WHAT IS PASSIVHAUS?

HISTORY, DESIGN PRINCIPLES AND ECONOMIC BENEFITS OF THE POPULAR EUROPEAN CERTIFICATION AND DESIGN SYSTEM

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History, Design Principles and Economic Benefits of the popular European certification and design system

Introduction

According to data compiled by the Lawrence Livermore National Laboratory, buildings accounted for approximately 30% of total national energy consumption in 2008.[1] The residential sector comprises approximately 15% of the total energy consumption of the US.[2] Not surprisingly then, building construction and home design have been the focus of many energy-efficiency initiatives, including green building efforts. One of the ways to achieve a significant reduction in national energy use and associated CO_2 emissions is through the implementation of energy efficient building design and construction techniques. There are many ways to approach the task of building an energy efficient home with a reduced environmental impact.

In the residential construction industry, several green building rating systems exist and offer potential energy saving benefits. For instance, an Energy Star certified home has been shown to have the potential to reduce energy consumption by 15% over a comparable conventional home built to meet the 2004 International Residential Code.[3] More than one million homes are Energy Star certified in the U.S.[4]

Certification under the US Green Building Council's Leadership in Energy and Environmental Design (LEED) has helped promote awareness of sustainable building techniques through a prescriptive building rating system that addresses sustainable site, water, energy, and material strategies. Since the release of LEED for Homes in 2008, more than 3,500 residential buildings, both single-family and multifamily structures, have been certified.[5] Many LEED-certified projects are in the category of affordable housing.

Over the past decade, green building has moved from esoteric to mainstream, with green building programs operating today in nations throughout the world. In North America, scores of green building programs are in existence, and each addresses energy efficiency differently. To date none provides energy savings as good as those of the latest European export – *PassivHaus*,[6]

The purpose of this report is to provide an overview of the *PassivHaus* phenomenon including a brief history, a summary of the certification standards, design and construction techniques, and the potential economic benefits and energy savings. Implications for public policy are also examined. As the use of green building standards, including *PassivHaus,* continues to expand and influence building practices, it is important to consider the most appropriate and effective ways to utilize aspects of these standards to inform policy decisions.

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[1] https://publicaffairs.llnl.gov/news/energy/energy.html#
[2] See page 15 for an illustration of U.S energy consumption (Figure 1)
[3] http://www.energystar.gov/index.cfm?c=new_homes.hm_index
[4] http://www.energystar.gov/index.cfm?c=new_homes.hm_index
[5] "LEED for Homes certified projects by project type." http://www.usgbc.org/DisplayPage.aspx?CMSPageID=2135
[6] The "Emerald" rating within the ICC 700-2008 National Green Building Standard requires energy efficiencies that are 60% better than code (http://www.nahbgreen.org/Guidelines/ansistandard.aspx). PassivHaus construction requires 70-90% energy improvement.

Brief History of the *PassivHaus* Phenomenon

The *PassivHaus* standard uses a strict certification process to promote construction of ultra-efficient homes. The performance-based standard first emerged in Europe. More than 25,000 homes have been built and certified under the Passive Haus Institut (PHI) standards since the first *PassivHaus* was designed and built in Darmstadt, Germany in 1991. The overwhelming majority of these homes have been built in central Europe and Scandinavia where the climate is similar to the northern United States.

Contemporary *PassivHaus* standards, design strategies, and construction methods grew out of research and development that began in the 1970s in response to the first energy crisis that resulted in a three-fold increase in the price of oil, from $3.56 per barrel in October 1973 to $11.65 in January 1974.[7] In response, super-insulated prototype homes were built by several organizations and research institutions in North America including the Arkansas Project, the Small Homes Council of the University of Illinois, Princeton's Center for Energy and the Environment, the Canadian National Research Council, and Minnesota's Housing Finance Agency. Amory Lovins accelerated the green building movement with the foundation of the Rocky Mountain Institute in 1982. Prototypes such as the Lo-Cal House in Illinois, the Saskatchewan Conservation House, and the David Robinson solar house aroused curiosity and inspired further research, especially in Europe.

The *PassivHaus* concept was given a significant boost in Europe during the late 1980s, beginning with the introduction of an energy standard requiring new buildings in Sweden and Denmark to be more energy efficient. These new standards were a catalyst for Swedish professor Bo Adamson and German physicist Dr. Wolfgang Feist as they developed the theoretical and scientific frameworks for *PassivHaus.* The idea was to radically reduce energy requirements in buildings through extraordinary insulation, the use of high efficiency ventilation systems, and attention to detail in constructing an air-tight building envelope. Their concept was advanced through a number of research projects funded by the German state of Hesse and resulted in the construction of four row houses (also known as terraced houses or town houses) designed for private clients. Dr. Feist continued to refine the *PassivHaus* concept and founded the PassivHaus Institut (PHI) in Darmstadt in 1996 to promote, control and increase the legitimacy of the new standard.

