Zero energy and carbon buildings based on climate-specific passive building standards for North America

Katrin Klingenberg, Mike Kernagis, Mike Knezovich

Abstract
In 2015, Passive House Institute US released a new, climate-specific passive building standard for North America. The new standard was the product of a three year research project funded by the U.S. Department of Energy, and performed in collaboration with Building Science Corporation. PHIUS’ work was spurred by its experience in attempting to implement the German standard, developed by Passivhaus Institut in Germany, to projects across North America’s various climate zones. In summary, the German standard led designers to some design errors, and was found not cost effective in much of North America. This paper describes why and how the new standard was developed, how it differs from the German metric and how it constitutes a cost optimized envelope design baseline for reaching zero energy and carbon in North America.

Keyword
passive house, climate-specific standard, cost effective, zero energy, carbon neutral

Introduction—origins of passive house
Although passive house is often regarded as a European concept, the passive building concept was actually the result of North American research efforts that were funded by the US and Canadian governments during the 1970s and 1980s in the...
wake of the oil embargo. That work established the fundamental building science principles that underpin the passive house concept (see Table 2):

- Quantifiable, energy performance design targets for demand and peak loads;
- Established, proven energy-balancing methods.

Renowned physicist William Shurcliff declared the passive house concept mature in 1988 and predicted further technological developments in materials, components, and integrated minimized mechanical systems. These principles—and conservation efforts in general—floundered in the United States and Canada because of political and economic factors. Meanwhile, the German Passivhaus Institut (PHI) worked diligently to refine passive design and introduce the concept to the German government.

The first convincing German proof of concept—a four-townhouse development in Kranichstein in Darmstadt Germany—was completed in the early 1990s. That project achieved its goal—a factor 10 reduction in energy demand in the Central European climate zone. (This target was established at the 1992 United Nations Conference on Environment and Development in Rio de Janeiro.) The Kranichstein project also demonstrated potential for mass-market adoption.

As Shurcliff had predicted, the project triggered the development of higher performance components and systems—a trend that continues today. The German institute’s thorough work clearly analyzed and catalogued results from proof-of-concept projects. It published results and generated curricula to disseminate information and promote adoption of passive house. The Germans’ work was also courageous—it adhered to the ambitious goal of a factor 10 energy reduction.

Through the 1990s and beyond, the passive house concept grew in adoption across Europe, although the total number is difficult to ascertain. Although some estimates are upward of 20,000, that represents projects that used the passive house design methodology and other low-energy designs, not certified passive houses. That number remains in the hundreds.

Notably, some nations have adapted the German-derived standard to their own climate and market conditions—Sweden, Switzerland, and Belgium being three prime examples.

### Table 1. US, mid-continent, North.

<table>
<thead>
<tr>
<th>Cities</th>
<th>ASHRAE 99.6% design temp. (°F)</th>
<th>ASHRAE 99% design temp. (°F)</th>
<th>HDD65</th>
<th>CDD65</th>
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<tr>
<td>Frankfurt (5)</td>
<td>14.5</td>
<td>19.1</td>
<td>5570</td>
<td>308</td>
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<tr>
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<td>40</td>
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<tr>
<td>Madison, WI (6A)</td>
<td>−7.0</td>
<td>1.6</td>
<td>7104</td>
<td>620</td>
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Table 2. Historic development of high-level performance programs and their comparison from 1970s to present.

