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STATE OF ART ON PASSIVE HOUSE STANDARDS ANALYSIS IN TERMS OF ENERGY PERFORMANCE

BY

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Abstract. The building sector is a major contribution to the total final energy consumption all over the world. Implementing energy-efficient technologies and strategies is considered one effective method to significantly reduce the energy consumption of buildings. With increased awareness of environmental concerns and rising energy costs, the Passive House Buildings are rapidly spreading in response to the increasing demand for energy efficient buildings. The Passive House (PH) standard offers a cost-effective approach to minimize the energy demand of buildings in line with the global principle of sustainability. By significantly decreasing energy consumption, Passive Houses provide affordable comfort. The present study provides a succinct overview of Passive House buildings' fundamental design principles and state of the art on passive house buildings analysis in terms of energy performance.

Keywords: Passive House, Energy Efficiency, Climate, Thermal comfort, Indoor air quality, Building energy performance.

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1. Introduction

In recent years, different energy-efficient building concepts have been developed and implemented, providing a quality living environment while reducing the use of energy (electricity, natural gas) for heating, cooling, and lighting. According to Janssen's definition (2004), energy efficiency improvement involves minimizing energy consumption without adversely affecting the level of services provided. Energy-efficient building examples include passive houses, green buildings with nearly zero energy consumption, and positive energy houses (Maxineasa, S.G., Isopescu, D.N., Vladoiu, C.L., 2021). Over time, the energy consumption of a building (especially in the use phase) was not a decisive factor in the design process (Assefa G. et al., 2010). However, in recent years, energy efficiency and energy autonomy have become defining criteria in construction performance (Kuzmal M.K. et al., 2013).

The performance and overall quality of a building can be measured in various evaluation systems from the concept stage onwards (Passive House Planning, 2007). There are several evaluation systems with different methods of approach and calculation, depending in particular on the specific regional characteristics of the country in which it is used. The most used assessment systems are:

- "Passive House" - a concept of passive buildings developed by the Passive House Institute in Germany (www.passivehouse.com);
- "BREEM - BRE Environmental Assessment Method" - an assessment system generally used in Great Britain by Building Research Establishment (www.breem.com);
- "LEED - Leaders in Energy and Environmental Design" - evaluation system made by the NGO US Green Building Council from the USA. (www.usgbc.org/leed);
- "GREEN STAR" - made by the Green Building Council association from Australia (www.gbca.org.au);
- "HQE - Haute Qualite Environnementale" - French energy efficiency standard (www.assohqe.org).

Passive House is a concept of energy-efficient houses, which had a significant impact on the design specialists, beneficiaries, and researchers in the field (Schnieders J. et al., 2015). The concept establishes the maximum admissible energy consumption for heating/cooling the building and limits the total primary energy consumption. The application of passive houses principles leads to achievement high energy efficient houses (nearly zero energy consumption for heating), concomitant ensuring a comfortable indoor environment in all seasons (Passive House Planning, 2007).

2. The Passive House concept

Until the Passive House concept was developed, there were several strategies to reduce building energy demand (Cojocaru A., Isopescu D.N, 2021). However, rethinking the concept of a building was based on improving the existing components and using different renewable energy systems with lower costs (Lupu M.L., Baciú I.R., Maxineasa S.G., 2019).

The additional thermal insulation for the building envelope components often results in additional costs that cannot be easily balanced by reducing fuel consumption (Liu Z., et al., 2019). The improved airtight envelopes and windows cause reduced ventilation rates, which is helpful for the thermal balance but increases relative room air humidity, leading to mould growth in thermal bridge areas (McGill G. et al. 2016). The Passive House concept responds to the abovementioned challenges, aiming to achieve indoor air quality and thermal comfort while minimizing energy demand with costs that can be amortized over time (Schnieders J. et al., 2011).