The prototype homes in Darmstadt exhibited <u>space heating demands that were 90% less</u> than the requirements for new buildings of the time. In 1996 the Economical Passive Houses Working Group developed the Passive House Planning Package (PHPP) and began production of the novel components that had been used, notably the windows and the high-efficiency ventilation systems, in the prototypes. The viability of the *PassivHaus* standard gained additional credibility following the Cost-Efficient Passive Houses as European Union Standards (CEPHEUS) Project, which confirmed the significant advantages of *PassivHaus* over standard construction practices in five European countries during the winter of 2000-2001.[8]

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[7] Martin Holladay, "The History of Superinsulated Homes in North America." Oct 10, 2010 http://www.greenbuildingadvisor.com/sites/default/files/History%20of%20Superinsulation%20-%20BC.pdf

[8] Mike Kernagis, "Passive House Takes Root in the United States" *Home Energy 2008* http://www.homeenergy.org/article_preview.php?id=485&article_title=Passive_House_Takes_Root_in_the_United_States

The Smith House in Urbana, Illinois was the first home to achieve official *PassivHaus* certification in North America. It was designed by architect Katrin Klingenberg and completed in 2003. The Smith House is a simple 1,450 square foot, shed-roofed building with insulation of at least R-56 on all six sides (roof, foundation and walls). In January of 2004, a month where temperatures reached -10 degrees Fahrenheit, the total electrical bill (which included electric resistance space heating) was a mere $35. Even more impressive, the house cost only $110 per square foot to build. This was more than Klingenberg would have liked but she says that, "the construction is actually standard balloon framing, and it is my belief that an experienced contractor could build such a house for only about 10% more than a standard home—an amount that could be easily recovered in energy savings over a ten year period."[9]

The Smith House (Urbana, Illinois)
Source:http://www.passivehouse.us/passiveHouse/PassiveHouseInfo.html

Passive House in the Woods (Hudson, WI).
Source: Tim Eian Studio.
http://testudio.com/portfolio/design/passive-house-in-the-woods/

Other buildings that have been built to *PassivHaus* standards in the U.S. include the Fairview House (built in Illinois for a survivor of Hurricane Katrina), the BioHaus at the Concordia Language Village in Bemidji, Minnesota, the Passive Project in Philadelphia, PA, and, most recently, The Passive House in the Woods in Hudson, Wisconsin.

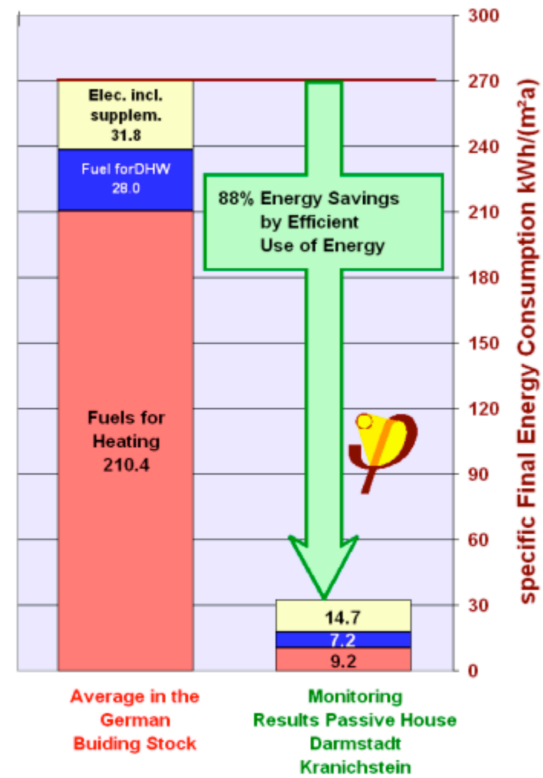
Passive House Standards (from the Passive House Institute U.S., PHIUS)

The term *PassivHaus* describes the fact that the energy required to heat these houses is so small that a conventional heating system can be eliminated. The heating needs can be met by a 1,500-watt electric-resistance heater (equivalent to the power rating of an average sized hairdryer). In practice, passive houses can be heated using existing internal sources including people (body heat), lights, and appliances; solar gain from windows; and a supply of fresh air that is warmed as it is drawn into the building through an earth tube (a passive geothermal heating-and cooling system). In other words, the homes use a mostly "passive" heating system. Passive Houses rely on a Heat Recovery System to provide adequate, controlled ventilation.

[9] "An Illinois PassivHaus," *Energy Design Update* 24, no. 5 (May 2004) http://www.naima.org/pages/resources/library/order/RP064.HTML

PassivHaus criteria represent the most rigorous building standard for energy-efficiency in Europe and the U.S. The standard requires that heating energy cannot surpass 15 kilowatt-hours (kWh) per square meter (1.39 kWh/sf or 4,756 Btu/sf) per year. According to the EIA, the average household energy use in 2005 was 43,700 Btu/sf.[10] Additionally, the building's total primary energy consumption (source energy required to produce heating, cooling, hot water, and electricity energy) cannot exceed 120 kWh per square meter (11.15 kWh/sf or 38,048 Btu/sf) per year.[11] This translates to a 70 - 90% reduction in energy consumption for space heating and cooling (Figure 2). For example, the BioHaus in Bemidji, Minnesota uses 85% less energy than a typical house its size.[12]

Figure 2.



Source: http://thegroundfloor.typepad.com/photos/uncategorized/2007/11/06/savings_of_passive_house.jpg

Listed below are the official criteria for certification by the Passive House Institute U.S. (PHIUS):

1. The building must not leak more air than 0.6 times the house volume per hour (air infiltration and exfiltration is ≤ 0.6 air changes per hour at 50 Pascals of pressure)
2. Specific heating and cooling demand is ≤ 15 kWh per square meter (= 1.39 kWh/sf or 4,756 Btu/sf per year)
3. Total building primary energy consumption is ≤ 120 kWh per square meter (= 11.15 kWh/sq. foot or 38,048 Btu/sf per year)
4. The ventilation system must operate at 75% efficiency or higher and have a low electric consumption of 0.45 Wh/m3.