<table>
<thead>
<tr>
<th>How far to go in reducing heating load</th>
<th>Prescriptive or performance emphasis</th>
<th>Approach to total energy</th>
<th>Approach to quality assurance</th>
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</thead>
<tbody>
<tr>
<td>PHI (1996–present)</td>
<td>Peak load limit ~10 W/m² (3.17 BTU/ft² or 1 W/ft²). Alternate limit 15 kWh/m² a (4.75 kBTU/ft²) annual heating and cooling demand each. Additional allowance for dehumidification on the cooling side in humid climates, supply air heating sufficient, airtightness 0.6 ACH50</td>
<td>Mostly performance</td>
<td>Annual source energy limit, floor area–based</td>
</tr>
<tr>
<td>DOE challenge home/zero energy ready home (2011–present)</td>
<td>IECC 2012 insulation levels, ducts inside, windows R 2.5–3.7, airtightness 1.5–3.0 ACH50, annual heating ~50% reduction from 2009 BA benchmark, annual cooling ~25% reduction</td>
<td>Dual path—all-prescriptive or prescriptive + performance</td>
<td>HERS rating before PV (site energy reduction relative to base case of same design)</td>
</tr>
<tr>
<td>PHIUS + (2012–2015)</td>
<td>Peak load limit ~10 W/m² (3.17 BTU/ft² or 1 W/ft²). Alternate limit 15 kWh/m² a (4.75 kBTU/ft²) annual heating and cooling demand each. Additional allowance for dehumidification on the cooling side in humid climates, airtightness 0.6 ACH50</td>
<td>Prescriptive + performance</td>
<td>Annual source energy limit, floor area–based</td>
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(continued)
<table>
<thead>
<tr>
<th>PHIUS + 2015 climate-specific passive building standards (2015)</th>
<th>How far to go in reducing heating load</th>
<th>Prescriptive or performance emphasis</th>
<th>Approach to total energy assurance</th>
<th>Approach to quality assurance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Based on economic analysis, “cost-competitive” level. Climate-specific limits on heating and cooling demands and loads. Peak heat load ~77% reduction, annual heating ~86% reduction from 2009 BA benchmark. Peak cooling ~69% reduction, annual cooling ~46% reduction</td>
<td>Mostly performance</td>
<td>Annual source energy limit, per person based for residential, floor area based for non-residential</td>
<td>Craft, third-party QA/QC including airtightness test and full commissioning of systems including verification of actual energy use of components under operation, post commissioning after 1 year of occupancy</td>
<td></td>
</tr>
</tbody>
</table>


History of passive building implementation in the United States and Canada

In 2002, Katrin Klingenberg began construction of her own passive house residence. The Smith House, a single-family home in Urbana, IL, provided a successful proof of concept in the United States.

Klingenberg went on to found a non-profit organization that partnered with the City of Urbana, IL, to build two single-family passive houses that qualified as affordable projects. Both these projects (Fairview I and II) were tested and monitored thoroughly by IBACOS, a US Department of Energy Building America (BA) partner.

These projects sparked tremendous interest, reviving concepts that had originally been developed in North America. The non-profit organization expanded its scope and mission to meet the growing demand for training and information to become what is now Passive House Institute US (PHIUS).

PHIUS eventually entered into operating agreements with Germany’s PHI under which PHIUS certified projects in North America to the PHI’s metrics and provided other services. The non-profit PHIUS and the privately held PHI were always, however, completely independent entities. In August 2011, the two organizations ceased any formal collaboration.

By that time, PHIUS had trained 800+ design and construction professionals. As a pioneer of this second generation of passive building, PHIUS became the primary source for passive house consulting and third-party certification services. By the beginning of 2012, PHIUS had certified 20 passive houses throughout the cold, marine, and mixed humid climate zones in the United States and Canada.

Almost every project offered a new challenge—each of the early projects could fairly be described as a first, because climate conditions often varied dramatically from those in Central Europe. PHIUS drew on the original writings and research done in North America in the 1970s and 1980s, the good work of the Germans, and collaborated with leading building science experts in the United States and Canada to develop solutions for the varied North American climates.

In 2012, the Department of Energy (DOE) recognized PHIUS’ work and entered a collaborative agreement with PHIUS to co-promote Challenge Home, now called Zero Energy Ready Home (ZERH), and the PHIUS+ passive building program in the US market.

By 2015, PHIUS expects to have fully certified 250 projects (this number reflects only projects in progress already enrolled in the program and does not include speculation on increase). The project count does not reflect units—a 57-unit multifamily project is, for example, counted as one project. The number of multifamily projects has grown sharply over the last 2 years, especially in the affordable sector. Consequently, the number of certified individual units will approach 1000 by the end of 2015 (Figure 1).

North America requires climate-adapted building envelope design

The German institute has always held the position that the original energy metric derived in Central Europe is universally applicable. To be sure, the concept of a
single, absolute energy performance standard for the entire world was and is a compelling and attractive concept. However, PHIUS—and the community of passive house practitioners—learned that a single metric is not workable.

Generally, North America presents design temperatures that are much more challenging than Europe’s (with some exceptions—for example, the Pacific Northwest). Many areas are significantly colder than Europe during the winter, while the number of heating degree days (HDDs) on an annual basis can look very similar. Madison, WI, is a perfect example: it has a colder design temperature than Oslo, Norway, while the total HDDs are almost 2000 HDDs lower than in Oslo (Table 2). Design temperatures and HDDs are only weakly correlated.

