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COST EFFECTIVENESS OF THE ZERO-NET ENERGY PASSIVE HOUSE

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Abstract:
The authors main idea is to build energy plus buildings by means of architectural processes to design passive houses according to the Darmstadt Standard with additional equipment powered by renewable energy. The article presents a comparative financial analysis of passive house buildings with an additional source of power to charge electric cars in Poland and the United States. The analysis is based on market data while also taking into consideration inflation and increases in energy costs. The methodology is based on the calculations required by USA banks for obtaining credit. The emphasis is also on the distinction between commonly used term passive house and the term passive house in accordance with the Darmstadt Standard. The authors are introducing a new terminology to define buildings wrongly named as "passive". Now Authors will name them Pseudo-Passive Buildings. The research shows that it is profitable to construct nearly zero-energy buildings with photovoltaic installation and the discounted rate on return of investment does not exceed the mortgage length.

Key words: *architectural design, energy plus buildings, financial analysis, renewable energy, zero-net energy passive house*

INTRODUCTION

All developed countries are considering the reduction of fossil fuels and conventional energy consumption with the goal of reducing CO_2 emissions [1]. USA have their own sourcing of fuels, but European countries depends also on Russian resources. The political situation in Russia and the war taking place in Ukraine has caused many European countries to try to be more independent in matters related to electricity and heat sources. Most European energy comes from solid fossil fuels and natural gas [2]. A third of global energy is consumed in the construction sector which also emits 40% of the total CO_2. Extreme weather conditions during the past four years (increase of heat and cooling annual demand) have caused higher CO_2 emissions [3, 4, 5, 6, 7, 8, 9, 10, 11]. Nowadays every environmentally conscious country tries to search for lowering energy use and finding other energy sources. Simultaneously sustainable design and construction of building design are being developed which fulfills the three pillars of sustainability – economic, social and environmental [12, 13, 14, 15]. That is why the solution proposed in this article is very up-to-date and focuses on the best practices solutions for energy savings and sourcing.

DEFINITIONS

Passive building – Passive House Building in accordance with the Darmstadt Standard

An energy-efficient house with extremely low heat and cooling demand that uses passive methods to obtain standard demands is referred to as *passive* house. A ***Passive House Building in accordance with the Darmstadt Standard*** is the one needing active – high technology heating and mechanical ventilation. The source of heating is mechanical ventilation - heated venting air. This type of passive house building consumes $EU_{CO+W} \leq 15$ kWh/m^2 a for heating and cooling demands (or thermal load ≤ 10 W/m^2). Its primary energy demand for cooling and heating $EP_{H+W} \leq 60$ kWh/m^{2}a. (The law in Poland states that all single-family buildings should perform at $EP_{H+W} \leq 70$ kWh/m^{2}a/.) The airtightness of the building should be ≤ 0.6 h^{-1}. (The regulations in Poland recommend that the airtightness for buildings with mechanical ventilation or air-conditioning should be ≤ 1.5 h^{-1}.) The excessive temperature frequency above 25°C should be ≤ 10% hours per year [16, 17, 18, 19, 20, 21].

The architect's responsibility is to properly design a house that does not use active, complicated, mechanical devices. The objective can be achieved by using basic components such as: good thermal insulation, windows and doors of an appropriate heat transfer coefficient, correct position of the object in relation to the word directions, heat gains from solar energy, airtightness, mechanical ventilation with heat recovery, and design without thermal bridges.

Unfortunately, in everyday language people tend to misuse the term passive building. That is why the authors of this article propose the new term, ***Pseudo-Passive Building.***

Pseudo-Passive Building

A building that consumes EU_{CO+W} ≤ 15 kWh/m^2a for heating and cooling demands. This can be any building, even without good insulation or poorly designed in passive systems, that by means of using high technology (photovoltaic, solar panels, wind turbines, hydroelectric power, heat pumps, etc.) can use ≤ 15 kWh/m^2a for heating and cooling.

Pseudo-Passive buildings appear on the market and are wrongly named passive ones. They just replace the energy source without lowering the real demands.