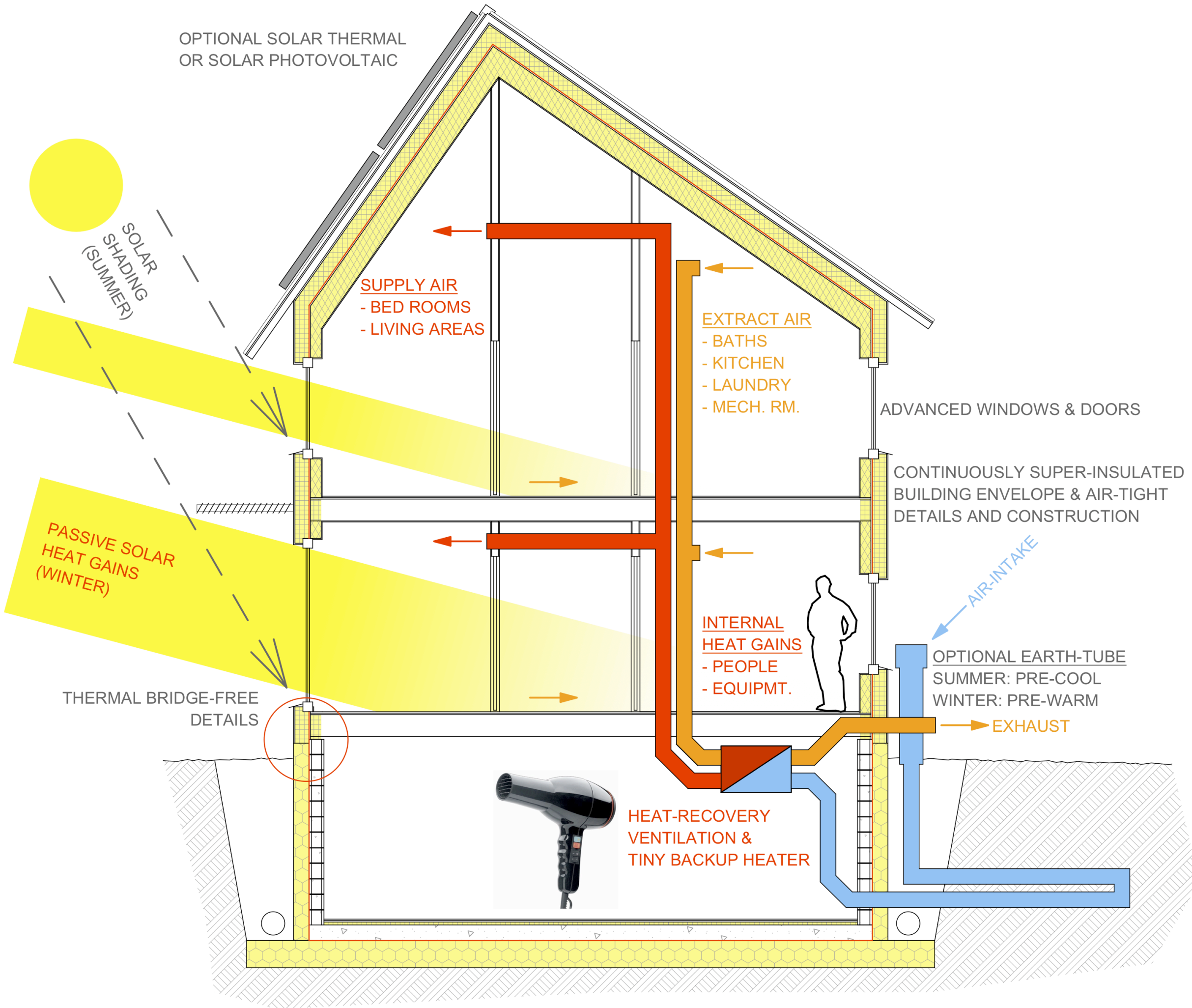
Passive House retrofit standards are the same as the new construction standards except that specific heat (and cooling) demand in a retrofit is ≤ 25 kWh per square meter (= 2.32 kWh/sf or 11,100 Btu/sf per year). The PHI has also established some general guidelines and recommendations for homeowners who want to improve energy efficiency even if a home won't be certified.

10 US EIA. 2005 RECS Energy Consumption Survey. Revised January 2009. http://www.eia.doe.gov/emeu/recs/recs2005/c&e/detailed_tables2005c&e.html

11 Ibid (Mike Kernagis)

12 "Wilkommen to das BioHaus," <http://waldseebiohaus.typepad.com/biohaus/design.html>

Figure 3.



Source: Tim Eian Studio. "Passive House 101," http://www.timeian.com/blog/?page_id=137

