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DIFFERENCES BETWEEN A PASSIVE HOUSE AND A NEARLY ZERO ENERGY BUILDING

BY

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Abstract. Due to the amount of non-renewable energy consumed in the built environment, the construction sector is considered to be one of the most important factors in achieving sustainable development at the global scale. Out of the entire life cycle of a building, the operation phase uses the highest volume of energy in order to create optimum indoor conditions. Taking this fact into account, in the last decades, different concepts have been developed in order to reduce the irrational rates of energy consumption. The passive house and the nearly zero-energy building are two of the most important concepts that have been developed. These are based on using performant thermal insulation materials with a high thickness in order to achieve an energy efficient construction. In addition to this, a passive house and a nearly zero-energy building must satisfy a series of limitations that are different from the first concept to the other. Therefore, civil engineering specialists should arrive at a complete understanding of these limitations in order to reduce energy consumption in the construction sector. The goal of the present paper is to describe, in a synthetic way, the requirements of a passive house and a nearly zero-energy building.

Keywords: non-renewable energy; built environment; sustainable development; life cycle; passive house; nearly zero-energy.

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1. Introduction

The construction sector is considered to have tremendous negative effects over the natural environment. It is known that the construction industry is responsible for consuming almost 50% of all raw materials used at the global scale, for producing more than 40% of the total greenhouse gases emissions, and also for consuming approximately 40% of the total amount of energy produced worldwide (Ding, 2014; Ingrao *et al.*, 2014; Marinkovic *et al.*, 2014; Maxineasa *et al.*, 2015; Messari-Becker *et al.*, 2013; Pacheco-Torgal & Labrincha, 2013; Pacheco-Torgal, 2014; Rossi, 2014; Solis-Guzman *et al.*, 2014). This level of environmental burdens is highly influenced by the amount of non-renewable energy consumed during the operation phase from the life cycle of a construction. Therefore, in order to significantly reduce the total ecological impact of the built environment, different solutions for reducing the energy consumption for creating the optimal indoor conditions should be considered.

According to the United States Department of Energy, in 2011, in United States of America, out of the total amount of household energy consumption, around 49% was used for the heating and cooling of the interior space of buildings (US-DOE, 2011). In the European Union (EU), in 2016, out of the total energy consumption, 25.4% was used in the residential sector for different purposes, such as space and water heating, and space cooling (Eurostat, 2019). Another example regarding the volume of energy consumption during the operation stage is presented by The World Bank. A report published by the institution states that in 2008, in India, out of the total amount of energy consumed, the heating and cooling of indoor building spaces was responsible for approximately 35% (The World Bank, 2008). In this context, it can be considered that improving the energy efficiency of buildings must be put on display as a solution that has to be applied in order to reduce the negative environmental impact of the construction sector.

Therefore, in the last years, within the EU, a series of regulations and recommendations regarding energy efficient buildings have been developed, with the goal of optimizing the household non-renewable energy consumption. There are a variety of strategies for designing and building houses with low consumptions of energy. One of the most important is reflected by the Passive House (PH) benchmarking standard that presents a clear methodology for achieving a reduced consumption of energy in diverse climates (Feist, 2008; Feist, 2011; Feist, 2013). By considering the PH recommendations, highly energy efficient building can be achieved. Different studies show that a passive house consumes approximately 80% less energy than a classical building in central Europe, and almost 62% less than the amount of energy needed by a modern building from the island of Ireland for heating (Colclough *et al*., 2017; Feist *et al.*, 2005; Schnieders & Hermelink, 2006). Another important building regulation that will be mandatory in the EU countries is reflected by the Directive regarding the nearly Zero-Energy Building (nZEB), that besides the limitation of energy consumption during the operation phase of buildings also imposes that a part of this amount has to be achieved by using renewable sources (EU, 2016).

Taken into account the planned 2020 implementation of the nZEB standard in Europe, a comparison between PH standards and nZEB standards is appropriate. The aim of the present paper is to describe the concepts of Passive House and nearly zero-energy buildings, by going over the boundaries of these concepts, in order to establish their main differences.

