Toolkit for passive house education: Questions, methods, tools

Alison Kwok[1], Walter Grondzik[2], Katrin Klingenberg[3], Mike Kernagis[3]

[1]University of Oregon, Eugene, OR
[2]Ball State University, Muncie, IN
[3]Passive House Institute US (PHIUS), Chicago, IL

ABSTRACT: The passive house concept, applied in the U.S., has been shown to reduce space-conditioning use by 65–90% (depending on climate) compared with 2009 IECC code buildings. The passive house method sets target performance criteria that must be addressed during design and met during construction. Passive house education and training for design professionals involve intensive classes on building science principles for envelope construction, thermal comfort, heat gain/loss, ventilation, shading, orientation, and calculations of total primary energy use. The design and construction process offers (and necessitates) collaborative efforts among the designer, builder, owner, and engineer. Understanding the passive house approach offers opportunities for enhanced student involvement, engagement and understanding of ways to reach net-zero energy performance and to address the 2030 Challenge. Infusing passive house principles into the architecture curriculum would provide a means by which this capacity can be made accessible to more designers earlier in their careers.

The objectives of this paper include: a) providing an introduction to the passive house standards relative to other efforts toward high performance design; b) outlining various dissemination models for passive house principles and building performance concepts (drawing upon approaches from several universities in North America—curriculum sequences from seminars, design-build projects, and studios); c) suggesting a toolkit of resources, equipment, tools, and exercises that institutions could use to infuse passivehouse into the curriculum, and d) discussing interactions between architectural education and the professional community and some of the successes and barriers to implementation of such collaborations.

KEYWORDS: Passive House, Knowledge Infusion, High-Performance Building, Education, Research Methods

INTRODUCTION

Passive house, as discussed in this paper, should be distinguished from passive solar design. Passive house is primarily an energy consumption limiting standard that addresses summer and winter heat flows as well as overall primary energy consumption. Passive solar design primarily focuses on the use of solar radiation as a means of providing space heating. Passive house and passive solar are not mutually exclusive concepts—but they are rather dissimilar. This paper will use lower case letters for the term passive house in order to recognize that it is a concept that goes beyond the purview or control of any one organization.

Passive house is a design standard that results in very-low energy buildings (PHIUS, 2014a). Key precepts of the standard include a limit on heating energy demand, a limit on cooling energy demand, a limit on source energy consumption, and a limit on air infiltration. Because passive house requirements focus on demand-side reductions, a passive house is not necessarily a net-zero energy building. It will, however be an exceptionally low energy building—and should be net-zero energy “ready.” The passive house standard is not a new idea, but is experiencing a growing emergence onto the North American design scene and a substantial growth in adoption. It can reasonably be described as a new design paradigm that slots nicely into growing concerns for energy conservation and carbon emission mitigation. Understanding the underlying reasons for the various performance metrics related to carbon emission reduction goals is essential to motivating the next generation to use them to benchmark their designs.

The fundamental question addressed by this paper is: How can a new paradigm be incorporated into architectural curricula? Broadly speaking, this question links into the ongoing tension (or dialog) between practice and academia regarding what should be learned in school and what should be learned in an office (Stevens, 2014). Somewhat more narrowly, the question links—assuming a desire to address the passive house paradigm in academia—to concerns about adding material to already packed architecture programs.

This is not a unique question. Similar parallels exist with the USGBC’s LEED green building rating system (or like programs; USGBC, 2014), with software (such as Autodesk Revit; Autodesk, 2014), or with broad concerns such as addressing the Architecture 2030 Challenge (Architecture 2030, 2014). Curricula, and the courses that comprise them, tend to adapt fairly well to new information at the “awareness” level of scope and complexity. A new lecture can be developed, some existing content can be squeezed, and additional readings can be assigned. Curricula are less accommodating to new information that requires extensive engagement in order to reach the "ability" level of comprehension. Most architecture programs have no flexibility to simply/easily add a course to address LEED, Revit, carbon-neutral design—or passive house. This is the challenge: How can an emerging topic area requiring reasonable time for ability development be dealt with in a conventional academic program?

