This article is based on the thesis of the finalist in the REHVA Student Competition in 2013, the work was supervised by Ph.D. Eng. Aleksander Panek.

Conceptual design of plus energy single family house in Warsaw, Poland

Plus energy house concept is already well explored but still inspiring a lot of discussion not only in Europe. This study answers the question about the possibility and viability of implementation of a plus energy house in Polish conditions in front of the draft of new Polish legislations.

MARCIN WRONOWSKI
M.Sc. Eng.
Faculty of Environmental Engineering, Warsaw University of Technology and Engineer at Buro Happold, Poland
wronowski.marcin@gmail.com

The first plus energy house was built 28 years ago in Freiburg as a private house of architect Rolf Disch. It was his form of manifest against German government plans of building new nuclear power plant close to this hometown. It was manifest which shown the world that each single family house can be a small eco-friendly power plant – plus energy house.

The simplest concept of a plus energy building is that it produces more energy on site than it uses on annual basis. This includes energy for heating, cooling, ventilation, lighting and all devices that are plugged in [**1**]. The system boundary of energy balance, which is used to evaluate building energy consumption, was set in EPBD recast and EN 15603:2008. The delivered energy is the electricity, district heating/cooling, and other fuels (renewables and non-renewables). Energy produced is on site renewable energy (solar, wind, hydro). The net energy is energy delivered minus exported energy [**2**].

Objective

The main purpose of this study was to investigate the possibility and viability of implementation of plus energy house concept in Polish conditions. Evaluation of the work objective was based on an energy and economic analysis based on the concept design of the building. Concept includes architectural, mechanical and energy design of the building. To minimize the costs of the house, it was assumed that all of the construction, mechanical and energy solutions proposed in design will be well known and common used on Polish market. The availability of the materials and products to construct the building were checked during its concept design.

Method

Architecture

The architecture of the building was inspired by the "home for life" house constructed in Aarhus, Denmark [**3**] **Figure 1**. The floor plan was adjusted to the needs of average Polish family.

Figure 1. The design of the Polish plus energy house was based on this Danish "Home for life", Arhus, Denmark [3].

Building shape, layout and orientation on the plot were design to maximize the passive solar gains and the natural daylight. Large glazed areas were located on the South and West façade of the building. Glazing on the north façade was minimized. Layout of the rooms was design to allow users to fallow natural sun path and to daylight rooms in time of their natural time of use during the day. To protect the building against overheating, external shutters were design. Closed during night/winter will decrease the heat transfer coefficient of windows up to 0,3 W/m^2K [**4**].

Building envelope

Reducing the amount of energy needed to heat and cool the house is the essential consideration, and means a tight, well insulated building envelope. Following the idea of energy efficient building, the building external partitions (roof U=0.685, walls U=0.123, ground floor U=0.122 and windows U=0.6) were designed to meet the heat transfer coefficient standard of passive house. For the best performance of the envelope detailed solutions eliminating thermal bridges were undertaken. This included connections between external walls and windows, roof and ground floor. Precise sealed construction connections allowed to achieve high airtightness of the construction (assumed to be 0.3 air changes per hour for the 50 Pa of pressure) [**5**].

Ventilation

The mechanical ventilation system with air-to-air heat exchanger coupled with ground heat exchanger was designed **Figure 2**. The chosen solution will minimize the amount of energy necessary for heating and cooling of air supply to the building. As Poland has moderate climate with both