2. Passive House

The Passive House standard came to life after a conversation between Professor Wolfgang Feist from the Institute for Housing and the Environment in Germany and Professor Bo Adamson from Lund University in Sweden in May 1988. The first Passive House was built in Darmstadt, Germany in 1990. After 6 years, The Passive House Institute was founded in Darmstadt, with the intention of promoting and improving the PH standards. Around the world, there are approximately 3700 PH structures, the majority of them built in Germany, Austria, and Scandinavian countries (Feist *et al.*, 2005; Sameni *et al.*, 2015; Yang *et al.*, 2017).

As stated above, by using the PH recommendations, a highly performant energy efficient building can be achieved, that in order to satisfy the users' needs over the operation phase from the life cycle of a construction, will require approximately 80% less energy than a conventional building (Dodoo *et al.*, 2011; Yang *et al.*, 2017). In order to clearly see how restrictive the PH benchmarking is regarding the energy consumption of a building, Table 1 presents a comparative analysis for different maximum values regarding the energy demand for different household operations.

The Passive House standard requires that buildings should satisfy the following requirements (Feist, 2013; Schnieders *et al.*, 2015; Taleb, 2014; Yang *et al.*, 2017):

1) heating and cooling demand should not surpass 15 kW/m^2 per year.

2) the complete primary energy consumption (heating, hot water, and electricity, etc.) should be equal to or less than 120 kW h/m^2 per year.

3) air tightness level should be equal to or less than 0.6 per hour at 50 Pa (N/m^2) as tested by a blower door, and less than 0.3 per hour at 50 Pa (N/m^2) is recommended.

4) the specific heat load for the heating source at set temperature is suggested, but not obligatory, to remain less than 10 W/m^2.

Table 1
Building Energy Requirements in Germany, According to Different Standards (Wang, 2015; Yang *et al.*, 2017)

Standard	Space heating demand Q_h, kW h/ (m^2 a)	Primary energy demand Q_p, kW h/ (m^2 a)
Non-renovated house, built in the years: 1960 - 1980	300	
German average value in 2002	160	
Insulation regulation (WSVO 1977)	≤ 250	
Insulation regulation (WSVO 1982)	≤ 150	
Insulation regulation (WSVO 1995)	≤ 100	≤ 160
Low-energy house (EnEV 2002)	≤7 0	
KfW-Efficient house 85 (EnEV 2009)	≤ 55	≤ 60
KfW-Efficient house 70 (EnEV 2009)	≤ 45	≤ 50
KfW-Efficient house 55 (EnEV 2009)	≤ 35	≤ 40
KfW-Efficient house 40 (EnEV 2009)	≤ 25	≤ 30
Passive House (PHPP)	≤ 15	≤ 120

As presented in Table 1, the maximum limit regarding the energy consumption in the case of normal buildings is considerably higher than that required by the PH standard. There is an important difference between a benchmarked passive house and a normal building. Due to the fact that the PH has a thick layer of thermal insulation, high energy efficiency windows and airtight building envelope, a low amount of heat is transferred outside. Fig. 1 shows a comparison between the heat transfer of a PH building and that of a conventional one (Feist, 2002; Yang *et al.*, 2017).

The designing and construction phases are highly important in order to achieve a building with a reduced amount of energy consumed for heating and cooling the indoor space. Compared with conventional buildings, PH buildings have super insulation with the purpose of reducing the heat loss through the construction's envelope elements. The thermal isolation materials that can be used to achieve the required energy consumption levels should have a low heat transfer coefficient, between 0.10 W/(m^2K) and 0.15W(m^2K) (Yang *et al.*, 2017).

Fig. 1 – Comparison between Passive House (right: with a high level of thermal insulation) and a traditional building (left: with considerable more heat losses compared to the Passive House building). Infrared temperature measurements (Feist, 2002; Yang *et al.*, 2017).