Basic Design and Construction Guidelines

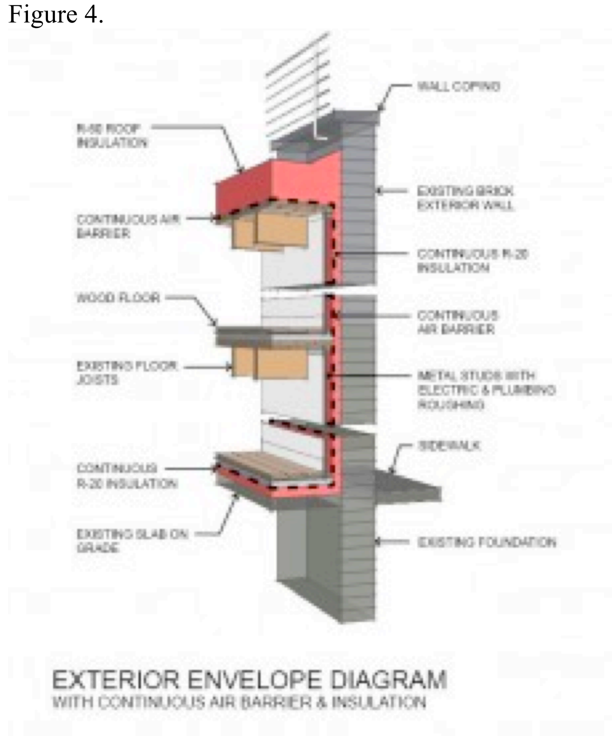
Meeting the rigorous *PassivHaus* standards does not require radical design changes or significantly higher construction costs. It can be achieved through an integrated design process, modest additional investments in key components, and skilled workmanship. Many passive house techniques such as super-insulation, building envelope sealing, installation of high performance windows, and use of efficient appliances can also be incorporated into older buildings as retrofits. The first passive house built in Germany had thick insulation, a tight building envelope, few thermal bridges, insulated glazing, and a balanced energy recovery ventilation system. These characteristics remain the core tenets of passive house design today.

Most Passive Houses built to date are compact buildings with a footprint of 800 – 1,500 square feet. These dimensions are modest when compared to the average single family home in the U.S., which has more than doubled in size since the 1950s from 980 square feet to nearly 2,500 square feet.[13] Passive Houses also tend to have a somewhat boxy appearance since it is important that the surface area of the passive house be less than or equal to its volume because of the energy loss that can occur in isolated spaces or corners. For the same reason, these buildings typically have open floor plans designed to maximize passive heating and cooling dynamics.

Orientation is another important factor to consider when building a passive house. In order to maximize solar heat gain and natural lighting, the broad side of the building should be aligned no more than 20 - 25 degrees east or west of due south in the northern hemisphere. This ensures that the southern wall and roof will be exposed to high levels of direct sunlight (Figure 3). This orientation also increases the opportunities for electricity and hot water generation with roof mounted photovoltaic (PV) panels and solar hot water collectors.

The majority of glazed surfaces (windows and doors) should be placed on southern walls to maximize natural lighting and solar heat gain during winter months. Heat gain from daylight can cover approximately one third of the heating demands of a passive house.[14] A general guideline developed in Canada states that 100 square feet of interior floor space requires 6 to 8 sf of south-facing windows to produce adequate heat during the winter.[15] Overheating during summer is avoided by building overhangs that cover the southern windows, or by installing adjustable louvers to control the amount of sunlight that enters the living space. Window placement should be limited on the northern side of the building to minimize heat loss.

Figure 4.



Source: Levenson McDavid Architects as seen in http://www.energycircle.com/blog/2009/08/21/passive-house-retrofit-characteristics-brooklyn-cohousing

Super-insulation and air tightness

Meeting the *PassivHaus* requirement that energy for heating and cooling cannot exceed 15 kWh per square meter (1.39 kWh/sf) can be difficult depending on the local climate. A kilowatt hour is defined as the quantity of electricity consumed over time: 1,000 watts in an hour. Therefore, the most important design features of a passive house are super-insulation, an airtight building envelope and proper installation of ultra-efficient windows with sealed frames (Figure 4). Studies

13 Margot Adler, "The Ever Expanding American Dream House," *National Pubic Radio,* July 4, 2006 http://www.npr.org/templates/story/story.php?storyId=5525283

14 CEPHEUS Final Report, page 11.

15 "Heating a Home with a Hairdryer," *The Electricity Forum* http://www.electricityforum.com/news/oct08/Netzerohomesaminimaldrainonthegrid.html

performed by Dr. Gautam Dutt in 1977 showed that at least 15-20% of the energy used to heat an average sized wooden frame house is lost due to warm air leaks in the attic alone.[16] The aggregate size of cracks and other breeches in the building envelope of older homes can approach 3-4 square feet (equivalent to a wide-open bedroom window!) and is directly responsible for drafts and high heating costs during winter months.[17] These findings led to the development of the blower door testing technique and the infrared heat viewer that allow researchers and construction teams to identify leaks and other points of heat loss.

The PHI recommends that the walls, ceiling and foundation exhibit a maximum heat transmission coefficient of 0.15 W/m^2K (equivalent to a rating of R-38). Heat transmission is measured in W/m^2K, defining the amount of energy consumed (W) per area (m^2) degree K (Kelvin). In colder climates these values typically approach R-60. Katrin Klingenberg's Smith House in Illinois uses 14-inches of polystyrene insulation to reach R-56 under the foundation slab. Basement walls are insulated to R-24, and 12-inch wall studs (as opposed to the industry standard 5.5 inch studs) were used to create a large cavity that is filled with blown-in fiberglass insulation to achieve an insulation value of R-60. The roof was built using 16-inch studs and insulated with blown fiberglass to achieve similar insulation values.[18] Purchasing additional blown-in or spray in insulation for the attic or previously un-insulated walls is one of the easiest and most cost effective ways to increase energy efficiency in older homes and buildings. The Passive House in the Woods, constructed in Hudson, Wisconsin, in 2010, is designed with R-70 walls and a R-95 flat roof.[19]

