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Achieving Passivhaus Standard in North America: Lessons Learned

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ABSTRACT

To help mitigate climate change, the incremental approach to making homes and buildings "less bad' or 30% better than code is not going to work. We need aggressive, actionable solutions now. The Passive House standard (Passivhaus in German) is one of the world's most aggressive, proven, voluntary approaches to radical energy reduction, assured indoor air quality, durability, and thermal comfort in the world today. The Passive House standard has roots in Sweden, Germany, Canada and the US. While much of the approach to good, low-energy and passive design is well known, it is still seldom practiced. This paper will introduce and explore the Passive House standard design approach and requirements as well as demonstrate its application to new and retrofit projects in the North American context. Drawing from expertise on the early Passive House projects in the US and Germany, as well as on the ground experience of more recent successful and unsuccessful Passive House projects in North America, a journey toward the best practices in design application, cost and certification will be discussed. A brief review of the various products and systems incorporated in North American projects to meet the aggressive requirements of the passive house standard will also be introduced.

INTRODUCTION

The Passive House standard originated from a conversation in May 1988 between Professors Bo Adamson of Lund University, Sweden, and Wolfgang Feist of the Institut für Wohnen und Umwelt (Institute for Housing and the Environment). Their concept was developed through a number of research projects, aided by financial assistance from the German state of Hesse. The eventual building of four row houses (also known as terraced houses or town homes) was designed for four private clients by architect's professor Bott, Ridder and Westermeyer.

The first Passivhaus buildings were built in Darmstadt, Germany, in 1990, and occupied the following year. In September 1996 the Passivhaus-Institut was founded in Darmstadt to promote and control the standard. Since then, an estimated 15,000 Passive Houses have been built, most of them in Germany and Austria, with most others in Scandinavia and various other EU countries.

THE PASSIVE HOUSE STANDARD

The requirements of the Passive House standard are very specific. In order to achieve certification as a Passive House, a project must demonstrate compliance with the following requirements:

- Airtight building shell ≤ 0.6 ACH @ 50 pascal pressure, measured by blower-door test

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- Annual heat demand requirement ≤ 15 kWh/m^2/year (4.75 kBtu/ft^2/yr)
- Cooling demand requirement ≤ 15 kWh/m^2/year (4.75 kBtu/ft^2/yr)
- Primary Energy ≤ 120 kWh/m^2/year (38.1 kBtu/ft^2/yr)

In addition, the following are recommendations, varying with climate:

- Window unit u-value ≤ 0.8 W/m^2/K (U-Factor = 0.14; R = 7.1)
- Ventilation system with heat recovery with ≥ 75% efficiency with low electric consumption @ 0.45 Wh/m3 (0.013 Wh/ft^3)
- Thermal Bridge Free Construction ≤ 0.01 W/mK (0.006 Btu/(fthF))

