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In Defense of the Passive House Standard

A point-by-point clarification of why the Passive House Standard sets a worthy goal for North America

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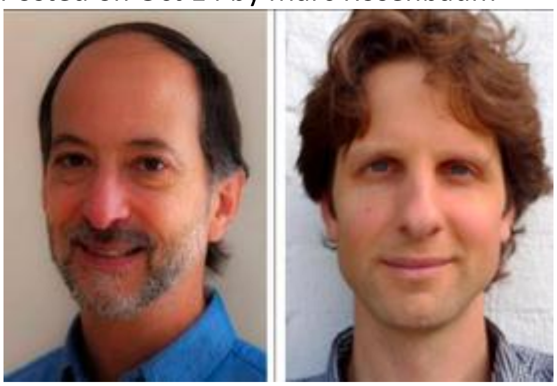

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By Marc Rosenbaum and David White

We recently read John Straube's paper, "Comparing Passivhaus Standard Homes to Other Low-Energy Homes," comparing the Passive House (PH) standard with the Building Science Corporation (BSC) cold-climate approach. After a careful reading we find that the conclusions reached are based on some significant misunderstandings about the Passive House standard. In this paper we will note these misunderstandings, page by page, and will compare the heating energy requirements and total primary energy requirements of the BSC example house (as given in Insight #25) with the PH standard applied to the same house.

Our intention in writing this article is to further the inquiry into Passive House and its application potential in North America. We have both spent a great deal of time investigating Passive House over the past few years, and draw on our own personal experiences to offer to the collective inquiry what we feel to be reliable information.

The Same Energy Budget In All Climate Zones

BSC alleges that PH has “a complete disregard for climate zone in its recommendations.” It is more accurate to say that its maximum energy use targets are the same in all climate zones, which necessitates more stringent design as the climate gets colder. This prescription may indeed bear some examination, yet it's not clear that it is less arbitrary than the BSC "5-10-20-40-60" approach described on Page Four. Passivhaus Institut in Germany is considering how the 15 kWh/m2/year space conditioning targets might be altered for extreme climates. Ultimately this discussion will include a deeper examination of what our per capita resource budget should be. Should people in colder climates use more energy in their homes than people in warmer climates, or should everyone have a budget no matter where they live?

In almost all cases Passive Houses do have heating systems. Passive solar design principles are not mandatory, as BSC correctly states, yet it is very difficult in cold climates for a single-family house to meet the standard without good orientation and locating most of the glazing on the south side. The Passive House Planning Package software (PHPP) does an excellent job of showing the energy balance through all the glazing by orientation, as well as clearly showing the losses separately from the gains. The results from design changes can be seen clearly and instantly and make the PHPP a powerful teaching tool even for experienced designers.

Delivering Heat With the Ventilation System is Not Required

BSC has the primary requirements of the PH standard correct, but misinterprets Dr. Wolfgang Feist's comment:

"As long as you build a house in a way that you can use the heat-recovery ventilation system — a system that you need anyway for indoor air requirements — to provide the heat and cooling, it can be considered a Passivhaus. Since you need a house to be tight, you need a supply of fresh air. If you need that anyhow, the idea is to do everything else — the heating and cooling and dehumidification — with the ventilation system."

BSC takes this statement for its converse, that any heating and cooling system that also provides ventilation (presumably as a portion of its total air flow) makes a Passive House. The rationale of the fresh air heating system is that such a small system has a very low incremental cost, after taking mechanical ventilation as a given, compared to a conventional German hot-water radiator system. Radiator systems are less common in the U.S., and how the mechanical-envelope cost tradeoff game is played here is a very interesting question to us. But it's worth noting that due to excellent window surface temperatures, the heating can be delivered at any point in the room, minimizing duct runs. Further, were heating/cooling equipment mass-produced for this purpose, it ought to be less expensive than conventional equipment.

PH standard agrees with BSC that delivering all the heating with the ventilation system may be overly restrictive, so this is not a requirement. Some use supplementary electric heat, while others use recirculating forced air systems. However, the peak load may not be as restrictive as it seems. Due to superlative envelope design, even light-construction passive houses experience negligible drops in temperature during unmet load hours. For this reason peak loads are calculated over a full 24-hour cycle, which means not only a less severe outdoor temperature, but also the use of that day's internal and solar gains to offset the load. This makes a big difference. For a current project in Syracuse, the 24-hour average temperature, used in place of ASHRAE 99.6% temperature, results in a 15% peak load reduction. Combining this with useful internal and solar gains leads to a total reduction of 38%.