Windows and doors, or glazed/transparent elements of the building envelope, represent another important area where extra investment and skillful installation are imperative in achieving *PassivHaus* certification and increased energy efficiency. The Passive House Institute U.S. (PHIUS) recommends triple glazed, argon-filled windows with triple low emissivity glazing that exhibit a heat transmission coefficient of 0.8 W/m^2K or lower (a U-value of 0.14 or an R-value of 8-9), or demonstrate an inside surface temperature of 17ºC when the outside temperature is –10ºC. These types of windows are net energy "winners" because they allow more solar heat to enter the building than they lose. Window frames should be super-insulated and thermally broken to avoid radiant asymmetry and condensation that can result in mold formation.[20]

Finally, designers of passive houses try to eliminate or reduce thermal bridging to less than or equal to 0.01 W/mK. A thermal bridge describes any place where heat can travel through a "shortcut" to bypass the building envelope and include building elements such as corners, edges, junctions and penetrations. Areas where thermal bridging typically occurs are at the intersection of walls to the foundation, walls to the roof, walls to other walls, window glass to frames, and window frames to walls. The PHIUS has developed four general rules designed to minimize thermal bridging. First, the building envelope should not be interrupted unless absolutely necessary. Second, thermal resistance should be as high as possible where interruptions in the insulation layer and envelope are unavoidable. Third, insulation layers should meet without interruption, misalignment, or gaps at

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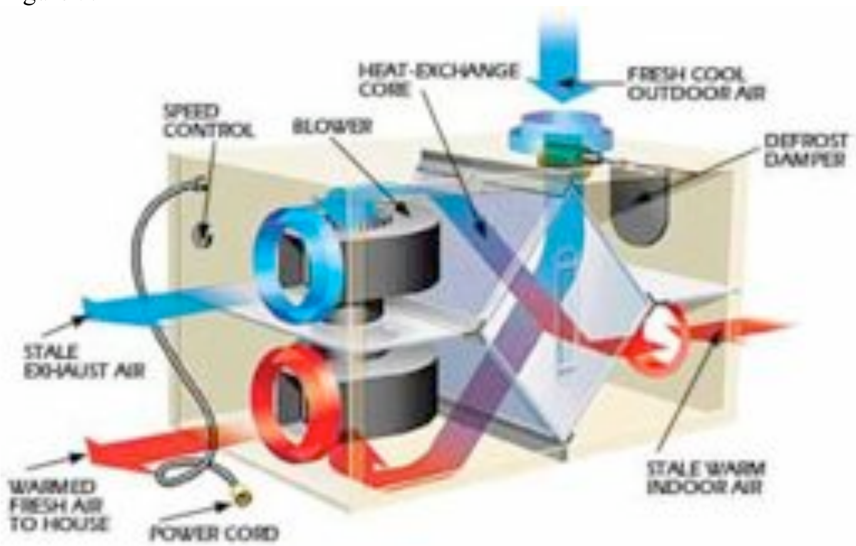
[16] New York Times. July 22,1979. Referenced in http://www.buildingscienceconsulting.com/summercamp/2010/Holladay-History_of_Superinsulation.pdf.
[17] Martin Holland, "The History of Superinsulated Homes in North America." 16 October 2009, 4th Annual Passive House Conference held in Urbana, Illinois.
[18] "An Illinois PassivHaus," *Energy Design Update* 24, no. 5 (2004)
[19] "Passive Aggressive," *Green Builder.* March 2010.
[20] Eric Storm & Tad Everhart, "Heating a Home with a Hairdryer," *Living Space Design.*

building element junctions (i.e., wall to slab, wall to wall, wall to roof). Fourth, building edges should be designed to have obtuse angles (between 90 and 180 degrees) to maximize the distance (and insulation) between adjacent edges.

Heating & Cooling Systems

Buildings with extremely tight envelopes produce several design and construction challenges, including the need for moisture control and systems for the maintenance of indoor air quality. A goal of the passive house design is to minimize the size of heating/cooling components (ducts and mechanical HVAC systems) by maximizing heat gain from other internal sources (people, appliances, solar radiation) without sacrificing indoor air quality, occupant health and comfort. This represents a significant engineering challenge. Passive houses rely on high-efficiency heat recovery ventilators (HRV) or energy recovery ventilators (ERV) to provide a continuous supply of fresh air to the building (Figure 5). HRV's exchange only heat, while ERV's exchange both heat and humidity. These devices allow for the heat and moisture contained in the outgoing air to transfer to the incoming fresh air without mixing the two streams.

Figure 5.