Another important aspect of a PH building is related to thermal bridges that should be treated with an increased amount of attention in order to achieve a thermal bridge free design, and also in order to have a minimum internal surface temperature of 13°C. PH standard requires the building's envelope to be airtight in order to avoid thermal energy loss. Airtightness is measured on site using the blower door method before the house is put in use. The installed windows should have lower thermal transmittance values, between 0.70 W/(m^2K) and 0.85 W/(m^2K), including the window frame. It is considered that a building that is constructed by adhering to PH requirements only needs the occupants' body heat and the heat resulted from the electrical equipment from the building in order to achieve the indoor conform temperature. Normally, a passive house located in a tempered climate should not need another heat source if the heat load inside the construction is kept lower than 10 W/m^2. Also, another important aspect is the ventilation system with heat recovery that should be insulated and sealed. It is recommended that the ventilation system used for improving indoor air quality is a mechanical one. Also, natural ventilation systems can be used in order to reduce energy consumption, mainly in the transitional seasons, when the exterior temperatures are at the same level with the ones from the interior space of the building. It is recommended that in order to maintain a volume of fresh air for the people inside the building, air exchange must be optimized. Usually, in order to recover sufficient heat for the building, the heat recovery rate needs to be over 75% (Schnieders, 2006; Wang, 2015; Yang *et al.,* 2017). Additionally, in order to achieve the requirements of the PH standard, lightning and electrical equipment need to be low energy consumers (Wang, 2015; Yang *et al.*, 2017)

3. Nearly Zero-Energy Buildings

One of the major questions for the state members of the European Union is how to define nearly zero-energy buildings. Therefore, the Energy Performance of Buildings Directive (EU) includes the definition of nearly zero-energy buildings and also presents measures that will accelerate the rate of building renovation towards more energy efficient systems and strengthen the energy performance of new buildings, making them smarter. As a consequence, the Ministry of Regional Development and Public Administration in Romania borrowed elements from this Directive into a plan for increasing the number of nearly zero-energy buildings (EU, 2010; EU, 2018; MDRAP, 2014; Kurnitski, 2013).

According to article 2.2 of Directive 2010/31/EU of the European Parliament and of the Council *'nearly zero-energy building' means a building that has a very high energy performance, as determined in accordance with Annex I. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources, including energy from renewable sources produced on-site or nearby;* additionally Annex I, article 1 stipulates that *the energy performance of a building shall be determined on the basis of the calculated or actual annual energy that is consumed in order to meet the different needs associated with its typical use and shall reflect the heating energy needs and cooling energy needs (energy needed to avoid overheating) to maintain the envisaged temperature conditions of the building, and domestic hot water needs.* (EU, 2010). In this context, the main aspects of NZEB are solar control, natural ventilation, construction materials and insulation, windows, and the design of the building (Sudhakar *et al.*, 2019).

Solar control represents a very important aspect that should be considered in the design phase of a nZEB building. In areas with high temperatures, the shading coefficient of the windows must be as low as possible because radiations of the sun are the cause of a high cooling load. As a result of the greenhouse effect, solar radiations can be a natural source of heating. Solar radiations are transferred through the window into the room, and the energy remains into the room in the form of heat. In consequence, to stop direct solar radiations from going into the building, performant solar covers are required. Trees, shrubs and other vegetation can also represent performant shading instruments. (Sudhakar *et al.*, 2019).

In high temperature climates, windows represent the principal heating source. Their size and direction have to be selected depending on climate, wind orientation and must be insulated and covered in a suitable manner so that thermal transmittance is kept low, allowing or preventing solar radiations entering the building. Insulating the window can be useless if the frame has a weak thermal bridge or leaks air (Sudhakar *et al*., 2019). Materials used for making the window frame are wood, polyvinyl chloride or different types of metal. Wood is a good material with low thermal transmittance, but should be protected from humidity. Out of all metals used in making window frames, the most common is aluminium, which is durable but is also a heat gain source with U-value of 205 W/m^2K. To prevent heat transfer into the building through the frame, a thermal break is added to it. Polyvinyl chloride frames vary from producer to producer, the difference between them is the amount of additive that is used in making the composite (Ghosh *et al*., 2015; Sudhakar *et al*., 2019).