Secondary requirements include maximum window U-values and minimum heat recovery efficiency. Both of these requirements have been relaxed somewhat in North America due to the scarcity of products that meet these requirements. We suggest that a key contribution of the PH standard in Germany is the market stimulation for dozens of innovative products - including low U-value, airtight windows and doors; very efficient HRVs/ERVs; combination mechanical systems; home run small diameter flexible duct work; excellent air tightness products; and more – to serve the demand created by the PH standard. It's worth noting that the PH standard for efficient ventilation includes both thermal and electrical efficiency, and only one product in North America meets these standards.

The most significant BSC misunderstanding of the PH standard for the purposes of comparing PHs to US houses is the PH method for calculating floor area. It uses a German standard procedure for "Treated Floor Area." It's the area inside the exterior walls, less interior walls and staircases as well as columns over a certain size; and also less 40% for secondary spaces such as storage, mechanical rooms and basements. In the case that BSC references, a raised ranch, we believe that PH would count all the finished conditioned basement area at 100% since it would have normal light and ventilation, but mechanical and storage spaces would be counted at 60%. The result is that the BSC 25 x 40 raised ranch would likely count at about 1,600 sf instead of the 2,000 sf that is based on exterior dimensions. This will be significant in the following comparison, as we compare the total energy of the BSC house (by BSC's own estimate) with its requisite performance to meet PH standard.

Dimensions to outside of framing: 25' x 40'
U.S. floor area: 2,000 sf
6" envelope thickness upper level (to outside of 2x6 frame): 24 * 39 = 936 sf
12" envelope wall thickness lower level (concrete + foam): 23 * 38 = 874 sf
Interior floor area: 1,810 sf
Less stairwell, 50 sf per floor: -100 sf
Less 40% of mechanical and storage space @150 sf: -60 sf
Less partitions, 4.5" @ 150 ft length: -56 sf
Treated Floor Area (Passive House): 1594 sf = 148 m2

Passive House originates in a specific heating energy demand reduction strategy aimed at cost effectiveness, and the Passive House Planning Package software reflects that. However, PHPP calculates cooling loads as well, and has a useful feature which informs the modeler what percentage of the time the building will overheat in the absence of any mechanical cooling. There are sophisticated natural ventilation worksheets in PHPP and detailed shading analysis which help the designer to minimize the cooling load before mechanical cooling is applied. Similarly, there are detailed worksheets to analyze lighting, appliance, and mechanical parasitic loads.

BSC is correct that PH includes the analysis of thermal bridges. This is because the measured energy use of the early PH's exceeded the modeled energy use, and the PH scientists learned that bridging - in a truly superior envelope - can result in significantly higher conduction loss percentages than in a typical building. Although 2D heat transfer analysis is often done in the US, we think that the formalization of thermal bridging calculation into the PHPP and the extensive cataloging of thermal bridging coefficients for construction details is another PH contribution to North American designers' understanding of how energy moves in buildings.

BSC re-states the 0.6 ACH50 air tightness requirement, and says that this results in designers having to choose simpler shapes. We ask, why should building form not contend with environmental performance? Tightly massed, simple shapes were the norm in cold climates until the advent of cheap non-renewable energy. Cost effectiveness is the principal mantra of the US building industry, and cost effectiveness begins with minimizing surface area of a building, so the owner buys less wall, roof, and foundation for the usable floor area gained. PH doesn't require any particular design type, but by basing the maximum space conditioning energy consumption on usable floor area it forces designs with more surface area to work harder to achieve the standard. That's a good strategy – prescriptive standards such as BSC's 5-10-20-40-60 rules of thumb, or ASHRAE 90.1, or most energy codes, don't take into account design as the greatest driver of how much energy a building uses. PH does – it's a performance standard rather than a prescriptive one. "Green" designers are clamoring for formal expressions of sustainability, and all too often expressing in ways that are useless or counterproductive, consequently leaning more heavily on mechanical solutions and setting bad examples for others. PHPP offers them a way to make forms that work.

The BSC discussion on airtightness states that the PH standard of 0.6 ACH50 is too difficult to achieve for production builders. In Germany and Austria, this has proven to be untrue. Are they better builders than we are? One very experienced PH architect told us that the problem with German builders regarding air tightness is that each of them carries a knife, "...and so they are happy, but not we." He then went on to show us air tightness products that evade the knife. We don't expect their builders are better than ours, but we need to support the North American builders with products and methods to achieve these targets.