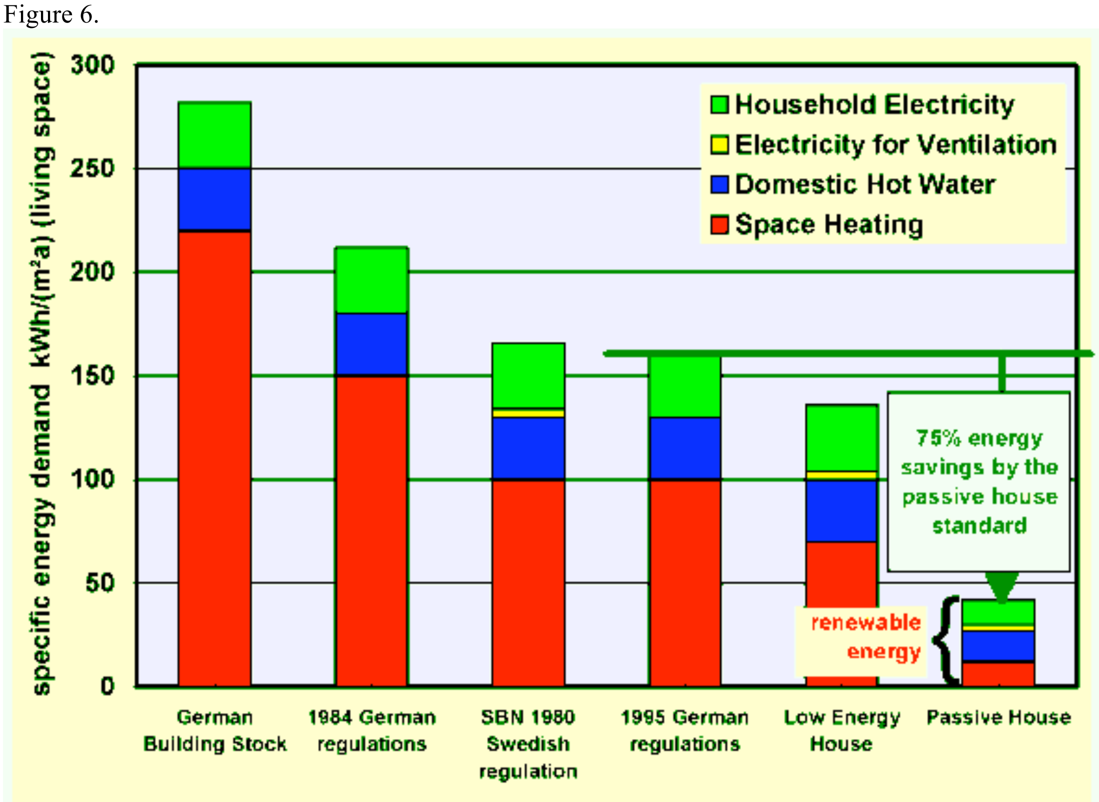
Source: http://www.popularmechanics.com/home/improvement/interior/1275121?click=main_sr

PassivHaus standards require that the HRV/ERV system must operate at 75% efficiency and consume 0.45 Wh/m^3. A system rated at 75% efficiency will exchange approximately 75% of the heat from exhaust air to the incoming air supply. The closer that figure is to 100%, the closer the incoming air will be to the existing indoor temperature. Energy efficiency and consumption depend upon the size and type of motor used in the ventilator. The Ultimate Air Recoup Aerator, for example, is an American made HRV that operates at 95% efficiency and uses 40 watts to deliver 70 cubic feet of air per minute (cfm). It also has an "EconoCool" feature that can be used during summer months to reduce cooling loads. It automatically shuts off energy recovery when the outdoor air temperature drops below 65 degrees in order to draw in the cooler night air.[21]

[21] Chad Ludeman, "Passive House Ventilation Design," *100K Homes,* January 20, 2010 http://www.100khouse.com/2010/01/20/passive-house-ventilation-design/

These ventilation systems have been proven to meet the *PassivHaus* standard for heating loads ≤ 10 W/m² (1.76 BTU/sf) while providing an average of 30 m³ of fresh air per person per hour. This rate of air exchange results in indoor air quality that in many cases, is superior to what is observed in homes using conventional HVAC systems. Fresh air is supplied to bedrooms and living rooms while stale air is continuously exhausted from bathrooms and kitchens, which are typically the most polluted areas (moisture, cooking fumes, etc). The incoming air supply can receive supplementary heating from an electric resistance coil usually rated at 1,000 to 1,500 watts. Additional preheating can be achieved using a geothermal heat exchanger and earth tube, which further reduces the need for an active heating system. Super-insulation, an airtight envelope and ultra-efficient ventilation systems combine to produce a building that could be heated by a 1,500 watt hair dryer (this is based on the assumption that there is 30m² (or 323 sf) of air per person, with a maximum specific heat load of 10 W/m² or 0.929 W/sf).[22]

Figure 6.



Source: CEPHEUS. "Why build Passive Houses?" http://www.cepheus.de/eng/

Economic Benefits

Passive Houses have been proven to reduce energy use by 70-90% when compared to conventional homes, representing a clear financial advantage over the average operating costs of homes built according to current codes (Figure 6). The 10 projects included in the CEPHEUS study recorded final energy savings for space heating and domestic hot water of 75% compared to standard

[22] Eric Storm & Tad Everhart, "Heating a Home with a Hairdryer," *Living Space Design.*

houses/apartments in the first year of operation.[23] Despite these impressive results, passive houses and other environmentally friendly building practices continue to be plagued by the perception that they are prohibitively expensive to build. However, according to the CEPHEUS final report, extra construction and engineering system investment was only 1-17% of the pure construction costs.[24] Compliance to the *PassivHaus* standard and the solar installations averaged 91 Euro per square meter (approximately $11/sf) of treated floor area, or 8% of building costs.[25] In Germany, where over 4,000 certified houses have been built, a passive house costs just 4-6% more than the standard alternative because economies of scale have decreased the prices of building materials and high efficiency appliances. Data collected in the PassiveOn project indicates that construction costs of passive houses in Italy, France, Spain, Portugal and the UK are only 3-10% higher than construction costs of standard homes in those countries.[26] In Canada, the installation of extra insulation increased the initial building cost of one home by $12,000, but the extra investment eliminated the need for a furnace, humidifier and air conditioner in the 1,500 square foot house.[27]

The Brooklyn Cohousing Project in New York City provides another example of the effectiveness and affordability of passive design principles in an urban setting. By focusing on super-insulation and tightening of the building envelope, Ken Levenson (a partner in Levenson McDavid Architects P.C.) estimates annual energy savings of approximately $66,000 through reduced heating costs, and 70% reduction in annual demand for air conditioning. The retrofit improvements will increase building costs by approximately $400,000, an average of $13,500 per household. However, the annual savings of $2,200 per household mean that the additional up front costs can be recovered in only 6 years.[28]

Reactions to PassivHaus

Although the *PassivHaus* is successful in terms of thermal performance, energy savings, and indoor environmental quality, there is some debate regarding this certification standard.