Having a natural ventilation system can improve the high level of moisture and play an important role in NZEBs. Good outdoor air quality is a fundamental demand to be certain that inside air quality achieves comfort standards (Sudhakar *et al.*, 2019). To ensure air flow, spacious openings for the wind to enter are necessary. Natural ventilation can use wind or the chimney effect. It is recommended to use both solutions to have a system that guarantees good ventilation (Naghman *et al.*, 2008; Sudhakar *et al.*, 2019). Also, special attention should be paid to heat loss through the ventilation system.

Materials used in traditional buildings are lightweight with low thermal mass, such as timber, in order to minimize heat storage that negatively affects the temperature inside at night (Sudhakar *et al.*, 2019). Thermal transmittance must be kept low by using insulation layers. It is recommended that the rooftop should be insulated due to the heating effect of solar radiations. Also, it is recommended to use a constant layer of insulation covering the entire building, therefore resolving the issue of thermal bridges (Sudhakar *et al.*, 2019).

In order to improve the level of the building's sustainability, depending on the location of the construction, different solutions can be adopted in order to replace the conventional construction materials. Wood, timber, Rockwool, hempcrete, straw, bricks, stone rocks, cotton, and sheep wool are known to be energy efficient insulation materials, and can be considered for an nZEB building. Synthetic materials such as aerated autoclaved concrete, vermiculite concrete, aerogels, vacuum insulation panels, and shape memory polymers can also be an option to improve energy efficiency and lifecycle greenhouse gas emissions. (Latha *et al.*, 2015; Nematchoua *et al.*, 2015; Sudhakar *et al.*, 2019).

4. Conclusions

From the entire life cycle of a building, the operation stage is considered to have the most significant negative environmental impact, due to the high amount of non-renewable energy consumption necessary for creating indoor living conditions. Taking into account the fact that the construction sector is an economic activity with one of the most significant negative ecological influences, in the last years, a number of building concepts and solutions have been developed in order to limit these negative effects by reducing the volume of non-renewable energy consumed through the life span of a building. As stated before, the nearly zero energy building and the passive house represent one of the most important concepts developed with the goal of improving the energy efficiency of the built environment.

Both these concepts impose a set of requirements regarding the limitations of energy use during the operation stage of the life cycle of a building. In order to satisfy these limitations, various solutions should be considered in the designing process. One of these is the need to consider a thermal bridge free design of the building, which implies that the influence of the punctual and linear thermal bridges should be significantly reduced, in order to achieve a zero disturbance of the heat flow. Therefore, different structural systems should be considered in the structural design in order to limit the appearance of thermal bridges. Also, performant thermal insulation materials that have a low thermal conductivity must be used. Another important aspect to take under consideration is that in order to achieve energy efficient buildings, windows that have low heat transfer coefficients must be installed.

A very important difference between the two analyzed energy-efficient building concepts is reflected by the requirement regarding the airtightness of the building that has to be met in the case of the passive house. This is an extremely important aspect that should be well reflected in the conception and designing phase by considering different construction details as well as performant technologies for supplying the volume of fresh air needed for building users. Also, in the case of a passive house, it is recommended to use ventilation systems with heat recovery. As a main conclusion, these two concepts are similar, while at the same time quite different. Taking into account the recommendations made by the Passive House Institute regarding the use of renewable energy, it can be stated that the passive house represents a perfect nearly zero energy building.

REFERENCES

Colclough S., Kinnane O., Hewitt N., Griffiths P., *Investigation of nZEB Social Housing Built to the Passive House Standard*, Energy & Buildings, **XLXXIX**, 344-359 (2018).

Ding G.K.C., *Life Cycle Assessment (LCA) of Sustainable Building Materials: An Overview*, Eco-efficient Construction and Building Materials, 38-62 (2014).

Dodoo A., Gustavsson L., Sathre R., *Primary Energy Implications of Ventilation Heat Recovery in Residential Buildings*, Energy Build, **XLIII**, 1566-1572 (2011).

