Passivhaus

Subjects: Construction | Architecture and Design | Applied Physics

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Definition

Passivhaus buildings are well-insulated buildings that achieve acceptable levels of comfort delivered by post-heating or post-cooling air. Additionally, Passivhaus buildings must adhere to the Passivhaus design criteria, as described in the Passive House Planning Package (PHPP). This article introduces the Passivhaus background and the basics of its design criteria.

1. Definition

A Passive House, or ‘Passivhaus’, which is the original German term, is: “[…] a building, for which thermal comfort (ISO 7730) can be achieved solely by post-heating or post-cooling of the fresh air mass, which is required to achieve sufficient indoor air quality conditions - without the need for additional recirculation of air.”

2. Passivhaus Background

Passivhaus evolved from passive solar architecture and super-insulated homes developed in Sweden to reduce space heating and to improve the thermal transmittance (U-values) of building fabrics, windows and doors. This lead to the commercial development of triple glazing windows, along with further developments in insulation, thermal bridging, airtightness and controlled ventilation.

The ‘Passivhaus’ term was forged from a research idea generated in 1988 by Professor Bo Adamson from Lund University (Sweden) and Professor Wolfgang Feist from the Institute for Housing and Environment (Germany). In 1990, as a result of their early experiments, the first Passivhaus dwellings were built in Darmstadt, Germany, and later, in 1996, the Passive House Institute (PHI) was established.

The Passivhaus standard is based on five fundamental design principles — super-insulation, thermal bridge free construction, airtight building envelope, mechanical ventilation systems with heat recovery (MVHR), and high-performance doors and windows —, which should ensure the quality of the indoor environment, especially on the indoor air quality. Energy-efficient electric appliances and lighting are necessary to achieve the low-primary energy demand required to obtain certification. The principal criteria for Passivhaus certification are presented in Table 1. Detailed design criteria are described in the Passive House Planning Package (PHPP) version 9. As part of the certification process, the PHPP analysis and post-completion tests (blower door and ventilation rates) are verified by a Passivhaus certification body.

Passivhaus buildings can achieve different certification levels, EnerPHit for refurbishment projects, PassivHaus Plus for near-zero-energy buildings, PassivHaus Premium for positive energy buildings and PassivHaus Classic for low-energy buildings.

Table 1. Overview of the principal PassivHaus certification criteria for Central European climates. Adapted from:

<table>
<thead>
<tr>
<th>PassivHaus certification criteria (residential)</th>
<th>Cool-moderate climate (Central Europe)</th>
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6
In cooler climates, the most crucial factors are heating load and heating demand so that the building does not require conventional heating systems to maintain comfortable indoor environment levels\textsuperscript{[2]}. Indoor thermal comfort is the focus of Passivhaus design. The supply-air heating load should not exceed 10W/m\textsuperscript{2} so that a comfortable indoor climate (indoor operative temperature \( \leq 25^\circ\text{C} \)) can be maintained without conventional heating. Thus, thermal comfort is taken into account in line with the peak supply-air heating load, by considering the volumetric capacity of the system, supplied flow rates (30m\textsuperscript{3}/h per person), indoor temperatures and treated floor area in the project\textsuperscript{[5]}. Excellent indoor environment comfort is linked directly to energy efficiency as an incentive; the PassivHaus standard originated as an ultra-low-energy concept rather than to reduce CO\textsubscript{2} emissions. By prioritising energy-efficient design, the Passivhaus standard addresses energy demand reduction and thermal comfort, unlike other low-carbon standards.

Passivhaus ventilation should remove the moisture when the infiltration air volume flow is insufficient to remove it\textsuperscript{[8]} — this would require a total outdoor airflow of 5-10 l/s per person (equivalent to 18-36m\textsuperscript{3}/h per person or 0.3-0.6 air changes per hour)\textsuperscript{[9]}. This airflow should guarantee that CO\textsubscript{2} peaks levels should be no higher than 1,500ppm, as described in the DIN1946 German standard, the foundation for Passivhaus ventilation design.

