The Passive House

Strategies for Extreme Efficiency

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The Passive House (PH) concept—slashing heating and cooling of buildings by up to 95% over a conventionally constructed home—represents one of today's highest energy standards for homes.

The PH concept is a comprehensive approach to cost-effective, high-quality, sustainable construction. Two goals are targeted: minimize energy losses and maximize passive energy gains. Achieving these goals has led to extraordinary results—a PH uses up to 95% less energy for space heating and cooling than a conventionally constructed house.

What makes a PH so special? Mostly, its extreme attention to detail—using highly insulating materials, as well as high-performance glazing; eliminating thermal bridging; establishing an airtight envelope; and balancing heat/energy recovery ventilation. These strategies can keep a house warm passively—by using existing internal heat sources (people, lights, and appliances) and solar energy admitted by the windows. Even the fresh air supply can be warmed without mechanical intervention by using an earth tube—a passive geothermal heating-and-cooling system.

According to the Architecture 2030 campaign, an average, conventionally built, single-family home in the Midwest uses 14.5 kWh per square foot per year site energy for space conditioning, domestic hot water, and household electricity. A new home built to code has a site energy use of approximately 12 kWh per square foot per year. Homes built to Energy Star standards are about 20% more efficient, at 9.6 kWh per square foot per year. The PH design principles require that a building use no more than 1.39 kWh (4.75 kBtu) per square foot per year for heating and cooling, and that its total source (primary) energy for space conditioning, water heating, and electricity not exceed 11.15 kWh (38 kBtu) per square foot per year based on “treated floor area”—the discounted net-usable conditioned floor area. To achieve these energy savings, designers and builders work together to systematically implement seven principles: 1) superinsulate; 2) eliminate thermal bridges; 3) make it airtight; 4) specify ERVs or HRVs; 5) specify high-performance windows and doors; 6) optimize passive solar and internal heat gains; 7) evaluate and optimize energy gains and losses.

Superinsulate

The insulation applied to a house slows heat transmission and helps maintain the contents at a relatively constant temperature. Warm contents stay warm and cool contents stay cool, even when the temperature on the outside hits the opposite extreme. In a PH, the entire envelope of the building—walls, roof, and floor or basement—is well-insulated. How well-insulated? That depends, of course, on the climate. To achieve the PH standard, the Tahan House, in Berkeley, California, required only 6 inches of blown-in cellulose insulation, while the Skyline House, in the far harsher climate of Duluth, Minnesota, needed 16 inches—almost three times as much. Often, the first feature of a PH to catch a visitor's attention is the unusual thickness of the walls, needed to accommodate the insulation.

PH designers choose from a wide range of materials to create superinsulated buildings, including conventional lumber or masonry construction, double-stud construction, structural insulated panels (SIPs), insulated concrete forms (ICFs), truss joist I-beams (TJIs), or straw-bale construction. Similarly, designers can choose from different types of insulation including cellulose, high-density blown-in fiberglass, polystyrene, spray foam, and straw bale.

Green building goes beyond the energy factor. For example, spray foams have a high R-value and are easy to apply, but they are petroleum-based products and some of the foaming agents contribute significantly to global warming. Manufacturers are seeking to develop spray foams that do not have these disadvantages. Vacuum-insulated panels (VIPs) are a relatively new and pricey option with an exceptionally high R-value per inch. VIPs allow thinner walls, for situations when that is a consideration.

No matter which insulation is selected, it needs to be installed correctly. The application can be inspected and performance measured using thermographic imaging. All objects emit infrared radiation (IR), and the amount of radiation emitted increases with the temperature of the object. Thermographic cameras can measure heat loss, identifying areas where insulation is insufficient, incomplete, damaged, or settled. Thermal images of properly constructed PHs show little heat loss.

Eliminate Thermal Bridges

Heat will flow out of a building fastest via the easiest path, passing quickly through a material that has a higher thermal conductivity—a thermal bridge. Thermal bridges can significantly increase heat losses, which can create areas in or on the walls that are cooler than their surroundings. In the worst-case scenario, this can cause moisture problems—when warm, moist air condenses on a cooler surface.

Thermal bridges occur at envelope edges, corners, connections, and penetrations. A bridge can be as simple as a wall stud with higher thermal conductivity than the surrounding insulated wall or as unsuspected as a balcony slab that is not thermally isolated from an interior concrete floor. Without a thermal break, the balcony will act as a very large cooling fin, sucking heat out of the house in the winter.