Active building, Net-Zero Utility Building or Plus-Energy Building

The active building is a building that by means of active systems and solutions achieve energy efficiency. The article presents the cost-effectiveness of a Passive House Building constructed in accordance with Darmstadt standard that is equipped with an additional source of electricity, and in that way becomes an active building, a Net-Zero Utility Building. An active building also provides electricity needed for house demands such as lighting, mechanical ventilation and ventilation heaters. Plus-Energy Building calculated in this article is a Passive House equipped with photovoltaic panels and produces enough energy for sustaining its own needs and to charge an electric car.

The research from Poland and the United States presented in this article provides a financial comparison analysis of conventional, passive houses, active buildings and energy plus buildings with additional photovoltaic installation for charging cars. The calculations are based on bank requirements for obtaining credit to finance the construction of a house.

– Costs of buildings (Based on the Polish Statistics Office [22], market data and data from Passive House Institute in Poland as well as discussion with developers in Northeastern Pennsylvania USA).
– Annual cost of energy (Based on market data as well as the current rate of the Pennsylvania Power and Light Company/PPL in the service areas) [23].
– Cost of capital (Based on data from PKO Bank Polski as well as the PNC bank in Pennsylvania USA).
– Increasing cost of energy (Assumed to be equal to the level of inflation in Poland and the USA).
– Cost of photovoltaic installation (Based on market data in Poland and the USA. Tax rebates have also been considered).
– Cost of electric cars (Based on Polish Instytut Badań Rynku Motoryzacyjnego (Automotive Market Research Institute as well as websites of different manufacturing companies promoting electric cars).

The economical life cycle for building components is crucial [24, 25, 26]. The lifespan of photovoltaic installations is limited, that is why the calculations in this article are limited to a fifteen-year duration of the mortgage.

The results of the analysis show the potential for profits for building energy efficient buildings with additional photovoltaic installations. Those buildings are not only energy sufficient for themselves, but produces more energy, that can be used to power electric cars (the ***plus-energy buildings***). Even if the bank loan costs would be higher, the energy costs and savings would balance the account.

LITERATURE REVIEW

The key role in energy usage is the human factor [27]. The energy usage in buildings can be significantly reduced by its users [28, 29, 30]. In pursuit of lowering energy demand, carbon reduction and economic savings, as well as the *rebound effect* or *take-back effect* cannot be overlooked. According to neoclassical economy, depending on the definition used for rebounding, this rebound effect can be insignificant or can lead to fuel consumption increase. The rebound effect is characterized by an increase in energy services supply with correlation to decrease in the effective price. The effect of this correlation can lead to undermining of technological savings [31, 32].

There is a general increasing tendency in energy consumption in buildings. ***Passive House Building in accordance with the Darmstadt Standard*** represent a downward trend on use of fossil fuels. The concept of introducing photovoltaic systems in buildings has been successfully implemented [33, 34, 35, 36, 37, 38]. The type of photovoltaic system installed in household can vary depending on the procurement policy of the country and the contracts negotiated for selling and buying renewable and conventional energy. The policies of the USA and Poland support the development of photovoltaic systems installed in residential buildings by means of subsidies [39, 40, 41, 42, 43].

The researchers agree that the photovoltaic system, one of source of renewable energy, is promising and its market value makes it economically viable [44, 45, 46, 47, 48, 49, 50].

Other major sources of CO_2 emissions in large urban areas are the transportation and logistics sectors, especially cars, delivery trucks, mass transit systems, etc. [51]. A way to counteract this is the transition from conventional vehicles (with an internal combustion engine powered by fossil fuels) to electric or hybrid cars. Researchers pointed out that there are some disadvantages to electric cars that slows down their development, as well as creates a hesitancy for consumers to buy them. Among others there are: high prices, short range, long charging time and insufficient number of charging stations [52, 53, 54]. The studies comparing hybrid and electric cars in USA show how up-to-date and important the transition from conventional to electricity cars is [55, 56, 57]. To help with the charging process, the authors present the option to charge the household car at home (own charging station) by means of a residential photovoltaic installation (smaller costs especially in comparison with petrol) and at night (During sleep of habitants charging time is not an issue). This proposal eliminates two of main disadvantages.