Passivhaus was developed for buildings in Central European countries. However, it has become more

<table>
<thead>
<tr>
<th>Specific heating demand</th>
<th>( \leq 15 ) kWh/(m\textsuperscript{2}a)</th>
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<tbody>
<tr>
<td>OR Specific heating load</td>
<td>( \leq 10 ) W/m\textsuperscript{2}</td>
</tr>
<tr>
<td>Specific cooling demand</td>
<td>( \leq 15 ) kWh/(m\textsuperscript{2}a) + 0.3 W/(m\textsuperscript{2}aK) \cdot \text{DDH}</td>
</tr>
<tr>
<td>OR Specific cooling load</td>
<td>( \leq 10 ) W/m\textsuperscript{2}</td>
</tr>
<tr>
<td>AND Specific cooling demand</td>
<td>( \leq 4 ) kWh/(m\textsuperscript{2}a) \cdot \sigma_e + 2 \cdot 0.3 W/(m\textsuperscript{2}aK) \cdot \text{DDH} - 75 kWh/(m\textsuperscript{2}a)</td>
</tr>
<tr>
<td>Specific total primary energy demand</td>
<td>( \leq 120 ) kWh/ m\textsuperscript{2}/a</td>
</tr>
<tr>
<td>Airtightness ( n_{50} )</td>
<td>( \leq 0.6 ) h\textsuperscript{-1} (@50Pa)</td>
</tr>
<tr>
<td>Overheating frequency</td>
<td>10% Percentage of time with operative temperature above 25°C</td>
</tr>
</tbody>
</table>

DDH refers to Dry Degree Hours.

\( \sigma_e \) Annual mean external air temperature (\(^\circ\text{C}\)).
popular, and examples are found beyond Europe. As of March 2018, the Passivhaus database\(^{[10]}\) had registered 212 buildings outside of Europe, built predominantly in the US (92), Canada (42), New Zealand (22), Japan (21) and China (16).

### 3. Passivhaus design concept

#### 3.1 Building form

Passivhaus buildings may have freedom in design, but their shape, size and orientation need to be planned carefully to minimise their on energy consumption. The ratio of the surface area of the building envelop to the volume (A/V ratio) of the building places a considerable load on heating and cooling demands, regardless of the thermal transmittance value (U-value) of the exterior of the building, also known as the building envelope\(^{[6]}\). Passivhaus buildings reduce energy consumption by avoiding energy losses in the way of heat or cooling through the building envelope. The more compact a Passivhaus building, the less energy it requires and the higher its A/V ratio, the greater potential for heat transfer. In simple words, small buildings have greater disadvantages, while larger buildings may have a lower A/V penalty for complex forms.

#### 3.2 Super insulation

Passivhaus buildings use super-insulation to decrease heat transfer through the external ceiling, walls and flooring. Super-insulation is critical when the indoor and outdoor temperature differences are high, but as this difference reduces, it becomes slightly less necessary, as there is no need to maintain an indoor temperature different from outdoors\(^{[11]}\). An extensive range of thermal insulation is available to achieve typical U-values (0.10-0.15W/m\(^2\)K) required for Passivhaus\(^{[12]}\). However, foam insulations should be avoided where possible, as they might compromise safety in terms of IAQ and fire\(^{[13]}\). External insulation in Passivhaus is typically between 20-40cm thick, and pipework and ductwork must be insulated as well, to avoid condensation and heat loss from the pipes.

#### 3.3 Thermal bridge-free construction

A thermal bridge is a part of the building envelope that conducts heat between indoor and outdoor environments, causing internal condensation and dampness. Thermal bridges have the potential to become a source of unquantified thermal loss and contribute as much as 50% of the transmission heat in PassivHaus buildings\(^{[14]}\) and condensation depending on the indoor air temperature, the surface temperature in walls or windows and air moisture content. Thermal bridges need to be modelled and assessed carefully at the design stage through virtual simulation, with software such as THERM. However, time can be saved by replicating any of the reference detail sources for PassivHaus, such as the IBO Book\(^{[15]}\)\(^{[16]}\).

The most common types of thermal bridges are ‘constructional’, whereby a construction material penetrates the insulation. Other options include geometric thermal bridges, caused by the shape of the building (i.e. corners), point thermal bridges, caused by structural connections or insulation fixing, and linear thermal bridges, caused by a gap between the edges of two pieces of insulation or when one building material meets another\(^{[17]}\).