The first Passive House prototype was built in Darmstadt, Germany, in 1990, which led to the founding of the Passive House Institute in the same city in September 1996 to promote and develop the Passive House standards (Schnieders J., Hermelink A, 2006). The Passive House concept was validated in Darmstadt with a reduction of approximately 80% in space heating compared to conventional new building standards. The Cost-Efficient Passive Houses as European Standards (CEPHEUS) project facilitated the commercialization of the products developed based on the Passive House standard and verified the effectiveness of the Passive House concept in five European countries during the winter of 2000-2001 (Schnieders J., Hermelink A, 2006). More than 38000 Passive House buildings are worldwide (Fig. 1), representing a total floor area of 3,500,000m². The Passive House is a freely accessible concept with the possibility to certify the projects as a recognizable symbol of quality. Upon analysing the passive house database, 2102 certified buildings were built. Many of these Passive House buildings are in Germany, Austria, and Sweden.

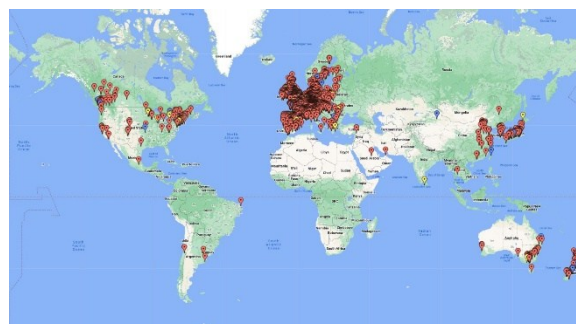


Fig. 1 – Passive Houses all over the world. Graphics: Passive House Institute Database.

According to Schnieders J, Feist W, and Rongen L. (2015), Passive Houses use 80%-90% less heating energy than conventional buildings for the same indoor space conditions for an additional cost of a maximum of 10%. Studies suggest this additional cost pays for itself in 25-40 years (Morrissey J., Horne R.E., 2011).

2.1 Passive House certification

In order to meet the Passive House certification requirements (Hopfe C., 2015), a building must fulfil the following requirements (Fig. 2):

1. The Space Heating/Cooling Energy Demand should be at most 15 kWh per square meter of net living space (treated floor area) per year or 10W per square meter peak demand.

2. The Primary Renewable Energy Demand (PER), the total energy for all domestic applications (heating, hot water, and domestic electricity), must be at most 60kWh per square meter of treated floor area per year.

3. Airtightness must be verified through an onsite pressure test in both pressurized and depressurized states, with a maximum of 0.6 air changes per hour at 50Pa pressure (ACH50).

4. Thermal comfort must be ensured for all living areas during winter and summer, with no more than 10% of the hours in a given year exceeding 25°C.

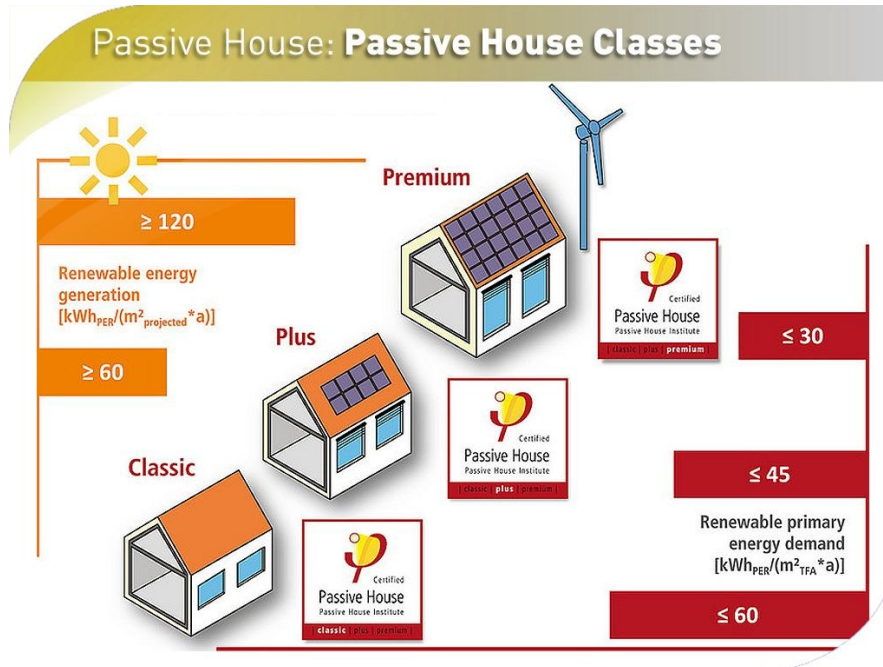


Fig. 2 – Passive House Classes and requirements. Graphics: Passive House Institute.