LEGISLATION

In 2009 the United States Federal Leadership in Environmental, Energy, and Economic Performance stated, that beginning in 2020 and by 2030 all new Federal buildings should be designed as zero-net-energy buildings. New federal buildings should not emit net greenhouse gasses and should be cost-effective – require a significantly reduced energy demand that covers energy balance from sources that do not produce greenhouse gases [58]. In 2015 the Department of Energy (USA) presented a definition for net zero-energy buildings (ZEB). The ZEB are energy-efficient buildings where annual energy demand is equal or lower to the renewable energy produced on-site [59]. Another document, Executive Order 13514 of U.S. Department of Energy, presents implementation of alternative fuels and electric vehicle strategies that emphasize the importance of electric cars [60]. Professors Adamson and Feist referred to a *passive house* as a *nearly zero-energy building.* In the Energy Performance of Building Directive following their proposal a definition of a nearly zero-energy building appeared. It states that nearly zero-energy buildings are characterized by a very low amount of energy demand. The energy demand that should be almost entirely covered by renewable energy also produced on-site, and it should fulfill the design aspects mentioned in annex I ('Common general framework for the calculation of energy performance of buildings') [61]. This document also states that a national plan of increasing the number of nearly zero-energy buildings should be developed by Member States of European Union (EU) and regularly communicated to the European Commission (EC). Furthermore, by of 31 December 2020, Member States of the EU will certify that all new buildings should be nearly zero-energy buildings.

In Poland there were three steps of implementing the strategies of the European Union. Beginning from 2014 through 2017 and ending in 2021, the new required parameters of new buildings were obligatory. Nowadays the primary energy for heating, ventilation and preparing of hot water are 70 kWh/m^2 a which is only 10 more than in passive buildings. In addition, thermal insulation of partitions, windows and doors will be required [21]. These regulations and directives are why the cost of passive house in relation to conventional building is not very high.

METHODOLOGY OF RESEARCH

Selection of the Typical Size of the House

Comparative analysis of the profitability of investing in energy-efficient housing was calculated for the following investments.

- Passive house.
- Net-zero energy active house.
- Net-zero energy active house with one electric car and solar-charging station for an electric car (15000 km/year).
- Net-zero energy active house with two electric car and two solar-charging stations for electric cars (combined 30000 km/year).

Calculations of the financial analysis were conducted for two countries, United States and Poland. The size of the house for both countries was assumed to be 100 m^2.

Estimation of the Initial Investment

The estimate of the initial investment was determined based on discussions with developers in the United States and Poland. In Poland ten companies were asked to estimate the initial investment. Five enterprises were micro (1-9 workers) and five enterprises were small (10-50 workers). An identical procedure was followed in the United States. Ten companies estimated the initial investment at the Northeastern Pennsylvania Annual Builders Show (Spring 2022). The values included in Table 1 and Table 2 reflect the prices in the Spring 2022.

The prices are changing because of inflation and fluctuations in the market. The cost of capital as well as the cost of energy in the United States and Poland are also changing. The economy is unstable at the present time. The financial analysis reflects only the situation at a particular timeframe (Spring 2022).

The additional investment needed to be environmentally friendly is being fully or partially recovered by lower utility bills (Table 3 and Table 4). A financial analysis has been conducted for all four different alternatives in the United States and Poland. A summary of the results is shown in Table 3 and Table 4 (United States and Poland respectively).

Table 1
Cost estimate for different building types in United States

Building Type	**Conventional Single-Family House (100 m²)**	**Single-Family Energy-Efficient Passive House (100 m²)**	**Net-Zero Energy-Usage Active House (100 m²)**	**Net-Zero Energy Active House plus 1 electric car with a solar-charging station**	**Net-Zero Energy Active House and 2 electric cars with a solar- charging stations**
Cost of Conventional Solutions	$250000	N/A ($250000)	N/A ($250000)	Conventional House with 1 conventional gasoline car ($270000)	Conventional House with 2 conventional gasoline cars ($290000)
Cost of Environmental – Friendly Solutions	N/A	$300000	$314000	$368000 Zero-energy House with 1 electric car and solar-charging station	$422000 Zero-energy House with 2 electric cars and a solar-charging stations
Difference in Cost (Additional investment needed to be environmental-friendly)	N/A	$50000	$64000	$98000	$132000