While design temperatures are colder, there is generally very good solar potential in North America. Striving to meet the German metric often led designers to over-glaze. But the glazed areas simply could not perform as well as the superinsulated wall assemblies, and larger glazed areas—intended to maximize solar gain—also increased the peak loads in buildings.

The result is increased temperature swings during a 24-h period, making the buildings more prone to overheating and causing uneven temperature distributions throughout the space.

Increased glazing and insulation levels also resulted in overspending beyond any reasonable cost-effectiveness—making dubious the claim that the PHI’s metric of 15 kW h/m² year is universally useful.

In summary, PHIUS and the North American passive house community learned that it is not possible, in all climates, to optimize for both cost and peak loads at the same time.

Figure 1. PHIUS + certified passive projects trend of the past 13 years, projection for 2015. Source: Wright and Klingenberg (2015).
Also of note, in warmer and milder climates (Northern California, for example), the target of 15 kW h/m² year actually encourages the designer to leave some cost-effective energy savings untapped. Because it was, relatively speaking, easy to hit that target in such climates, designers stopped pushing the conservation envelope when they hit the number—although they could cost-effectively have gone even further with envelope improvements.

In hot and humid climates like Florida’s, designers found out that the cooling targets under the German metric were unattainable altogether. In cooling-dominated climates, insulation simply does not yield the dramatic return in energy savings that it does in heating-dominated climates.

Eventually, PHIUS came to an inescapable conclusion: the underlying passive principles are physics-based and indeed apply everywhere in the world and in any climate. The target metric, however, should be defined specific to climate and also be based on economic/market conditions.

**North America requires a climate-specific approach to balanced ventilation**

Balanced mechanical ventilation with heat recovery has been one of the pillars of passive house design from day 1. Experiences with the original Canadian passive housing built in a very cold climate led to the introduction of mechanical ventilation in the 1980s in response to moisture and mold problems. Three main issues in low-load airtight homes were addressed:

1. Ventilation losses were reduced through a centrally placed whole house ventilation system with heat recovery.
2. Moisture and indoor pollutants such as CO₂, radon, and volatile organic compounds (VOCs) could be controlled.
3. Improved hygrothermal performance of the envelope resulted in superior durability.

At the time, the recommended ventilation air change rate per hour was initially set at 0.5 ACH. Germany’s PHI also recommended the ventilation system with heat recovery and prescribed 0.3 ACH, which closely matches currently recommended ventilation rates in the United States.

As with envelope design, experience taught PHIUS and PHIUS-trained consultants that requirements for balanced ventilation with heat recovery—as well as the current recommended ventilation rates and systems design guidelines—need to be optimized by climate zone. In addition, it became clear that mechanical ventilation with heat recovery makes sense in cold climates; other climates require different solutions.

In terms of ventilation rates, the German prescription was problematic. In cold climates, the specified ventilation rates provided indoor pollutant source control, but those rates also brought in very dry air, creating an overly dry indoor...
environment. In humid climates, the prescribed ventilation rates added to the dehumidification loads:

- All this highlighted a need to lower the ventilation rate and to generally re-evaluate ventilation rates in more extreme climates.
- In cold, dry climates, new guidelines were needed in order to provide moisture recovery that would prevent over-drying.

These new guidelines were necessary for good, energy-efficient systems’ design and indoor air quality.

It became clear that ventilation guidelines should respond to different conditions in various climates. Peak heat, cooling or latent loads and annual demands, should determine the ventilation system design strategies, specifications, and cost-effectiveness. For example, experience showed that heat recovery can be beneficial in cold climates from an economic as well as efficiency perspective, but in mixed and milder climates heat recovery should not be the most important factor. The energy that could be recovered is often not large enough to justify expensive, highly efficient heat recovery systems. In general, the lesson learned was that the European guidelines were biased toward moderately cold climate conditions.

In response, the PHIUS Technical Committee, a volunteer body based on modified consensus and comprising international building science experts and North American passive house practitioners, issued a new ventilation system assessment protocol. It concluded that the coefficient of performance (COP—heat recovered, including fan energy recovered) is the best general indicator to evaluate suitable ventilation systems for all climates. The value of high heat recovery efficiency depends on climate: it has more value in colder climates than in milder ones. For example, a ventilator with relatively low recovery efficiency that has a very efficient motor may be a better choice in a mild climate because there is more limited heat recovery opportunity. In this case, lowering energy consumption of the motor has greater value in lowering the primary (source) energy and corresponding carbon emissions.