Feist W., *Anforderungen an qualitätsgeprüfte Passivhäuser*, Passivhaus Projektierungs Paket, Darmstadt: Passivhaus Institut, 2002.

Feist W., *Certification Criteria for Residential Passive House Buildings*, Passive House Institute, https://passiv.de/downloads/03_certfication_criteria_residential_en.pdf, 2013.

Feist W., *Definition of passive houses*, https://passivhaustagung.de/en/PassiveHouseE/passivehouse.html/, 2008.

Feist W., *Improving Energy Efficiency by a Factor of 10 – the Passive Standard*, 2007 Energy efficiency global forum and exposition, Washigton D.C., 2011.

Feist W., Schnieders J., Dorer V., Haas A., *Re-Inventing Air Heating: Convenient and Comfortable Within the Frame of the Passive House Concept*, Energy and Buildings, **XXXVII**, 1186-1203 (2005).

Ghosh A., Norton B., Duffy A., *Measured Overall Heat Transfer Coefficient of a Suspended Particle Device Switchable Glazing*, Applied Energy, **CLIX**, 362-369 (2015).

Ingrao C., Lo Giudice A., Tricase C., Mbohwa C., Rana R., *The Use of Basalt Aggregates in the Production of Concrete for the Prefabrication Industry: Environmental Impact Assessment, Interpretation and Improvement*, Journal of Cleaner Production, **LXXV**, 195-204 (2014).

Khan N., Su Y., Riffat S.B., *A review on Wind Driven Ventilation Techniques*, Energy Build., **XL**, 1586-1604 (2008).

Kurnitski J., *Cost Optimal and Nearly Zero-Energy Buildings (nZEB): Definitions, Calculation Principles and Case Studies*, Springer-Verlag London, 7-21 (2013).

Latha P.K., Darshana Y., Venugopal V., *Role of Building Material in Thermal Comfort in Tropical Climates*, Journal of Building Engineering, **III**, 104-113 (2015).

Marinkovic S.B., Malesev M., Ignjatovic I., *Life Cycle Assessment (LCA) of Concrete Made Using Recycled Concrete or Natural Aggregates*, Eco-efficient Construction and Building Materials, 239-266 (2014).

Maxineasa S.G., Ţăranu N., Bejan L., Isopescu D., Banu O.M., *Environmental Impact of Carbon Fibre-Reinforced Polymer Flexural Strengthening Solutions of Reinforced Concrete Beam*, International Journal of Life Cycle Assessment, **20**, 1343-1358 (2015).

Messari-Becker L., Bollinger K., Grohmann M., *Life-Cycle Assessment as a Planning Tool for Sustainable Buildings*, Proceedings of the Third International Symposium on Life-Cycle Civil Engineering (IALCCE 2012), Taipei, 1558-1562, 2013.

Nematchoua M.K., Raminosoa C., Mamiharijaona R., Tchinda R., *Study of the Economical and Optimum Thermal Insulation Thickness for Buildings in a Wet and Hot Tropical Climate: Case of Cameroon*, Renewable and Sustainable Energy Reviews, **L**, 1192-1202 (2015).

Pacheco-Torgal F., *1 - Introduction to the Environmental Impact of Construction and Building Materials*, 1-10 (2014).

Pacheco-Torgal F., Labrincha J.A., *The Future of Construction Materials Research and the Seventh UN Millennium. Development Goal: A Few Insights*, Construction and Building Materials, **XL**, 729-737 (2013).

Rossi B., *Discussion on the Use of Stainless Steel in Constructions in View of Sustainability*, Thin-Walled Structures, **LXXXIII**, 182-189 (2014).

Sameni S., Gaterell M., Montazami A., Ahmed A., *Overheating Investigation in UK Social Housing Flats Built to the Passivhaus Standard*, Building and Environment, **XCII**, 222-235 (2015).

Schnieders J., Feist W., Rongen L., *Passive Houses for Different Climate Zones*, Energy and Buildings, **CV**, *15*, 71-87 (2015).