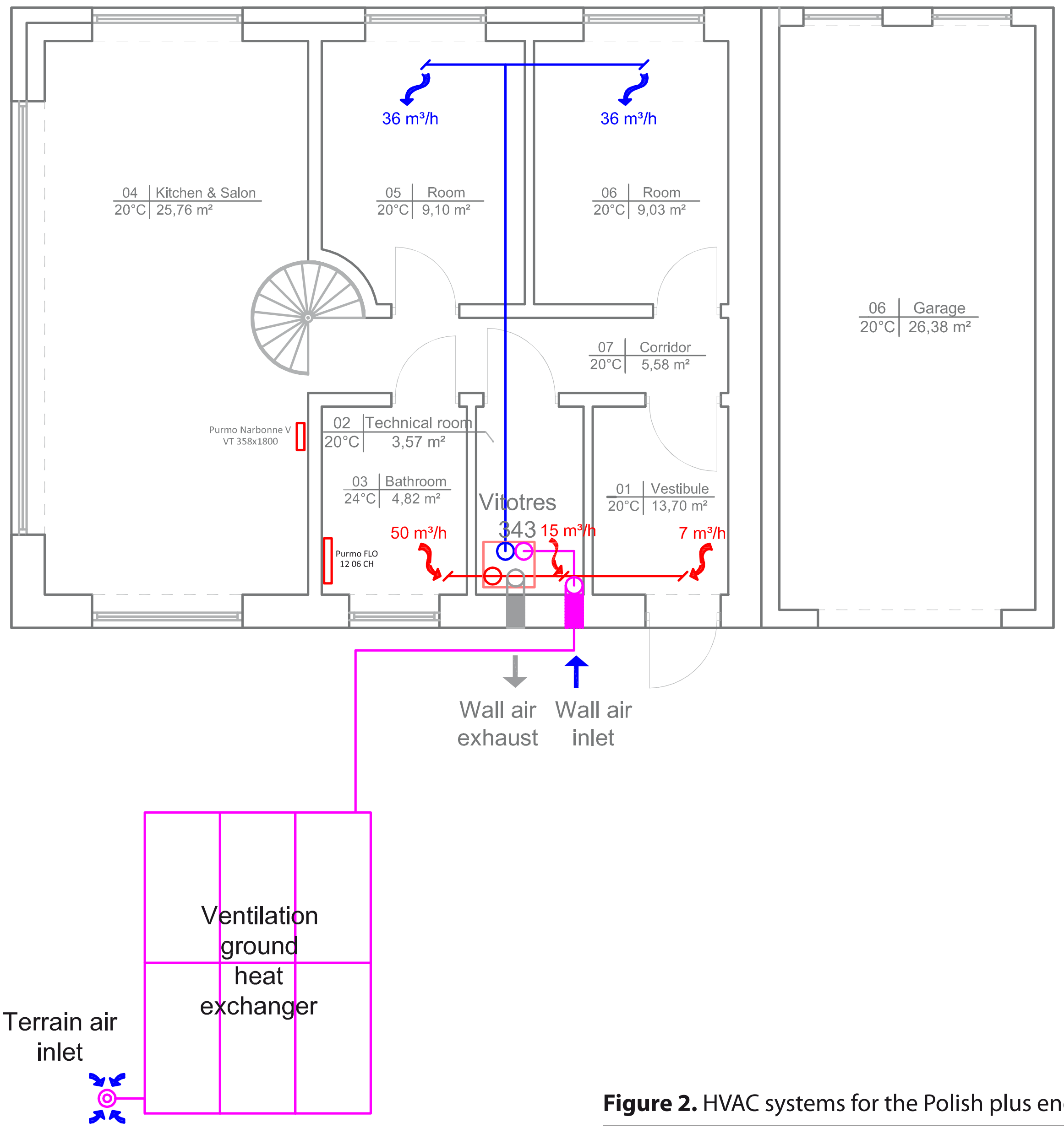

Figure 2. HVAC systems for the Polish plus energy house.

maritime and continental elements, together with mechanical ventilation, a natural ventilation system was designed. The roof windows and windows on the ground floor will be equipped with automatic motors, which through the BMS and readings of internal and external conditions will regulate the openings of the windows.

The volume of the supply and extracted air was designed in accordance to the Polish standard PN-83/B-03430 [**6**]. For the design ventilation, in order to maximize its efficiency, four modes of work were distinguished [7]:

- t_e below 6°C – supply air goes through ground heat exchanger (where is heated) and air-to-air heat exchanger (heat transfer from exhaust air to supply air),
- $t_e \in$ (6°C; 19°C) – ground heat exchanger is not used; air is supplied from wall air intake and goes to air- to-air heat exchanger,
- $t_e \in$ (19°C; 24°C) – mechanical ventilation is not working, building is naturally ventilated (supply and extract fans are off)
- t_e od 24°C – supply air goes through ground heat exchanger (where is cooled) and it passes next to the air-to-air heat exchanger through the summer circumvent; air supply temperature is lower than the external temperature; ventilation system works as a cooling system.

Building heat load and HVAC design

In order to maximize the efficiency and to minimize the space required for the HVAC system the compact HVAC Vitotres 343 was chosen [**8**]. It is designated specially for low energy buildings and it's used for ventilation, central heating and DHW heating with solar backup.