It is true that the incremental energy benefit of the air tightness target is very small, even by PH standard. We agree that the air tightness requirement may be separately specified because of a concern over durability of superinsulated envelopes. One of the authors was also given the following explanation by an experienced PH planner: in a Passive House, the use of a low velocity, high-temperature forced air system, with delivery not infrequently at ceiling level, means that the ability of the heating system to mix the air is very poor. For this reason even a small amount of infiltration can be a comfort problem, as cold air collects at floor level.

Dual core HRVs are not used in Europe to reach the required high efficiencies; they usually require more electrical power due to higher pressure drop. Rather, counterflow heat exchangers are common, and were available in North America years ago but have virtually disappeared from the market. Again, we need, here in North America, the innovative products PH has spawned.

ASHRAE 62.2 Assumes That Envelopes Leak

BSC is correct that the NFRC rating method for window U-value leads to higher values than the European convention. It is also true that the quality of windows needed for achieving PH performance in cold climates is difficult to find on the North American market, certainly from the major manufacturers, and this has been recognized by builders of low-energy-use houses in cold climates here for three decades (in the late 1970s one of the authors built windows for his own house with 4 to 6 layers of optically clear 4 mil polyester between two layers of clear glass ☺.) U.S. windows have a long way to go even to achieve parity with what is currently available in Europe. As California (and the rest of the US as a result) did with refrigerator efficiency, we need a government mandate with minimum window performance to raise the bar for everyone and bring much better windows to the market with a small increase in cost (the real price of refrigerators has dropped since 1970, although energy efficiency has improved by factor 4). PH arrived at maximum window U-value requirements from the consideration of human comfort and radiant heat exchange, not principally from energy requirements, and this is more challenging in cold climates. Right now we can't meet the PH recommendation for interior surface temperature in cold climates with windows available here.

The discussion in the BSC paper on over-ventilation and its energy penalties lacks key information: ASHRAE 62.2 explicitly assumes 0.02 cfm/sf of infiltration as a component of the total air change in the building. BSC's 50 cfm of ventilation for the 2,000 sf, three bedroom house is added to 40 cfm of assumed air leakage, resulting in a 90 cfm ASHRAE expectation in this house. The PH requirement for this house is about 80 cfm, with much less infiltration – about 10 cfm seasonal average– so the total is close to ASHRAE 62.2. Thus PH ventilation is not tantamount to using a mechanical ventilation system to impose air leakage, but rather diverts the typical leakage through the mechanical ventilation system, so that it can serve both heat recovery and space heating. IAQ is also improved – as we all agree, cracks are of questionable cleanliness.

PHPP does warn against overventilation leading to overly dry air (at around 110 cfm for this house). To our knowledge, ventilation rate is not increased to deliver heat in cold climates.

At this point we begin to inform the numerical discussion using the calculation of Treated Floor Area. To provide a peak load of 10 W/m2 of TFA for the 2,000 sf home would require only 81 cfm (68°F room, 126°F air, 1600 sf TFA), not 115. And as we demonstrate above, this is a good ventilation rate by ASHRAE standards for a house with PH air tightness. This means that a fresh air heating system provides about 30% less power than BSC supposes; but as noted above, the peak load could be almost 40% lower than BSC supposes.

Passive Houses Can Have Hydronic or Forced-Air Heating Systems

In our experience, many PH have been built with conventional hydronic and forced air heating systems. It is worth noting that in very low-load buildings the radiant floor will not be perceived as being warm (2°F above air temp at peak load) unless it's concentrated in a small area like a bathroom. Recirculating air systems are common in the authors' current PH work, yet they are much smaller than American systems – around 0.15 cfm/sf. This is not only because the envelope and ventilation heat losses are minimized – it's because those envelopes justify a paradigm shift in peak load calculation, as noted above. The ductwork is still ventilation scale, and there is substantial capital savings in equipment size (even for single family homes), perhaps more as some of the German modular systems make their way to North America.

While durability and air quality may not be explicit in the text of the PHPP, they are both of paramount importance to the community that developed and implements PH in Europe, as they are to all of us. Some are implicitly addressed in the PHPP, for instance in the air tightness standard and the ventilation guidelines.

