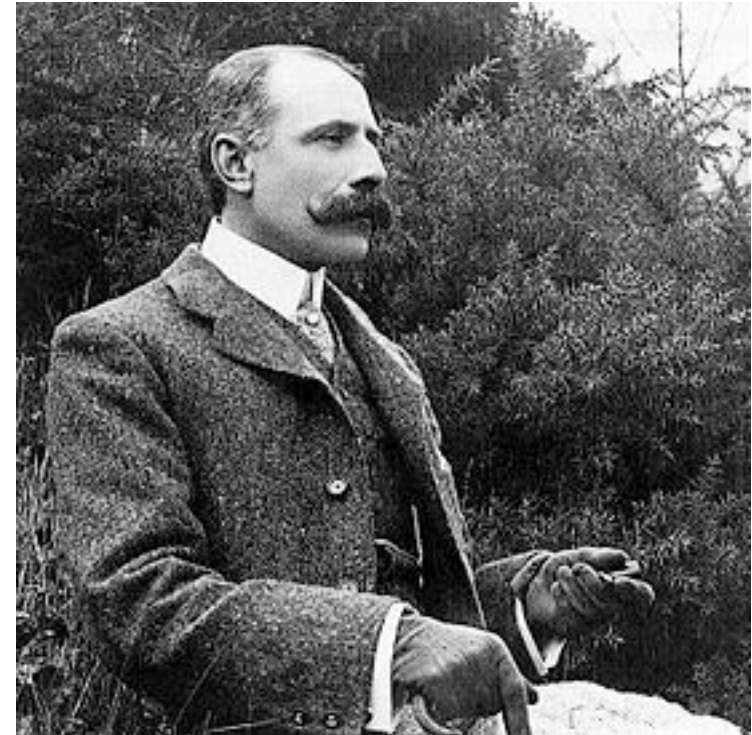


Passive Solar House

4th Lecture

Elgar

- Salut D'Amour, Op. 12

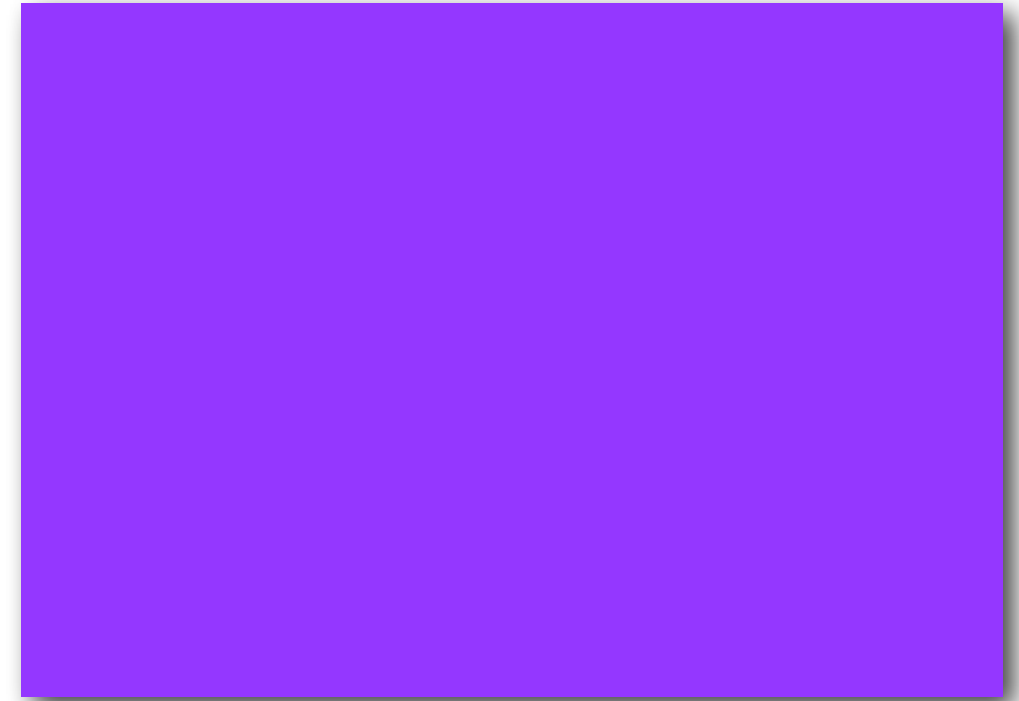


The Passive Solar House

- James Kachadorian

The Passive Solar Concept





The term passive house (Passivhaus in German) refers to the rigorous, voluntary, Passivhaus standard for [energy efficiency](#) in a [building](#), reducing its [ecological footprint](#).

It results in [ultra-low energy buildings](#) that require little energy for space heating or cooling. A similar standard, [MINERGIE-P](#), is used in [Switzerland](#). The standard is not confined to residential properties; several [office buildings](#), [schools](#), [kindergartens](#) and a [supermarket](#) have also been constructed to the standard. Passive design is not an attachment or supplement to architectural design, but a design process that is integrated with architectural design. Although it is mostly applied to new buildings, it has also been used for refurbishments.

Estimates of the number of Passivhaus buildings around the world in late 2008 ranged from 15,000 to 20,000 structures. As of August 2010, there were approximately 25,000 such certified structures of all types in Europe, while in the United States there were only 13, with a few dozens more under construction. The vast majority of passive structures have been built in German-speaking countries and .

[Scandinavia](#)



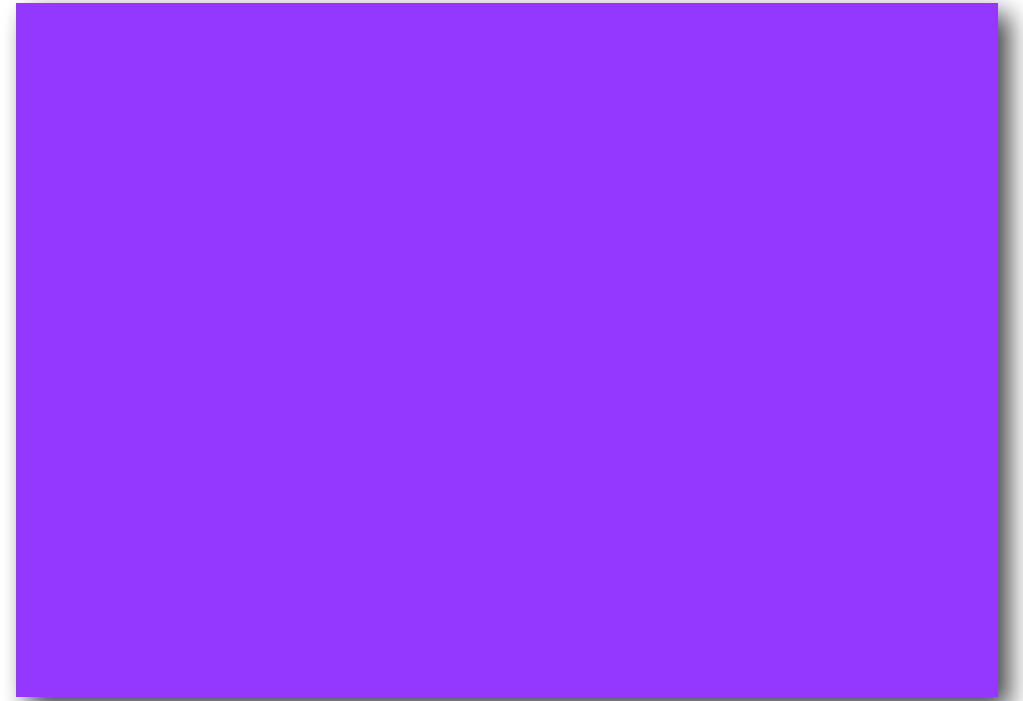
Prof. Bo Adamson of Sweden, co-ordinator of the **Passivhaus** concept.