There is no clear pattern of previous experiences from which to draw direction. USGBC, in the opinion of the authors, has not engaged the issue of how to embed either LEED awareness or ability into architecture programs. Faculty are left to their own devices as to how this might be accomplished—with no USGBC institutional support. Autodesk, on the other hand, provides free software and tutorials to encourage faculty and students to become familiar (and then proficient) with programs such as Revit. Interestingly, the objectives of USGBC and Autodesk would seem to be the same; namely to encourage use of their respective products. Their modes of diffusion are, however, radically different.

Currently (with a few exceptions) architects gain operational knowledge of passive house design post-graduation through participation in a multi-day training course and completion of an exam. Students are not excluded from this path, but would rarely have either the time or the money to take the CPHC (Certified Passive House Consultant) training (PHIUS, 2014b). This situation tends to delay awareness of passive house opportunities until after graduation and acts to distance active engagement from the venue (architecture school) where many are most amenable to learning.

The passive house community would like to see a greater infusion of passive house design knowledge into North American schools of architecture. Such an infusion would increase awareness of a viable high-performance design option among those arguably most predisposed to be excited by such an option. The passive house standard is, however, a topic where ability (versus awareness) would best spur adoptions. How to make this ability available to architecture students is addressed in more detail below.

1.0 DISSEMINATION MODELS

There are various models for supporting passive house education within architecture curricula. These examples describe the range of possibilities that might lay the foundation for resources, training, and raising of student/faculty awareness.

1.1. A freely-distributed resource package

Make readily available(at no cost to the user) a resource package of slides, videos, and notes that can be adopted (and adapted) by faculty members to use in lectures, projects, and/or a design studio. Such a resource package does not currently exist and external funding is probably required to support both development and dissemination.

1.2. A roving expert show

One or more Certified Passive House Consultant (CPHC) experts might travel to architecture schools and offer one- or two-day workshops, guest lectures (in studio, lecture, and/or seminar classes), or brownbag Q&A sessions with students and faculty. A resource package might be left behind. External funding would be required to support travel and pay for the expert's time.

1.3. Intensive summer workshops

Experience tells us that there is no shortage of interest on the part of students, but interested faculty need training on passive house concepts and an exchange of ideas about how to conduct a class. A series of intensive weeklong faculty workshops could provide experience with classroom exercises, passive house software, and use of equipment—as well as curricular discussions about implementation issues at various types of institutions. External funding would be required to support presenter and participant travel and accommodations under this option.

1.4. A modestly-priced resource package

Faculty members are encouraged to obtain a purchased resource package for lectures, projects, and/or a class. PHIUS (the Passive House Institute US) has developed a package of materials specifically for higher education venues, with lecture notes and slides that are used in the existing national CPHC training sessions.

2.0 EDUCATIONAL RESOURCES

In addition to the information resources noted in section 1, a number of tools can serve as resources for faculty and students in seminars, lecture classes, design-build settings, or independent study efforts. The experience gained through use of such tools can enhance learning outcomes and provide validation to design decisions. The following list of equipment is not exhaustive, but is intended to suggest how passive house principles, concepts, and design questions can be illustrated through their use.

2.1. Equipment

- Blower door: The current passive house standard requires that air infiltration be limited to 0.6 ACH (air changes per hour) during/after construction. Enabling students to conduct a blower door test on a range of constructiontypes, loose or tight, can be instructive to understanding qualitative and quantitative aspects of air tightness. The learning curve for use of a blower door is moderate; the cost is typically $2300-$2800.

- Carbon dioxide meter: Passive house buildings are designed to provide excellent indoor air quality using a heat recovery or energy recovery ventilator to supply fresh outdoor air. Questions about the effectiveness of such a system can be tested with a carbon dioxide meter. Comparisons can be made to ASHRAE Standard 62 *Ventilation for Acceptable Indoor Air Quality* (ASHRAE 62, 2013), which states that indoor air is "acceptable" if it is less than 700 ppm above outdoor air levels (usually around 400 ppm). Carbon dioxide meters cost around $400-$500; those with datalogging capabilities around $700. The learning curve is nominal.