The new rating protocol has been applied to ventilators currently available in North America and rated by the Home Ventilation Institute (HVI) and listed in their database (www.HVI.org). The HVI is the central testing agency for ventilators in North America.

COPs and adjusted sensible recovery efficiency (SRE) ratings were generated for the units according to the new rating protocol. The units and corresponding COPs are listed in the PHIUS website (http://www.phius.org/wufi-passive-tools-publications/wufi-passive-and-other-modeling-tools/calculators-and-protocols). Units with a COP of 18 and above are recommended by the PHIUS Technical Committee for use in passive buildings.

The net result is there are more cost-effective ventilators available in the North American market suitable for passive buildings for moderately cold and mixed climates than it had initially appeared under the German rating criteria.
North America requires a climate-specific approach to space conditioning and distribution

The simplified German “functional” definition of a Passivhaus is as follows: a building that can be kept comfortable by conditioning the ventilation air alone, without employing an additional recirculation system.

The problem in North America is that this can be achieved in only a few, small regions of the continent, specifically where temperature differentials are not extreme and peak loads can be kept economically below 10 W/m² through envelope upgrades.

Even in the few regions where it is possible to meet those peak loads, the economic argument for the passive house in Germany falls apart in North America. Here is why: in Germany, the energy recovery ventilators are replacing very expensive hydronic heating systems. But here in the United States and Canada, much less expensive forced air furnaces are the norm. So, there is simply much less money to be saved.

PHIUS recognized that the overall goal should be design guidelines that lead to selection of systems that are economical and that are minimized according to climate conditions.

In some zones—those very similar to Central Europe’s—ventilation-integrated space conditioning can be adequate. But in other, more extreme North American climates, the peak load conditions exceed the carrying capacity of the recommended ventilation air volume to provide sufficient heating, cooling, and dehumidification. Consequently, most current passive projects in North America do not have fresh air–integrated space conditioning systems, but separate the ventilation from the space conditioning entirely.

In some cases, hybrid solutions—where a small portion of the total peak load is integrated in the ventilation system and then supplemented with additional point sources distributed throughout the space—are required. And in yet others, small recirculation systems downstream of the ventilation system are employed to increase the carrying capacity of the air volume and to take advantage of the distribution of space conditioning through one ducted system.

The PHIUS Technical Committee is currently conducting research toward climate-specific recommendations for space conditioning and distribution.

Climate-appropriate passive design tools and software

The Passive House Planning Package (PHPP) developed by the PHI was one of the first comprehensive calculators that accounted for the following:

- Factors that go into the design of an ultra-high-performance envelope;
- Minimized mechanical systems in cool, moderate climates;
- Immediate feedback of impacts of design changes on the energy balance.
Experience revealed limitations of applying the PHPP in all climates. The tool operates on static monthly averaged climate data. This method shortens and simplifies the modeling time by essentially “flattening” the dynamic modeling process. But it comes at the price of lesser granularity.

Flattening and simplification can be justified

- For moderate heating-dominated climates that have no cooling requirements or humidity issues;
- Where heat and moisture exchanges with the opaque envelope components have little effect on the overall building energy balance.

In other climates, the static modeling approach is inadequate. The LeBois House, a single-family home in the hot humid climate of Louisiana, is a prime example. The home was modeled in PHPP and then monitored for 2 years after it was completed and inhabited. Monitoring made it clear that PHPP’s cooling demand and sensible peak algorithms were off by a large margin and that latent loads needed to be accounted for in the German standard (which they were not at the time).

On the positive side, the project performed significantly better on the sensible cooling demand side than PHPP had predicted, by about 35%. This indicated that the PHPP algorithms were likely optimized for cold climate design strategies and still “blind” to passive design strategies for hot climates. Only a dynamic energy model (based on hourly climate data) could account for impacts of radiant barriers and provide the ability to accurately predict impacts of thermal mass and moisture storage on the overall energy balance.

Overall, the project was a huge success: PHIUS learned what was needed for designing passive projects in hot and humid climates. PHIUS also identified requirements for a new passive design tool to meet the hot and humid challenge. Significantly, the project proved that passive principles, the underlying physics, do apply and result in significant energy savings in a hot climate.

In 2011, PHIUS partnered with Fraunhofer Institute for Building Physics and Owens Corning to collaborate on a new passive design tool that addressed the issues that PHIUS had identified in the field and that would more accurately predict energy performance for passive houses in all climates. The effort yielded WUFI® Passive, a whole building simulation tool validated for all climates.

