.... If we're really only talking about around half a percent, or 1 percent max, and that's including the Passive House consultant and the third-party verifier, to create a building that's really robust, that performs very well, that achieves the energy targets you're setting for, half a percent more is really a no-brainer."

Though figures differ in locales where the base codes are less rigorous than in Massachusetts or the UK, the inherent benefits of Passive Houses endure, including energy efficiency, air quality, durable quality of construction, and a factor that becomes more prominent with climate change: disaster resilience. In the event of flooding, severe snowstorms, hurricanes, and other extreme events causing power outages, Thomas and others point out, a Passive House will maintain its temperature considerably longer than an ordinary building. Torres Moskovitz notes that PHIUS certifies a metric for *passive survivability*, a term popularized after Hurricane Katrina (Wilson). For occupants at risk during such events—whose numbers are unlikely to stop increasing, regardless of whether knowledge about long-range climatic phenomena goes in or out of favor during short-term political cycles—the high standards embodied in Passive House buildings may be a nonmetaphorical matter of life and death.

CONCLUSION

"The biggest challenge," AISC's Carter observes, "is, a lot of what you would do for this isn't common. And so typically, what isn't common will tend to cost more." Though Passive House's learning curves strike some observers as formidable, some architects view it as the future of sustainable design. The LEED system has been operating longer and is the first environmental standards organization most U.S. architects recognize; Passive House is "the new kid on the block in many circles," Becker comments. Yet it is "a standard that is growing at a much faster rate than LEED is. I asked Claude [the AI firm Anthropic's large-language model] what year the number of Passive House-certified buildings will surpass LEED; it was going to be before 2030." [Differently phrased iterations of this inquiry, it should be noted, elicit different results from the AI.] "I think it is going to become the dominant standard pretty soon," aided by its adoption in stretch codes.

Certain misconceptions about Passive House, Torres Moskovitz points out, are easily debunked: "People think that the buildings are hermetically sealed and can't open up, meaning your windows are all fixed, and you have no freedom to open it. That's not the case." Passive House buildings bear no relation to the poorly ventilated 1970s energy-crisis-era buildings that were associated with sick building syndrome. She draws a comparison between the loose seals of double-hung windows, which pass over each other in moving, and the better seals found in casement tilt-and-turn windows, which not only have more daylight entering because of a higher glazing-to-mullion percentage but also have tighter insulation with "a multi-lock system all around." In a Passive House, "in fact, you get more natural light and more ability to have ventilation, fresh air. It's just that you would not want to open your windows on a hot, steamy day, because you're wasting energy."

Levenson points out one broadly appealing aspect of the system for architects: "Passive House re-engages the architecture itself, the fabric of the building, and makes the architecture the driver of performance. It's empowering architects to reclaim their position of power in different ways, where everything has been handed over to the engineers of one stripe or another to develop." The rigorous Passive House standards, implemented with any material, send a message that should be widely welcome: that what's built today is never built exclusively for today.

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