The high thermal performance of building envelope and energy efficient ventilation system results in low final energy demand for heating $\Phi_{HL,A}$=30,2 [W/m²].This is a condition to adopt air heating system in the building. Traditional hydronic radiators will be used only in the rooms with the highest energy losses (bathrooms and saloon with kitchen). The air will be supplied at the temperature of t_h=35 –45°C [9]. It will be customized by a BMS to meet building heating demand based on the external and internal air temperature readings.

In order to reduce energy demand for domestic hot water a solar installation for the building was designed. The installation with Viessmann, Vitosol 200-F type SV2 panels, was sized for a 4 person family according the Viessmann technical guidance [**10**]. Installation consisting of two solar panels will be located on the south roof surface with inclination of 35°.

Building energy consumption

Based on the design of HVAC system the total building energy consumption was calculated. This includes energy necessary for heating, ventilation, domestic hot water preparation, HVAC equipment, lighting and plug in loads. The only form of energy required for the building is electricity.

Heating demand for the building was calculated according to PN-EN-ISO 13790 [**11**] and covers energy needed for air heating and convection heating. The heating demand for the DHW was calculated assuming the average hot water consumption of 50 l/day/person for 4 person family. The calculations of heat produced by solar panels and heat demand were undertaken in the Polysun 5.6 Edu simulations software. Total building electricity consumption was calculated as 7456.80 kWh/year, that gives result of 75.25 kWh/m²/year **Figure 3**.

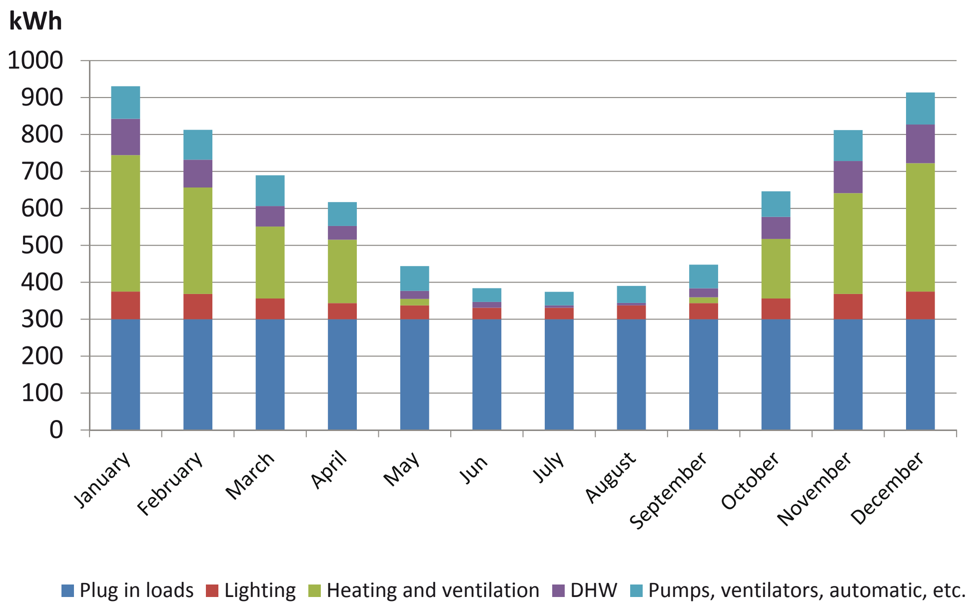

Figure 3. Break down of building electricity consumption by month.

Energy system

The building energy system will consist of solar and photovoltaic panels, installed on its roof. The size of the PV system was determined to offset annual building energy consumption. To maximize the economic efficiency of the investment it was decided that the building will be connected to the local electric grid.

Tied up installations according to Polish government plans for the new energy law, will introduce the feed-in tariffs for every kWh generated from renewables (for small installations up to 10KW – 0,31 €/kWh) [**12**].

Polycrystalline photovoltaic solar panels Vitovolt type 2P235RA of Viessmann Company were chosen for the energy production system [**13**]. The PV panels will be located on the south roof surface with inclination of 35°. With 38 panels total generator output is P = 9.93 kWp. Connection of the modules was based on the calculation of the voltage limits. Panels will be in 4 strings with three strings with 10 modules and 1 string with 8 modules.

