Chapter 186 Passive House Institute and US Green Building Council

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Abstract (250)

Sustainable architectural design is constantly evolving as humans pursue the desire to balance the built environment and its ecological impact. Several organisations such as the Passive House Institute and the US Green Building Council have developed certification criteria and guidelines to design, build and operate energy-efficient buildings. This chapter is not intended as an exhaustive review but to define and discuss the principles to design buildings to the Passivhaus Standard and the Leadership in Energy and Environmental Design (LEED), giving the reader a better understanding of their core values.

These are voluntary building certifications that recognise the design and construction team and the owners on pursuing energy-efficient buildings that go beyond the national standards helping to minimise energy use and CO_2 emissions. The Passivhaus prioritises the energy-efficient design by addressing the energy demands and thermal comfort. LEED looks at several aspects during the design, construction, and operation of a building to develop eco-friendly solutions. While both certifications are different in their approach to sustainable building and energy-efficient design, they share the same goal to improve the quality of life of building occupants while minimising its impact on the environment.

Keywords

Energy-efficient buildings, Passivhaus, Passive House, LEED, sustainable architecture, US Green Building Council

Introduction

Sustainable architectural design is a term that has been in constant evolution mainly due to Climate Change concerns (see Chapter 15, 16). Over the last few decades, sustainable architectural design has been known as green architecture, energy-efficient buildings, passive architecture, eco-architecture, and many other names (see Chapter 93 and 96). Nonetheless, always with the same goal to achieve a balance between the built environment and its ecological impact. Since the 1970s, the construction industry has faced numerous changes to reduce energy demand and improve indoor environment conditions by minimising heat loss through passive and active techniques. Existing components and energy systems were improved. However, some pioneering buildings achieved incredible heat demand reductions; the additional costs were so excessive that they could not be amortised by saving fuel costs.

At this point, we are in a transition between traditional building practices and net-zero energy buildings using different design approaches for low energy demands. Net-zero energy buildings, also known as nZEB, refers to a theoretical balance where the energy needed to run a building is offset with on-site or off-site energy production, usually through renewable sources. This transition is possible as well-established building design approaches and methods that not only offer a template to deliver ultra-low-energy but are also economical and resource-efficient whilst providing high levels of occupant comfort and resilience to future climate changes have been developed.

To address the energy and environmental concerns in the construction industry, different institutions and organisations, such as the Passive House Institute and the US Green Building Council, have formulated benchmarking systems (see Chapter 147) to promote low-energy design and construction; and also, to quantify and recognise such achievements through voluntary certifications. Such systems include Passivhaus Standard–by the Passive House Institute–, Leadership in Energy & Environmental Design (LEED)–by the US Green Building Council–, and Building Research Establishment Environmental Assessment Methodology (BREEAM)–by the Building Research Establishment.

When using these design methods, one must be careful as adopting a standard or regulation does not guarantee the desired results, and buildings can exhibit performance gaps. For instance, the UK's Standard Assessment Procedure (SAP) for new dwellings does not assess energy efficiency. However, it relates the investment to the building performance effectiveness leading to additional CO_2 emissions (Kelly, Crawford-brown and Pollitt, 2012) therefore providing misleading estimations.

Construction of new net-zero or nearly zero energy buildings (nZEB), retrofitting, and refurbishing homes can significantly reduce related CO_2 emissions and contribute to climate change mitigation actions. Building design, particularly home design, at the Passivhaus Standard is an excellent example of achieving this. Passivhaus designed buildings can save up to 90% of the energy used for heating and cooling versus traditional buildings. To produce sustainable buildings, several factors should be considered (Yazyeva and Mayatskaya, 2021):

- correct application of optimal design methods,
- building design should provide a degree of flexibility, allowing changes to the project when adverse conditions arose,
- support from mathematical/virtual modelling to estimate the energy consumption and indoor environment conditions, and
- consider sociological aspects to improve the function, microclimate and aesthetic parameters

New building design and construction must contribute to the mitigation of the challenges faced for global environmental protection. While low energy consumption will help avoid CO_2 emissions as a fundamental part of climate protection and sustainable development, it is crucial to define the approach to building construction and design within the early stages to get the best results. The following section focuses on describing the Passive House Institute and US Green Building Council's efforts to improve the sustainable built environment.