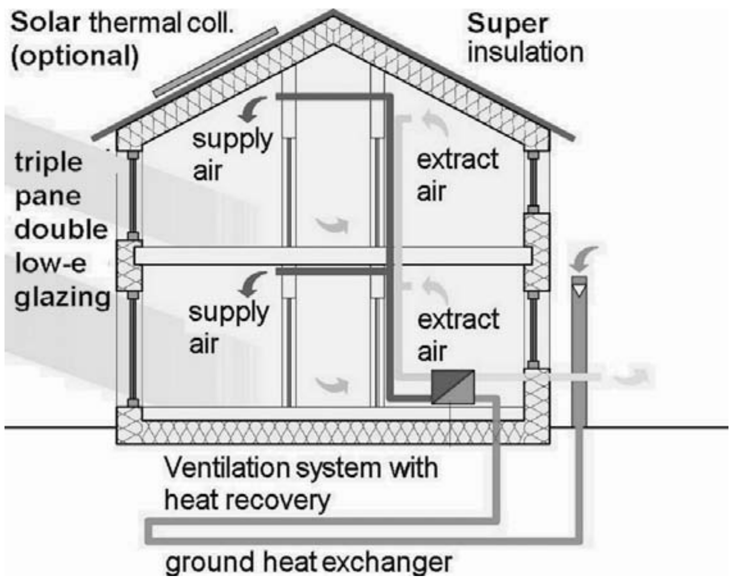

Figure 1 *Passivhaus building section showing typical systems.*

APPLYING THE PASSIVE HOUSE STANDARD

In order to demonstrate compliance with the standard, projects are modeled using the Passive House Institutes' software tool, Passive House Planning Package (PHPP). The PHPP tool contains years of thoughtful research and application from Europe, and more recently from North America, to help planners determine energy balance and optimize building systems to meet loads from gains and losses. It is well advised to utilize the services of a Certified Passive House Consultant (CPHC) to assist in modeling and managing the iterations of various design approaches. Using the PHPP software tool without training is not advised.

In addition to the requirements and recommendations noted earlier, principles of thermal comfort, indoor air quality and moisture management are inherent in the Passive House standard.

Successful designs carefully manage the requirements and recommendations, balancing them with first costs, to achieve a superior indoor environment. Selection of construction materials, finishes and furnishings are even more important in a Passive House due to the tightness of the home. Increasingly, selection of low chemical, zero VOC and non-toxic products and systems are incorporated in these designs. Proper ventilation design, also due to the airtightness, is vitally important to a successful project.

LESSONS LEARNED

While there are over 15,000 Passive Houses (including single and multifamily homes, schools, factories and offices—both new and retrofit) certified under the Passsivhaus standard in Germany, Austria and various other EU countries, there are approximately 13 certified projects in North America and several dozen projects attempting certification as of December 2010.

In putting together this paper, the author reached out to the Passive House Institute US, as well as designers, builders and homeowners who have both successfully, and even unsuccessfully, attempted certification for both new and retrofit projects. The projects reviewed for this paper include both residential and light commercial applications of the standard.

The types of lessons learned can be classified roughly into the following categories:

- Air tightness
- Heating, Ventilating & Cooling
- Insulation & Thermal Bridging
- PHPP Load Modeling
- Cost Issues

Each lesson category, upon analysis of how and when the lesson was properly applied or could have been avoided, can be allocated into project phases, as follows:

- Design
- Procurement
- Construction
- Post Occupancy

Lessons Learned by Category

The following lessons are not in any particular order of importance and it might be said that each of them are equally important as each of them carry consequences for achieving or not achieving Passive House certification.

Air Tightness. Air tightness may well be the most important challenge and lesson for US application of the Passive House standard. Whether building new or approaching a retrofit project, the importance of attention to detail and quality assurance and control cannot be overstated. Measured Energy Star certified homes perform in the 3-6 ACH at n_{50} (variations are for different climate zones). These homes only represent about 17% of all new US homes in 2008 (not all are homes are tested or verified) and a much smaller fraction of all US homes. By some estimates, average US homes may perform 2 or more times worse in air tightness than the typical German home shown in Fig. 2.

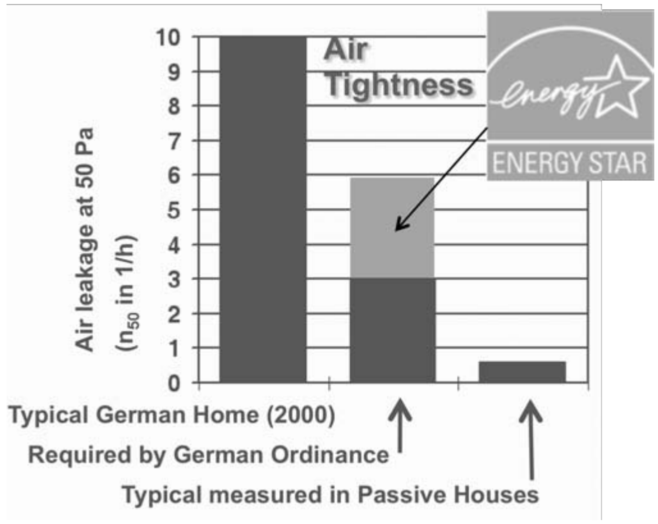

Figure 2 *Relative air tightness of typical German home, Energy Star, and Passive House.*

In existing construction—retrofit applications, air tightness can be one of the most difficult challenges. Depending on the scope of work involved in the retrofit, it may even be impossible. Bronwyn Barry, an energy analyst with Quantum Builders of Berkeley, California learned on the retrofit of the Larkspur residence that while air tightness was going to be a challenge, her team was able to overcome it and achieve better than 0.6 ACH at 50 Pa.