WUFI Passive includes the simplified static passive house verification similar to PHPP and adds critical capabilities. For example, it offers a more detailed and granular whole building dynamic simulation—it does not flatten the modeling process. This makes for more accurate assessment of comfort conditions and adds the ability to model the hygrothermal performance of wall assemblies.

These features enable designers to meet the annual demand requirements, maintain comfort, and avoid risky wall assemblies. The dynamic mode also enables designers to assess thermal storage much more accurately and to assess hygric
storage in building components and its effects on the energy balance. This is critical for accurate energy models in mixed, hot, dry, and humid climates.

The most current release of WUFI Passive offers functionality to model thermal bridges and to model the interaction of envelope design with the mechanical ventilation system. Effects of air flows between rooms and space conditioning distribution can be modeled and accurately assessed from a comfort perspective.

In addition, the software verification mode now verifies projects to the new climate-specific PHIUS + 2015 passive building standards for North America.

**Defining a new climate-specific passive house standard**

In summary, passive principles originated in North America. The German refinement of them and the German-developed energy metric, tool, and design recommendations have proven to work very well in the German climate—and similar climate zones. But when applied in climates other than the cool, moderate heating-dominated baseline climate, the German Passivhaus metric and design guidelines were wanting.

This has had the unfortunate consequence in North America of impeding adoption of passive house principles, which are indeed universally valuable. What designers needed, however, are guidelines on how far to go with passive, conservation-first measures before it becomes more economical to go to active energy generation through renewables.

In addition, designers, builders, and policy-makers are increasingly recognizing the value of performance-based energy metrics—like passive house. Performance-based targets and per-square-foot energy metrics deliver better ability to account for energy or carbon saved over the currently used methodologies of prescriptive codes or reductions over a baseline home.

Consequently, in 2011, the PHIUS Technical Committee embarked on the plan to identify a methodology to generate new passive standards for all climate zones. The effort was conducted in partnership with Building Science Corporation (BSC) and funded by a Building America grant.

The committee began its work by developing four foundational principles for the standard to follow:

1. **Being biased toward conservation** by constraining the envelope design through definition of annual heating and cooling demands and peak loads by climate that have to be met using passive measures first;
2. **Meeting a total primary energy maximum per person** for all energy uses in a building, which is essentially the equivalent to a carbon limit responding very directly to the amount of carbon savings that need to be achieved in the building sector to stabilize the climate;
3. Specifying airtightness to assure the building envelope durability, possibly also based on climate;
4. **Assuring cost-effectiveness** by referencing a zero energy baseline.
The sweet spot then is defined as the optimum design between demand and supply or, more specifically, between energy conservation and energy generation. In a sustainable world, we must look at zero energy and carbon as our goal, and passive design measures take us toward zero. This is the first step in design. From there, two steps need examination:

1. Exergy (low-grade energy) sources such as heat recovery, sub-soil heat exchange, solar thermal, and convective mechanical cooling;
2. Renewable energy sources.

The cost-effectiveness is not justified by a certain level of conservation alone; it is justified by the optimal combination of both conservation and generation, to reach zero energy and, beyond, zero carbon.

The cost of solar technology has come down dramatically over the past few years. This changes the context of passive design significantly. Assuming that zero is the realistic goal in the near future, the cost of photovoltaic (PV) has a significant impact on where the design optimum lies. Zero is realistic right now and positive is not far off, which argues for recalibrating the standard on a regular basis to reflect changing economics and other variables. The new standard is dynamic and will be re-evaluated regularly on a 3- to 5-year cycle.

Table 2 shows a summary of the historical development of passive design guidelines, standards, and their specific characteristics starting with the passive house pioneers and ending with the new PHIUS + 2015 climate-specific passive building standard.

**Methodology and results**

To develop and validate new climate-specific passive building standards, PHIUS and BSC ran models for a typical single-family home in BEopt, with carefully chosen and defined design constraints and energy baseline features, for 110 climate data sets in North America (Figure 3). (BEopt is a cost/energy optimizer tool developed by the National Renewable Energy Laboratory.)

All baseline decisions were carefully conceived and evaluated by the PHIUS Technical Committee. The most optimal and cost-competitive combination of measures from each run was chosen based on the greatest overall benefits (quantifiable financial benefits, as well as benefits such as resilience and carbon reductions). Therefore, the cost-optimal point of measures was first determined in BEopt. Then, heating and cooling demands, as well as peak load targets, were further tightened to a point that would yield additional carbon reductions and resiliency benefits—the ability of the temperature in the home to maintain livable conditions through power outages under extreme conditions (Figures 2).