Prof. Wolfgang Feist of Germany, co-ordinator of the **Passivhaus** concept, and founder of the **Passivhaus Institut**.

History

The Passivhaus 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, **Germany**). Their concept was developed through a number of **research projects**, aided by financial assistance from the German state of **Hessen**.








First examples

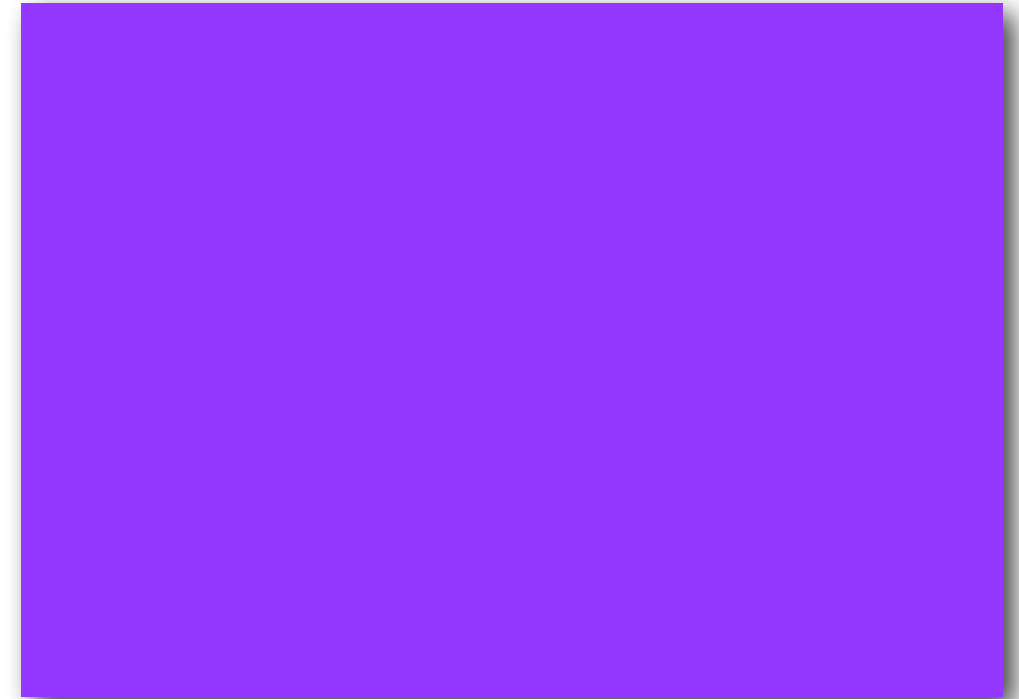
The eventual building of four **row houses** (terraced houses or town homes), was designed for four private clients by the **architectural firm** of **professors** Bott, Ridder and Westermeyer. The first Passivhaus **residences** were built in **Darmstadt**, Germany in 1990, and occupied by the clients the following year.



The world's first Passive House, Darmstadt-Kranichstein, Germany

Building component	Description	Phototgraph
Roof	Grass roof: Humus, non-woven filter, root protective membrane, 50 mm	
Exterior wall	Fabric reinforced mineral render; 275 mm of expanded polystyrene insulation	
Basement ceiling	Surface finish on fibreglass fabric; 250 mm polystyrene insulation boards;	
Windows	Triple-pane low-e glazing with Krypton filling: U_g -value 0.7 W/(m ² K).	
Heat recovery ventilation	Counterflow air-to-air heat exchanger; Located in the cellar (approx. 9°C in the winter), carefully sealed and thermally insulated, the first one to use electronically commutated DC fans.	

Building component	Description	Photo	U-value W/(m²K)
Roof	Grass roof: Humus, non-woven filter, root protective membrane, 50 mm formaldehyde-free chip board; Wooden light-weight beam (I-beam of wood, stud link of hardboard), counter lathing, sealing with polyethylene sheeting bonded without jointing, gypsum plasterboard 12.5 mm, wood-chip wallpaper, emulsion paint coating, entire cavity (445 mm) filled with blown-in mineral wool insulation .		0.1
Exterior wall	Fabric reinforced mineral render; 275 mm of expanded polystyrene insulation (EPS) (installed in two layers at that time, 150+125 mm); 175 mm sand-lime brick masonry; 15 mm continuous interior gypsum plastering; wood-chip wallpaper, emulsion paint coating		0.14
Basement ceiling	Surface finish on fibreglass fabric; 250 mm polystyrene insulation boards; 160 mm concrete; 40 mm polystyrene acoustic insulation; 50 mm cement floor finish; 8-15 mm of parquet, adhesive; sealing solvent-free		0.13
Windows	Triple-pane low-e glazing with Krypton filling: U_g -value 0.7 W/(m²K). Wooden window with polyurethane foam insulated framework (CO2-foamed, HCFC free, handcrafted)		0,7
Heat recovery ventilation	Counterflow air-to-air heat exchanger; Located in the cellar (approx. 9°C in the winter), carefully sealed and thermally insulated, the first one to use electronically commutated DC fans.		heat recovery rate approx. 80%



Further implementation and councils

In September 1996 the [Passivhaus-Institut](#) was founded, also in Darmstadt, to promote and control the standards. Since then, thousands of Passivhaus structures have been built, to an estimated 25,000+ as of 2010. Most are located in Germany and [Austria](#), with others in various countries worldwide.