The achievement of the criteria mentioned above, the Passive House standard recommends an intelligent building design that integrates passive strategies known worldwide and the implementation of the five Passive House principles: high and quality thermal insulation, superior and high insulated windows, airtightness of the building, absence of thermal bridges and ventilation with heat recovery (Klingenberg, K, 2018).

2.2 Climate zones

The design principles are the base for the optimization and are related to the seven climate zones (Fig. 3) identified by the balanced cost-optimized building configurations. The properties of the Passive House components vary based on the climate zones, providing a non-mandatory but a reference point for the quality of it and building optimization (Schnieders J., et al., 2011).

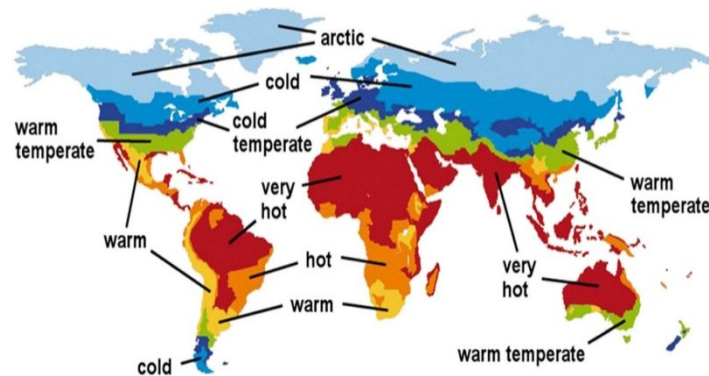


Fig. 3 – World map of Passive House climate zones following Schnieders J. (2011).
Graphics: Passive House Institute.

Concluding, the design principles based on the climate zone can significantly simplify the Passive House design process. It is recommended to use certified components for different climate zones, whose specifications and parameters offer high certainty in fulfilling the Passive House standards (Martinez-Soto A., et al., 2020).

For example, the more compact a building is and has a simpler geometrical shape, (Figure 4), the easier it is to meet an energy-efficiency standard in a cold and hot climate. The ratio that influences the building's energy requirements is the surface-area-to-volume ratio (S/V), indicating how large the surface area (wall, ceiling, roof, window surface areas) is to the building volume (Cojocaru A., Isopescu D.N., 2021). Moreover, the orientation of the window surface areas should face toward the equator in heating-dominated climates, where solar gains from the low winter sun are high, or both north and south in cooling-dominated climates, where solar load mainly occurs on the roof and the

east and west facades. Additionally, technical spaces, sanitary rooms, and kitchens should be situated in the same part of the building to simplify the ventilation duct systems. Mechanical ventilation with heat recovery may not be necessary for warm climates. In addition, humidity recovery is more suitable for climates with cold winters or humid summers than hot and dry climates (Feist W., et al., 2005).



Fig. 4 – Certified Components Database. Graphics: Passive House Institute.

2.3 Passive House Principles

Resuming, the first principle (Fig. 5) of the Passive House standard is quality thermal insulation, which refers to the thermal transmittance of the envelope. For opaque building components of the exterior envelope, a thermal transmittance (U-value) of no more than $0.15 \text{ W}/(\text{m}^2\text{K})$ is required in most cool-temperate climates. This means that a maximum of 0.15 watts per degree of the temperature difference and per square meter of exterior surface may be lost.

The second principle (Fig. 5) necessitates well-insulated window frames with low-emissivity (Low-E) glazing filled with argon or krypton to prevent heat transfer. In cool-temperate climates, this calls for a thermal transmittance for the entire window, including the window frame (U-value) of $0.80 \text{ W}/(\text{m}^2\text{K})$ or less, with total solar energy transmittance (g-values) of approximately 50%. To achieve this objective, triple-pane insulated glazing with low emissivity and the solar gain ratio combines warm edge insulating glass spacers and sealed krypton or argon gas-filled inter-pane voids. Moreover, it is essential to correctly install the windows to avoid the thermal bridge and heat loss. The window should be positioned within the insulation plan of the thermal envelope in the wall section. The position of the window in the wall section should be determined based on the heat flow of the window and also the heat flow of the wall to avoid creating a window installation thermal bridge. The 0-degree isotherm should be straight through the wall-window section to ensure optimal thermal efficiency.