The simulation of the PV system was performed in the Polysun 5.6 Edu software. Based on the proposed design the amount of the electricity generated by the system was simulated as 88 033.5 kWh/year. The simulation included already the energy losses during the AC conversion to DC and energy losses related to energy distribution.

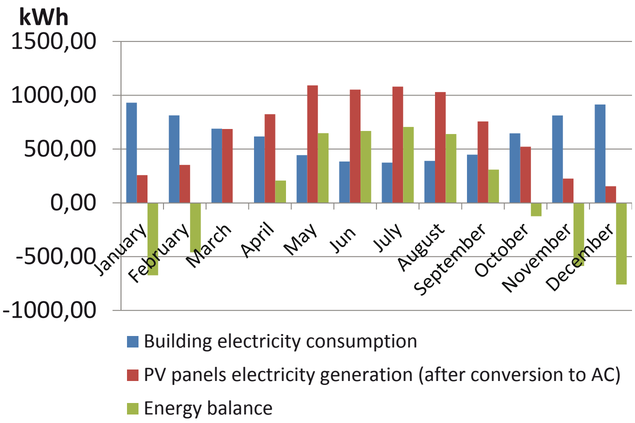

Figure 4. Building energy balance.

PRELINARY RESULTS - Building energy balance

For the designed building energy production (88033.5 kWh/year) exceed energy consumption (7462.10 kWh/year) on the annual basis over 8%. However the results for the individual months show huge disproportion between energy generated and energy demand. The biggest energy demand occurs in the winter months, when the heating demand for the building is the biggest (energy for running of the heat pump and support equipment). Also winter is time when artificial lighting consume the most. Short days and low sun radiation during winter months (November – February) cause that this is the time of the year with the lowest energy production. With the increasing time of sun operation and with increasing solar angle the amount of the electricity produced by PV increase rapidly. Decreasing heating demand and the need for artificial lighting result that from April till September energy generated exceed building energy needs.

FINAL RESULTS - Economical analysis

One of the main important factors for the investor (developers and private person) for choosing the exact solution is the feasibility of the investment. For the design of plus energy house a simple financial analysis was performed. It includes calculation of the construction and annual energy costs.

In the calculations of the building energy costs all of the existing financial incentives were taken into account. That include non-refundable surcharge of 30 000 PLN from Polish Fund for Environmental protection for achieving the high performance building standard (18.55 kWh/m²/year final energy demand for heating and ventilation [**14**]), as well as the refundable of 45% of credit for solar panel installation [**15**].

The final costs of construction of the plus energy house were calculated as 29% higher than the costs of traditional house constructed nowadays in Poland (final energy demand for heating and ventilation =105 kWh/m²/year) [**16**] **Table 1**.

Table 1. Total cost of plus energy and standard house.

Plus energy house	Standard house
Net area: 99.1 m²	Net area: 99.1 m²
EUco* =18.55 kWh/m²	EUco*= 105 kWh/m²
Total costs of construction: 72 971.93 €	Total cost of construction: 56 896.03 €
The difference in cost compared to a standard home	
16 075.9 €	0
28.25%	0%

*EUco - Useful energy demand for heating and ventilation

The big differences in costs cause the barrier which might be hard to overcome. But, when we look at the annual energy costs which include the planned feed-in tariffs, we find that the designed building against to the traditional house is not generating costs, what's more, it's bringing profit to its owner. Based on the annual energy consumption and annual energy generation from PV's it was calculated that the annual energy generated will bring profit of 1612.43 €/year.

Calculation of simply payback time shows that the additional investment costs (16 075.9 €) will be paid after 10 years of building operation. As feed-in tariffs are valid for 15 years, for next 5 years building will bring clear profit to its owner. A detailed financial analysis including inflation and changes in energy prices might show shorter payback time. The final results might be close to the American experience, where for single plus energy family houses the SP is no longer than 8 years [**17**].

SUMMARY

The presented work proves that the construction of plus energy houses in Poland is possible and economically reasonable. With plans of a new energy law (will introduce to the market feed-in tariffs) and with the already existing financial incentives (promoting energy efficiency), Polish construction and energy industry is staying right now in front of the big changes. Final government decision will move them towards sustainability or back to times when coal was main energy source. ■

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