Assessing the economic value of resiliency and carbon reductions is a major study in itself and fell outside the scope of the standard-setting research. With regard to parameters for comfort during power outages by climate, the PHIUS
Technical Committee is undertaking that work, using WUFI Passive. It will confirm the peak load criteria that identify the design threshold of where a home or building is designed to maintain temperatures not dangerous to human health under extreme conditions and with no access to power. Once that study is completed, there will be a scientific rationale of how far exactly to push beyond the cost-optimal point of the curve to assure resiliency. In the meantime, the Technical Committee acknowledged that the new peak loads are approximations based on preliminary peak load studies that need broader verification.

The single-family home typology was chosen, not to make the case that this is a residential single-family standard only, but because

- The typical single-family home is the most common building type (and therefore must be addressed).
- It represents the energetically worst-case scenario of any building type due to its surface-to-volume ratio. Once a cost-optimized per-square-foot energy metric could be determined in this worst-case scenario, it was reasonable to conclude that larger building types will meet the targets even more economically.

The most important specific parameters that were preprogrammed before any calculations were run were as follows:

![Figure 2. Conceptual plot of the path to ZNE—new climate-specific passive building standards push past lowest cost point 2 to point 3 to assure resiliency. Source: Wright and Klingenberg (2015).](image-url)
1. A typical 2000 ft² (approx. 200 m²) gross floor area home with three bedrooms on a slab was chosen. A base wall assembly was defined as a proxy for R-value—a 2 × 4 wall with exterior foam insulation.

2. The window area was limited to 15% of the gross floor area to be distributed on all orientations.

3. The glazing could be concentrated by the optimizer up to 40% of the total on one specific side (e.g. on the south side in cold climates to allow for sufficient solar gain without falling into the trap of over-glazing; north, in hot climates to minimize overheating). Window quality was constrained to meeting the comfort criteria in all climates, meaning that a minimum surface temperature has to be maintained in any given climate by choosing the appropriate window R-value. In cold climates that meant to not allow any window specifications lower than triple pane windows as the starting point, in warmer climates double pane windows sufficed.

4. A small active PV system of 2 kW was added to determine when the optimizer switches from envelope upgrades to investing in PV as the more cost-effective option. The onsite fraction of the total kW h/year generation was also allowed to offset the source energy criteria.

**Figure 3.** Climate locations for Phase 1 economic analysis.

The Technical Committee decided to use 30 years as the base for the cost–benefit calculations as opposed to 100 years, which was used as baseline by the PHI to determine the cost-effectiveness for the German standard. The tech committee considered 30 years more realistic in the US and Canadian economic context.

In reviewing base assumptions for the model, the committee also decided that the internal loads currently assumed in the German model were unrealistic in the United States and Canada. While the committee agreed that the defaults for internal loads should be stringent compared to the current national average use of miscellaneous electrical loads, they also acknowledged that the current European defaults are only one-seventh of the actual current internal load average in the United States. This has led to a significant mismatch of what is assumed and what happens in reality.

Corrected higher initial internal loads in return impacted heating as well as cooling demand criteria on an annual basis. Higher internal loads make it easier to meet the heating demand threshold and also increase the cooling demand. The internal climate conditions had a direct impact on where those demand criteria need to be defined when setting standards for specific external climates.

**A familiar three-pillar foundation for the new standard**

The German passive house standard was based on three pillars. Our research led to adaptations to all three (Figure 4):

1. The space conditioning criteria were reset on the basis of economic feasibility as described above. The change was to
   (a) Shift to climate-specific thresholds on specific annual heating and cooling demands and peak heating and cooling loads, which were set at a cost-optimal “sweet spot” slightly beyond BEopt’s cost optimum in order to achieve increased resilience benefits. This ensures efficiency measures will have reasonable payback relative to operational energy savings. The peak load thresholds may be adjusted to ensure hourly comfort or the ability of the home to thermally coast through power outages (further quantification and verification of such resilience thresholds through comfort crossover studies in WUFI Passive to be published soon).
   (b) The energy metric per square foot referenced a newly defined interior floor area that is similarly calculated to the conditioned floor area (CFA) as is customary in the United States and Canada. This yields per-square-foot values for passive buildings that can be compared directly to per-square-foot energy metrics for code construction, further facilitating accurate accounting of savings. The German standard references a very different floor area definition, based on German real estate law that yields on average a floor area different from the US and Canadian customary calculations by 20%–25%, rendering the results not suitable for direct comparison.
2. The source energy limit was reconsidered on the basis of a global CO$_2$ emission budget to make the assessment more fair and the calculation more accurate. Adaptations were as follows:

(a) Targets set to a per-person limit rather than per square foot of floor area, at least for residential projects. This follows the fair share principle and removes the penalty for those who seek to reduce their carbon footprint by building small homes.

