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Small Zero-Utility Passive Houses as a Method of Lowering Smog and Protecting the Environment

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INTRODUCTION

There is a growing awareness among the younger generations about environmental responsibilities. The Earth's population is increasing while natural resources are decreasing. In 1800, the population of the Earth was about one billion. In 1900, the population was 1,6 billion, but by 2000, the population grew to 6 billion. Population grew by 4,4 billion over the last one hundred years (Ernst, 2000). The population is 7,6 billion people in 2018 (The World Bank). Many educated young people feel a moral obligation to lower the carbon footprint and protecting our planet.

Maintaining the current level of amenities and comfort are environmentally damaging. The eyes of the modern world are focused on the problem of using the environment (Haoa et al., 2020) and climate change. We are concerned about the impact of air pollution on human health and ecosystems (De Marco et al., 2019), especially exposure to air pollution in the early years of life (He et al., 2019; Shao et al., 2020). Recent economic, cultural and environmental changes are putting pressure on society to reexamine the present methods and strategies. There is an urgent need to search for alternatives to the way that we currently shelter ourselves.

The term sustainable development has become a symbol of the search for a new mindset. The definition of sustainable development was introduced by the United Nations report, Our Common Future (1987). This report encourages us to respect the needs of future generations as we implement our present decisions. The report is also encouraging society to consume only what is needed to minimize the environmental footprint. We need to detach ourselves from a dependence on many existing systems and resources. We also need

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to adopt more sustainable source of energy and building practices (Guerrero Delgado et al., 2020; Kuzemko, Britton, 2020).

The purpouse of the chapter is presentation of sollution for small zero-utility passive houses as a method of lowering smog and protecting the environment. The experience from USA can be used as a background for considerations this problem in Poland. For the calculation, the authors chose Rybnik (Poland). Rybnik is at the forefront of cities in Poland with the highest air pollution PM10, PM25 (World Health Organization).

CRITERIA OF THE PASSIVE HOUSE

The concept of a passive house was created in the United States (USA) during the energy crisis (1974-1976). An experimental passive house (Lo-Cal Homes) was built in Urbana, Illinois in 1976. They were followed by Saskatcheway Conservation Houses which were built in 1977. In the early 1980's, the energy crisis in the USA was over and the concept of a passive house was abandoned. The concept of the passive house was continued in Germany. After 1991, a number of passive houses were built by Passivhaus Development in Germany. A positive experience with passive houses in Germany increased their popularity in Canada and the United States. Passive houses were beginning to be built in the United States between 2002 to 2006 (Sharon, 2016; Wright & Klingenberg, 2015).

A passive house is a construction concept which has already been proven in practice. The main characteristics and the design principles of a passive house are as follows (Wright & Klingenberg, 2015):

- High energy efficiency. A passive house creates significant energy savings (up to 75% compared with the average new building and a 90% savings compared with an average older house).
- Using energy sources inside the building like solar heat entering the building and minimizing mechanical systems.
- Balance heat/moisture recovery ventilation. A ventilation system in a passive house constantly supplies fresh air. Air quality can be superior. A higher efficiency heat recovery system minimizes the heat loss due to intensive ventilation. The constant ventilation allows the radon level to be controlled inside the house.
- Use appropriate energy efficient windows and doors (optimizing window performance and solar gain). Windows need to maximize the solar gain for the winter and minimize the solar gain for the summer. It is recommended to use triple glaze windows with an R-9 rating.
- Provide superior insulation of the building shell including exterior walls, roof and floor slab.

Insulation needs to be continuous with air-tight construction and no thermal bridges (R-44 insulation factor). Even if the thermal bridges could be tolerated in terms of their energy impact, they could still present a risk of surface mold or condensation. It is necessary to avoid installation of double-vapor barriers to facilitate drying in at least one direction.

During the construction of the passive house, it is necessary to use energy efficient building materials and a quality ventilation system. The comfort of living in a passive house is not compromised. To the contrary, passive houses are praised for a high level of comfort.

CALCULATING THE ENERGY REQUIREMENTS

Buildings use 43.1% of the total energy consumption in the United States (USA) and are responsible for 47.7% of CO_2 emissions (U.S. Energy Information Administration; Buildings Energy Data Book 2012). Addressing energy efficiency in buildings will make a significant contribution to the goal of addressing the energy sustainability crisis. Increasing energy efficiency is the most cost-effective way of lowering energy use. Energy efficiency is being called *low-hanging fruit.* Addressing energy efficiency can lower energy demand without compromising our lifestyle or comfort level.