- Infrared (IR) camera: Passive house construction detailsmust avoid thermal bridging. Occurrences of thermal bridging can be observed (or its absence demonstrated) via thermal imaging. IR cameras range greatly in price depending on image resolution, thermal sensitivity, battery life, and operating system compatibility. The learning curve for use of an IR camera can vary from nominal to moderate (depending upon project needs).

- Dataloggers: A key goal of passive house construction is to maintain excellent indoor thermal comfort conditions. Indoor air temperature, relative humidity, and surface temperatures can be continuously monitored using microdataloggers. Comparisons can be made to ASHRAE Standard 55 *Thermal Environmental Conditions* for *HumanOccupancy* (ASHRAE 55, 2013), which specifies a thermal comfort zone defined by a number of thermal parameters. Dataloggers can run around $100 per unit (with multiple-input capability); handheld sensors without datalogging capabilities run from $50-$500. The learning curve for either type is nominal.

- Infrared temperature sensors: Passive house designs aim for an average room air temperature that does not differ by more than 7.56F° (4.2C°) when compared to the average surface temperature of the enclosure. Indoor surface temperatures can be easily measured with IR temperature sensors that cost $35–$60 and involve no learning curve.

-Sample construction assemblies: Cut-away sample assemblies for wall, window, roof, or floor construction–essentially a kit of parts–can facilitate visualization of how materials are assembled, the proper location of the air barrier, and how thermal bridging can be avoided. An assembly might cost less than $50 (or be donated by a local builder).

2.2. Software

- Passive House Planning Protocol (PHPP): Is an Excel-based tool that provides the basis for verification ofa design proposal against the passive house standard through a series of inputs and approved calculations that yield a proposed building's heating, cooling, and primary energy demands.
- Wärmeund Feuchteinstationär(WUFI): Is PC-based software that can calculate and visualize heat and moisture transfer in an envelope assembly over time. It considers vapor diffusion and liquid transport in building materials, as well as sensible heat transfer.
- WUFI-Passive: Is a recently-released modelling tool combining the capabilities of both static PHPP analysis and the dynamic modelling of WUFI. Pre-packaged input decks, extracted from sample software runs, would allow students to play with design variables without the effort of from-scratch data input. Collaboration between the Fraunhofer Institute, PHIUS, and Owens Corning produced this tool specifically for North American climates. Fraunhoferprovides free trials for institutions conducting research and deep discounts for classes.
- THERM: Is PC-based software that models heat-transfer effects through building components where thermal bridging may be of concern.

The skillful use of a combination of equipment and software in appropriate educational settings will allow a student to spend a reasonable amount of time to gain an understand of a given concept or principle. Beyond this awareness phase, students would then learn to apply passive house strategies to their own design projects to reach the ability plateau.

3.0 CURRENT EFFORTS AT UNIVERSITIES

Passive house education efforts at Miami University (seminar), North Dakota State University (design-build), and the University of Oregon (seminar) were described in a 2013 paper (Kwok et al.). The delivery process for curricular innovation reveals several barriers to embedding concepts into the architecture curriculum, along with a need for greater dialogue on concepts and principles, construction techniques, energy targets, and the need for collaboration among building professionals (designers, contractors, engineers, and consultants). In each case, it took a champion at each university to implement course activities into the curriculum.

3.1. Miami University

The Department of Architecture and Interior Design at Miami University (Ohio) offers two course options for students to engage in the study of passive house: a Passive and Low Energy seminar and a Passive House Malta Summer Workshop. Both elective courses are offered to graduate and undergraduate students; with enrollment comprising predominately third and fourth year architecture students and several graduate students. The courses are run in succession with the intent that students who enroll in the Passive and Low Energy Seminar will follow up the experience with the Malta workshop. Both courses are relatively new offerings in the department and are entering their second year of instruction.

