NORTH AMERICAN WAY FOR PASSIVE HOUSE BASED NEAR ZERO ENERGY BUILDINGS

1. INTRODUCTION

Until August of 2011 PHIUS (Passive House Institute US and PHI (the German Passivhaus Institut) were collaborators. Both organizations worked off of design guidelines established by the German institute. The German institute's work initially picked up where government funded work done (in the wake of the oil embargo) in the US and Canada during the 1970s and 1980s left off. The passive house concept and fundamental principles--energy metric design guidelines for demand and peak loads and energy balancing methods--had been established by then.

Renowned physicist William Shurcliff declared the technology and concept mature in 1986 and predicted further developments in materials, components and minimized mechanical systems. Building on this work the German institute worked diligently to refine passive design in order to introduce the concept to the German government.

The first convincing proof of concept research project—a four-townhouse development in Kranichstein in Darmstadt Germany—was completed in 1990. That project achieved its goal—a factor 10 reduction in energy demand in the Central European climate zone, which was the target set at the 1982 Earth Summit in 1982. It also demonstrated potential for mass market adoption.

The project also helped trigger the development--predicted by Shurcliff in1986—of better performing components and systems. The German institute's work was extremely thorough-- it clearly analyzed and catalogued results from proof-of-concept projects. It published results and generated curricula so that passive concepts and methods could be shared and taught. The German's work was also courageous—it adhered to the ambitious goal of a factor 10 energy reduction. Moreover, it gave new life to the basic principles that had floundered in the United States and Canada because of political and economic factors.

1.1 The problem identified

In 2002 Katrin Klingenberg and her husband set out to build a proof of concept passive project in the United States, The Smith House, a single family home, that was successful. It was followed a few years later by the two houses (Fairview I and II), which were monitored and tested by the U.S. Department of Energy Building America partner IBACOS.

The Passive House Institute US (founded in 2003) collaborated with PHI until 2011 on reviving passive building to the United States. This time—as opposed to earlier decades--conditions were more favorable and this second generation of passive building gained momentum. By August of 2011 PHIUS construction and training activities had led to 20 certified passive homes throughout cold, marine and mixed humid climate zones in the US and Canada. Approximately 800 building professionals had been trained using the principles to design and build passive homes in the various climate zones.

From the beginning, PHIUS' work in the US was informed by but mostly independent from the German institute. That was by necessity, as North America's multiple and more extreme climate zones presented new challenges for passive building.

When PHIUS began applying the principles and the German-develop standard in the United States and Canada, it was not entirely without risk. PHIUS was a pioneer of this second generation of passive building and therefore the primary source for passive house consulting and third party certification services. As a consequence almost all of PHIUS' projects were "firsts."

PHIUS received consulting requests from all over the country and Canada and almost every project offered a new climate challenge. Driven by building science, it sought to resolve the new issues presented by multiple and more extreme climate zones in the United States. PHIUS drew on the original writings and research done in North America in the 70s and 80s, the good work of the Germans, and collaborated with leading building science experts in the United States and Canada.

1.2 North America requires climate-adapted building envelope design

The concept of a single, one-size-fits-all absolute energy target for heating and cooling demands and loads –for the world over—was and is a compelling and attractive concept. It offered simplicity and universality.

PHIUS—and the community of passive house practitioners—learned from experience, however, that it’s not workable. Applying one energy metric in all climates (that change gradually in temperature from north to south) obviously will lead to different requirements for the building envelope. In a very cold climate more insulation and higher resistance to heat loss is required to maintain the same energy consumption over a year. Using a minimized mechanical system size with increasing peak loads and greater temperature deltas in very cold climates would increase required insulation levels as well. The R value of the envelope, following the laws of physics, has to adjust by climate on a continuum. It has to increase as the climate gets colder, decrease as the delta in temperatures gets smaller in warmer climates.

Applying the standard equally everywhere had unintended consequences. For example, in very cold climates, to meet the German specified heating demand of 15 kWh/sqm yr designers were forced to seriously overinsulate and to overglaze (with expensive high performance windows!). The projects had to rely heavily on solar gain to make the energy balance work.