One of the ways Quantum Builders overcame the air tightness challenge was to build a mock-up wall section for testing. This proved to be not only good preparation, but it also proved this approach would work at full scale. Quantum's solution to the air barrier challenge was to maintain the existing home siding, redwood plywood, and seal the joints and seams with airtight mastic as seen in Fig. 3.

Figure 3 *Larkspur retrofit showing original redwood plywood siding sealed with mastic (air barrier) and 3 inches of new high-density mineral wool insulation.*

Heating, ventilating and air conditioning (HVAC). HVAC challenges are a bit harder to boil down into lessons learned with the Passive House standard. This is primarily because every system is so sized and designed for a very specific building, envelope, orientation and climate, that the lessons are rarely transferable, with the exception of possibly broad approaches (systems used) or a similar building types, and scale, in the same climate.

Mostly people want to know that the system chosen, along with whatever backup may have been included, is going to work or worked. Answers to questions about how well they are working (actually achieving the modeled energy performance results) are not well known at this time, due to the limited number of projects completed and even less monitored.

One example with some performance results is the Waldsee BioHaus project in Bemidji, Minnesota. BioHaus is a light commercial structure for Concordia Language Villages designed by architect Stephan Tanner of INTEP. BioHaus is performing slightly beyond expectations at just 12,000 Kwh/yr (total energy) at 400 m^2 (5,000 ft^2) this equates to about 30 Kwh/m^2/yr. BioHaus used an earth to air fresh air pre-temping and has a bypass for a flat plate heat recovery to avoid winter freeze up – a main issue to consider in climate zone 7. Review of the building management system has shown that it has worked at temperatures of 30 below F. Mr. Tanner noted that "One still pays a premium (for the earth tube and flat plate heat recovery) and a duct base electrical booster heater is much cheaper".

Both the BioHaus and the recent retrofit of Amory Lovins' 1984 Rocky Mountain Institute headquarters in Old Snowmass, Colorado used a super efficient (85%) heat recovery ventilator (HRV) made in Germany. While these European products are becoming increasingly available via distributors in the US, it is apparent that the real winner will be US manufacturers that see a market for superefficient HVAC systems, made at sizes that can scale to the lower end of the energy demand for homes and small buildings.

In a recent conversation with Amory Lovins about the key lessons learned in his 1984 passive design, he noted flexibility as number one. Designing in the ability to adapt the home and office over the past 28 years as new technologies were introduced has proven invaluable. Specific examples he cited include the installation of piping in the slab for a radiant heating system, which was never used for over 25 years—and was recently "charged" via solar thermal and a compact boiler as a backup for design days. Another example is the ¾" intentional gap between heavy timber beams and the exposed interior roof decking—this gap was quite useful in wiring for several lighting retrofits and recently for installation of hundreds of energy monitoring points.

Thermal Envelope. The building envelope, which includes walls, roof, floor slab and fenestration, is another critical category of challenges and lessons in applying the Passive House standard. The approach to detailing discussed earlier is one of the keys to success—is the detail buildable? How will quality be assured? Are there alternate approaches to achieving the same thermal envelope? Are materials readily available?

Whether using double studs, structural insulated panels, ICF's or I-joists for walls, the insulation(s) used, and the ability to achieve a quality installation of them, is of critical importance. Other challenges with the envelope design in new construction are less often to do with which insulation or how much insulation, but have to do with detailing for elimination (minimization) of thermal bridging.