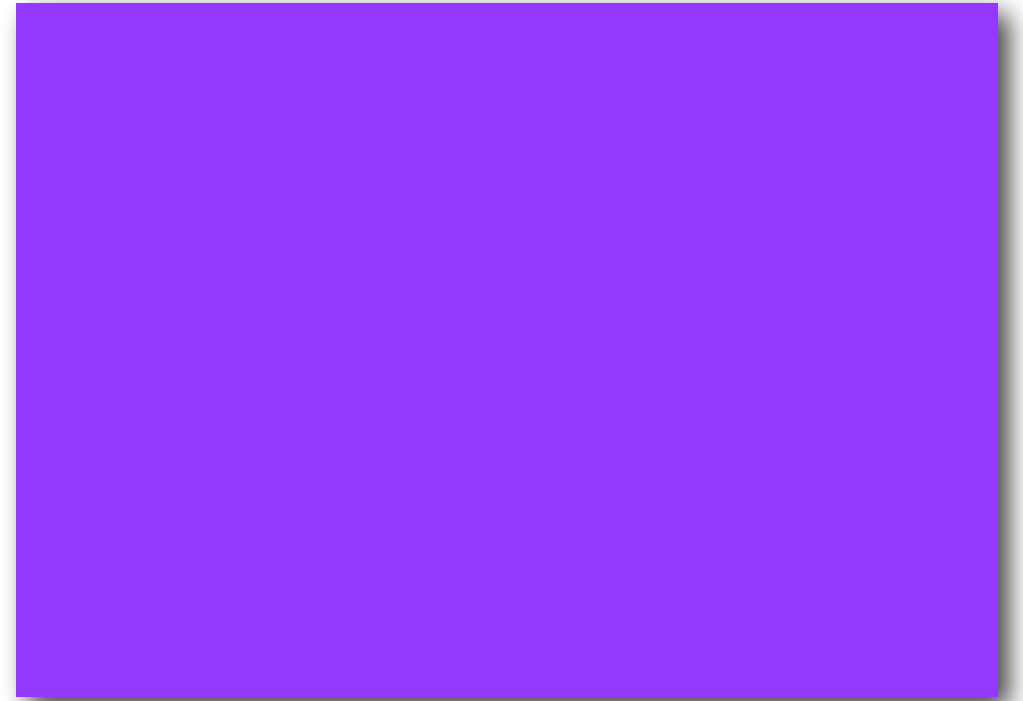
After the concept had been validated at Darmstadt, with space heating 90% less than required for a standard new building of the time, the Economical Passive Houses Working Group was created in 1996. This group developed the planning package and initiated the production of the innovative components that had been used, notably the windows and the high-efficiency ventilation systems. Meanwhile further passive houses were built in [Stuttgart](#) (1993), [Naumburg](#), [Hesse](#), [Wiesbaden](#), and [Cologne](#) (1997).

The products developed for the Passivhaus standard were further commercialised during and following the [European Union](#) sponsored [CEPHEUS](#) project, which proved the concept in five European countries over the winter of 2000–2001.

In [North America](#) the first Passivhaus was built in [Urbana, Illinois](#) in 2003, and the first to be [certified](#) was built in 2006 near [Bemidji, Minnesota](#) in [Camp Waldsee](#) of the German [Concordia Language Villages](#).

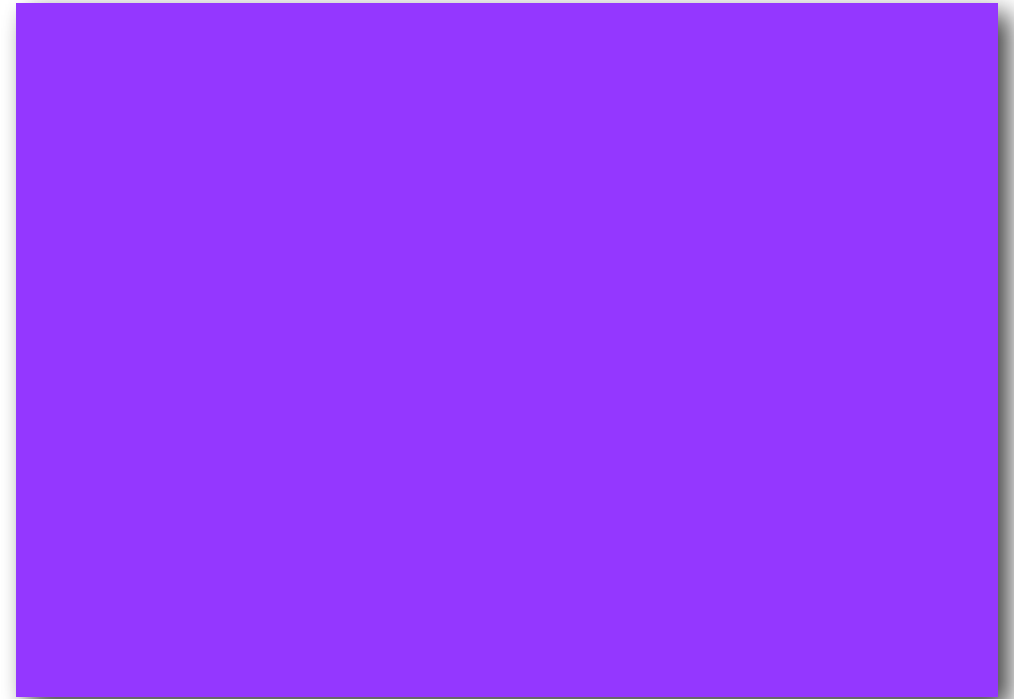
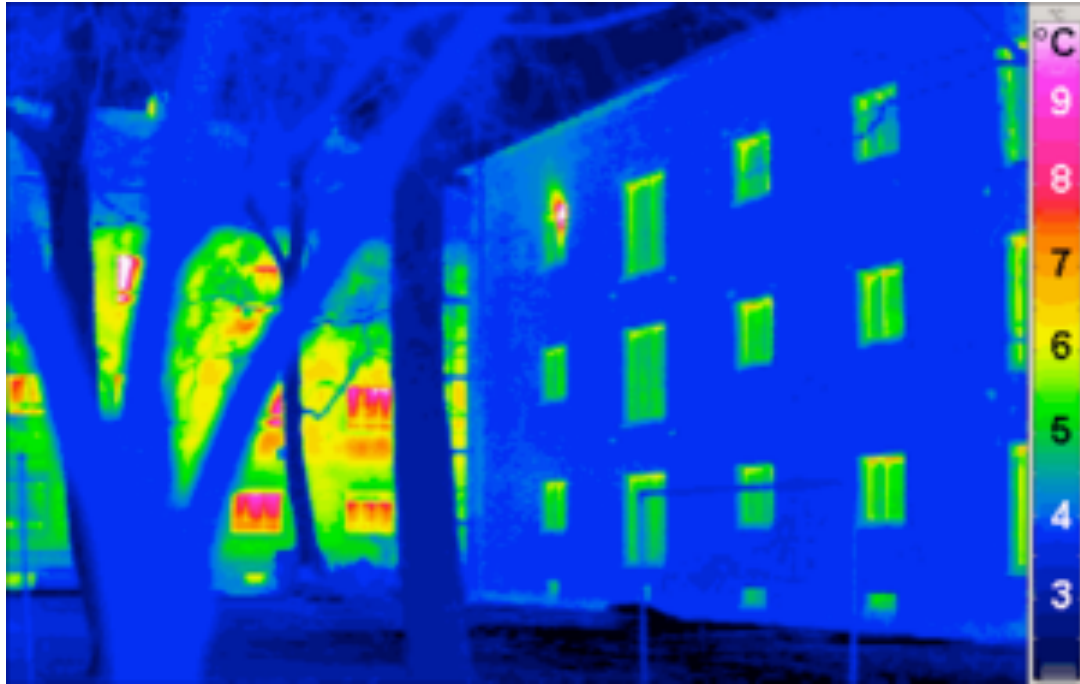
The first US passive retrofit project was certified in July 2010: the remodeled 2,400 sf craftsman O'Neill house in [Sonoma, California](#).