Passive House Institute

In 1998, Professor Wolfgang Feist from the Institute for Housing and Environment in Germany and Professor Bo Adamson from Lund University in Sweden developed the Passivhaus method and built the first Passivhaus dwelling in Darmstadt, Germany in 1990. These developments led to the founding of the Passive House Institute in 1996, which continues today as the leading global centre of research and development to advance and adopt the Passivhaus performance standard. Over time, the Passivhaus standard evolved from a method for cold climates to warmer or temperate climates where cooling is also of primary concern in addition to heating.

Passivhaus or Passive House refers to a building design method for ultra-low energy buildings that are extremely comfortable and economical to operate. As the term Passive House could also refer to other examples of passive architecture, the term Passivhaus is used in this section. Passivhaus evolved from Swedish super-insulated homes and passive solar energy to minimise space heating and the heat that escapes (leaks) from a building structure and through the different building elements (i.e., walls, doors, windows), also known as thermal transmittance or U-values (Adamson, 2011).

The Passive House Institute (PHI) defines Passivhaus as *"[…] 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* (PHI, 2017)". The Passivhaus design has five (5) essential principles (Figure 1), including the following: (1) thermal insulation, (2) thermal bridge reduced design, (3) airtight building envelope, (4) adequate ventilation strategy and (5) high-performance doors and windows (Moreno-Rangel, 2021).

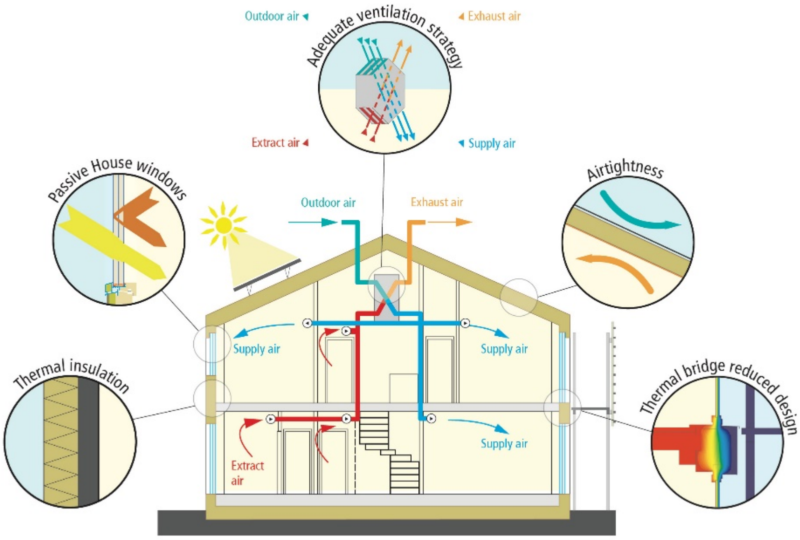

Figure 1. Passivhaus principles. Source: Passive House Institute, https://passivehouse.com/ (PHI, 2015).

Table 1 illustrates the main criteria requirements for Passivhaus certification. The performance standards are typically calculated utilising the Passive House Planning Package (PHPP) software that guides and supports architects and building designers from a project's early stages. The different levels for Passivhaus certification include *EnerPHit* for refurbishment projects, *Passivhaus Plus* for nearly zero-energy buildings (nZEB), *Passivhaus Premium* for positive energy buildings and *Passivhaus Classic* for low-energy buildings.

Table 1. Overview of the main criteria requirements for the Passivhaus certification.

Passivhaus Certification Criteria (Residential)	**Cool-Moderate Climate (Central European)**	
Specific heating demand	≤15	kWh/(m^{2}a)
OR specific heating load	≤10	W/m^2
Specific cooling demand	≤15	kWh/(m^{2}a) + 0.3 W/(m^{2}aK). DDH
OR specific cooling load	≤10	W/m^2
AND specific cooling demand	≤4	kWh/(m^{2}a). σe + 2 • 0.3 W/(m^{2}aK). DDH-75 kWh/(m^{2}a)
Specific total primary energy demand	≤120	kWh/m^2/a
Airtightness n50	≤0.6	h-1 (*@50 Pa*)
Overheating frequency	10%	Percentage of time with operative temperature above 25 °C
σe Annual mean external air temperature (°C). DDH refers to Dry Degree Hours.		