One of the challenges faced by Wagner Zaun Architecture in the design of the Skyline House was the thermal envelope. Because the client didn't choose to pursue the Passive House approach until the construction drawings phase, there were limitations to any rearrangement in orientation and fenestration.

While the ultimate performance of the Skyline House is superior to most (75% better than a typical code-compliant home), it was not able to meet the Passive House standard. The blower test came in at 0.7 ACH at 50 Pa, and the heating energy demand was 23 kWh/m^{2}a (7.3 kBtu/f^2/yr).

However, as noted by the architect, Rachel Wagner, we have been monitoring the energy consumption of the Skyline House and the occupant comfort/experience, and it is a huge success.

In retrofit applications, one of lessons learned in the Larkspur remodel was that the significance of thermal bridging and an un-insulated slab could not be overcome without adding more insulation. They simply could not reach the Annual Heat Demand requirement without adding insulation on top of the slab and to the exterior walls. See Fig. 4. The thermal bridging on Larkspur became one of the larger conductive losses (per the PHPP model) after the retrofit.

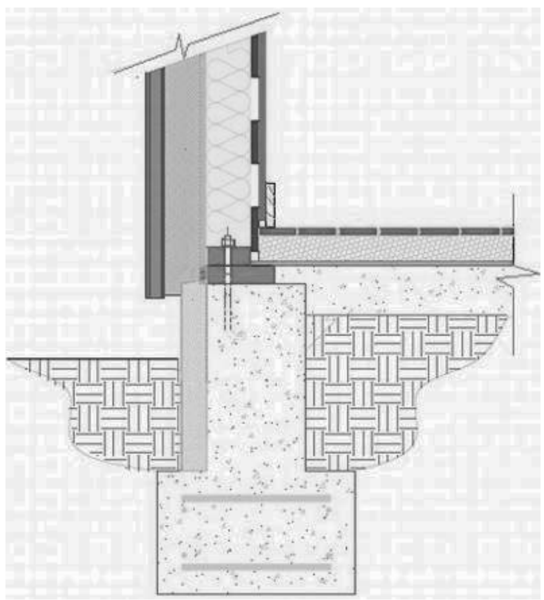

Figure 4 *Larkspur remodel showing 3 inches of high-density insulation added on top of the existing slab.*

Passive House Planning Package (PHPP). As there are relatively few projects that have been modeled with the PHPP tool in the US, the lessons learned were harder to extract. As noted earlier, it is clearly important that the tool be applied as early in the conceptual or pre-design phase as possible. While this seems obvious, it was surprising how many teams didn't think to, or the client didn't express interest in, Passive House until much later in the design or even construction phases.

Another lesson noted by Rachel Wagner is that you should not underestimate the importance of passive solar application. The passive solar opportunity should be maximized, as it can push a project below the desired 15 kWh/m^2 annual energy demand. One must use the PHPP software to evaluate the effectiveness of the passive solar strategies. "It is amazing to watch the dance between heat gained and heat lost (through the windows), via the software" – Rachel Wagner.

One suggestion from the author's view is that to encourage wider and earlier adoption and use, PHPP should ideally be improved to include a much more user-friendly "front-end" interface and perhaps be written in another software code to get away from the current Excel based format. Although Excel is widely used and understood, there is danger in misuse unless cells are “locked-out” from changes.

Cost. The cost effectiveness for a retrofit project to meet Passive House standard is a difficult challenge. It seems to depend primarily on the scope of the retrofit before adding Passive House requirements. In other words, if a project is already anticipating a siding replacement, window replacement, and perhaps some insulation or air barrier work, then the overall incremental costs (i.e., the difference between a code compliant window and a super window for example) are the costs that need to be considered for payback. Establishing this baseline is an important step in calculating overall cost effectiveness.

Too often it seems that projects are calculating payback or cost effectiveness using individual components or systems. Is this triple glazed super-window more expensive than a double glazed unit? A holistic view, which includes the whole system or whole-house, should be considered to understand the full cost-benefit accounting for energy and dollars.