The world's first [standardised](#) passive [prefabricated house](#) was built in [Ireland](#) in 2005 by Scandinavian Homes, a Swedish company that has since built more passive houses in [England](#) and [Poland](#).



Present day

Estimates on the number of passive houses around the world range from 15,000 to 20,000. The vast majority have been built in German-speaking countries or [Scandinavia](#). The first certified passive house in the [Antwerpen](#) region of [Belgium](#), was built in 2010. The city of [Heidelberg](#) in Germany recently gave birth to the Bahnstadt project, which is seen as the world's largest passive house building areas.



Standards

The dark colours on this [thermogram](#) of a **Passive house**, at right, shows how little heat is escaping compared to a traditional building to the left.

While some techniques and technologies were specifically developed for the Passive House standard, others, such as [superinsulation](#), already existed, and the concept of [passive solar building design](#) dates back to antiquity. There was also other previous experience with [low-energy building](#) standards, notably the German *Niedrigenergiehaus* (low-energy house) standard, as well as from buildings constructed to the demanding energy codes of Sweden and [Denmark](#).



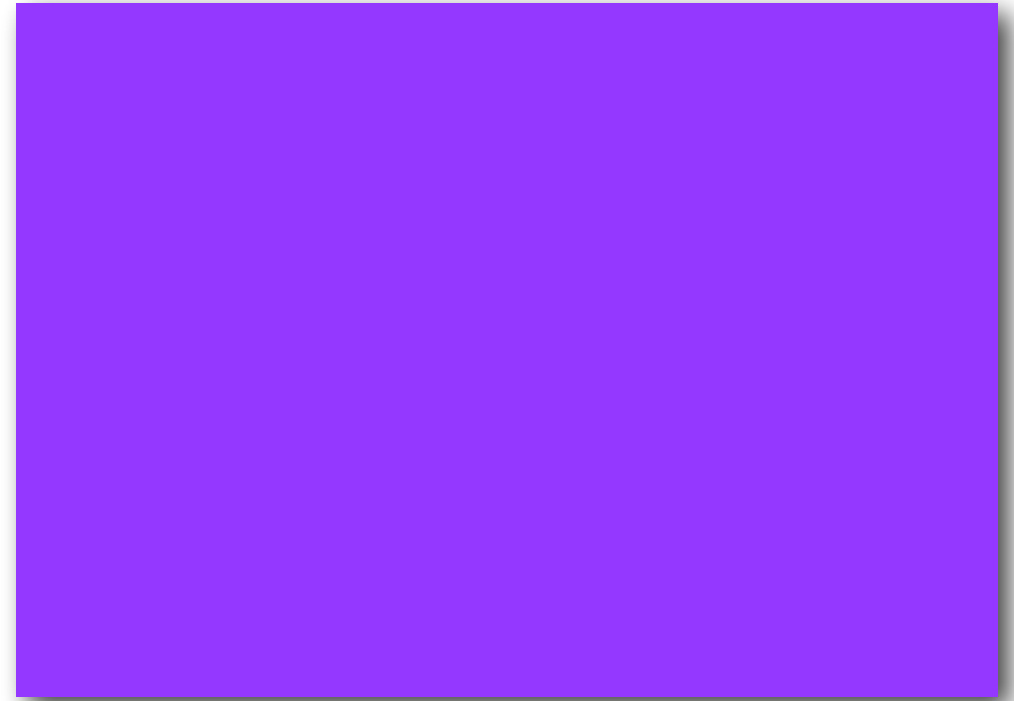
Standards

The Passivhaus standard for central Europe requires that the building fulfills the following requirements:

The building must be designed to have an annual heating demand as calculated with the Passivhaus Planning Package of not more than 15 kWh/m² per year (4746 btu/ft² per year) in heating and 15 kWh/m² per year cooling energy OR to be designed with a peak heat load of 10W/m²

Total **primary energy** (source energy for electricity and etc.) consumption (primary energy for **heating, hot water** and **electricity**) must not be more than 120 kWh/m² per year (3.79×10^4 btu/ft² per year)

The building must not leak more air than 0.6 times the house volume per hour ($n_{50} \leq 0.6$ / hour) at 50 Pa (N/m²) as tested by a **blower door**



Recommendations

Further, the specific heat load for the heating source at design temperature is recommended, but not required, to be less than 10 **W**/m² (3.17 **btu**/h.ft² per hour).