The most critical aspects for Passivhaus buildings in cold climates are the heating load and heating demand to avoid the use of conventional cooling/heating systems to provide comfortable indoor environments. While in temperate and warm climates, such as those found throughout Latin America, the cooling load and demand are as crucial as the heating calculations. Passivhaus indoor temperatures (≤25°C) in homes are delivered through the supply-air heating/cooling loads that should not exceed 10 W/m^2. To deliver the desired thermal comfort levels, the mechanical ventilation system with energy recovery should supply 30 m^3/h/per person of fresh air, thereby linking energy-efficient design to high levels of thermal comfort and indoor air quality. These ventilation rates are based on the DIN1946. This German standard suggests that these ventilation rates are adequate to guarantee that the indoor CO_2 peak levels are not higher than 1,500 pm and help remove moisture (Moreno-Rangel *et al.*, 2020). The Passivhaus standard prioritises the ultra-low-energy concept in buildings rather than the reduction of CO_2 emissions. The Passivhaus prioritises the energy-efficient design unlike other low-carbon standards, by addressing the energy demands and thermal comfort.

Although the Passivhaus standard was developed for Central European climates, recent examples had appeared outside of Europe, making it popular worldwide. The Passivhaus Trust defines the Passivhaus as the fastest-growing energy-efficient standard in the world, with an estimated number of over 70,000 buildings in 2020. The following section briefly describes the design concept for Passivhaus buildings. Additional detailed guidance is available in the Passive House Planning Package (PHPP) manual.

Passivhaus design principles

Passivhaus buildings have freedom in the **building form** design, but their orientation, shape and size must be planned carefully. The relationship between the building exterior's surface area (A) – also known as the building envelope – and the building volume (V) indicated by the A/V ratio changes as the building is modified. Hence, the A/V ratio is essential for cooling and heating demand, regardless of the building envelope thermal transmittance value (U-value) (Schnieders and Hermelink, 2006). As smaller buildings typically have higher A/V ratios (1.1–1.3 m^2/m^3), they also establish higher penalties than larger buildings with lower A/V ratios (0.46 m^2/m^3).

Passivhaus homes take advantage of **super-insulation** in external flooring, walls and ceiling to decrease the heat/cooling transfer between indoors and outdoors. Insulation is crucial when the difference between the desired indoor and outdoor temperature is high. However, in temperate climates, this can be less crucial (Wassouf, 2014) as these differences are typically lower. The typical U-values (0.10–0.15 W/m^{2}K) for Passivhaus walls (Schnieders, 2003) can be delivered using an extensive range of thermal insulation. Natural fibres from vegetal or animal origins are crucial elements for CO_2 emissions sequestration without compromising the indoor air quality. For instance, Passivhaus buildings have included mineral wool of thicknesses between 200 – 400 mm and 500 mm thick straw bale walls.

Passivhaus doors and windows influence thermal comfort as they reduce, or even eliminate, the risk of condensation, drafts and mould growth. The units are designed to maximise the solar gains to warm the building passively. The windows combine two or three glass layers and are usually filled with inert gas, such as argon or krypton. The window unit G-value refers to solar gain efficiency and gauges the solar heat transfer that infiltrates through a window section compared to the energy that reaches it. The higher the G-value, the higher the solar transmission. Typical U-values for Passivhaus windows are <0.8 W/m^{2}K and should be implemented thoughtfully. Window sizing is a crucial design element as smaller windows reduce heat loss and solar gains, reduce contact with the exterior and impact the opening size and ventilation. Passivhaus windows are traditionally limited to 0.8 W/m^{2}K (Feist *et al.*, 2015). However, this varies in warmer climates where the units can have higher U-values (PHI, 2011; Schnieders, Feist and Rongen, 2015) as the temperature difference between indoor and outdoor is diminished. Windows are vital to balance overheating in summer and heat gains in winter. Similar to windows, doors should be airtight and have a U-value of 0.8 W/m^{2}K.

Traditionally, **ventilation** in Passivhaus dwellings is achieved through Mechanical Ventilation with Heat Recovery (MVHR) systems to provide an uninterrupted supply of fresh air whilst optimising occupant comfort and reducing energy losses for heating/cooling by recovering heat from extracted air (Hopfe and McLeod, 2015). Nonetheless, ventilation can be achieved through other mechanical, natural or hybrid methods as long as they do not compromise the heating/cooling loads and demands and provide appropriate air flows. Passivhaus dwellings should deliver a 0.3 air change rate per hour (ach/h) as a whole house minimum and guarantee a fresh air demand of 30 m3/h per occupant and a minimum extract rate from wet rooms and kitchens and bathrooms of 60 m^3/h and 40 m^3/h, respectively.