The North American continent has design temperatures that tend to be mostly much more challenging (with some exceptions – e.g., the Pacific Northwest). It gets significantly colder during the winter while the number of heating degree days on an annual basis can look very similar to those in Europe. Madison, Wisconsin is a perfect example: it has a colder design temperature than Oslo Norway while the total heating degree days are almost 2000 HDDs lower than in Oslo.

While design temps are colder, there is generally very good solar potential in North America. Therefore designers in the US and Canada tried to compensate by becoming essentially “solar passivhauses” to get close to the annual heating demand target. But that approach caused overheating and comfort issues and made meeting peak load targets much more difficult. Larger window areas to maximize solar gain increased the peak loads in buildings that counteracted the comfort requirements. This leads to increased temperature swings during a 24 hour period, makes the buildings more prone to overheating and causes uneven temperature distributions throughout the space. The appealing principle of the home being “one comfort zone” was no longer the case. Arguably, increased glazing and insulation levels also resulted in overspending beyond any reasonable cost effectiveness—making dubious the claim that 15 kWh/sqm yr is somewhat magically the cost optimum/sweet spot between demand and supply everywhere in the world.

On the other hand, in warmer and milder climates the targets of 15 kWh/sqm yr actually leaves room for designers to leave significant cost-effective energy savings on the table. A prime example is the milder climate in California. And in extreme hot and humid climates like Florida it turned out that the energy targets for cooling were unattainable altogether. Insulation is just not yielding as dramatic a return in energy savings in cooling dominated climates because the temperature delta is much smaller than in cold climates.

We came to the obvious 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 possibly be based on economic/market conditions.

1.3 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 one. Experiences with the original Canadian passive housing built in a very cold climate let to the introduction of mechanical ventilation in the 1980's 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. Indoor pollutants such as moisture, CO2, Radon and VOCs could be controlled for occupant health.

3. Hygrothermal performance of the envelope resulting in superior durability was greatly enhanced.

At the time, the recommended ventilation air change rate per hour to accomplish all this was initially set at 0.5 ACH. The European passivhaus adopted the ventilation system with heat recovery recommendation in the mid 90s and defined 0.3 ACH as the necessary ventilation rate.

As PHIUS and PHIUS-trained consultants applied the passive building principles throughout North American climates it became clear that requirements for balanced ventilation with heat recovery—as well as the current recommended ventilation rates and systems design guidelines—need to be optimized for specific climate zones.

We came to another obvious conclusion: the original cold climate-oriented philosophy that mechanical ventilation with heat recovery is needed for all passive houses and buildings does not apply in every climate.

In cold climates relatively high ventilation rates were effective in providing indoor pollutant source control, but also were bringing in very dry air resulting in over drying the indoor air. This let to considerations of possibly lowering the ventilation rate. In addition, design guidelines for moisture recovery to prevent over drying in the cold dry climates and to aid rejection of humid outdoor air in warm humid climates was not only an option, but necessary for good energy efficient systems design in such climates.

Different peak conditions in various climates, peak heat, cooling or latent loads, will determine the design strategies and specifications. Heat recovery is beneficial in cold climates but in mixed and milder climates heat recovery was not really necessary. The energy that could be recovered was not large enough to justify expensive heat recovery upgrades.

In short, once again, different climate zones require specific ventilation system specifications and differing design guidelines; one size here does not fit all.

Minimized space conditioning and distribution systems design guidelines also need to be redefined and chosen according to varying climate conditions. The simplified German definition of a passivhaus (being a building that can be kept comfortable by conditioning the ventilation air alone without employing additional recirculation systems) can be applied economically only in a few very small regions of the North American continent.

In most more extreme North American climates the peak load conditions exceed the carrying capacity of the recommended ventilation air volume for heating, cooling and dehumidification. 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 a ducted system.

The PHIUS Tech Committee has not yet made any recommendations on types of ventilation and/or appropriate ventilation rates and space conditioning systems and distribution by climate. Research toward the goal is underway. A first preliminary study was conducted determining what heat recovery efficiencies for heating and sensible cooling should be used in energy models for what climate.

1.4 Passive design tools and Software

The Passive House Planning Package (PHPP) developed by the German Passivhaus Institut was the first comprehensive calculator that accounted for:

- all factors that go into the design of a high performance envelope
- for minimized mechanical systems in cool moderate climates
- allowed for immediate feedback of impacts of design changes on the energy balance

Here again, however, experience has revealed the limitations of applying this tool in all climates. The tool operates based 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.