This principle, called tunneling through the cost barrier, is explained in the book, *Natural Capitalism* by Paul Hawken and Amory and Hunter Lovins.

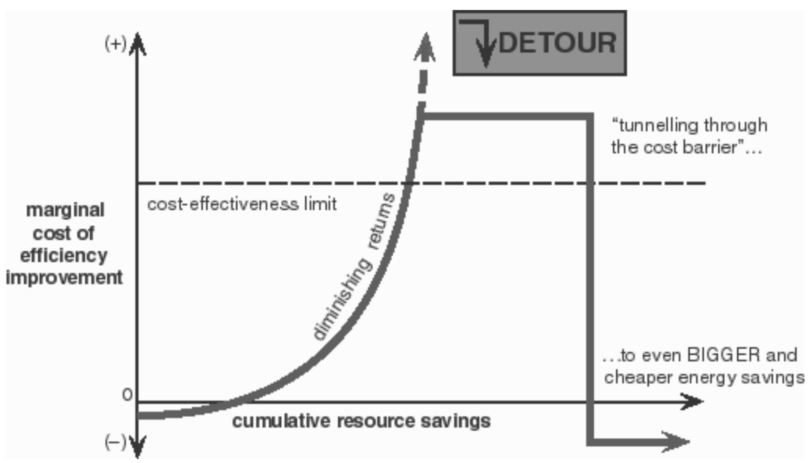

Figure 5 *Tunneling through the cost barrier.*

The “tunneling” principle can be effective when people tend to limit their investment in efficiency to a somewhat artificial “cost-effectiveness limit” for a single component. When indeed, further investment in higher performance or more efficient equipment and holistic solutions will yield greater immediate savings, often in capital expense. The most common cited example is investing in more insulation and better windows until the perimeter heating system can be eliminated.

On the Larkspur remodel, Bronwyn Barry reported that the overall cost effectiveness was not there for a typical US customer. Her client was dedicated to radically improved efficiency and reduced emissions in a healthy and comfortable home. Ms. Barry did think that it is very cost effective to apply the Passive House standard to new construction.

A key take away from this research is the need for a uniform life cycle cost approach to Passive Houses. Ideally, a tool built into the PHPP modeling tool would make sense. This combined with a guide to discount rates, net present value, ROI, IRR, and the total cost of ownership (PMI + utilities and maintenance) would go a long way in bringing the number of certified Passive Houses upward.

Lessons Learned by Phase

Many of the lessons learned in applying the Passive House standard in the US can be traced to the design phase. The phrase "design phase" used here is broadly describing all of the activities from pre-design through construction documents.

The application of the PHPP modeling tool early (and often) was a key lesson cited by one party interviewed. In their case, the assumptions about insulation level were discovered to be inadequate when modeled in PHPP during the construction phase. Similar to other modeling tools, PHPP was designed to inform the design process, not document or verify it.

The quality of the detailing and product specification can often be linked to procurement and construction phase issues. On several projects, air tightness and thermal bridge detailing led to omissions or constructability issues in subsequent phases. When these areas were not well thought-out and detailed on paper, they ended up needing to be resolved in the field, sometimes with compromising results. Several projects were not able to meet the blower door test requirement or the heating/cooling energy demand requirement as a result.

Quality assurance and control during construction was a close second to design phase lessons most often stated by designers, builders and owners. Even with very good quality construction details and specifications, follow-through with assuring compliance with details and product procurement can prove quite challenging. Inexperienced suppliers and subcontractors have sometimes resorted to alternate construction methods or materials due to perceived or real constructability issues and even substituted products where either unfamiliarity or availability (possibly cost) was claimed.

CONCLUSION

For certain the Passive House standard is aggressive. It may well be the worlds most aggressive energy design standard. It is also proven to work—on thousands of homes and buildings, in challenging climates. However, it is the intent with which the team (owner, builder, designer and all supporting cast members) approaches the application of the standard, which most likely determines the outcome. In other words, if you set your goals low—you're likely to meet them. Aggressive goals take teamwork.

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