(b) The source energy factor for grid electricity increased from the German 2.6 factor used under the PHI certification protocol to 3.16, consistent with the US national average according to National Renewable Energy Laboratory (NREL) data, to now accurately reflect US carbon emissions.

(c) The lighting and miscellaneous plug load defaults increased to 80% of the RESNET defaults to better reflect actual US usage and make the internal heat gain calculations consistent with those assumptions.

(d) To bridge the change to more realistic US source energy factor and lighting and plug load defaults, the standard temporarily relieved the source energy limit to 6200 kW h per person per year. This is intended to be tightened again to 4200 kW h within a few years with the expectation that new technological developments and an increase in efficiency of systems will justify this improvement.

(e) The standard sets a maximum source energy limit. When calculating a project’s source energy use, the estimated fraction of onsite PV or other renewable electricity is used to offset (reduce) that project’s calculated source energy use. This puts PV on a similar footing to how solar hot water is currently treated. (For a typical residence, most of the output of a 2-kW PV array would “count,” depending on the climate.)

3. The airtightness requirement was reconsidered on the basis of addressing moisture and mold risk, using dynamic hygrothermal simulations. The change was from a volumetric limit of 0.6 ACH50 to 0.05 CFM50 per square foot of gross envelope area. This allowed the airtightness requirement to scale appropriately based on building size. Under the German requirement, a larger building could in actuality be up to seven times more leaky than a small single-family home that tested the same.

In its structure, the standard also retains the feature of three hurdles—or limbo bars—to net zero (energy or carbon). The designer’s attention is directed first to reducing heating and cooling energy use by passive means (including some mechanical devices that yield low-grade energy), then to reducing total energy demand by efficient equipment (and some renewables), and finally to net zero by more renewable generation.

The DOE study was published in July 2015 (Wright and Klingenberg, 2015). The parameters and the methodology on how to set the standard were finalized.
and 110 climate studies for various cities in North America are completed. Originally, a standard-by-zone model was envisioned. This idea has been replaced by an algorithm that accurately calculates the respective heating, cooling demand, and peak loads by location (Table 3). Specific location criteria can be found on the website www.phius.org by clicking on the location of interest (Figure 5).

A formal feedback process on the published DOE draft report was held and concluded. The new standard was launched by PHIUS on 15 March 2015.

Table 3. Summary of new PHIUS + 2015 climate-specific passive building standards and secondary design recommendations.

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<th>Parameter</th>
<th>Unit</th>
<th>Requirement</th>
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<td>Primary Energy</td>
<td>kBTU/ft²/yr</td>
<td>( \frac{\text{Bedrooms} \times 6200 \text{ kWh} \times 3.412 \text{ kBTU/kWh}}{6000 \text{ CFM/ft² shell @ 50 pa}} )</td>
</tr>
<tr>
<td>Airtightness</td>
<td>cfm/ft²</td>
<td>0.05 cfm/gross ft² shell @ 50 pa</td>
</tr>
<tr>
<td>Annual Heat Demand</td>
<td>kBTU/ft²/yr</td>
<td>1.0 - 12.0</td>
</tr>
<tr>
<td>Annual Cooling Demand</td>
<td>kBTU/ft²/yr</td>
<td>1.0 - 21.4</td>
</tr>
<tr>
<td>Peak Heat Load</td>
<td>BTU/ft²/hr</td>
<td>0.8 - 5.4</td>
</tr>
<tr>
<td>Peak Cooling Load</td>
<td>BTU/ft²/hr</td>
<td>1.8 - 8.9</td>
</tr>
</tbody>
</table>

**Figure 4.** Summary of new PHIUS + 2015 climate-specific passive building standards and secondary design recommendations.

**Figure 5.** PHIUS + 2015 climate-specific passive building standards (www.phius.org).
Table 3. Zone median space conditioning targets, by diminishing returns heuristic.