The concept of a passive house is addressing energy efficiency and lowering our energy consumption to 10% of the previous consumption. A passive house requires as little as 10% of the energy used by Central European constructions. In terms of heating oil, a passive house used 1.5 to 2 liters of heating oil per square meter per year. Passive house designs also use the sun's energy for heating and cooling by increasing or decreasing exposure to the sun (Wright & Klingenberg, 2015).

Sustainable forms of energy like solar photovoltaic, etc. are normally more expensive than the traditional sources like fossil fuels or nuclear. Therefore, energy efficiency needs to be addressed first before sustainable forms of energy are considered. Passive houses are doing exactly that. Table 1 shows a comparison of energy consumption between a traditional building and a passive house.

Table 1 Comparison of energy consumption

Building Type	**Average Energy Use ($kWh/m^2/year$)**	**Passive House Energy Use ($kWh/m^2/year$)**
Single-family Detached	241	27.7
Single-family Attached	223	27.4
Multi-family (2-4 units)	294	36.6
Multi-family (5 or more units)	313	31.2
Mobile Home	483	46.4

Source: Environmental Protection Agency (EPA) website, http://www.epa.gov, Wright Graham, S. and Klingenberg, K. (2015) *Climate-Specific Passive Building Standards.* U.S. Department of Energy (Passive House Institute US)

Peak load for heating or cooling in a solar passive house is from 10 W/m^2 to 17 W/m^2.

HEATING, AIR-CONDITIONING AND VENTILATION

In 2015, the Passive House Institute US released new climate specific passive house building standards for North America. Those standards were developed based on a three-year research project funded by the United States (USA) Department of Energy (DoE). The research was conducted by the Building Science Corporation (Climate-Specific Passive Building Standards, 2015).

A passive house is continuously supplied with fresh air via the ventilation system which does a better job in constantly bringing fresh air than opening a window ever could. Passive house residents, however, may open a window whenever they want, but there is no reason for that. Heating, air-conditioning and ventilation systems provide the necessary fresh supply of air and remove the stale air to maintain high indoor air quality inside the building.

These systems also control temperature, humidity, odors, carbon dioxide and airborne contaminants. The fresh air exchange of the ventilation system in a passive house is recommended as follows:

- Kitchen – 1.1 m^3/minutes,
- Bathroom – 0.75 m^3/minute,
- Bedrooms – 0.56 m^3/minute (per person).

The ventilation takes place in optimal locations and an optimal quantity of air is being exchanged (Shurcliff, 1988). It is recommended to keep the inside air ducts within the thermal envelope of the house. An energy recovery ventilation system recovers both sensible and latent heat from the outgoing (exhaust) air stream by transferring it to the incoming (supply) air stream. All of the components of the passive house need to be designed in the simplest possible way according to the following expression, “It seems that perfection is reached not when there is nothing left to add, but when there is nothing left to take away” (Antoine de Saint Exupery).

GRID-CONNECTED PHOTOVOLTAIC (PV) SYSTEM

Low energy consumption in a passive house makes an excellent environment for a photovoltaic power generation system. Based on the data (Table 1), the expected energy use in a single-family house is 27.7 kWh/m^2/year. Assuming a 100 m^2 house, the expected annual energy use is 2770 kWh/year. By using the PV calculator available at the National Renewable Energy website (National Renewable Energy Laboratory), we can determine the appropriate size of the PV system. The system needs to be connected to the grid, so that the energy can be traded as needed. During the time that the PV system generates more energy than the demand, the power will be sold to the grid. On the other hand, during the nighttime, the power can be purchased back from the grid. In the United States (USA), power companies are obligated to provide the opportunity for free and equal power trade. After entering the location of the PV system (Rybnik, Poland) and the direct current system size (DC System Size), as shown in Table 2, the results can be shown as Table 3.

Table 2 PV system specifications

Location and Station Identification	
Requested Location	Rybnik, Poland
Weather Data Source	(INTL) RACIBORZ, POLAND 15 mi
Latitude	50.08° N
Longitude	18.2° E
PV System Specifications *(Residential)*	
DC System Size	3 kW
Module Type	Standard
Array Type	Fixed (open rack)
Array Tilt	20°
Array Azimuth	180°
System Losses	14.08%
Inverter Efficiency	96%
DC to AC Size Ratio	1.2
Economics	
Average Retail Electricity Rate	No utility data available
Performance Metrics	
Capacity Factor	10.7%

Source: National Renewable Energy Laboratory (NREL), PVWatts Calculator, https://pvwatts.nrel.gov/pvwatts.php (17.01.2020).