Passivhaus buildings should adhere to high levels of **airtightness** to avoid thermal losses through air infiltration. Air barriers that seal construction joints and penetrations across the building envelope are essential to attaining the mandatory airtightness level (Sherman and Chan, 2004). These barriers are typically placed on the warm side of a building and protect the insulation and building structure from moisture. The wind barrier layer, typically placed outside the building fabric, protects the building envelope from cold air. Both layers are mandatory and must be considered from the early design stage. An on-site airtightness test or blower door test measuring total leakage through the building envelope is also required to verify airtightness conditions. Passivhaus buildings should carry under-pressure and over-pressure blower door test and achieve $\leq 0.6h^{-1}$ (Hopfe and McLeod, 2015) in the n50 test—airtightness target defined by the number of air changes per hour at a reference of ±50 Pascals.

Thermal bridges are components of the building envelope that conduct energy, in the means of heat or cooling, between the interior and exterior of building structures. The thermal bridges can result in significant energy losses, internal condensation and dampness. The most common thermal bridge types are geometric, correlated to the building shape, and constructional when a construction material penetrates the insulation. Thermal bridges should be minimised by design, modelled and assessed via virtual simulation or replicated from reference detail sources for Passivhaus buildings such as those in the IBO Book (Waltjen *et al.*, 2009; IBO, 2017).

Finally, it is necessary to incorporate **energy-efficient technologies** for domestic hot water and electrical appliances to meet the final energy demand requirements. "*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* (Hopfe and McLeod, 2015)." Hot water connections for washing machines and dishwashers, LED bulbs, fluorescent lamps and airing cabinets are examples of practices that decrease energy consumption without compromising indoor environmental comfort levels (Schnieders, 2003; Hopfe and McLeod, 2015).

US Green Building Council

In 1993, Mike Italiano, David Gottfried and Rick Fedrizzi founded the US Green Building Council (USGBC). The USGBC seeks a sustainable, prosperous future through Leadership in Energy and Environmental Design (LEED), helping buildings and communities regenerate and sustain all life's health and vitality. LEED emphasises the transformation of buildings and communities through their design, construction, and operation while supporting healthy, environmentally and socially responsible improvement of the quality of life.

In 2000, the USGBC launched the LEED certification with support from the US Natural Resource Defense Council with contributions to their guidelines from several other organisations and individuals. Since then, their guidelines had suffered a transformation. These comprise several versions from the pilot known as LEED New Construction (NC) v1.0 to the current–August 2021–LEED v4.1 launched in April 2019 (USGBC, 2019). The LEED rating system recognises the difference between building typologies; hence there are individual criteria accordingly to the building's use (see LEED rating systems). However, no matter the LEED rating system one chose, their guidance can be applied to the building itself or every phase of the building lifecycle, design, construction, operations and maintenance.

Although the LEED certification focuses on energy use, its accreditation is based on a comprehensive evaluation of six categories. Nonetheless, the energy element has a significant share, more than 30% (Clay, Severnini and Sun, 2021). These categories are (Akşit and Baştanoğlu, 2021):

- *Energy and atmosphere* rewards the energy strategies, including energy-efficient design, construction, commission, control of energy use, energy-efficient equipment, systems and lighting, renewable and clean energy, and other innovative strategies.
- *Materials and resources* encourages the selection of sustainable materials and products while advocating for minimisation, recovery and recycling of waste and better indoor air quality.
- *Indoor environmental quality* recognises the importance of providing control of and better indoor air quality, acoustics and thermal comfort while maximising natural light and views. Therefore, the aim is to boost occupants' productivity and prevent human health issues.
- *Sustainable sites* focuses on the project's location, promoting the use of existing structure, infrastructure, and available on-site resources. It also prioritises location with access to mass transportation and rewards smart transport solutions. This category also seeks to prevent building developments in open or unhabituated areas. Minimising the building's negative impact on waterways and ecosystems encourages landscapes to harmonise the area's natural features. Finally, it also seeks mitigation strategies for control rainwater runoff, soil erosion, light pollution, heat island effect and pollution from construction.
- *Water efficiency* looks at the use of water indoors and outdoors, promoting a more efficient and wise use.
- *Innovation in operations* has the objective to reward the use of ground-breaking features and practices in sustainable buildings.