In a PH, there are few or no thermal bridges. When the thermal bridge coefficient, an indicator of the extra heat loss caused by a thermal bridge, is less than 0.01 watts per meter per Kelvin (W/m-K), the detail or wall assembly is said to be thermal-bridge-free. Heat loss through this detail is negligible, and interior temperatures are sufficiently stabilized to eliminate moisture problems. It is critical for the PH designer and builder to plan for reducing or eliminating thermal breaks by limiting penetrations, and by using heat transfer-resistant materials. Thermographic imaging can be used to determine how effective the elimination of thermal bridges has been.

Make It Airtight

Airtight construction helps the performance of a building by reducing or eliminating drafts—hot or cold—thereby reducing the need for space conditioning. This also helps to prevent warm, moist air from penetrating the structure, condensing inside the wall, and causing structural damage.

Airtight construction is achieved by wrapping an intact, continuous layer of airtight materials around the entire building envelope. Special care must be taken to ensure continuity of this layer around windows, doors, penetrations, and all joints between the roof, walls, and floors. Insulation materials are generally not airtight; the materials used to create an intact airtight layer include a combination of various membranes, tapes, plasters, glues, shields, and gaskets. These materials are becoming increasingly durable, easy to apply, and environmentally sound, which in turn is making it easier for a builder to meet the stringent airtightness requirement of the PH standard.

A home’s airtightness provides a measurable dimension of its construction quality. Testing requires the use of a blower door, which is essentially a large, specialized fan that is sealed into an exterior door frame. The blower door can be used to either depressurize or pressurize a house to a designated pressure so a technician can measure how much air is infiltrating the building through all its gaps and cracks. Specific leaks can be detected during the test either with tracer smoke or by examining thermographic images. It is best to conduct the blower-door test at a point during construction when the airtight layer can still be easily accessed and any leaks can be readily addressed.

PHs are extremely airtight. At a standard test pressure of 50 Pascal (Pa), a PH must allow no more than 0.6 ACH (air changes per hour). PHs built from timber, masonry, and prefabricated elements have all met this standard.

Airtightness does not mean that you can’t ever open the windows. PHs have many operable windows to take full advantage of natural ventilation to help maintain comfortable temperatures.

Specify Energy or Heat Recovery Ventilation

Perhaps the most common misperception regarding PHs concerns airflow. With the past problems of poor indoor air quality of “too-tight” houses built in the late 1970s and 80s, many builders balk at airtight homes. Even though a PH is “tight,” it does breathe. However, rather than breathing unknown volumes of air through uncontrolled leaks, PHs breathe controlled volumes of air by mechanical ventilation, which circulates measured amounts of fresh air through the house and exhausts stale air. The health and comfort of the occupants come first, and good indoor air quality is indispensable.

A PH is ventilated using an energy-efficient, balanced mechanical ventilation system. PHs use energy recovery ventilators (ERVs) or, in cold, dry climates, heat recovery ventilators (HRVs), which incorporate air-to-air energy recovery to transfer from the exhaust air to the incoming fresh air, significantly reducing the energy needed to heat incoming air. State-of-the-art ventilation systems have heat recovery rates of 75% to 95%.

The ventilation system exhausts air from the rooms that produce moisture and unwanted odors, such as the kitchen and bathrooms. Humidistats monitor when moisture levels are elevated, initiating an increase in the ventilation. The exhaust air is drawn through the ventilator, passing through a heat exchanger to transfer the heat to the incoming fresh air. Exhaust air is not mixed with the incoming air—only its heat is transferred.

The ventilator filters the fresh air and removes excess moisture. The system is generally very quiet and draft-free. The PH Planning Package (PHPP; see below) recommends an ACH of 0.3 to 0.4 times the volume of the building, and a guideline for supply air of 18 cubic feet per minute (cfm) per occupant.

The main difference between an HRV and an ERV is that the HRV conserves heat and cooling energy, while the ERV does both and transfers humidity as well. In summer, an ERV helps keep the humidity outside; in winter, it helps prevent indoor air from becoming too dry. For in-between seasons, when no conditioning is needed, a bypass can be installed for either system to avoid heating the incoming air. Alternatively, the ventilation system can be turned off altogether, and windows can be thrown open to bring in fresh air.

Either system’s efficiency can be increased by prewarming or precooling the incoming air by passing the incoming air through earth tubes. Since the ground maintains a more consistent temperature throughout the year than the outdoors, passing the air through tubes buried in the earth either preheats or precools the air, depending on the season. Preheating and precooling can also be accomplished indirectly, by circulating water in an underground pipe and using it to heat or cool the air with a water-to-air heat exchanger.