The Passive and Low Energy course meets three days a week for 50 minutes each session. The focus of the course is passive house design as a means for achieving net-zero construction. Students are instructed in the importance of airtight construction, super-insulation, thermal-bridge-free design, solar heat gain, ventilation, and hot water systems to achieve low- and net-zero results. Students also explore passive house energy modeling software (PHPP or WUFI-Passive)

The Passive House Malta Summer Workshop is conducted every other summer. In 2011, seventeen students traveled to the 15th International Passive House Conference in Innsbruck, Austria for one week, and then to the island of Malta for three weeks. In Innsbruck, students attended an introductory full-day seminar, held by Dr. Wolfgang Feist, one of the founders of the Passive House Institute in Germany. Students were expected to attend all general sessions of the conference, workshops held during the conference, attend the building trade show, and participate in an all-day building tour of various passive house projects under development in the area. Following the conference, the class proceeded to the island of Malta, were it studied traditional Maltese stone construction and current concrete construction methodologies. Students were introduced to heat transfer analysis software and were required to analyze the thermal qualities of current Maltese construction and offer alternative solutions to improve the thermal performance of the construction.

3.2. North Dakota State University

In 2011, a three-semester design-build course was offered at NDSU with the goal of designing, constructing, exhibiting, certifying, and occupying a passive house structure. Students engaged several clients, consultants, governing authorities, manufacturers, and researchers. They provided design and energy solutions to prospective clients on four different sites using the Passive House Planning Package (PHPP) and full-scale construction as primary modes of investigation through various stages of design and implementation. One of these projects moved forward to pre-certification and construction.

In the design studio component (one studio of six credits with 22 students), students researched, analyzed, and designed through various-scale investigations, completing typical phases of a design project such as schematic design, design development, and construction documentation and specifications. Experts and studio faculty introduced building science and passive house principles during visits to certified buildings in the region. In addition to PHPP, Athena and USGBC's LEED for Homes provided a comprehensive approach to evaluating environmental impacts. The studio instructor used WUFI and THERM to further the energy analysis by the students. Students constructed full-scale modules of various construction systems such as structural insulated panels (SIP), double-wall stick frame, and solid wood construction to analyze super-insulated passive house performance for a cold climate.

In the construction seminars (two seminars of three credits each, with 15 students),students and studio faculty completed pre-certification of the passive house project (a cabin) with the Passive House Institute US (PHIUS). The students then constructed the650 ft^2 (60 m^2) cabin in St. Paul, MN at the Eco-experience Exhibit. The exhibit lasted ten days after which the students dismantled the various building modules and created installation instructions and a labelling system for re-installation at the permanent site. The modules were transported to the permanent location.

The documentation studio (one studio of six credits with 14 students) students—using the work of the Design & Construction semesters—translated months of documentation (photos, writings, models, drawings, full scale modules, and document sets) into two books.

3.3. University of Oregon

The Department of Architecture at the University of Oregon offered a four-credit seminar course in the Spring Term of 2012 called Passive House Design and Detailing. This course fulfilled an advanced technical elective requirement and was offered to undergraduate and graduate architecture students. There were two prerequisites for the course: Building Construction and Environmental Control Systems I, since the students needed a basic understanding of wood framed construction, passive strategies, thermal comfort, and heating and cooling systems to adequately engage the material. The course met twice a week on Tuesday and Thursday for 1 hour and 50 minutes over the ten-week term. Typically, a lecture on a specific aspect of the passive house concept was given on Tuesday; on Thursday, the students were assigned an in-class activity that complemented Tuesday's lecture material. At the end of class on Thursday, a take-home exercise, which the students completed in pairs, was assigned and due the following week. The last four weeks of the term, the students worked in pairs to develop the design of a small passive house for a hypothetical site in Eugene, Oregon. In lieu of in-class activities during the final four weeks, in-class checkpoints for the final project kept the students on track. Faculty and local professionals attended a poster review session on the last day of class to provide feedback to the students on their final projects.