Buildings can be awarded different levels of certification (certified, silver, gold or platinum) within each rating system. These certification levels are awarded based on a point-based rating system influenced by the degree to how each credit is addressed. Some studies argue that the extensive variety of LEED credits is challenging for the project teams; therefore, selecting the correct LEED credits at an early stage has the most significant impact (Pham *et al.*, 2020). Accordingly to the USGBC website, by the end of 2019, there were over 146,400 projects registered with LEED.

Leadership in Energy and Environmental Design (LEED) rating systems

The following lines are not intended to be an exhaustive review of the LEED rating systems as they are constantly evolving. However, they intend to explain to the reader the different systems and what they address. For more detailed information about the Guide, rating system, and credit library for each LEED rating, see (USGBC, 2019).

The LEED for Building Design and Construction (LEED BC+C) looks at the design and construction of new buildings and major renovations. LEED B+C provides holistic guidance for healthy, resource-efficient, cost-effective and green buildings. It aims to deliver buildings that enhance the quality of life of its occupants. It is intended for schools, retail, data centres, warehouses & distribution centres, hospitality, healthcare, homes & multifamily low-rise and mid-rise buildings.

LEED for Building Operations and Maintenance (LEED O+M) is intended for existing buildings seeking to change their efficiency and resource management to reduce their environmental impact through the current life of the building, even if they were not designed to be energy efficient. It is recommended for existing schools, retail, data centres, warehouses & distribution centres and hospitality buildings.

LEED for Interior Design + Construction (LEED ID+C) seeks to improve the air quality, lighting–including daylight–, health and productivity of indoor spaces. This rating was designed for those projects where the design team does not have control over the whole building operation but recognises that what we use indoors impacts the planet and building occupants. As such, its scope is limited to commercial interiors, retail and hospitality.

LEED for Homes (LEED HOMES) promotes healthy and comfortable homes providing clean air and incorporating 'safe' materials while minimising energy and water use. This rating is proposed for building design and construction of single or multifamily homes of up to eight stories. The certification can be for homes & multifamily low-rise (>3 stories) and mid-rise buildings (3-8 stories).

Finally, LEED for Neighborhood Development (LEED ND) supports developing, designing, and constructing more sustainable, well-connected neighbourhoods. It looks at aspects within the neighbourhood such as sidewalks, green areas & parks, as well as the interaction between cyclists, pedestrians and vehicles on the road. The LEED ND rating system can be applied to projects at any stage, from planning through construction. As such, it can be achieved through a plan and built project certification criteria.

Summary

Sustainable architectural design is constantly evolving as humans pursue their desire to balance the built environment and its ecological impact. Organisations such as the Passive House Institute and the US Green Building Council developed criteria and guidelines to design, build and operate energy-efficient buildings. This chapter looked at the Passivhaus Standard and the Leadership in Energy and Environmental Design (LEED).

Professor Wolfgang Feist and Bo Adamson developed the Passivhaus Standard. In 1996, the Passive House Institute was founded in Germany to support the development, research and certification of other Passivhaus buildings. The Passivhaus Standard prioritises the energy-efficient design by addressing the energy demands and thermal comfort. It is based on five fundamental principles: super-insulation, thermal bridge free construction, airtight building envelope, adequate ventilation strategy and high-performance doors and windows.

Mike Italiano, David Gottfried and Rick Fedrizzi founded the US Green Building Council (USGBC), which launched the LEED in the 2000s. LEED looks at energy and atmosphere, materials and resources, indoor environmental quality, sustainable site, water efficiency and innovation credit categories during the design, construction, and operation of a building to develop eco-friendly solutions. LEED also recognises that the use of the building should be taken into account when developing a project. Hence they have developed different rating systems for Building Design and Construction (LEED BC+C), Building Operations and Maintenance (LEED O+M), Interior Design + Construction (LEED ID+C), Homes (LEED HOMES), and Neighborhood Development (LEED ND).

While both certifications are different in their approach to sustainable building and energy-efficient design, they share the same goal to improve the quality of life of building occupants while minimising its impact on the environment.

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