Table 2
Cost estimate for different building types in Poland

Building Type	**Conventional Single-Family House (100 m²)**	**Single-Family Energy-Efficient Passive House (100 m²)**	**Net-Zero Energy-Usage Active House (100 m²)**	**Net-Zero Energy Active House plus 1 electric car with a solar-charging station**	**Net-Zero Energy Active House and 2 electric cars with a solar- charging stations**
Cost of Conventional Solutions	500000 PLN	N/A (500000 PLN)	N/A (500000 PLN)	Conventional House with 1 conventional gasoline car (600000 PLN)	Conventional House with 2 conventional gasoline cars (700000 PLN)
Cost of Environmental – Friendly Solutions	N/A	600000 PLN	621000 PLN	822000 PLN Zero-energy House with 1 electric car and a solar-charging station	1023000 PLN Zero-energy House with 2 electric cars and a solar-charging stations
Difference in Cost (Additional investment needed to be environmental-friendly)	N/A	100000 PLN	121000 PLN	222000 PLN	323000 PLN

Table 3
Estimated values of energy savings in the United States

Energy Efficient Passive House (100 m²)	**Net-Zero Energy Active House (100 m²)**	**Net-Zero Energy Active House (with one electric car)**	**Zero-Energy Active House (with two electric cars)**
Savings $2940 ($3300 – heating and air-conditioning of conventional house; $360 – heating and air-conditioning of a passive house)	**Savings $3300** ($3300 – heating and air-conditioning of conventional house)	**Savings $4800** ($3300 – heating and air-conditioning of conventional house; $1500 – of gasoline for a conventional car)	**Savings $6300** ($3300 – heating and air-conditioning of conventional house; $3000 – cost of gasoline for two conventional cars)

Table 4
Estimated values of energy savings in Poland

Energy Efficient Passive House (100 m²)	**Net-Zero Energy Active House (100 m²)**	**Net-Zero Energy Active House (with one electric car)**	**Zero-Energy Active House (with two electric cars)**
Savings 8800 PLN (10000 PLN – heating and air-conditioning of conventional house; 1200 PLN – heating and air-conditioning of a passive house)	**Savings 10000 PLN** (10000 PLN – heating and air-conditioning of conventional house)	**Savings 19000 PLN** (10000 PLN – heating and air-conditioning of conventional house; 9000 PLN – cost of gasoline for a conventional car)	**Savings 28000 PLN** (10000 PLN – heating and air-conditioning of conventional house; 18000 PLN – cost of gasoline for two conventional cars)

RESULTS OF RESEARCH

Estimation of the Energy Savings

The estimated profit from energy savings as a result of using environmental-friendly solutions are shown in Table 3 and Table 4. The data in those tables are reflecting the savings in the United States and Poland respectively. The annual income from the energy savings is compensating for the higher initial investments of applying environmental-friendly solutions. It was assumed that the cost of energy as well as the income from energy savings will increase with the rate of inflation.

Calculating the Net Present Value, Internal Rate of Return and Payback Time

The comprehensive financial analysis of profitability of investing in environmental-friendly passive, active and plus energy buildings was conducted. The financial analysis calculations were done for the following:

1. Passive house in comparison to a conventional house.
2. Net-zero energy active house in comparison to a conventional house.
3. Plus-energy (passive house + photovoltaic) house with one electric car (charged from a solar array) in comparison to a conventional house and gasoline car.
4. Plus-energy (passive house + photovoltaic) house with two electric cars (charged from a solar array) in comparison to a conventional house and two gasoline cars.

Identical calculations were conducted for the economic situations in the United States and Poland. One of the eight sets of calculations is shown in Appendix A. The results of the financial analysis calculations are shown in Table 5 and Table 6 for the United States and Poland respectively.