#### 3.4 High-performance doors and windows

High-performance doors and windows reduce, or even eliminate, the risk of condensation, mould growth and drafts while achieving acceptable thermal comfort. Passivhaus windows, including frames, are designed to make the most of solar gains warming up the building. They have two or three layers of glass, usually clear, which can be filled with different gases. The solar heat transfer that enters through a proportion of the window compared to the energy that reaches the window is known as G-value. A higher G-value means higher solar transmission. A suitable Passivhaus window has a higher U-value (<0.8W/m\(^2\)K) than its walls (0.10-0.15W/m\(^2\)K), so they should be used carefully. Passivhaus windows are usually limited
to 0.8W/m²K [5]; however, this can change in warmer climates [18] [19]. As with windows, doors must have a U-value of 0.8W/m²K and be airtight. Window sizing is an important issue, in PassivHaus dwellings windows tend to be small to reduce heat loss and solar gains. However, this has an impact on the opening size and ventilation that may lead to overheating [20].

Installation is as important as the characteristics of the windows and doors. A correctly installed window will avoid thermal bridge losses while improving the overall U-value by up to 50%. If they are positioned “within the insulation plane of the thermal envelope and that insulation overlaps the frame as far as possible, the thermal bridge loss coefficient of installation can be 0 [2].” Passivhaus approved windows are the best way to optimise solar gains.

3.5 Airtightness

The building envelope should adhere to high levels of airtightness to avoid thermal losses through air infiltration. The most common uncontrolled air leakage occurs due to poorly installed doors, windows, services (pipes and ducts), suspended floors, ventilation systems, internal partitions, poorly designed construction systems, and small cracks and holes in the building envelope [21]. Air barriers that seal construction joints and penetration across the envelope are indispensable to achieve good airtightness [22].

The airtight barrier also works as a vapour control layer — usually in the warm side of the building — to protect the insulation and building structure from interstitial warm air and moisture. An additional wind barrier layer — usually on the outside of the building fabric — helps to stop cold air entering the building. Both layers are a requirement and should be appropriately marked in the design. The on-site airtightness test (blower door test) measures total leakage through the building envelope. An under-pressure and over-pressure blower door test are part of the PassivHaus certification process. The airtightness result must achieve an $n_{50} \leq 0.6h^{-1} @50Pa$ [2]. The airtightness target is defined by the number of air changes per hour at a reference of ±50 Pascal, known as $n_{50}$ test (see [23] for more details). As a consequence of the high airtightness achieved, air exchange is reduced around 27% in PassivHaus buildings [24], making ventilation systems essential to ensure proper airflows.

3.6 Mechanical ventilation with heat recovery (MVHR) systems

The MVHR system’s primary purpose is to provide a continuous supply of fresh air while optimising occupant comfort by recovering heat from extracted air [2] thereby reducing energy losses in the way of heat or cool, as well as to protecting against outdoor air pollution [6]. Passivhaus air change rates should not exceed 30m³/h/person [1]. Lower airflow rates may compromise the health and well-being of the occupants and higher may result in dry air. The supply air is delivered to the living areas — rooms where the occupants spend extended periods of time — and extracted from wet rooms — rooms where occupant activities may produce increased moisture or odours. The recommended extract airflow () rates from wet rooms are 60m³/h for kitchens, 40m³/h for bathrooms and 20m³/h for other rooms. Passivhaus dwellings should also meet a minimum whole-house air change rate per hour (ach/h) of 0.3 guaranteeing:

- Fresh air demand: 30m³/h x number of occupants.
- Recommended minimum extract rate from wet rooms (kitchen + bathroom): 60m³/h + 40m³/h.
- Minimum air change rate: 0.3ach/h x treated floor area x floor to ceiling height (maximum of 2.5m height).

3.7 Energy-efficient electric appliances and lighting

Once the heat and cooling demands are met, and efficient technologies for domestic hot water are implemented, electrical appliances are the most significant component of any final energy demand in dwellings. “It is a part of the Passive House philosophy that efficient technologies are also used to minimise the other sources of energy consumption in the building, notably electricity for household appliances [2],” Hot water connections for washing machines and dishwashers, airing cabinets, fluorescent lamps and LED bulbs are examples of techniques that may help to reduce energy consumption, without sacrificing


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Keywords

Passivhaus;Low-energy buildings;Energy-efficient buildings

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