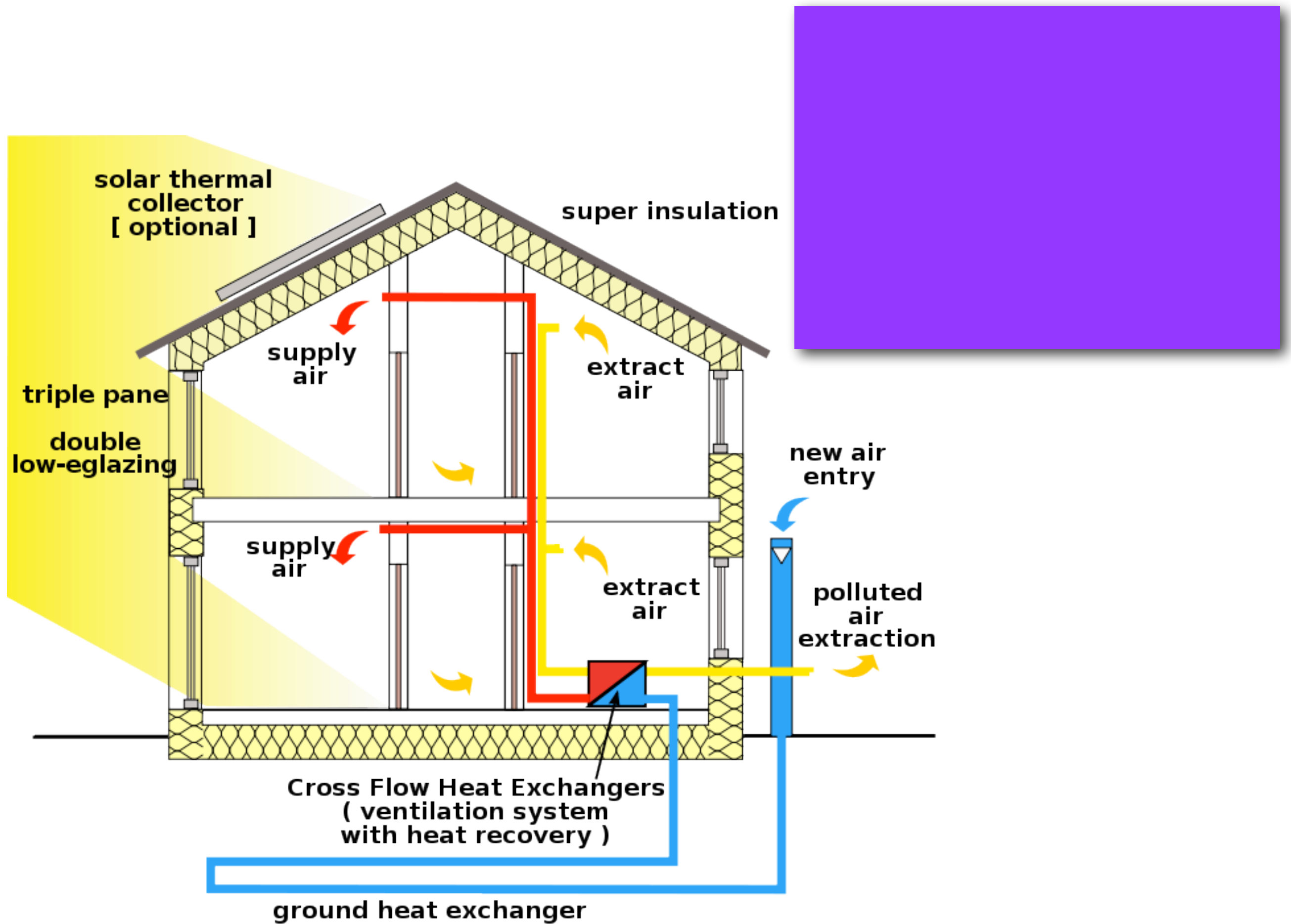
These standards are much higher than houses built to most normal building codes. For comparisons, see [the international comparisons section](#) below.

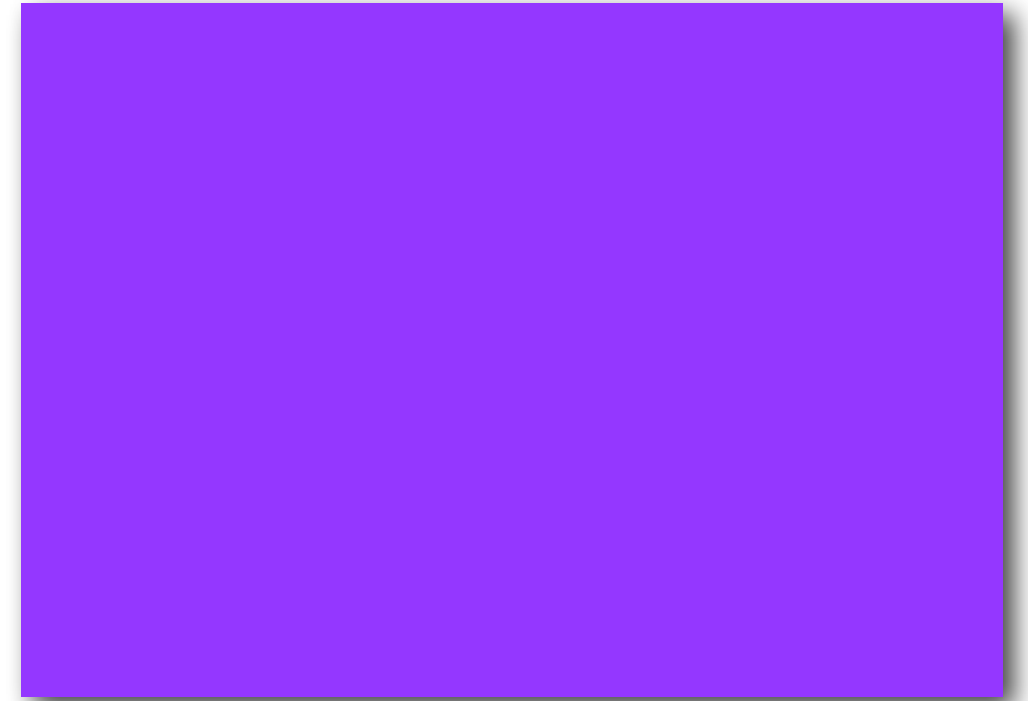
National partners within the 'consortium for the Promotion of European Passive Houses' are thought to have some flexibility to adapt these limits locally.