Specify High-Performance Windows & Doors

PH designers choose windows and doors based largely on their insulating value. Low-emissivity (low-e) coatings have significantly affected the heat conductivity of windows. These coatings are microscopically thin, transparent layers of metal or metallic oxide deposited on the surface of the glass. The coated side of the glass faces into the gap between the two panes of a double-glazed window. The gap is filled with low-conductivity argon or krypton gas rather than air, greatly reducing the window’s radiant heat transfer. Various low-e coatings allow for high, moderate, or low solar gain to provide a range of options for houses in all climates, from heating-dominated to cooling-dominated. Builders can choose triple-pane low-e-coated, argon-filled windows with special low-conductivity spacers and insulated frames with little thermal bridging. These windows eliminate perceptible cold radiation or convective cold airflow, even in periods of heavy frost.

Optimize Passive Solar & Internal Heat Gains

Not only must PHs minimize energy loss, they must also carefully manage a home’s energy gains. The first step in designing a PH is to consider how the orientation of a building—and its various parts—will affect its energy losses and gains. There are many issues to be considered: Where should the windows be for maximum sunlight when sunlight is wanted, and minimal heat gain when heat gain is unwanted? The more natural lighting there is, the less artificial lighting will be needed. Designers can enhance residents’ enjoyment of available sunlight by orienting bedrooms and living rooms to the south, and putting utility rooms, closets, etc., to the north, where sunlight is not needed.

PH windows are oriented to take advantage of the passive solar energy, but the goal is not simply to have as much solar gain as possible. Some early superinsulated buildings suffered from overheating, because not enough consideration was given to the amount of solar gain the home received. Good design considers solar gain within the home’s overall conditioning needs—and within the budget. Even very efficient windows can lose more heat over a year than they gain, depending on their location, and large windows are expensive.

In the northern hemisphere, windows on the north side receive very little direct solar heat gain, while those on the south can receive a great deal of it. In summer, and especially in cooling-dominated climates, preventing excess solar heat gain is important. This is accomplished by shading the windows, either with roof eaves of the proper length, which block the high-angled summer sun but allow the lower-angled winter sun to enter. Deciduous trees or vines on a trellis can filter out sunlight in the summer but allow it in the winter when the vegetation has been shed. In climates with significant cooling loads, unshaded east- and west-facing windows should be limited and those used should have low-solar-gain, low-e coatings. Otherwise, during the morning and late afternoon, low-angled sunlight can generate a great deal of heat through these windows.

Another, less obvious source of heat gain is internal. Given the exceptionally low heat loss in a PH, heat from internal sources can make a difference. Household appliances, electronic equipment, artificial lighting, and people can all have an effect on heat gain. While designers may not be choosing how many or which appliances will be installed, they often select lighting, and must take into account this heat gain when calculating the overall internal energy gain.

Evaluate Energy Gains & Losses

The Passive House Planning Package (PHPP) is an energy-modeling tool that helps integrate each PH component so that the final design will meet PH requirements. The PHPP starts with the whole building as one zone of energy calculation. The designer inputs all of the house's basic characteristics, including orientation, size, window location, insulation levels, and so on. The PHPP then computes the energy balance of the design. If needed, the designer can change a house's components within PHPP to model the impact of those changes on the overall energy balance. The PH standard is met when:

- the space heating and cooling requirement of the design is less than or equal to 4.75 kBtu per square foot per year (15 kWh/m2/yr.);
- the primary energy demand of the design is less than or equal to 38 kBtu per square foot per year (120 kWh/m2 /yr.); and
- the airtightness of the building is at or below 0.6 ACH at 50 Pa.

The PHPP also effectively models solar water heating for combined space and domestic water heating, natural ventilation (such as night cooling), and the efficiency of energy recovery ventilation.

Up-Front Costs & Energy Savings

Among all the components that contribute to increasing the efficiency of a home's thermal envelope, high-performance windows and doors cost the most. Upgrading from double-pane vinyl-framed windows to high-performance fiberglass windows with insulated frames and triple-pane, argon-filled glazing can cost an additional $10,000 or more for a typical home. Interestingly enough, high-end architectural wood-frame, double-pane window packages upgraded to European high-performance specifications cost only about 10% more.

Costs for a house built to both PH *and* green standards will be 10% to 15% higher than for a house built only to PH standards. In a green-built home, many types of standard materials are replaced, and often these increased costs exceed the costs of energy-efficiency features.

With a focus on energy efficiency and conservation, a PH can get by with a smaller, and therefore less costly, renewable energy system, putting net-zero energy (or even net-positive energy) and carbon-neutrality within reach.

From Concept to Reality

In Europe, thousands of homes have been built or remodeled to meet the PH standard, while in the United States, PH design has just begun—but it has the potential to have a dramatic impact on the nation's energy use. Residential energy use constitutes about one-fifth of the total U.S. consumption, and space heating and cooling of U.S. homes represents more than half of a household’s total energy use.

Access

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