The BSC Design Uses 365 More Therms Per Year

The BSC paper concludes with a comparison of a BSC 5-10-20-40-60 house and a PH. We use BSC numbers here, the correct numbers for a PH, and matching conversion efficiencies for mechanical systems. Starting with heating, BSC gives the 2,000 sf house a heating load of 12,500 kWh/yr, which is served by a natural gas furnace at 96% efficiency, so the energy usage is 13,021 kWh annually. Our understanding is that BSC houses can achieve better performance than this, so note that this number may be high. PHPP converts this to primary energy with a factor of 1.05 (recognizing that it takes energy to deliver the gas to the house) so the primary energy for heating is 13,672 kWh.

The PH would have a Treated Floor Area of 1,594 sf – which is 148 m2 (see TFA calculation above). Its maximum allowed heating load would be 148 m2 x 15 kWh/m2/year, or 2,220 kWh. With the same gas efficiency and primary energy conversion, this is 2,428 kWh/year of primary energy.

BSC adds 4,000 kWh of gas at 92% efficiency for DHW, resulting in 4,565 kWh/year of primary energy, and 4,000 kWh of electricity for lights, appliances, and mechanical parasitics, with a primary energy factor of 3.0, resulting in 12,000 kWh/yr in primary energy. Total primary energy for the BSC house is 30,237 kWh/year – for the PH it is 18,928 kWh/year. Per square meter TFA the figures are 204 kWh/m2yr for the BSC house and 128 kWh/m2yr for the PH. So the PH doesn't quite make it either (maximum primary energy must be below 120 kWh/m2/yr), although PHPP assumptions for electricity PE factor, DHW usage, plug loads, etc. would in fact make it certifiable (another discussion).

Recognizing that the DHW and electricity in this comparison have been the same in both houses, let's focus on the difference in heating energy. The difference in fuel consumption is 365 therms/year. Is this a trivial quantity? We don't think so. Using BSC's approach of making up the primary energy difference with PV, it would require about 3 kW of PV to offset the 11,244 kWh/yr of additional primary energy required for heating. At $8,000/kWp installed, this is $24,000. Is this less costly than spending the money to upgrade the BSC house - already quite good - to PH standards? We think not. Also note that PV is very energy-and-materials intensive to make, and is for the former reason assigned a PE factor of its own in PHPP calculations. Further, the extra insulation and air tightness of the PH won't wear out (one author was an early adopter of grid-tied PV – his first inverter has long since bit the dust), are most economically provided during initial construction (while PV can wait), and guarantee survivable conditions during an extended fuel outage. These may be reasons that the heating energy demand target stands separately from the primary energy target in the Passive House standard.

BSC goes on to assume the levels of improvement that would be required to bring the BSC house to PH levels. It is not necessary to cut the losses in half to cut the heating demand in half. The gains – solar and internal – remain more or less constant, so the net is reduced by half long before the R values are doubled. This is a point of leverage for the method - a typical Passive House has around 30-50 kWh/m2a of losses, with the gap to 15 kWh filled by solar and internal gains.

The R-values needed to meet the PH standard depend on the location of the house. A superinsulated house modeled on PHPP for Burlington Vt will use double the heating energy of the same house in Boston, because Burlington is 40% colder and has slightly lower wintertime solar gains. This suggests that a prescriptive rule of thumb such as the BSC 5-10-20-40-60 will result in substantially different energy consumption when used over multiple climate zones. We'd like to see some flexibility in the PH standard for climate, and also an approach that makes achieving the standard with smaller houses no harder, or even easier, than for larger ones, but we like the defined target aspect of PH, which sets it apart from all North American approaches we are aware of.

Idiots and Maniacs

BSC concludes that PH is too restrictive architecturally, more expensive, and not significantly more efficient than the BSC approach. We think that European experience belies all three claims. There is much discussion in our community about the PH standard that is not fully informed. We suggest that studying Passive House and the PHPP is time well spent, both to understand the experience and insight that has gone into the PH standard, and to sharpen one's understanding of energy flows in very low energy use buildings. The information regarding peak loads and useful gains mentioned in this article alone could inform the BSC house – it may be closer to cost effectiveness thresholds than thought.

George Carlin said, "Have you ever noticed that anybody driving slower than you is an idiot, and anyone going faster than you is a maniac?" Well, that might be a maniac we see hurtling down the road, but the fact that he's still going begs the question, how much faster can we go without getting pulled over? The nature of the climate challenge asks us to reduce the energy used in buildings as quickly as possible. We'll progress fastest if we share our knowledge and experience without attachment to any one particular way of doing things.

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