One of the benefits of the *PassivHaus* is that the high energy performance of the building minimizes carbon emissions associated with energy consumption during building occupation. However, when one considers the embodied energy in petroleum-based products, such as polystyrene insulation, does the *PassivHaus* actually have drastically reduced carbon emissions throughout its full life-cycle? For this reason, it is very important to think beyond the energy performance, and consider the use of local, natural materials for their embodied energy reduction.

An Irish study compared the embodied and operating energies of a highly insulated house with a heat recovery ventilation system to a naturally ventilated system. The study found that, although the embodied energy for extruded polystyrene insulation is high, the operating energy savings are

[23] CEPHESU Final Report, 2001: 90.
[24] CEPHEUS Final Report, 2001: 85.
[25] CEPHEUS Final Report, 2001: 92.
[26] "Passive-on Description Document," *Passive-on Consortium.*
[27] "Heating a Home with a Hairdryer," *The Electricity Forum*
http://www.electricityforum.com/news/oct08/Netzerohomesaminimaldrainonthegrid.html
[28] Ken Levenson, "Passive House Retrofit Characteristics: Brooklyn Cohousing," *Energy Circle,* August 21, 2009
http://www.energycircle.com/blog/2009/08/21/passive-house-retrofit-characteristics-brooklyn-cohousing

more significant (assuming a 50-year time period). The study concluded that the naturally ventilated house with an additional 150 mm of polystyrene insulation without a mechanical ventilation heat recovery system would have similar embodied and operating energy use as the building with only the MVHR system and no additional insulation. This study was based on the maritime, temperate climate of Ireland and UK. This finding suggests a need for development of an effective substitute for polystyrene as an insulating material.

Aesthetic Criticism

In the United States, people are commonly impressed by the excellent thermal performance of a passive house. However, people criticize the American PassivHaus buildings (the few that exist in the U.S) for being too modern, different from traditional homes, or even ugly. Although the design is restricted by surface-to-volume ratio requirements, and the need for superinsulation, the final design of a passive house could take on just about any style (Figure 7). For example, a traditional Cape Cod design pays close attention to the surface-to-volume ratios, and therefore would serve as a good model for a *PassivHaus*.

Figure 7.

Sources (clockwise from top left):
Crimmitschau house. http://www.PassivHausprojekte.de/projekte.php?detail=806
London house. http://www.PassivHausprojekte.de/projekte.php?detail=1777
Oberursel house. http://www.PassivHausprojekte.de/projekte.php?detail=1444
Stanton house (Urbana, IL). http://www.passivehouse.us/passiveHouse/PHIUSProjects.html

A few examples of projects built in Europe and the United States illustrate the diversity of passive house styles possible (Figure 7). Many more examples can be found in the PassivHaus projects databases available online.[29] *PassivHaus* certification is also not limited to single family housing; rather, it can be applied to most building types. Likewise, several types of construction can achieve *PassivHaus* certification, such as masonry, timber or insulated concrete form.

Should *PassivHaus* inform policy?

Since the *PassivHaus* standard has not yet been modified for North American climates the impact of the standard in the U.S. has been limited. The energy use criteria are currently the same regardless of the climate, and therefore it is more challenging to build to *PassivHaus* standards in very cold climates. Although Passive House has not been tailored for specific regions in the US, there is a helpful resource for getting started with Passive House design in one's own climate. The document, entitled "First Steps: What can be a passive house in your region with your climate," written by the founder of Passive House, Dr. Wolfgang Feist, can be found online.[30] PHIUS is currently developing and testing *PassivHaus* concepts for application in different climates within the US. Cold climates, like that of Minnesota, will require additional insulation, whereas hot climate regions will require a focus on cooling loads. Humidity is a challenge that PHIUS will continue to research in order to determine appropriate applications of vapor barriers for given climates such as those in the southeastern US.

Although *PassivHaus* standards will probably not inform policy in the way other green building standards have, the passive strategies inherent in the building and envelope design will continue to advance the construction industry as the US pursues more energy efficient buildings.

Concluding thoughts

The main goal of building a *PassivHaus* is to collect and retain heat without the need for active systems like furnaces, boilers or air conditioners. Most passive buildings exhibit a simple, compact, relatively open floor plan oriented to face due south in order to take advantage of solar heat gain and natural lighting. Their foundation, ceiling and walls are super-insulated (e.g., R-60) to prevent heat from escaping during the winter and entering during the summer. An airtight building envelope ensures that the ultra-efficient heat recovery ventilation (HRV) system can maintain a relatively homeostatic environment despite extreme outdoor conditions. Installing advanced windows and doors, and using efficient appliances result in additional energy savings and provide a level of energy consumption that is 70-90% less than a conventional single family home.