The third principle (Fig. 5), ventilation heat recovery, emphasizes efficient heat recovery ventilation for good indoor air quality and energy savings. In order to avoid thermal heat loss, closed windows and airtightness are essential. Therefore, an ideal air exchange must be controlled and optimized to evacuate the stale air and introduce fresh, breathable air for the occupants. In a Passive House, a heat exchanger must transfer at least 75% of the heat from the exhaust air to the fresh air, adding air filters for air quality. The heat and humidity recovery uses a circular honeycomb matrix of heat-absorbing material and well-insulated and sealed ventilation ducts. Additionally, using a bypass scenario for warm periods and natural singular or cross ventilation is advised when indoor temperatures are close to exterior temperatures (Ochs F., et al., 2011).

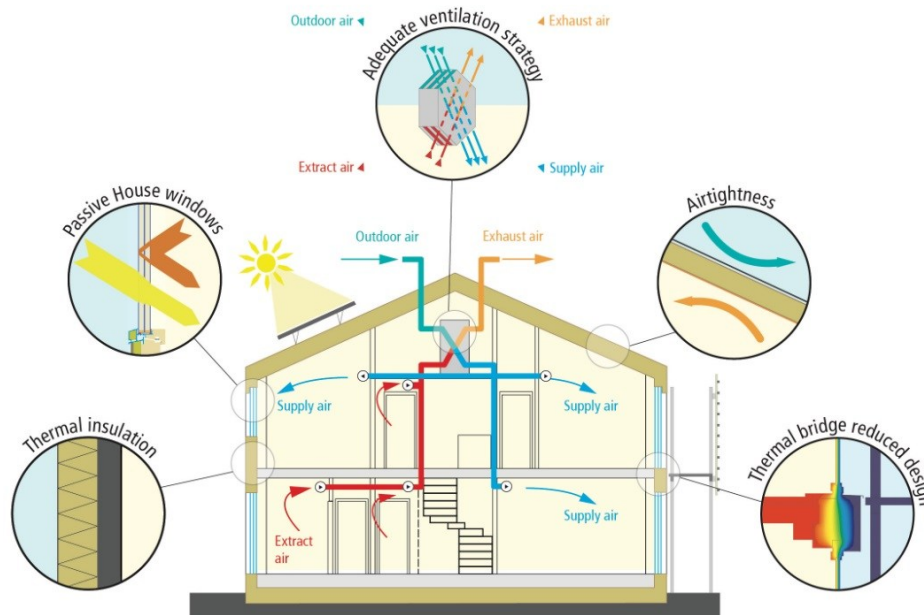


Fig. 5 – The five basic principles of Passive House. Graphics: Passive House Institute.

The fourth principle (Fig. 5), airtightness of the building, requires uncontrolled leakage through gaps to be less than 0.6 of the total building volume per hour during a pressure test at 50 Pascal, both pressurized and depressurized, in order to avoid thermal energy loss. The importance of airtightness lies in low energy consumption, good indoor air quality, and ensuring the proper operation of the ventilation system, including exhaust air systems, without heat recovery. Draft occurrences and uncontrolled humid airflow affect the thermal envelope (Wang Y., et al., 2017), and the limit given above loads comparable in magnitude

to ventilation loads from mechanical ventilation with heat recovery systems, obtained with modest effort and minimal additional cost. The evaluation of airtightness performance needs to be done on site using blower door methodology.

The fifth principle (Fig. 5), the absence of thermal bridges, demands that all edges, corners, connections, and penetrations be planned and executed in detail to avoid thermal bridges. Thermal bridges and leakages could lead to risk for condensation and reduced comfort by the indoor temperature difference. The minimum internal surface temperature should not be less than 13°C to circumvent the occurrence of thermal/cold bridges. In cases where thermal bridges cannot be avoided, minimizing them to the greatest extent is mandatory (Colclough S. *et al.*, 2018).