Schnieders J., Hermelink A., *CEPHEUS Results: Measurements and Occupants' Satisfaction Provide Evidence for Passive Houses Being an Option for Sustainable Building*, Energy Policy, **XXXIV**, 151–171 (2006).

Solis-Guzman J., Martinez-Rocamora A., Marrero M., *Methodology for Determining the Carbon Footprint of the Construction of Residential Buildings in Andalusia (Spain)*, Ecological Indicators, **XXV**, 239-249 (2013).

Sudhakar K., Maximilian W., Shanmuga P.S., *Net-Zero Building Designs in Hot and Humid Climates: A State-of-Art*, Case Studies in Thermal Engineering, **XIII**, (2019).

Taleb H., *Using Passive Cooling Strategies to Improve Thermal Performance and Reduce Energy Consumption of Residential Buildings in U.A.E. Buildings*, Frontiers of Architectural Research, **III**, *2*, 154-165 (2014).

Wang Y., *Optimization for Building Control Systems of a School Building in Passive House Standard*, Ph.D. Diss., Media Technical University of Munich, 2015.

Yang W., Jens K., Fu-Yun Z., Hartmut S., Werner L., *A State of Art of Review on Interactions Between Energy Performance and Indoor Environment Quality in Passive House Buildings*, Renewable and Sustainable Energy Reviews, **LXXII**, 1303-1319 (2017).

* * * EU, *Commission Recommendation 2016/1318 of 29 July 2016 on Guidelines for the Promotion of Nearly Zero-Energy Buildings and Best Practices to Ensure That, by 2020, All New Buildings are Nearly Zero-Energy Buildings*, Section 2.1.1 (2016).

* * * EU, *European Commission Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the Energy Performance of Buildings (recast)*, Off. J. Eur. Communities, L 153, 2010.

* * * EU, *European Commission Directive 2018/844 of the European Parliament and of the Council of 30 May 2018 Amending Directive 2010/31/EU on the Energy Performance of Buildings and Directive 2012/27/EU on Energy Efficiency*, Official Journal of the European Union, L 156/75, 2018.
* * * Eurostat, *Energy Consumption in Households*, https://ec.europa.eu/eurostat/statistics-explained/index.php/Energy_consumption_in_households, 2019.
* * * *Nearly Zero Energy Buildings (nZEB) Romania. Plan de creştere a numărului de clădiri al căror consum de energie este aproape egal cu zero*, Ministerul Dezvoltării Regionale şi Administrație Publice, 2014.
* * * *Residential Energy Consumption Survey - Total Consumption by Energy End Uses*, United States Department of Energy (US-DOE), http://www.eia.doe.gov/emeu/recs/recs2005/c&e/summary/pdf/tableus12.pdf, 2011.

DIFERENȚELE DINTRE CASELE PASIVE ŞI CLĂDIRILE CU CONSUM DE ENERGIE APROAPE ZERO

(Rezumat)

Ținându-se cont de faptul că fondul construit existent este responsabil pentru consumul unor cantități importante de energie obşinută din surse neregenerabile, sectorul construcțiilor este considerat unul dintre cei mai importanți factori în atingerea unei dezvoltări sustenabile la nivel global. Din întreg ciclul de viață al unei clădiri, în faza de utilizare un volum semnificativ de energie este consumat cu scopul de a crea condițiile optime de utilizare a spațiului interior. Luând în considerare acest lucru, în ultimele decenii au fost dezvoltate o serie de concepte pentru a reduce ratele iraționale ala consumului de energie. Casa pasivă şi clădirea cu un consum de energie aproape zero sunt considerate două dintre cele mai importante concepte ce au fost dezvoltate până în prezent. Acestea se bazează pe utilizarea de materiale termoizolatoare performante cu o grosime mare pentru a obține o construcție eficientă energetic. De asemenea, casele pasive şi clădirile cu un consum de energie aproape zero mai trebuie să îndeplinească o serie de condiții care sunt diferite de la un concept la altul. Obiectivul prezentei lucrări este acela de a descrie în linii mari care sunt cerințele pe care trebuie să le respecte o casă pasivă şi o clădire cu un consum de energie aproape zero.