Throughout the term, the seminar collaborated with the Center for the Advancement of Sustainable Living (CASL), a student-initiated program at the University of Oregon. CASL is renovating a small single-family house–the CASL house–near the University of Oregon campus using passive house principles. Many of the activities and exercises during the term asked students to investigate aspects of the CASL design, including the assemblies, connections, and mechanical system. Several of the students enrolled in the seminar were also involved with the construction of this project. During one course period, the students had the opportunity to visit the CASL house and see passive house strategies implemented firsthand, including advanced framing, types and applications of insulation, and the heat recovery ventilation system. During this visit to the CASL house, a blower door test was conducted to show the students how to interpret the results.

A small grant ($5000) for the course enabled the participation of guest speakers. The guest speakers were given a lecture topic to cover during the first hour of the course, and were asked to share examples of their own work during the second hour. In some cases, they led the week's in-class activity. Guest speakers were selected based on their experience/expertise with passive house and related software tools. All of the guest speakers were located on the west coast; most were located in Oregon or Washington and within driving distance of Eugene. For this reason, the relatively small grant went a long way.

Several students, recently minted Certified Passive House Consultants, provided support throughout the term. These students had a strong understanding of passive house principles and the associated software and were able to provide support to the seminar students during activities and exercises, as well as assist in the development of course materials.

4.0 BARRIERS AND SOLUTIONS TO IMPLEMENTATION

Infusing the curriculum through seminars, lectures, and design-build studios, reveals several barriers. A few of the barriers and solutions are described in this section.

4.1. Curricular inertia

University teaching schedules and studio programs are often set a year in advance. Teaching loads are often already heavy, particularly in departments where faculty teach design studio, required lecture courses, and electives. It is often incumbent on an interested faculty member to "relinquish" a current elective to champion a new course or studio topic. It can easily take 3 to 4 years to start a new program, specialization, or emphasis within a department of architecture. What can be done in the short term?

4.2. Institutional culture

Passive house activities are generally most easily infused in curricula that strike a balance between theory and application. Passive house construction techniques—super insulation, triple glazed windows, minimal heating systems (depending on climate), ventilation and extreme air tightness—challenge the way that building envelopes have been traditionally designed. In architecture departments, where the aesthetic appeal of a design is the predominate studio criteria, getting faculty and students to embrace strategies that will ensure higher building performance is often a challenge. There is a lot of material to cover in a short amount of time. Again, if there are a number of passive house champions on the faculty and administration, there is less likelihood of the topic becoming marginalized. Evocative assignments and guest lectures in building construction, structures, and enclosure classes that challenge (and inspire) students to dig deeper, can be successful.

Another barrier to the implementation of passive house instruction in some departments is the “bias/influence” that LEED has in the minds of some faculty and many students. Sending a cadre of students and faculty through the CPHC training program is an excellent way to jumpstart a change in culture.Students gain more useful, applied knowledge through the testing and training requirements associated with becoming a CHPC. Energy standards obtained through branded certification processes hold great allure to students and many feel that obtaining LEED accreditation will improve their chances for employment upon graduation. Actively engaging another certification process is simply a huge barrier for many. Unfortunately, there is a substantial difference between LEED and passive house certifications.Passive house is based on collective building energy performance rather than point acquisition; LEED addresses water and materials in addition to energy. Moving toward high-performance building outcomes would be enhanced by knowledge of both LEED and passive house.

4.3. Tools and expertise

A working knowledge of passive house concepts and techniques, and familiarity with the PHPP energy modeling or WUFI-Passive software, is difficult to accomplish in a 16-week semester course (or a 10-week quarter) that meets just 2–3 hours per week. A companion studio that runs parallel with a lecture/seminar course would be beneficial so students could apply passive house concepts to their studio design projects and test them using the PHPP. Faculty expertise (see below) is necessary to support such implementations—along with resources to obtain the software.