Passive Houses have become popular in Western Europe and Scandinavia since Dr. Wolfgang Feist built the first one in 1991. Homeowners and builders in the U.S. have been slow to follow suit. Numerous studies and field tests have shown that these super-insulated, high-efficiency homes can be built to accommodate a wide range of climates with only modest increases in building costs that can be repaid through energy savings in 5-10 years. It is unrealistic to require that all new homes in the U.S. meet *PassivHaus* standards today, but policy makers could hasten the transition to a low

[29] The European database is available at: http://www.PassivHausprojekte.de/projekte.php?lang=en PassivHaus projects in the US can be found at: http://www.passivehouse.us/passiveHouse/PHIUSProjects.html

[30] http://passive.bg/files/files/83dede941ff2a5e60dd8e0d1cbfc24acFirstStep.pdf.

carbon, low impact housing stock by supporting research aimed at the development of substitutes for petroleum-based polystyrene and adopting increasingly strict standards that reflect energy efficiency possible through the application of the best of *PassivHaus* technology. The technology and expertise have already been developed and it is time for the U.S. to recapture the lead in energy efficient housing that European nations established following the oil crisis of the 1970s.

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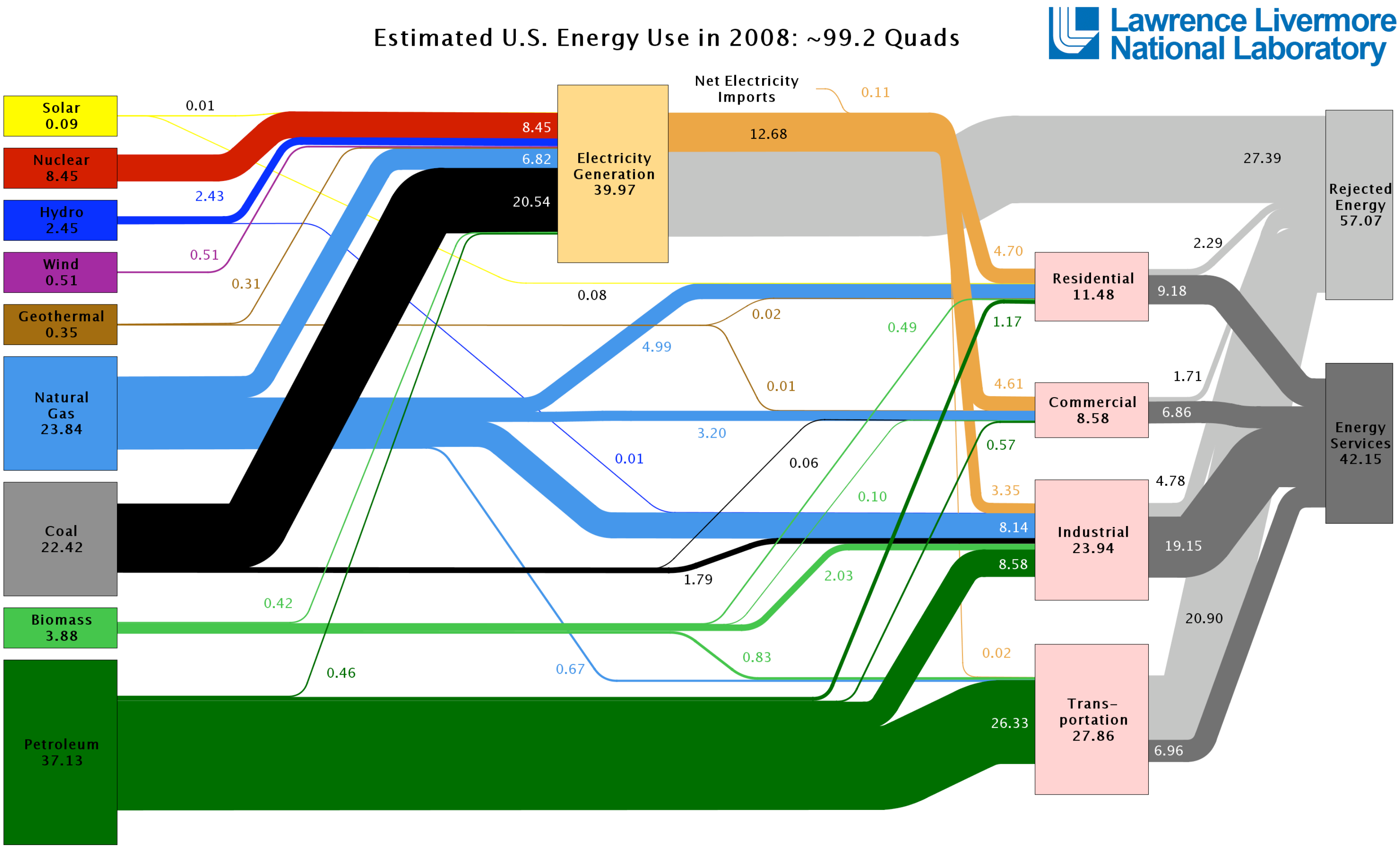
Figure 1. Estimated U.S. Energy Use in 2008



Source: LLNL 2009. Data is based on DOE/EIA-0384(2008), June 2009. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. Distributed electricity represents only retail electricity sales and does not include self-generation. EIA reports flows for non-thermal resources (i.e., hydro, wind and solar) in BTU-equivalent values by assuming a typical fossil fuel plant "heat rate." The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 80% for the residential, commercial and industrial sectors, and as 25% for the transportation sector. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

Source: US Department of Energy. http://www.eia.doe.gov/aer/

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