Table 5

Summary of financial analysis for the United States

	Passive House (100 m²)	**Net-Zero Energy Passive House (100 m²)**	**Net-Zero Energy Passive House (100 m²) One electric car (15000 km/year)**	**Net-Zero Energy Passive House (100 m²) + Two electric cars (15000 km/year each car)**
Initial Outlay	$50000[1]	$64000[2]	$98000[3]	$132000[4]
Net Present Value (NPV) (15 years)	-$5900	-$14500	-$26000	-$37500
Internal Rate of Return (IRR)	4.7%	4.4%	4.4%	4.3%
Profitability Index (PI)	0.88	0.77	0.73	0.72
Return on Investment	12.8 years	13.9 years	14.5 years	14.8 years
Discounted Rate on Return of Investment	17 years	19 years	20 years	21 years

[1]Additional cost of building a 100 m² passive house compared to a regular energy efficient house ($50000).

[2] Additional cost of building a 100 m² passive house compared to a regular energy efficient house ($50000).
3.6 kW PV system powering the house ($14000). Total $64000.

[3] Additional cost of building a 100 m² passive house compared to a regular energy efficient house ($50000).
3.6 kW PV system powering the house ($14000).
3.6 kW PV system charging the electric car ($14000).
Additional cost of electric car compared to gas-powered car ($20000).
Total $98000).

[4] Additional cost of building a 100 m² passive house compared to a regular energy efficient house ($50000).
3.6 kW PV system powering the house ($14000).
3.6 kW PV system charging the electric car ($14000).
Another 3.6 kW PV system charging the second electric car ($14000).
Additional cost of electric car compared to gas-powered car ($20000).
Additional cost of second electric car compared to gas-powered car ($20000).
Total $132000.

Table 6
Summary of financial analysis for Poland

	Passive House (100 m^2)	**Net-Zero Energy Passive House (100 m^2)**	**Net-Zero Energy Passive House (100 m^2) One electric car (15000 km/year)**	**Net-Zero Energy Passive House (100 m^2) + Two electric cars (15000 km/year each car)**
Initial Outlay	100000 PLN [1]	121000 PLN [2]	222000 PLN [3]	323000 PLN [4]
Net Present Value (NPV) (15 years)	21666 PLN	20070 PLN	39915 PLN	38492 PLN
Internal Rate of Return (IRR)	8.6%	8.5%	8.5%	8.5%
Profitability Index (PI)	1.21	1.17	1.17	1.19
Return on Investment	9 years	7.9 years	8.1 years	8.1 years
Discounted Rate on Return of Investment	12.3 years	12.8 years	12.7 years	11.7 years

[1]Additional cost of building a 100 m^2 passive house compared to a regular energy efficient house (100000 PLN).
[2] Additional cost of building a 100 m^2 passive house compared to a regular energy efficient house (100000 PLN).
3.6 kW PV system powering the house (21000 PLN). Total 121 000 PLN.
[3] Additional cost of building a 100 m^2 passive house compared to a regular energy efficient house (100000 PLN).
3.6 kW PV system powering the house (21000 PLN).
3.6 kW PV system charging the electric car (21000 PLN)
Additional cost of electric car compared to gas-powered car (80000 PLN).
Total: 222000 PLN.
[4] Additional cost of building a 100m^2 passive house compared to a regular energy efficient house (100000 PLN).
3.6 kW PV system powering the house (21000 PLN).
3.6 kW PV system charging the electric car (21000 PLN).
Another 3.6 kW PV system charging the second electric car (21000 PLN).
Additional cost of electric car compared to gas-powered car (80000 PLN).
Additional cost of second electric car compared to gas-powered car (80000 PLN).
Total: 323000 PLN.

DISCUSSION AND CONCLUSIONS

Based on the summary of the financial analysis, the net present value (NPV) of the investment was calculated. If the NPV is positive, the investment is profitable. The other factors to compare are the profitability index (PI) and payback time needed to recover the initial investment. The profitability index needs to be above 1 for the investment to be considered profitable. Based on the data shown in Table 5 and Table 6, it became obvious that environmental-friendly solutions are more profitable in Poland than in the United States. The reason for that discrepancy is higher building costs in the United States and at the same time lower energy costs. For the purpose of calculations, it has been assumed that energy costs will increase at the same rate as inflation. In recent times the cost of energy is increasing at a higher rate than inflation. This fact will make energy-efficient building more profitable. However, a high inflation rate significantly increases the cost of capital and decrease profitability. Many environmental-oriented people often considered the environmental advantages before the profitability factor. It has been proven that many people are willing to voluntarily pay a higher rate for renewable energy.