Note that the flattening and simplification can be justified for moderate heating dominated climates that have no cooling requirements or humidity issues, and where the effect of heat and moisture exchange with the opaque envelope components on the overall building energy balance is negligible.

In other climates, it has been found to be not granular enough, however. The LeBois House, a single family home in the hot humid climate of Louisiana is a prime example. The home was modeled in PHPP, built and monitored for two years after it was completed and inhabited.

During that process it became clear that the cooling demand and sensible peak algorithms were off by a large margin and that latent loads really needed to be accounted for in the standard (which they were not at the time).

On the positive side, the project was performing significantly better on the sensible cooling demand side than PHPP had predicted, by about 35%, indicating that the algorithms were likely optimized for cold climate design strategies and still “blind” to and not accounting for significant passive design strategies for hot climates (impacts of radiant barriers, inability to accurately predict impacts of thermal mass and moisture storage on the overall energy balance, e.g.).

Overall the project was a huge success: We learned what was needed for designing passive projects in hot and humid climates and what the requirements on a new passive design tool were in such a climate. We were also able to show, 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 we had found 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 passive house verification similar to PHPP, and adds critical capabilities. For example, it offers a more detailed and granular *dynamic* simulation—it does not flatten the modeling process. This makes for more accurate assessment of comfort conditions and hygrothermal performances of wall assemblies. This provides vital information for making design to meet the annual demand requirements, maintain comfort, and avoid risky wall assemblies. WUFI Passive in dynamic mode is also capable to assess thermal storage much more accurately as well as hygric storage in building components and their effects on the energy balance. This benefits energy models in mixed, hot, dry and humid climates. The latest release has been improved even further. It is now also possible to model the interaction of envelope design with the mechanical ventilation system. Effects of air flows between rooms and space conditioning distribution can now be modeled and taken into account as well.

2 THE TRADITIONAL DEVELOPMENT IS AT A CROSSROADS

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, design guidelines, and design tool can be greatly improved. In colder climates unreasonably high investment costs have led people to abandoning the concept and uptake remains to this day insignificant (Minnesota for example). In warmer climates like coastal California passive house is easily beaten by emerging hybrid solar thermal and photovoltaic technology because it does not go far enough and does not harvest enough saving through conservation to make it a financial slam dunk. The zero-energy argument, bypassing passive as the baseline first, is hence a competitive proposition.

Standards, tools and design guidelines help us to quantify, measure against and meet certain goals we have communally agreed upon. They need to be updated and refined from time to time as the conditions change and as we learn more. It is an evolutionary process. If standards become rigidly frozen in time, cease to match reality accurately and are not informed by feedback loops accounting for the system’s learning they have lost their usefulness.

Consequently, in 2011 the PHIUS Technical committee, a volunteer body based on modified consensus and comprised of international building science experts and North American passive house practitioners, embarked on the plan to identify a methodology to generate new passive standards for all climate zones. The committee has identified four foundational principles that the standard should follow:

1. **Being biased towards 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. **Airtightness to assure the building envelope durability** possibly also based on climate.

4. **Cost effectiveness** by state referencing a zero energy baseline

The sweet spot then is defined as the optimum design between demand and supply or more specifically energy conservation and energy generation. In a sustainable world we must look at zero energy as our goal and passive design measures take us towards near zero. This is the first step in design. From there we need to examine two steps:

(a) low exergy (low grade energy) sources such as geothermal, solar thermal, convective mechanical cooling etc

(b) renewable energy sources

We should not justify the cost effectiveness of a certain level of conservation standalone, we are trying to justify the optimal combination of both, conservation and generation, to reach zero energy and beyond to possibly reach zero carbon.

The cost of solar technology has come down dramatically over the past few years. This changes the conversation significantly. Figuring that zero is our most realistic goal in the near future then the cost of PV has a significant impact on where the design optimum lies. Now zero has indeed realistically become our new target, maybe positive energy eventually and that alone is reason to recalibrate the standards, and on a regular basis.

3. NEW PASSIVE BUILDING STANDARDS FOR NORTH AMERICA: IMPETUS AND PROGRESS

To develop new standards we are running models for a typical single family home, with carefully chosen and defined design constraints and energy baseline features, in BEopt. (BEopt is an optimizer tool developed by the National Renewable Energy Laboratory). All baseline decisions were carefully conceived and evaluated by the PHIUS tech committee.