Space heating requirement

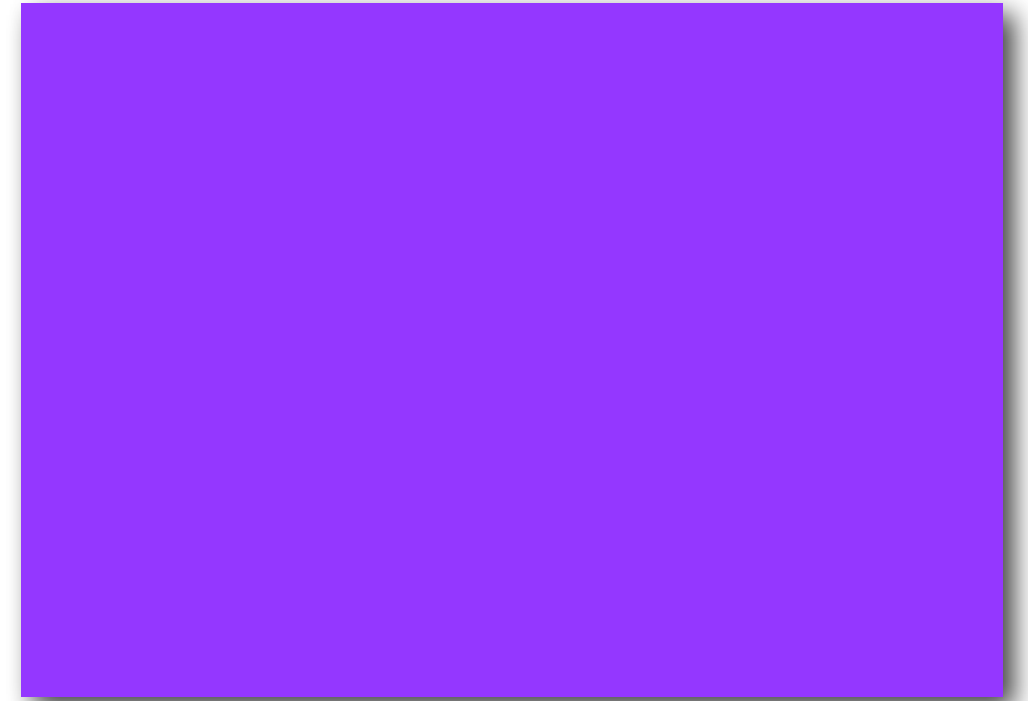
By achieving the Passivhaus standards, qualified buildings are able to dispense with conventional heating systems. While this is an underlying objective of the Passivhaus standard, some type of heating will still be required and most Passivhaus buildings do include a system to provide supplemental space heating. This is normally distributed through the low-volume [heat recovery ventilation](#) system that is required to maintain air quality, rather than by a conventional hydronic or high-volume [forced-air](#) heating system, as described in the [space heating](#) section below.





Construction costs

In Passivhaus buildings, the cost savings from dispensing with the conventional heating system can be used to fund the upgrade of the building envelope and the heat recovery ventilation system. With careful design and increasing competition in the supply of the specifically designed Passivhaus building products, in Germany it is now possible to construct buildings for the same cost as those built to normal German [building standards](#), as was done with the Passivhaus apartments at [Vauban, Freiburg](#). On average, however, passive houses are still up to 14% more expensive upfront than conventional buildings.



Evaluations have indicated that while it is technically possible, the costs of meeting the Passivhaus standard increase significantly when building in Northern Europe above 60°latitude. European cities at approximately 60° include Helsinki in Finland and Bergen in Norway. London is at 51°; Moscow is at 55°.

These facts have led a number of architects to construct buildings that use the ground under the building for massive heat storage to shift heat production from the winter to the summer.

Some buildings can also shift cooling from the summer to the winter. At least one designer uses a passive thermosiphon carrying only air, so the process can be accomplished without expensive, unreliable machinery.



Design Construction

The **Passivhaus** uses a combination of **low-energy building** techniques and technologies. Achieving the major decrease in heating energy consumption required by the standard involves a shift in approach to building design and construction. Design may be assisted by use of the 'Passivhaus Planning Package' (PHPP), which uses specifically designed **computer simulations**.

To achieve the standards, a number of techniques and technologies are used in combination:



Passive solar design and landscape

Passive solar building design and energy-efficient landscaping support the Passive house energy conservation and can integrate them into a neighborhood and environment. Following passive solar building techniques, where possible buildings are compact in shape to reduce their surface area, with principal windows oriented towards the equator - south in the northern hemisphere and north in the southern hemisphere - to maximize passive solar gain. However, the use of solar gain, especially in temperate climate regions, is secondary to minimizing the overall house energy requirements. In climates and regions needing to reduce excessive summer passive solar heat gain, whether from the direct or reflected sources, can be done with a Brise soleil, trees, attached pergolas with vines, vertical gardens, green roofs, and other techniques.



Passive houses can be constructed from dense or lightweight materials, but some internal **thermal mass** is normally incorporated to reduce summer peak temperatures, maintain stable winter temperatures, and prevent possible overheating in spring or autumn before the higher **sun angle** "shades" mid-day wall exposure and window penetration. Exterior wall color, when the surface allows choice, for reflection or absorption **insolation** qualities depends on the predominant year-round ambient outdoor temperature. The use of **deciduous** trees and wall **trellised** or self attaching vines can assist in climates not at the temperature extremes.

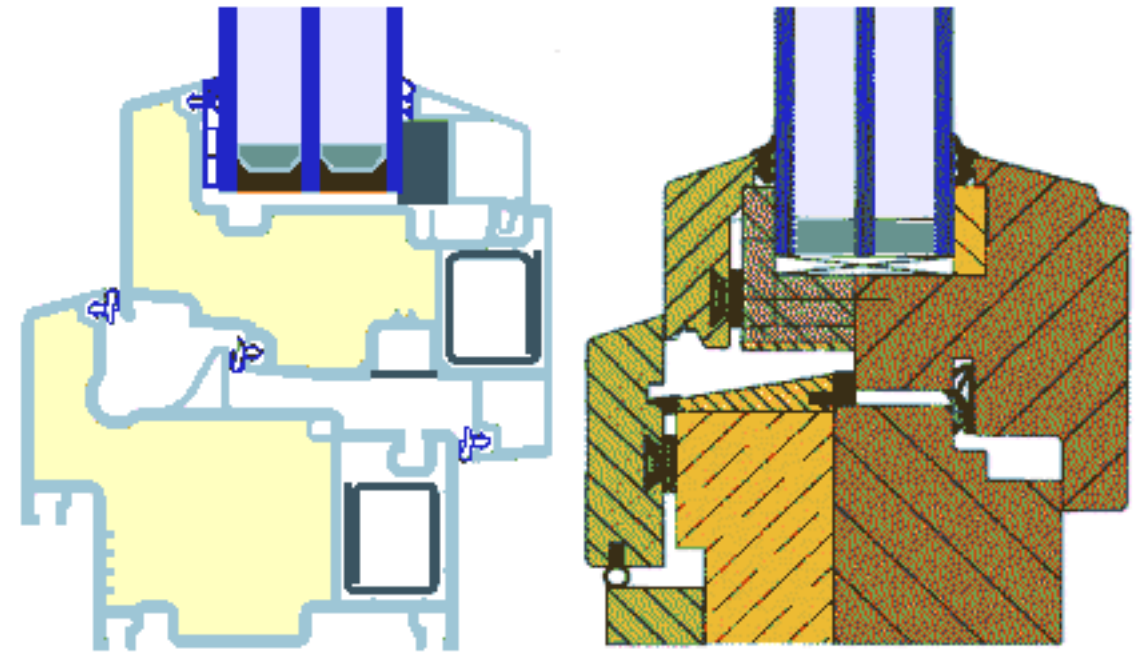


Superinsulation

Passivhaus buildings employ **superinsulation** to significantly reduce the heat transfer through the walls, roof and floor compared to conventional buildings. A wide range of **thermal insulation** materials can be used to provide the required high **R-values** (low **U-values**, typically in the 0.10 to 0.15 W/(m².K) range). Special attention is given to eliminating **thermal bridges**.