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Appendix A

Financial Analysis of the Passive House Project in Poland
Technical and Financial Assumptions

- Cost of building an energy efficient house (100 m^2) 500000 PLN
- Annual cost of energy for an energy efficient house (100 m^2) 10000 PLN
- Cost of building a passive house (100 m^2) 600000 PLN
- Annual cost of energy for a passive house (100 m^2) 1200 PLN

The additional initial investment required to build a passive house is 100000 PLN. The funding for the project will be secured through a bank in the form of a mortgage loan repaid over fifteen years. The weighted average cost of capital (WACC) is equal to the interest rate of the loan. At the present time, the cost of credit is 8%.

WACC = .08 (8%)

The financial profitability of the project can be assessed by calculating the following indicators.

- Net present value (NPV)
- Internal rate of return (IRR)
- Profitability index (PI)
- Return on investment (Number of years needed for the full return on the investment)
- Discounted rate of investment (Number of years needed for the full return on the investment considering the discounted income)

The most important indicators of the profitability of the investment are the net present value (NPV) and the internal rate of return (IRR).

The net present value (NPV) of the project is the discounted income minus the initial investment. NPV can be calculated using the following equation.

$NPV = CF_o + CF_1/(1+WACC) + CF_2/(1 + WACC)^2 + \ldots CF_n/(1 + WACC)^n$

where:

CF_0 = initial investment (100000 PLN)

WACC = cost of capital (8%)

CF_1, CF_2, ……. CF_n – incomes in different years

If,

NPV > 0 (The investment is a good investment.)

NPV < 0 (The investment is a bad investment..)

Net present value represents the growth of the investor's assets. Therefore, the objective is to maximize the NPV.

The annual saving of energy can be calculated as the difference between the energy used in a conventional house and the energy used in a passive house.

Annual energy saving = 10000 PLN – 1200 PLN = 8800 PLN/year

Assuming that the cost of energy will keep increasing by 8% annually, the annual energy saving over the 15 years is shown in Table A.

Table A

Year of Operation	**Annual Income ($)** (Assuming annual 8% increase in energy cost)	**Factor Discounting the Income** $1/(1+WACC)^n$	**Discounted Income ($)** ($CF_n$)
1	8 800	0.926	8 148
2	9 504	0.857	8 144
3	10 264	0.794	8 149
4	11 085	0.735	8 147
5	11 971	0.680	8 140
6	12 928	0.629	8 131
7	13 962	0.582	8 125
8	15 078	0.538	8 111
9	16 284	0.498	8 109
10	17 586	0.461	8 107
11	18 992	0.426	8 090
12	20 511	0.394	8 081
13	22 151	0.364	8 062
14	23 923	0.337	8 062
15	25 836	0.312	8 060

Table 1 also contains the annual discounted income over 15 years (discounted by the cost of capital WACC = .08).

The calculated NPV after 15 years is 21666 PLN. The return on investment was calculated to be 9 years. The discounted return on investment was calculated to be 12.3 years.

Internal rate of return (IRR) represents the return received by the company on the project investment. IRR needs to be higher than the cost of capital. Internal rate of return can be calculated by solving the following equation.

$$0 = CF_o + CF_1/(1+IRR) + CF_2/(1 + IRR)^2 \ldots\ldots + .CF_n(1 + IRR)^n$$

where:

CF_0 – initial investment

CF_1, $CF_{2,}$………..CF_n – annual income received from energy savings.

Substituting the numerical values and solving the equation for IRR, the internal return rate was calculated to be IRR = .086 (8.6%). The internal rate of return (8.6%) is much higher than the cost of capital.

Profitability index (PI) is the ratio of the total income divided by the initial expense. The profitability index can be calculated using the following formula.

$$PI = [CF_1/(1+WACC)^1 + CF_2/(1 + WACC)^2 \ldots\ldots\ldots + .CF_n/(1 + WACC)^n]/CF_0$$

Substituting the numerical values, the profitability index was calculated to be PI = 1.21. The profitability index indicates that for each 1 zl investment the company assets increased to $ 1.21 PLN.