The most important specific constraints that were preprogrammed before any calculations were run are:

1. A typical 2000 sqft gross floor area home with three bedrooms on a slab is chosen. A base wall assembly is defined as a proxy for R-value – a 2x4 wall with exterior foam insulation.

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

3. The glazing can be concentrated by the optimizer up to 40% of the total on one specific side (for example 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 is 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 means to not to allow any window specifications lower than triple pane windows as the starting point.

4. A small active photovoltaic system of 2 kW is added to determine when the optimizer switches from envelope upgrades to PV as the more cost effective option. The onsite fraction of the total kWh/yr generation is now also allowed to offset the source energy criteria.

The tech committee decided to use 30 years as the base for the cost benefit calculations as opposed to 100 years which is used as baseline for the German standard. The tech committee considered 30 years more realistic in the US and Canadian economic context.

The detached single family baseline was chosen because it is the predominant housing type in North America (the German model is a town end house). Because the small detached home typology is the worst case scenario, any other larger building type including townhomes, multifamily or commercial buildings will perform better due to improved compactness.

In reviewing base assumptions for the model the committee also decided that the internal loads that are currently assumed in the European model are 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 $1/7^{th}$ of the actual current internal load average in the United States. This leads to a significant mismatch of what is assumed and what happens in reality. Corrected higher initial internal loads in return impact heating as well as cooling demand criteria on an annual basis. Higher internal loads will make it easier to meet the heating demand threshold but will increase the cooling demand hence shift the relationship of the two. The internal climate conditions have a direct impact on where those demand criteria need to be defined when setting standards for specific external climates.

At the time of this writing the draft report for the DOE study is almost complete, the parameters and the methodology for the study have been decided on and 80 of the 110 climate studies for various cities in North America have been completed. As the project progresses the dynamic modeling side of WUFI Passive will be used to verify hygrothermal wall assembly performance by climate and to assure that the comfort criteria by zone are maintained when annual heating or cooling demands are slightly increased or reduced.

As the project has progressed, questions have arisen as in how much simplified these new standards should be. Originally a standard by zone model was envisioned. This idea has been replaced by the goal to develop an algorithm that accurately calculates the respective heating, cooling demand and peak loads by location.

The new climate specific standards findings are scheduled to be presented for the first time during the 9th Annual North American Passive House Conference in San Francisco, September 12-13, 2014.

4. CONCLUSIONS

In North America passive building is becoming the foundation for NZEB because of its longstanding successful record, the proven effectiveness of a quantifiable energy performance standard and associated quality assurance programs.

The focus is on designing climate specific airtight highly insulated building enclosures with integrated micro load mechanical systems first to meet stringent climate specific energy standards, then to add renewable energy sources to get close to zero, reach zero or overproduce and eventually zero out carbon.

A new generation of modeling tools has facilitated the evolution to more granular climate specific energy targets. BEopt and WUFI Passive enable the designer today to compute and analyze large amounts of data for greater granularity. Using BEopt has allowed us to determine that the original one size fits all standard in many climates results in pushing designs up into the diminishing returns part of the curve and how to fix this by adjusting the energy targets by climate. And using WUFI Passive allows the designer to predict the impact on comfort conditions caused by predominant solar passive house designs (large temperature swings and overheating conditions, e.g.), in a more granular way and to be able to prevent this by making appropriate design choices. Thermal mass and hygric storage impacts in hot and humid climates can now be taken into account more accurately as well during the modeling process.

Heating and cooling devices designed in interdependence with the airtight highly insulated enclosure are now much smaller than in traditional homes. The principle is to size the system appropriately for the low loads according to climate. Ventilation systems are most commonly separate from the space conditioning and distribution system, though some small integrated systems and recirculation solutions are employed as well. Balanced ventilation systems remain a central part of the design in the climate specific approach: in cold, mixed and hot climates alike with or without heat recovery a balanced ventilation system assists convection in the redistribution of heat gains and space conditioning loads. It has to be designed and specified according to climate. But first and foremost and common to all climates, its main purpose in airtight buildings -- as in the early days of passive housing -- is source control and fresh air distribution assuring good indoor air quality.