A disadvantage resulting from the thickness of wall insulation required is that, unless the external dimensions of the building can be enlarged to compensate, the internal floor area of the building may be less compared to traditional construction.

In Sweden, to achieve passive house standards, the insulation thickness would be 335 mm (about 13 in) (0.10 W/(m².K)) and the roof 500 mm (about 20 in) (U-value 0.066 W/(m².K)).



Advanced window technology

Typical **Passive House** windows

To meet the requirements of the Passivhaus standard, windows are manufactured with exceptionally high *R-values* (low *U-values*, typically 0.85 to $0.70 \text{ W/(m}^2\cdot\text{K)}$ for the entire window including the frame). These normally combine triple-pane *insulated glazing* (with a good solar heat-gain coefficient, low-emissivity coatings, sealed argon or krypton gas filled inter-pane voids, and 'warm edge' insulating glass spacers) with air-seals and specially developed thermally broken window frames.

In Central Europe and most of the United States, for unobstructed south-facing Passivhaus windows, the heat gains from the sun are, on average, greater than the heat losses, even in mid-winter.



Airtightness

Building envelopes under the Passivhaus standard are required to be extremely **airtight** compared to conventional construction. Air barriers, careful sealing of every construction joint in the building envelope, and sealing of all service penetrations through them are all used to achieve this.

Airtightness minimizes the amount of warm — or cool — air that can pass through the structure, enabling the mechanical ventilation system to recover the heat before discharging the air externally.



Ventilation

Use of passive **natural ventilation** is an integral component of passive house design where ambient temperature is conducive — either by singular or cross ventilation; by a simple opening or enhanced by the **stack effect** from smaller ingress with larger egress windows and/or **clerestory**-operable **skylight**.

When ambient climate is not conducive, mechanical **heat recovery ventilation** systems, with a heat recovery rate of over 80% and high-efficiency **electronically commutated motors** (ECM), are employed to maintain air quality, and to recover sufficient heat to dispense with a conventional central heating system. Since passively designed buildings are essentially **air-tight**, the rate of air change can be optimized and carefully controlled at about **0.4 air changes per hour**. All ventilation ducts are insulated and sealed against leakage.



Some Passivhaus builders promote the use of **earth warming tubes** (typically ≈ 200 mm ($\sim 7,9$ in) diameter, ≈ 40 m (~ 130 ft) long at a depth of ≈ 1.5 m (~ 5 ft)). These are buried in the soil to act as earth-to-air heat exchangers and pre-heat (or pre-cool) the intake air for the ventilation system. In cold weather the warmed air also prevents **ice** formation in the heat recovery system's **heat exchanger**. Concerns about this technique have arisen in some climates due to problems with condensation and mold.

Alternatively, an earth to air heat exchanger can use a liquid circuit instead of an air circuit, with a heat exchanger (battery) on the supply air.

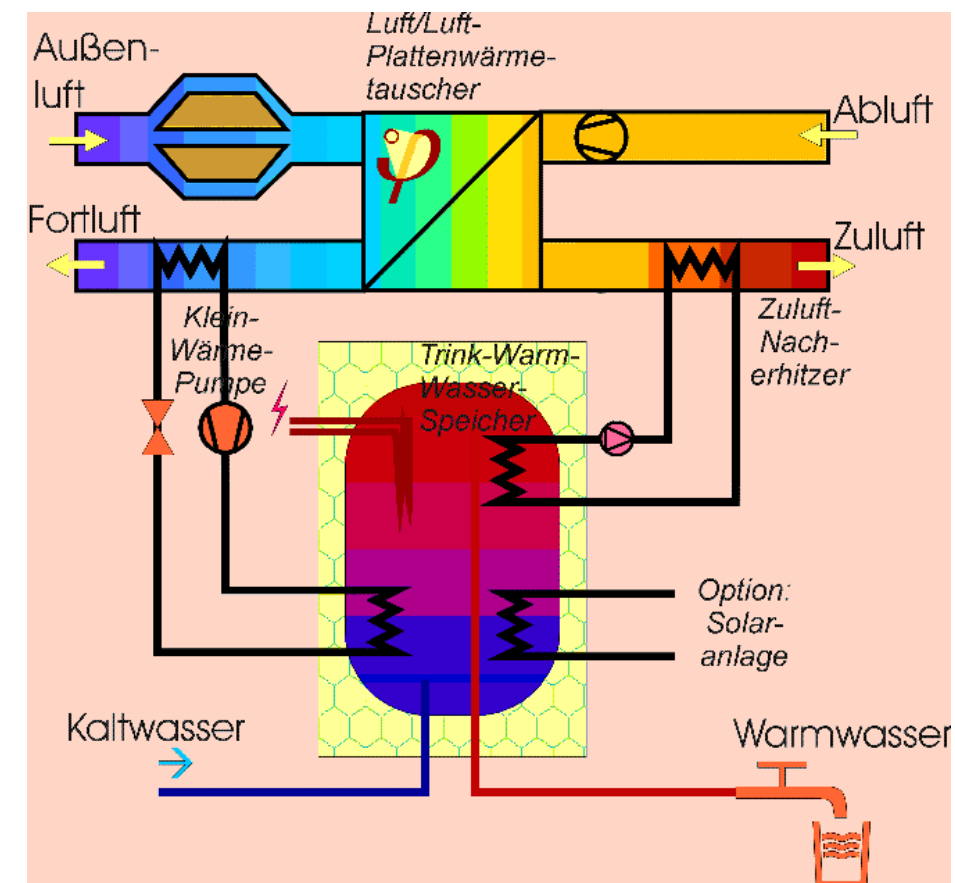


Space heating

Passivhaus: In addition to the heat exchanger (centre), a micro-heat pump extracts heat from the exhaust air (left) and hot water heats the ventilation air (right). The ability to control building temperature using only the normal volume of ventilation air is fundamental.

In addition to using passive **solar gain**, Passivhaus buildings make extensive use of their intrinsic heat from internal sources—such as waste heat from lighting, **white goods** (major appliances) and other electrical devices (but not dedicated heaters)—as well as body heat from the people and other animals inside the building. This is due to the fact that people, on average, emit heat equivalent to 100 **watts** each of **radiated thermal energy**.