2.4 Energy balance and planning tools

The design and standards of the Passive House building are verified using the Passive House Planning Package (PHPP). This package calculates the building's annual and peak heating, cooling loads, and total energy demand (Feist W., *et al.*, 2015). Initially introduced in 1998 and continuously developed after that, the tool has been enhanced with additional essential modules to facilitate the global practical planning of energy-efficient projects. These modules include calculating characteristic values for windows, shading, heating load and summer behavior, cooling, and dehumidification demand, ventilation for large and non-residential buildings, and incorporating renewable energy sources. Furthermore, the PHPP facilitates EnerPHit certification for retrofitting existing buildings (Huang H., *et al.*, 2020). The validation and extension of the PHPP tool is an ongoing process grounded in measured values and new research findings (Feist W., *et al.*, 2015).

In addition, to help automatize the analysis, The Passive House Institute developed design PH, a 3d modelling interface that works together with PHPP. The plugin includes an automatic analysis algorithm capable of deducing element types and area groups, enabling surfaces to be color-coded for visual verification in the 3D model. This feature facilitates the accurate incorporation of all heat-loss surfaces and quickly results for specific space heat demand.

2.5 The monitoring of Passive House Buildings

Recent studies on constructed passive houses show good behavior of the buildings over time, with better performances than the standards imposed by the Passive House Institute (Wang Y. *et al.*, 2015). The data obtained from the measurements state that the total energy consumed in a passive house is reduced by 50% compared to the total energy consumed in a conventional house. The energy consumed for heating in an inhabited passive house is 65% less than that consumed in a conventional house and 35% less than that consumed in a "low energy" energy-efficient building (Schnieders J, Hermelink A., 2006).

However, some studies emphasize a negative element of the passive house concept. If the building is not used correctly, especially during the transition period from the warm to the cold season or vice versa, the indoor air can overheat. The increased risk of overheating has been analysed in homes in the UK (Fletcher M et al., 2017) and Australia (Hatvani-Kovacs G et al., 2018). McLeod RS, Hopfe CJ, and Kwan A. (2013) state, in a study, carried out in Europe, that the risk of overheating is more frequent in the case of passive buildings at the expense of conventional buildings. Improving the thermal envelope through additional thermal insulation and tightness negatively influences the risk of overheating (Fosas D., et al., 2018). However, natural ventilation (especially at night) often solves this problem (Kaklauskas A, Rute J, Zavadskas EK, et al., 2012). However, there is no significant difference in the frequency of overheating between Passive House and non-Passive House building (McGill, G. et al., 2016). In addition, recent research provides evidence against Passive House overheating through both modelling and physical measurements (Fosas, D. et al., 2018). The evaluation and monitoring of energy-efficient buildings is the barometer of the level of fulfilment of the comfort of the indoor environment (Mlecnik et al., 2012).

3. Conclusions

In its early development, the Passive House standard was primarily designed to address the energy needs of heating-dominant regions in Central and Northern Europe. The primary goal was to minimize the energy consumption required to maintain comfortable indoor temperatures without relying on conventional heating systems. In the present day, the Passive House standard is a rigorous and performance-based measure of energy efficiency that applies to all climate types worldwide. There are various tools available that enable comprehensive building design to meet the standard. Several studies show a minimum performance gap between the measurements calculated with the PHPP and the measurements on constructed Passive Houses.

Because the Passive House certification ensures a certain level of energy efficiency it became mandatory to some German cities. This will raise the question of the role of the Passive House standards in other countries.

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STADIUL ACTUAL ÎN ANALIZA STANDARDELOR PASSIVE HOUSE ÎN CEEA CE PRIVEȘTE PERFORMANȚA ENERGETICĂ

Sectorul construcțiilor contribuie semnificativ la consumul total de energie finală în întreaga lume. Implementarea tehnologiilor și a strategiilor de eficiență energetică este considerată o metodă eficientă de a reduce semnificativ consumul de energie al clădirilor. Odată cu creșterea conștientizării problemelor de mediu și a costurilor ridicate ale energiei, clădirile realizate în standardul de Passive House sunt tot mai răspândite, ca un răspuns la cererea tot mai mare de clădiri eficiente energetic. Prin reducerea semnificativă a consumului de energie, casele pasive oferă un confort accesibil. Prezentul studiu oferă o prezentare succintă a principiilor fundamentale de proiectare a clădirilor în standardul de Passive House și o analiză actuală a performanței energetice a acestora.