<table>
<thead>
<tr>
<th>Zone</th>
<th>Specific space heating demand (kBTU/sf-iCFA year)</th>
<th>Specific space cooling demand (kBTU/sf-iCFA year)</th>
<th>Peak heating load (manual J) (BTU/sf-iCFA h)</th>
<th>Peak cooling load (manual J) (BTU/sf-iCFA h)</th>
<th>Recommended maximum window U (winter comfort) (BTU/h sf F)</th>
<th>Window Solar Heat Gain Coefficient (SHGC) indication</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>13.2</td>
<td>0.2</td>
<td>8.4</td>
<td>5.0</td>
<td>0.10</td>
<td>Hi</td>
</tr>
<tr>
<td>7</td>
<td>7.5</td>
<td>0.4</td>
<td>7.6</td>
<td>4.6</td>
<td>0.12</td>
<td>Hi</td>
</tr>
<tr>
<td>6A</td>
<td>6.3</td>
<td>2.6</td>
<td>7.4</td>
<td>5.9</td>
<td>0.13</td>
<td>Hi</td>
</tr>
<tr>
<td>6B</td>
<td>6.0</td>
<td>1.6</td>
<td>8.0</td>
<td>5.8</td>
<td>0.14</td>
<td>Hi</td>
</tr>
<tr>
<td>5A</td>
<td>6.0</td>
<td>3.2</td>
<td>6.5</td>
<td>6.2</td>
<td>0.16</td>
<td>Hi</td>
</tr>
<tr>
<td>5B</td>
<td>5.6</td>
<td>1.5</td>
<td>7.3</td>
<td>6.0</td>
<td>0.16</td>
<td>Hi</td>
</tr>
<tr>
<td>4A</td>
<td>4.8</td>
<td>5.3</td>
<td>6.3</td>
<td>6.4</td>
<td>0.18</td>
<td>Varied</td>
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<td>4B</td>
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<td>4.75</td>
<td>6.4</td>
<td>6.6</td>
<td>0.21</td>
<td>Varied</td>
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<td>4.5</td>
<td>0.7</td>
<td>5.6</td>
<td>6.1</td>
<td>0.23</td>
<td>Med-Hi</td>
</tr>
<tr>
<td>3A</td>
<td>3.0</td>
<td>9.6</td>
<td>6.4</td>
<td>7.95</td>
<td>0.20</td>
<td>Hi</td>
</tr>
<tr>
<td>3B</td>
<td>1.6</td>
<td>3.0</td>
<td>5.65</td>
<td>8.05</td>
<td>0.29</td>
<td>Lo-Med</td>
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<tr>
<td>3C</td>
<td>0.9</td>
<td>0.07</td>
<td>5.4</td>
<td>4.9</td>
<td>0.40</td>
<td>Hi</td>
</tr>
<tr>
<td>2A</td>
<td>1.4</td>
<td>12.9</td>
<td>5.45</td>
<td>8.0</td>
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<td>Lo</td>
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<td>2B</td>
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<td>13.4</td>
<td>4.7</td>
<td>10.7</td>
<td>0.28</td>
<td>Lo</td>
</tr>
<tr>
<td>1A</td>
<td>0</td>
<td>16.8</td>
<td>1.75</td>
<td>7.8</td>
<td>N/A</td>
<td>Lo</td>
</tr>
</tbody>
</table>

Conclusion

In North America, passive building is quickly becoming the foundation for zero energy and zero carbon buildings. The high-performance community has long been searching for a design methodology that facilitates optimization of supply side measures and demand side measures. Climate-specific passive building standards facilitate just that.

The passive house concept has a longstanding successful record and now specifically responds to the North American construction sector’s cost structure, energy prices, and PV costs. The quantifiable energy performance standard and its associated quality assurance programs have been recognized by law and policy-makers as an effective tool for achieving energy and carbon savings.

While more feasible to meet in extreme climates, the new standard still pushes a very aggressive overall energy use intensity (EUI), more stringent than any other green rating or DOE high-performance home program. The new standard still assures that projects meet the overarching goal of global carbon reductions.

The experience in the United States has shown that applying the technology without adaptation to culture and climate will not result in optimal outcomes. The guiding design criteria for the envelope must be climate-specific as well as calibrated against current and local cost structures. Proper application of climate-specific design criteria indeed presents the most cost-effective and broadly applicable approach to zero carbon buildings.

PHIUS’ and BSC’s research toward climate-specific passive building standards, therefore, can serve as a model to facilitate similar developments globally in all climate zones and cultures. With the specific local conditions in mind, work is underway to transfer the standards’ development methodology and to generate similar standards for countries worldwide.

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