Together with the comprehensive **energy conservation** measures taken, this means that a conventional **central heating** system is not necessary, although they are sometimes installed due to client skepticism.





Instead, Passive houses sometimes have a dual purpose 800 to 1,500 **watt** heating and/or cooling element integrated with the supply air duct of the ventilation system, for use during the coldest days. It is fundamental to the design that all the heat required can be transported by the normal low air volume required for ventilation. A maximum air temperature of 50 °C (122 °F) is applied, to prevent any possible smell of scorching from dust that escapes the filters in the system.

The air-heating element can be heated by a small **heat pump**, by direct **solar thermal energy**, **annualized geothermal solar**, or simply by a **natural gas** or **oil burner**. In some cases a micro-heat pump is used to extract additional heat from the exhaust ventilation air, using it to heat either the incoming air or the **hot water storage tank**. Small wood-burning stoves can also be used to heat the water tank, although care is required to ensure that the room in which stove is located does not overheat.



Beyond the recovery of heat by the heat recovery ventilation unit, a well designed Passive house in the European climate should not need any supplemental heat source if the heating load is kept under 10W/m^2 .

Because the heating capacity and the heating energy required by a passive house both are very low, the particular **energy source** selected has fewer financial implications than in a traditional building, although **renewable energy** sources are well suited to such low loads.



Lighting and electrical appliances

To minimize the total primary energy consumption, the many **passive** and **active daylighting** techniques are the first daytime solution to employ. For low light level days, non-daylighted spaces, and nighttime; the use of creative-sustainable **lighting design** using low-energy sources such as 'standard voltage' **compact fluorescent lamps** and **solid-state lighting** with **Light-emitting diode-LED** lamps, **organic light-emitting diodes**, and **PLED** - polymer light-emitting diodes; and 'low voltage' **electrical filament-Incandescent** light bulbs, and **compact Metal halide**, **Xenon** and **Halogen lamps**, can be used.



Solar powered exterior circulation, security, and **landscape lighting** - with **photovoltaic cells** on each fixture or connecting to a central **Solar panel** system, are available for **gardens** and outdoor needs. Low voltage systems can be used for more controlled or independent illumination, while still using less electricity than conventional fixtures and lamps. Timers, **motion detection** and **natural light** operation sensors reduce energy consumption, and **light pollution** even further for a Passivhaus setting.

Appliance consumer products meeting independent energy efficiency testing and receiving **Ecolabel certification marks** for reduced electrical-'natural-gas' consumption and product manufacturing **carbon emission labels** are preferred for use in Passive houses. The ecolabel certification marks of **Energy Star** and **EKOenergy** are examples.



Traits of passive houses

Typically, passive houses feature:

Fresh, clean air: Note that for the parameters tested, and provided the filters (minimum F6) are maintained, **HEPA** quality air is provided. 0.3 air changes per hour (ACH) are recommended, otherwise the air can become "stale" (excess CO₂, flushing of indoor air pollutants) and any greater, excessively dry (less than 40% humidity). This implies careful selection of interior finishes and furnishings, to minimize indoor air pollution from **VOC's** (e.g., **formaldehyde**). This can be counteracted somewhat by opening a window for a very brief time, by plants, and by indoor fountains.

Because of the high resistance to heat flow (high R-value insulation), there are no "outside walls" which are colder than other walls.



Homogeneous interior temperature: it is impossible to have single rooms (e.g. the sleeping rooms) at a different temperature from the rest of the house. Note that the relatively high temperature of the sleeping areas is physiologically not considered desirable by some building scientists. Bedroom windows can be cracked open slightly to alleviate this when necessary.

Slow temperature changes: with ventilation and heating systems switched off, a passive house typically loses less than 0.5 °C (1 °F) per day (in winter), stabilizing at around 15 °C (59 °F) in the central European climate.

Quick return to normal temperature: opening windows or doors for a short time has only a limited effect; after apertures are closed, the air very quickly returns to the "normal" temperature.



International comparisons

In the [United States](#), a house built to the Passive House standard results in a building that requires space heating energy of 1 [BTU](#) per square foot (11 kJ/m^2) per heating [degree day](#), compared with about 5 to 15 BTUs per square foot ($56\text{-}170 \text{ kJ/m}^2$) per heating degree day for a similar building built to meet the 2003 Model Energy Efficiency Code. This is between 75 and 95% less energy for space heating and cooling than current new buildings that meet today's US energy efficiency codes. The Passivhaus in the German-language camp of [Waldsee](#), Minnesota uses 85% less energy than a house built to Minnesota building codes.

In the [United Kingdom](#), an average new house built to the Passive House standard would use 77% less energy for space heating, compared to the circa-2006 [Building Regulations](#).

In [Ireland](#), it is calculated that a typical house built to the Passive House standard instead of the 2002 Building Regulations would consume 85% less energy for space heating and cut space-heating related [carbon emissions](#) by 94%.



Comparison with zero energy buildings

A net zero-energy building (ZEB) is a building that over a year does not use more energy than it generates. The first 1979 Zero Energy Design building used passive solar heating and cooling techniques with air-tight construction and super insulation. A few ZEB's fail to fully exploit more affordable conservation technology and all use onsite active [renewable energy](#) technologies like [photovoltaic](#) to offset the building's primary energy consumption. Passive House and ZEB are complementary synergistic technology approaches, based on the same physics of thermal energy transfer and storage: ZEBs drive the annual energy consumption down to 0 kWh/m² from the already low PassivHaus criteria of 120 kWh/m² with help from on-site renewable energy sources. [Energy Plus houses](#) are similar to both PassivHaus and ZEB but emphasize the production of more energy per year than they consume, e.g., annual energy performance of -25 kWh/m² is an Energy Plus house.



Tropical climate needs

In a tropical climate, it could be helpful for ideal internal conditions to use **Energy Recovery Ventilation** instead of **Heat Recovery Ventilation** to reduce the humidity load of ventilation on the mechanical dehumidification system. Although dehumidifiers might be used, heat pump hot water heaters also will act to cool and condense interior humidity (where it can be dumped into **drains**) and dump the heat into the **hot water tank**. **Passive cooling, solar air conditioning**, and other solutions in **passive solar building design** need to be studied to adapt the Passive house concept for use in more regions of the world.

There is a certified Passive House in the hot and humid climate of **Lafayette, Louisiana, USA**, which uses **Energy Recovery Ventilation** and an efficient one ton air-conditioner to provide cooling and dehumidification.

Solar access is a very important factor in any design of a passive house as it allows the structure to use the solar energy to heat and lighten the space naturally, replace electrical water heaters with solar-energy-based water heaters, in addition to providing a healthy environment inside the building.

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