Table 3 Calculated energy produced by the PV power station
Results – 2809 kWh

Month	Solar Radiation ($kWh/m^2/day$)	AC Energy (kWh)	Value ($)
January	1.39	112	N/A
February	1.78	130	N/A
March	2.60	205	N/A
April	3.92	287	N/A
May	5.46	399	N/A
June	4.87	347	N/A
July	5.04	365	N/A
August	4.96	356	N/A
September	3.44	245	N/A
October	1.91	147	N/A
November	1.48	114	N/A
December	1.26	102	N/A
Annual	3.18	2,809	0

Source: National Renewable Energy Laboratory (NREL), PVWatts Calculator, https://pvwatts.nrel.gov/pvwatts.php (17.01.2020).

Based on the results of the calculations (Table 3), the yearly amount of electric power is expected to be 2809 kWh/year which will meet the demand for energy in the passive house The PV system can be located on the roof of the house or as an open rack. The PV panels need to be facing south at a 20° tilt.

ELECTRIC CAR SOLAR CHARGING SYSTEM

By increasing the size of the photovoltaic (PV) system, it is possible to attach to an electric car charging station to the house. Based on the total kilometers (km) driven per year, we can calculate the size of an additional PV system needed to recharge an electric car daily. If the electric car will be driven 15000 km/year, the approximate amount of electricity to recharge the car daily is 2800 kWh/year. Therefore, an additional 3 kW photovoltaic powerstation would provide the energy needed for transportation purposes. This concept would provide zero-energy and zero-emission for living and transportation.

THE ENVIRONMENTAL BENEFITS

The environmental benefits of the proposed 6 kW solar photovoltaic power system has been determined using the Greenhouse Gas Equivalency Calculator available on the Environmental Protection Agency (EPA) website, http://www.epa.gov/cleanenergy/energy-resources/calculator.html.

Based on the amount of electric energy equal to 5618 kWh (generated by the PV system), the greenhouse gas emission will be lowered by 4 tons of carbon dioxide. In addition to this, there will be an additional greenhouse reduction due to the superior insulation of the passive house. The total annual greenhouse emission reduction will be 17.16 tons. This reduction of greenhouse gas emissions is equivalent to the following:

- 0.843 (3.62) passenger vehicles driven for one year,
- 9.856 (42.282) miles driven by an average passenger vehicle,
- 447 (1.917) gallons of gasoline consumed,
- 390 (1.673) gallons of diesel consumed,
- 4.377 (18.777) pounds of coal burned,
- 0.053 (0.227) tanker trucks worth of gasoline,
- 0.022 (0.09) railcars worth of coal burned,
- 9.2 (39.5) barrels of oil consumed,
- 162 (695) propane cylinders used for home barbeques,
- 506.577 (2173215) number of smartphones charged.

The amount of greenhouse gas emissions avoided is equivalent to the following:

- 1.4 (6.0) tons of waste recycled instead of landfilled,
- 0.193 (.828) garbage trucks of waste recycled instead of landfilled,
- 169 (725) trash bags of waste recycled instead of landfilled,
- 0.0009 (0.00386) wind turbines running for a year,
- 151 (648) incandescent lamps switched to LEDs.

In the listings above, the numbers in front represent the environmental impact of PV system. The numbers in parentheses represent the total environmental impact of the solar passive house.

CONCLUSIONS

Passive buildings in North America are becoming a foundation for zero-energy and zero-carbon buildings (Buildings Energy, 2012; Mansoori, Enayati & Agyarko, 2016; Photovoltaic Energy, 2019). The passive house performance standards have been recognized by law and policy makers as an effective method for drastically lowering energy use and global carbon reduction. The envelope of the passive house must be climate specific as well as adjusted to local availability of the construction materials and the cost structure. The standards for individual countries in the world have not been developed yet. There are, however, well-developed German standards (Photovoltaic Energy

Barometer, 2019) which may be applied to Poland due to very similar climate characteristics. Lower energy consumption by a passive house with peak load below 2000 W (100 m^2 house) is very friendly towards a PV system. The PV system makes the passive house a zero-energy and zero-carbon building.

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Abstract.
The chapter describes the concept of sustainable development to minimize the environmental footprint and introduces the concept of the zero-utility solar passive house. The purpouse of the chapter is presentation of sollution for small zero-utility passive houses as a method of lowering smog and protecting the environment. The different concepts of the solar passive residential dwellings are being discussed and evaluated from the perspective of lowering carbon emissions. Energy savings as a result of increasing energy efficiency are also being calculated. The chapter analyzes the procedure for selecting the photovoltaic (PV) system to power the passive house and charge an electric car. Authors calculate the environmental benefits. There were some suggestions and recommendations for industry.

Keywords: Passive houses, protecting the environment, sustainability