Also, many schools lack the funding to support large equipment purchases such as a blower door. Often the energy management department of a local utility company is happy to demonstrate blower door testing and thermal imaging. Portable tool lending libraries (dataloggers, etc.) may also be supported by local utilities. Institutional seed grants to acquire tools for sustainability projects are often available.

4.4. Faculty expertise

Not many faculty are trained as a CPHC or have explored passive house enclosure details in depth to acquire a critical understanding of the issues. Additionally, students can have inconsistent preparation in building science fundamentals.Because of the high level of knowledge and software expertise required to design passive house buildings, guest speakers can be a critical component of a course’s success. Their first hand experience with passive house projects and the unique perspective regarding their particular discipline and expertise can be quite powerful.

Design-build studios that require full-scale construction can strain limited resources and personnel. Even though design-build can be greatly beneficial in creating a deep understanding of energy and performance issues, there are very few legal frameworks that allow such projects to be covered under practice laws such as general and professional liability insurance.

There are two main schools of thought regarding introduction of a new educational paradigm: a) jump in and just do it (many Solar Decathlon projects happen this way) with teams learning along the way, or; b) start by gradually building up equipment and software resources, inviting guest speakers, and hosting a one-day workshop and tour (if possible).

CONCLUSIONS

A dialogue on passive house concepts and principles, construction techniques, and energy targets, establishes a need for collaboration among building professionals (designers, contractors, engineers, and consultants)—the ultimate “integrated design practice.” A curriculum that infuses passive house concepts and principles is a means of exposing students to analysis tools like WUFI ora blower door, but also opens the door to a dialogue on ways to infuse the curriculum with new courses that address the 2030 Challenge. The focus of this paper was on the academic environment, rather than mimicking professional training. We believe that courses and activities that provide tangible methods and tools for students to learn at multiple scales, is the most effective way of moving the curriculum. This paper represents a point-in-time snapshot of available passive house tools and resources. As new research emerges, the concepts and principles should remain the same, but improvements in building technologies (materials, HRV/ERVs, sealants, vapor and air barriers, and so on) will be important for students to familiarize themselves with these as they move into practice.

ACKNOWLEDGEMENTS

Many people and organizations have contributed knowledge, materials, ideas, and opinions to the passive house movement. We acknowledge the faculty(and administration) at institutions that have taken steps to start up new courses and activities.

REFERENCES

ANSI/ASHRAE. 2013. Standard 55-2013: *Thermal Environmental Conditions* for *HumanOccupancy*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. Atlanta, GA.

ANSI/ASHRAE. 2013. Standard 62.2-2013: *Ventilation and Acceptable Indoor Air Quality in Low- Rise Residential Buildings.*American Society of Heating, Refrigerating and Air- Conditioning Engineers, Inc. Atlanta, GA.

Architecture 2030. 2014. *The 2030 challenge*. http://architecture2030.org/2030_challenge/the_2030_challenge Accessed December 2014.

Autodesk. 2014. *Autodesk Revit products*. http://knowledge.autodesk.com/support/revit-products Accessed December 2014.

Kwok, Alison, M. Hogan, M. Rogero, and M. Srivastava, 2013. *Passive aggressive: infusing passive house principles into the curriculum*, Proceedings from the ARCC Spring Research Conference, Charlotte, North Carolina, March 27–30, 2013, 321-329p.

PHIUS.2014a. *What is passive building?*http://www.phius.org/what-is-passive-building-/the-principles. Passive House Institute US. Accessed December 2014.

PHIUS. 2014b. *PHIUS CPHC training program*. http://www.phius.org/get-professional- training/certified-passive-house-consultant-cphc-training/program-overview

Passive House Institute US. Accessed December 2014.

Stevens, Garry. 2014. *Why architecture should leave the university.* http://www.archsoc.com/kcas/leaveuniversity.htmlAccessed December 2014.

USGBC. 2014. *LEED rating systems*. http://www.usgbc.org/leed US Green Building Council. Accessed December 2014.